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Assessing the Fuel Potential of Jatropha and Neem oils for Power Generation Gas Turbines Engines in Nigeria

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Abstract : *The research work investigates the potential of locally sourced Jatropha and Neem oils as prospective biodiesel feedstock for fuelling gas turbine engines in Nigeria. The oils and resulting biodiesels were characterized for specific gravity, viscosity, lower heating value, acid value and free fatty acid using the American Oil Chemist's Society method. The deduced specific gravities and viscosities of the oils met Pryde's specification while the acid and free fatty acid values exceeded the requirement. On the other hand while the specific gravities, viscosities and free fatty acid values of both the Jatropha and Neem biodiesels conform to the American Society of Testing and Materials Biodiesel (ASTMB) condition, their acid values exceeded it. The obtained lower heating values for the oils are 36.50 and 34.10 MJ/kg for Jatropha and Neem respectively and 38.00 and 36.7 MJ/kg for the respective biodiesels as against 37.22 MJ/kg specified by the ASTMB. Furthermore, the specific gravities and viscosities were compared with the ASTM D 2880-03 gas turbine fuel oil standard. The specific gravity of the biodiesels met the standard while their viscosities did not. Also a fuel flow rate analysis of the biodiesels in four different megawatt engine at design point revealed increased fuel flow rate compared to diesel and natural gas used. Overall, the oils were found suitable but there is need rid them or reduce their acid values.*

Keywords: *Jatropha oil, Neem Oil, Gas turbine engine, Specific gravity, Viscosity*

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I. Introduction

The role played by the gas turbine (GTE) in Nigeria's power generation sector cannot be over emphasized. Gas turbine engines (GTEs) are the major thermal plants connected to the national grid. These engines operated either in the simple open cycle or combined cycle configuration. Even though they can be fired with diesel, natural gas is largely used because of its availability in the country. Nigeria is reputed to have huge deposits of natural gas which is put at 5.3 trillion cubic meters as at the end of 2016 and estimated to last for 117 years at the present rate of consumption [1]. Natural gas is fossil fuel, and regardless of its abundance in the country, its exploration and use is associated with exhaust pollutant emissions and green house gases (GHGs). These negatively impact the ecosystem and cause environmental degradation. In order to protect the environment therefore, stringent pollutant emissions legislations [2, 3, 4] have made it mandatory engine manufacturers to evolve low emission designs. One way of achieving low emissions is through the use of carbon neutral fuels like biodiesel [5]. Apart from the detrimental effect of fossil fuels on the environment, fossil fuels are finite sources of energy and will one day deplete considering the present rate of consumption. In addition, the erratic supply of these fuels has put pressure on the government to diversify the country's energy mix to include biofuels. One such biofuel is biodiesel.

Biodiesel is a fuel comprised of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of American Society for Testing and Materials ASTM D6751[4], (ASTMB). Biodiesel can be produced from feedstocks such as soya, cotton, jatropha, tobacco seed oils etc, or tallow, fish oil, lard etc, or restaurant waste oil, and other sources like algae and bacteria through transesterification. Nigeria is abundantly blessed with all of these feedstocks. However, the commercial production of biodiesels from some of these feedstocks that are edible will put pressure on their usage as food thereby escalating their prices in the country. It is therefore important to place emphasis on non edible ones like jatropha so as to reduce the burden on consumable ones. Biodiesel is nontoxic, biodegradable, and renewable and can reduce global warming GHGs. It can be used on most diesel engines with little or no modification. GTEs are fuel flexible energy converters [5]. This makes biodiesel a suitable alternative fuel for the GTE in the country. Not only will its inclusion in the country's energy mix promote the use of clean-burning renewable fuel but also reduce her over dependence on fossil fuels among several other benefits.

The GTEs in the market are fossil fueled. While some are designed to run on either liquid or gaseous fuels, others can operate either in dual or tri-fuel configurations. A typical dual-fuel operation of gas turbine is a switch between natural gas and diesel while for tri-fuel natural gas, liquefied petroleum gas (LPG) and diesel are used. The quality of the fuel used is however paramount regardless of the fuel configuration of the engine. Firing the engine with quality fuel improves its output, prolongs its service life and increases the GTE operator profit [6]. The quality of the fuel used in a GTE is determined by the physicochemical properties of the fuels. These properties are expected to meet the minimum requirement of a specified standard. ASTM D2880 is the standard specification for industrial GTEs. GTE manufacturers specify that fuels meet this standard [7, 8], even though, each manufacturer may have extra requirements outside those contained in the standard. The requirements may vary for the different manufacturers depending on the engine type. Often manufacturers also advocate for a review of fuel specifications prior to trying to use fuels that do not meet all of their specifications. Based on the recommendation and the outcome of interaction with operators of these engines, manufacturers are willing to evaluate any fuel intended for use in their engines, even though the fuel may not meet all of the condition listed in their technical literature. Consequently, a candidate fuel is not hastily expunged possible fuels based only on the fact that it exceeds one or more specifications. Sometimes the necessary modifications are made in order to meet individual limiting requirements that may be agreed upon by both the manufacturers and operators of the engine.

The use of vegetable oil in the diesel engine dates from the early days of the engine. According to Knothe [9], Rudolf Diesel the inventor of the engine cited the use of peanut (groundnut) oil in a small diesel engine by the Otto Company in the Paris exhibition in 1900. He carried out an extensive research on vegetable oil use for fuelling the diesel engine. However, with passage of time, petroleum fuels became widely available in a variety of forms including diesel and it was cheap. The engine design was then altered to go with the properties of petroleum diesel. The modification resulted in an efficient and very powerful engine [9]. However because petroleum fuels later became widely available and cheaper than vegetable oil, the world’s attention shifted to petroleum diesel. Nevertheless, as the years rolled by, from time to time petroleum fuel shortages were experienced particularly in the 1930s and 1940s as well as in the1970s and early 1980s. The effects of these shortages prompted a renewed research interest in the use of vegetable oil for the diesel engine [10]. Today, environmental concerns as a result of anthropogenic green house gases emission have further stimulated research interest in this area. Compared to the diesel engine, not much work on the use of vegetable oils in the GTE has been carried out. However, from available literature, the high viscosity of vegetable oil has been cited as the major issue associated with vegetable oil fuels for the engine [11, 12, 13, 14]. The high viscosity results in poor fuel atomization causing operational problems and sometimes engine deposits. In addition to high viscosity, low LHV, low volatility and high reactivity were also revealed as issues with the use of straight vegetable oils. Furthermore, high reactivity of the oils was shown to be the consequence of the presence of unsaturated fatty acids in the vegetable oil. Therefore in order to use the oils in the engine they were preheated. Preheating the oil reduced the viscosity of the vegetable oils. Apart from preheating vegetable oils, other methods such as transesterification, microemulsification, pyrolysis and blending the oil with petroleum-diesel are employed [9]. Transesterification, microemulsification and pyrolysis, convert the oil into biodiesel, with near petroleum diesel physicochemical properties [15, 16, 17]. Though several vegetables oils are available for the production of biodiesel the choice of the optimal one depends on factors such as geography, climate and economics [9]. The use of biodiesels and their blends with petroleum-diesel in diesel engines have received substantial attention. A number of researches have found their performance on biodiesels comparable to that of petroleum diesel [15, 16, 18, 19]. Unlike the diesel engine, scanty literature is available on biodiesel fired GTEs. Somorin and Kolios [20] carried out a comparative techno-economic performance analysis of a jatropha biodiesel fired gas turbine plant with natural gas and diesel. The study found only a slight loss in the power output and plant efficiency of the engine but uneconomical considering the present electricity generation prices in Nigeria excepting combined cycles plants. In a related research, Solomon [21] found out that the power output of an aero-derivative GTE marginally increased when fuelled separately with jatropha and neem biodiesels in place of natural gas and petroleum diesel, however, not without a trade-off of higher fuel flow rates. Kallenberg [14] experimentally examined the effects of vegetable oil and biodiesel in a gas turbine. The engine ran on the vegetable oil but the atomization of the fuel was poor. Fuelling the gas turbine with biodiesel was also found to be slightly more expensive than vegetable oil and No.2 diesel oil. Numerous researches have also been conducted on determining the suitability of jatropha oil (J-Oil) and neem oil (NM-Oil) for biodiesel production [17, 22, 23, 24]. The investigations have shown that the oils have great potentials for biodiesel fuel production in spite of the high value of viscosity recorded. Therefore investing in the commercial production of biodiesels from vegetable oils is not only in tandem with best global practices but also a furtherance to the Nigeria Biofuel Policy of 2007 [25]. The aim of this research therefore is to investigate the suitability of locally sourced J-Oil and NM-Oil as possible feedstocks for the production of biodiesels as alternative fuels for the GTE.

II. Materials And Methods

Dry seeds of the jatropha and neem seeds were sourced from the open market in Zaria, Kaduna State. The seeds were prepared and oil extracted mechanically from each of them in the National Research Institute for Chemical Technology (NARICT) Zaria. The investigated oils as well the ensuing biodiesels were then characterized for the physicochemical properties; acid value, free fatty acid (FFA), refractive index, iodine value and viscosity according to the American Oil Scientist Standard (AOCS). The lower heating value (LHV) of the NM-Oil and neem biodiesel (NM 100) were adopted from the work of Abdulkadir et al [15] while that of J-Oil and resulting jatropha biodiesel (JB 100) was taken from that of Belewu et al [24] and Shanono and Enaburekhan [16]. The results were compared to the ASTMB standard specification. The design specification of the selected GTEs investigated were obtained online and their power outputs, thermal efficiencies alongside the LHVs of the oils and biodiesels were used in equation 1[26, 27, 28, 29] on the excel software to evaluate the fuel flow rate of the GTEs for each of the fuels investigated. The equation is given as:

$$Thermal\ Efficiency\ \eta_{th} = \frac{W_{net}}{m_{f\ X\ LHV}} \tag{1}$$

where W_{net} = net work done by the GTE
m_f =fuel flow rate

Table 1 Technical Specification of the Investigated Gas Turbines [26, 27, 28]

S/N	GT Model	Manufacturers	Power Output (MW)	Thermal Efficiency (%)	Pressure Ratio	Heat Rate (kJ/kWh)	Turbine Speed (rpm)
1	SGT6-5000 F	Siemens	250	39.3	18.9	9160	3600
2	GE Frame 9E	General Electric	126	34	12.6	10653	3000
3	LM 6000 PD SPRINT™ (Aeroderivative)	General Electric	42.3	41.1	30	8763	3627
4	TM 2500+ Mobile Gas Turbine	General Electric	29	38	22.5	9316	3600

III. Results And Discussion

The results of the physicochemical properties characterization of the investigated oils and the resulting biodiesels are presented in Table 1

Table 2 : Physicochemical Properties Of J-Oil, NM-Oil, JB 100 And NM 100

S/N	Physicochemical Properties	J-Oil	NM-Oil	SVO [30]	JB 100	NM 100	ASTMB
1	Specific gravity @ 15oC	0.9139	0.9257	0.91-0.93	0.8548	0.8469	0.88
2	Viscosity(mm^2) @ 40°C	48.09	35.82	30-50	5.218	4.551	1.9-6.0
3	Acid value (mgKOH/g)	7.854	5.61	0.02-20	1.02	0.8014	0.50
4	Free fatty acid (mgKOH/g)	3.927	2.805	2	0.51	0.4007	2.5
5	Lower Heating Value (MJ/kg)	36.50	34.10	36	38.00	36.7	37.22

Fuel potentials of J-oil and N-oil and the resulting biodiesels JB 100 and NM 100 have been investigated. A contrastive representation and discussion of the results are done in Fig 1-7.

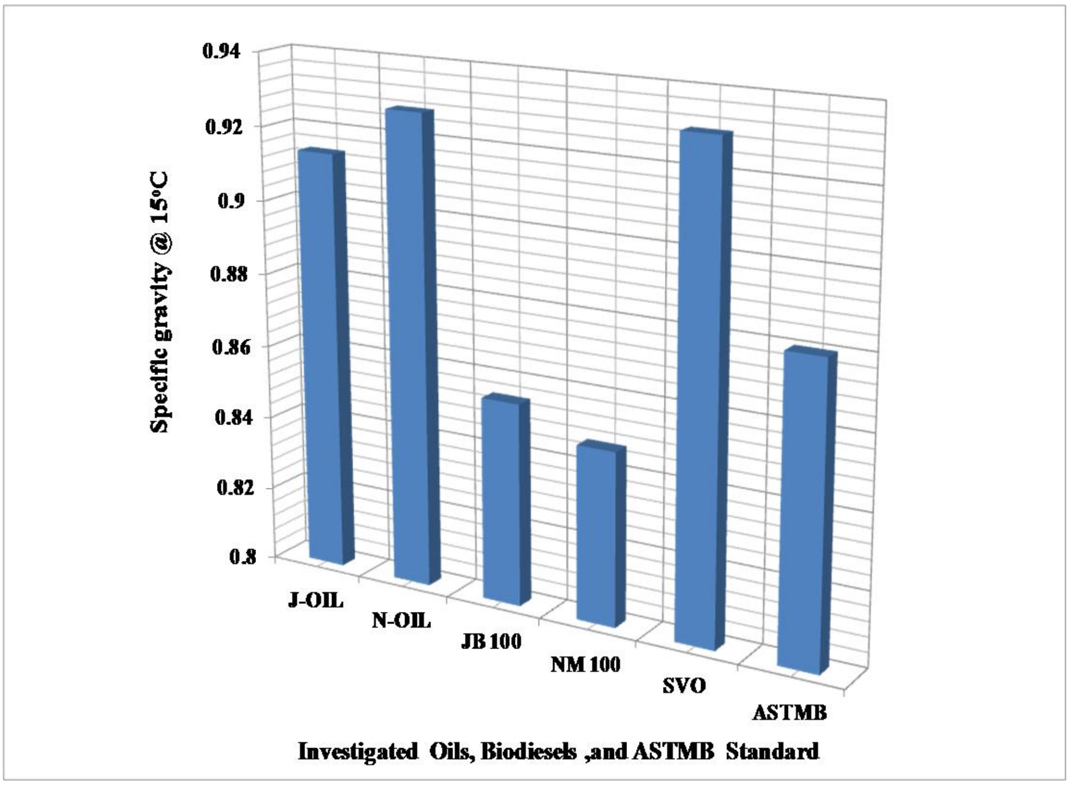

Fig 1 Specific Gravity of the Investigated oils, Biodiesels and the ASTMB Standard

Fig 1 shows the graph of the values of the specific gravity deduced from the study. From the figure it can be seen that the specific gravity for the oils is higher than those of the resulting biodiesels. The specific gravity for N-oil is 0.9275 and is slightly higher than that of J-oil found to be 0.9139. In contrast the specific gravity of JB 100, 0.8548 is observed to be slightly greater than that of NM-100, 0.8469. This observation is expected and reveals the effect of the transesterification of the oil. While transesterifying the oils reduced the specific gravity of both oils, the reduction is more pronounced for NM 100. Furthermore, the specific gravities of the two oils are observed to be a little lower than the standard for SVO as given by Pyrde [30].The specific gravity of a fuel is the ratio of the density of the fuel relative to that of water at a specified temperature. It is crucial and most basic GTE fuel property because it is a precursor for a number of other fuel properties like LHV, viscosity, and cetane number. Furthermore it determines the quantity of fuel storage and transportation. The values of the specific gravity obtained herein are in good agreement with those published in the literature [15, 17, 22] and found to be slightly lower than the 0.88 given by ASTMB.

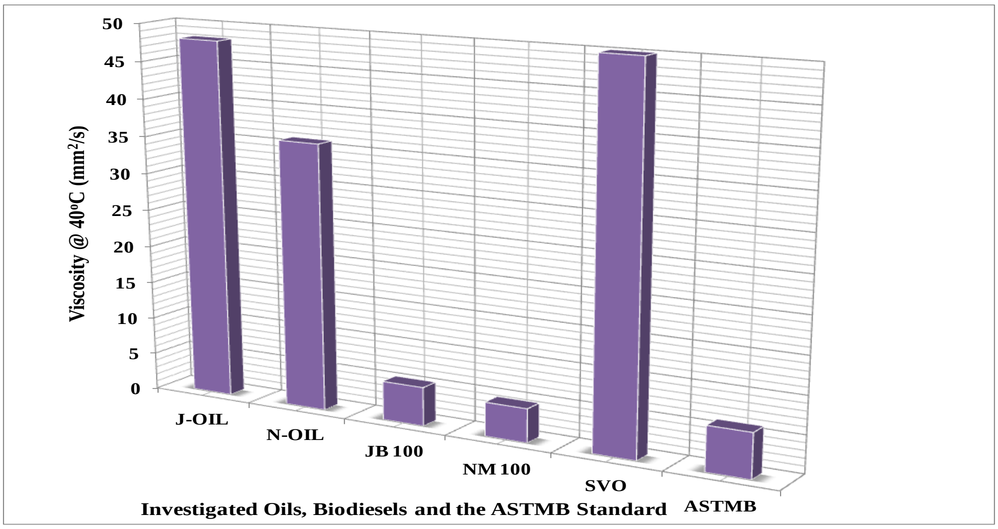

Fig 2: Viscosity of the Investigated Oils, Biodiesels and the ASTMB Standard

The fig 2 shows the variance of viscosities of the oils, biodiesels and ASTMB specification. The values of the viscosity for J-oil, N-oil, JB 100 and NM 100 are 48.09, 35.82, 5.218 and 4.551 mm^2/s respectively compared the maximum value 6.1 mm^2/s for ASTMB. It is observed that the viscosity of J-oil is higher than that of N-oil; thus making it more viscous than N-oil. Furthermore, the viscosities of both oils were also seen to be lower than the Pryde [30] maximum limit for SVO. However, the viscosity value for N-oil is observed to be the lowest. The observation indicates that the two oils can be used for producing biodiesel. On transesterification of the oils, the viscosities of both oils reduced tremendously as expected. The viscosity of JB 100 was found to be slightly higher than that of NM 100. In terms of viscosity therefore NM 100 would be the preferred fuel. The values obtained, 5.218 and 4.551 mm^2/s fall within the range specified by the ASTMB standard. Viscosity is a measure of the resistance of the fuel to flow and is temperature dependent. It plays a critical role in terms of power required to pump fuel through the fuel system as well as having significant effect on the formation of well atomized spray and hence on the rate of fuel evaporation and combustion. The higher the viscosity the higher the resistance to flow and power required to pump the fuel except when the fuel is preheated. The viscosities obtained in the work are found to be well above the ASTMB minimum value of 1.9 mm^2/s and lower than the maximum value. This is significant because the value of the minimum viscosity is limited and some pumps may not be able to operate satisfactorily for too low a value while too high a value could cause excessive pressure losses in the piping system in addition to the extra power required to pump the fuel in the engine. However the viscosities of the biodiesels are in good agreement with the ASTMB standard. The values are comparable with those found in the literature [23, 24].

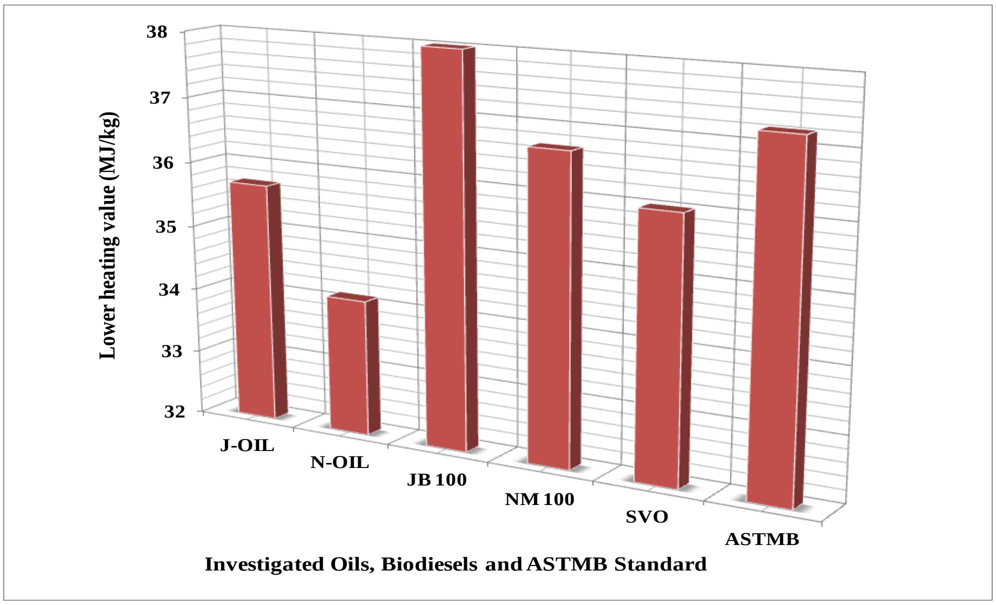

Fig 3: Lower Heating Value of the Investigated Oils, Biodiesels and the ASTMB Standard

The Lower heating value (LHV) of a fuel is one of the combustion properties of most interest for a GTE as it pertains to the heat liberated when it is combusted to completion under standard conditions. The LHV of the oils and biodiesels described in this study are found to be 36.50, 34.10, 36.00, 38.00, 36.70 MJ/kg compared to 37.22 MJ/kg for ASTMB standard. The LHV for J-oil is seen be just 0.50MJ/kg higher than the specification published in the literature [26] while N-oil much lower. For the biodiesels, the LHV of JB 100 is seen to be slightly higher than the standard specified by ASTMB, while NM 100 LHV falls a little below it. This means in terms of the LHV the JB oil is expected to perform better in the engine since the higher the LHV the better the performance of the engine. In addition the fuel consumption is expected to be higher with the NM 100 in the engine since it has the least LHV. It also observed that transesterifying N-oil to NM 100 only minimally increased the LHV. In order to elevate the resultant LHVs therefore, blending them with petroleum diesel will be necessary. The blending will boost the LHVs to near petroleum diesel LHV.

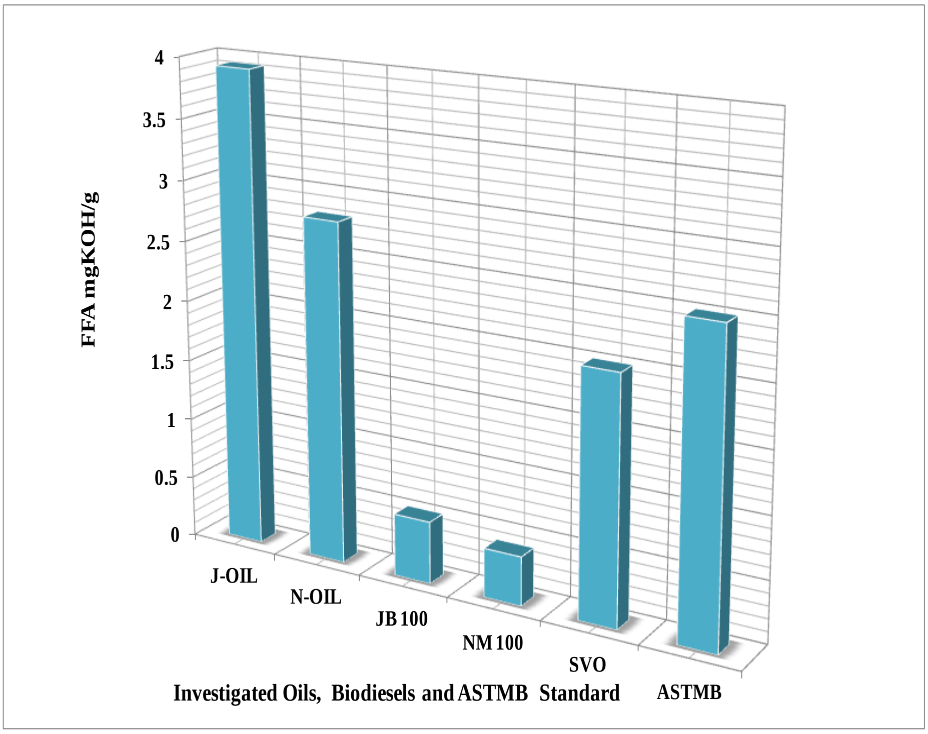

Fig 4 FFA Value of the Investigated Oils, Biodiesels and the ASTMB Standard

The presence of free fatty acid (FFA) in oil contaminates it and reduces the quality and yield of biodiesel production from it. Higher values are undesirable, else two step transesterification is carried out while producing the biodiesel in order to have good quality yield. The FFA contents of the oils investigated were found to be 3.927 and 2.805 mgKOH/g for the J-Oil and N-Oils respectively. After transesterification, these reduced to 0.51 and 0.4007 mgKOH/g for JB 100 and NM 100 respectively. These values are similar to those in the literature [23, 24], though not without slight differences which might be due to the climatic conditions and nature of the soil on which the feedstocks were cultivated. Nevertheless the FFA values are well below those in the literature [18, 22].

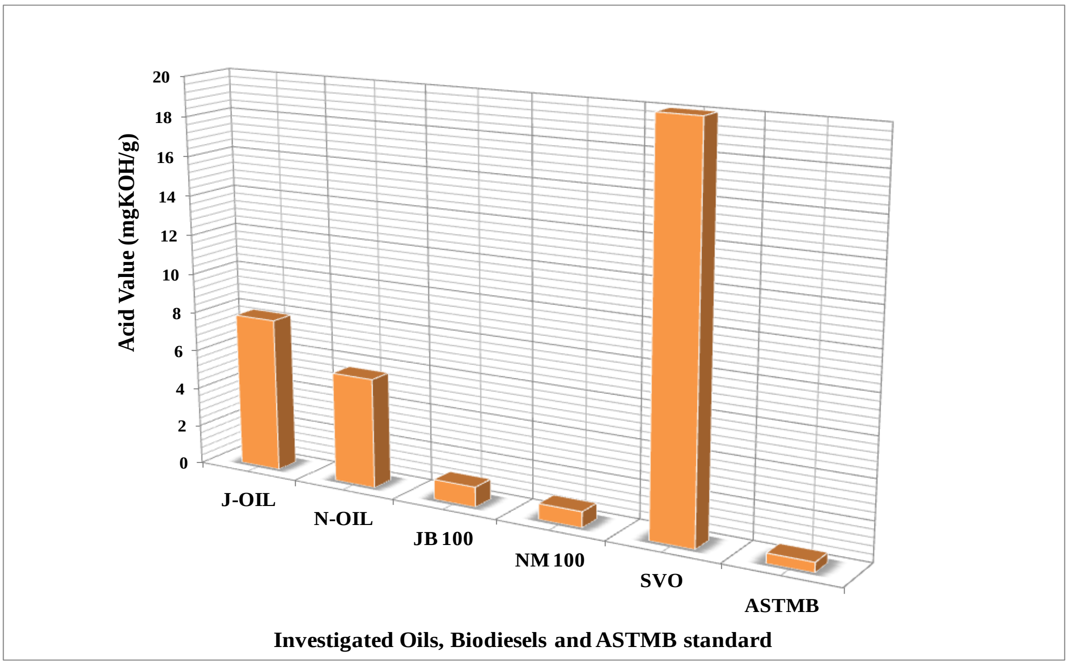

Fig 5 : Acid Value of the Investigated oils, Biodiesels and the ASTMB Standard

Fig 5 is a comparison of the acid values of the J-oil and N-oil respectively and those of the resulting biodiesels JB 100 and NM 100 as well as the Pryde's acid value specification for SVO [30] and the ASTMB. As expected the transesterification process had a significant impact on the acid value of J-Oil and NM-Oil. The acid value of the J-Oil reduced from 7.854 mgKOH/g to 1.02 mgKOH/g for JB 100 while for NM Oil and NM 100 it is from 5.61 mgKOH/g to 0.8014 mgKOH/g respectively. This observation is comparable to those reported by Ndana et al [17] and Nityanda et al [18]. Acid value is one of the crucial properties for biodiesel quality check: The lower the value, the better the fuel. It quantifies the amount of corrosive fatty acid as well oxidation products present in the fuel and should be lower than the 0.50 mgKOH/g stipulated by the ASTMB Earlier versions of ASTM specifically ASTM D6751-03 permitted a maximum acid value of 0.80 mgKOH/g. Fuels whose acid values exceed the ASTM specification reveal their possibility to corrode GTE parts particularly in the fuel injector, turbine section of the engine as well as fuel tanks, more so that this value is increased during storage because of hydrolysis of fatty acid. The acid values for JB 100 and NM 100 deduced from this work slightly exceeds that fixed by ASTMB as shown in figure 5. The acid value for JB 100 was found to exceed the allowable ASTMB limit by 0.52 mgKOH/g while the value for NM 100 surpassed the ASTMB limit by 0.3014 mgKOH/g which is less than that of JB 100. Therefore in order to effectively operate the GTEs understudied with these fuels there may be the need to treat the fuels so as to bring the acid value to meet the maximum allowable value in the ASTMB specification.

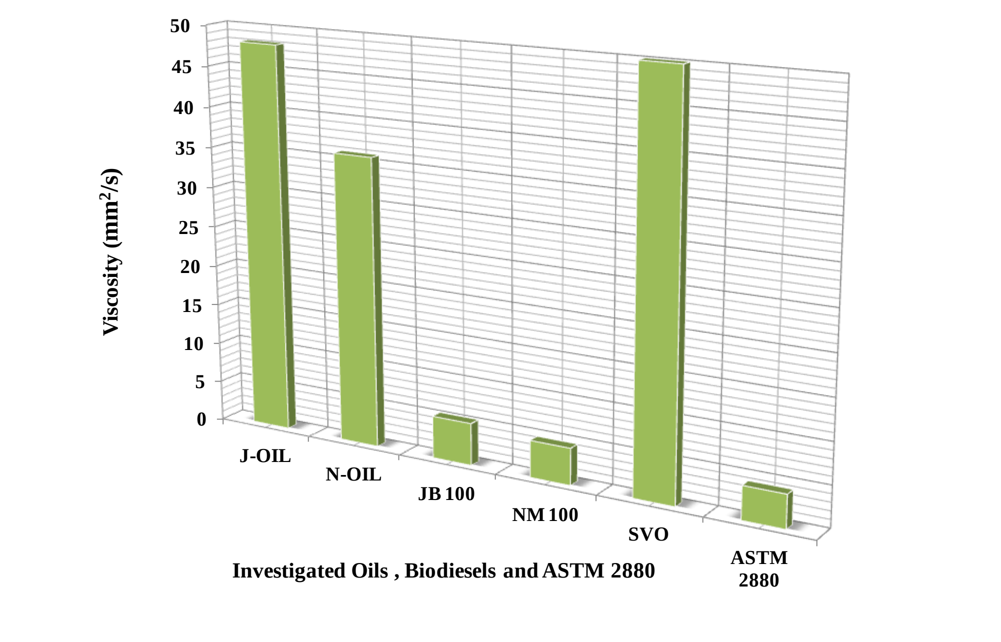

Fig 6 Viscosity of the Investigated oils, Biodiesels and the ASTM 2880-03

Fig 6 shows the viscosity values of the investigated oils and biodiesels compared to the Pryde specification and ASTM 2880-03 standard specification for No. 2 GT fuel oil. The fuel oil physicochemical properties are similar to that of ASTM D 975 automotive diesel fuel oil. The values of the viscosity for J-oil, N-oil, SVO, JB 100, NM 100 and ASTM 2880-03 are 48.09, 35.82, 50.00, 5.218 and 4.551 and 4.1mm^2/s respectively. It is observed that viscosity of J-oil is higher than that of N-oil but only marginally lower than that of SVO as given by Pryde, yet more viscous than N-oil. On transesterification however, the viscosities of both oils reduced tremendously as anticipated. Similarly the viscosity of the resulting JB 100 was found to be slightly higher than that of NM 100. The individual viscosities of the two biodiesels marginally exceed the maximum value stipulated by ASTM 2880-03. NM 100 would be the preferred fuel to JB 100 in the terms of viscosity. The use of additives such as diethyl ether and viscoplex could reduce the viscosities to that of the ASTM 2880-03 standard in order to mitigate high viscosity related problems in the engine as earlier mentioned.

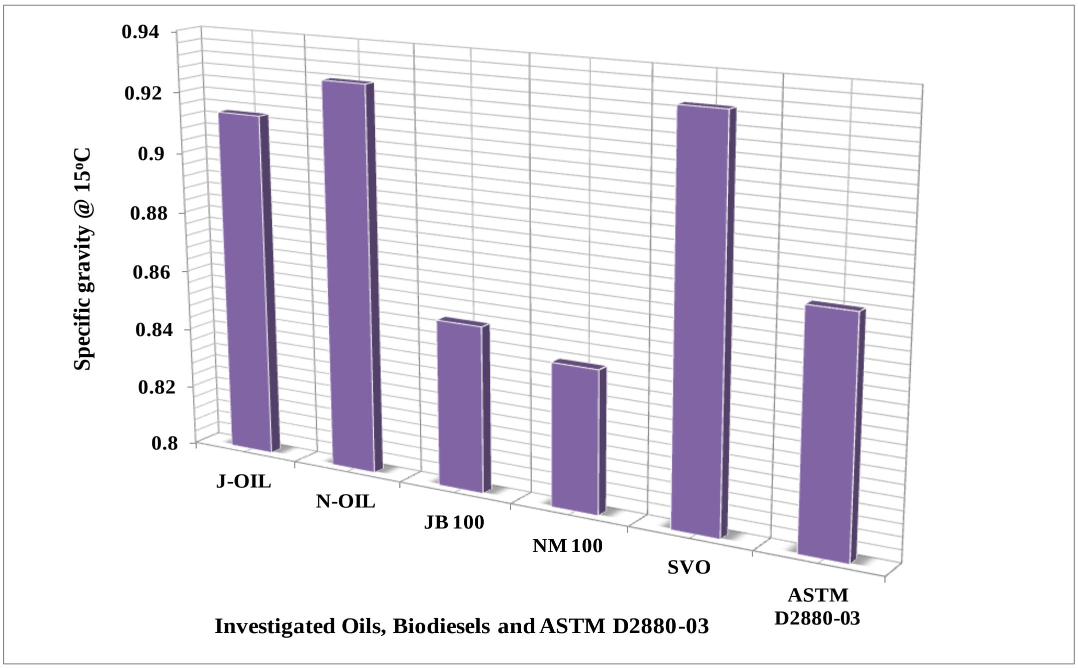

Fig 7: Specific Gravity of the Investigated Oils, Biodiesels and the ASTM 2880-03

Fig 7 shows the graph of the values of the specific gravity deduced from the study. From the figure it can be seen that the specific gravity for the oils is higher than those of the resulting biodiesels. The specific gravity for N-oil is 0.9275 and is slightly higher than that of J-oil found to be 0.9139 but both lower than the Pryde's specification for SVO. In contrast the specific gravity of JB 100, 0.8548 is observed to be slightly greater than that of NM-100, 0.8469. This observation is expected and reveals the effect of the transesterification of the oil. While transesterifying the oils reduced the specific gravity of both oils, the reduction is more pronounced for NM 100. The specific gravity of a fuel is the ratio of the density of the fuel relative to that of water at a specified temperature. It is a crucial and most basic GT fuel property because it is a precursor for a number other fuel properties like LHV, viscosity, and cetane number. Furthermore it determines the quantity of fuel storage and transportation. The values of the specific gravity obtained herein are in good agreement with those published in the literature [23, 24].

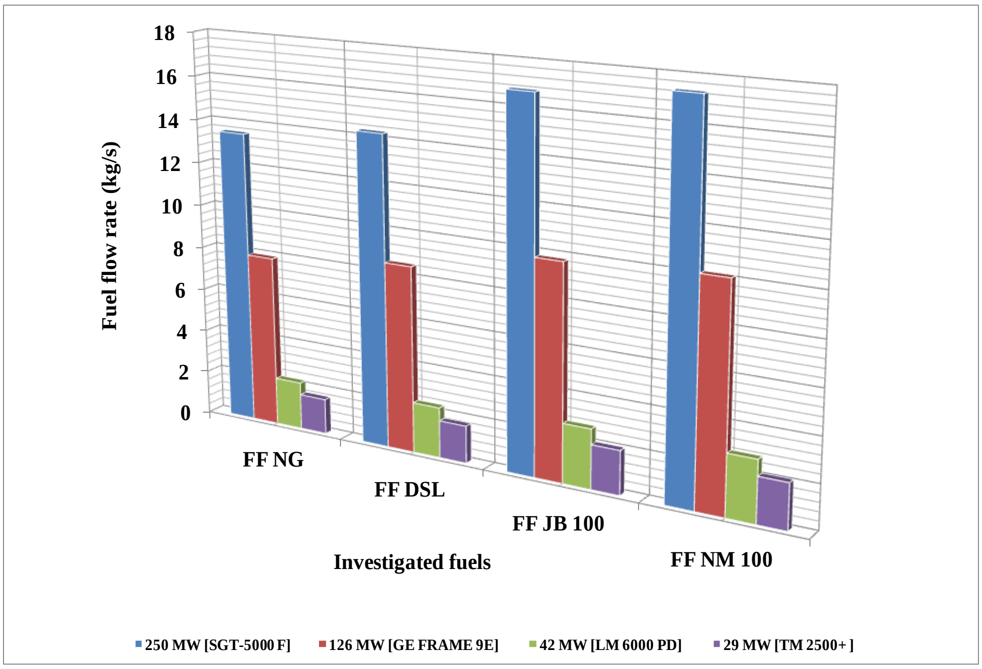

Fig 7 Fuel Flow Rate of the Investigated Fuels for each GT at design point Power Output

The fuel flow rate (FF) of the investigated fuels at the rated megawatt (MW) of each GTE investigated is shown in fig 7. Expectantly higher fuel flow rates were observed for all the engines with the biodiesels compared to diesel and natural gas. It is also observed that the highest fuel flow rate existed in the SGT-5000F 250 MW engine followed by the GE Frame 9E 126 MW then the LM 6000 PD 42 MW and lastly the 29 MW TM 2500+ engine. The observed fuel flow rate pattern is consistent with knowledge available in literature [13, 14]. The bigger the megawatt of the engine, the higher the fuel flow rate. The fuel flow for NM 100 is 17.33 kg/s while those of JB 100, DSL and NG are 16.74, 14.26 and 13.49 kg/s respectively for SGT-5000F. A similar trend is also observed with all the other engines. The obtained results are a reflection of the effect of the inferior LHVs of the biodiesels to that of diesel and natural gas as shown fig 3. Therefore in order to compensate for the energy required for these lower LHV fuels more fuel is added to the system. Similar trends are reported in the literature [12, 14]. Overall, the fuel consumption is higher with JB 100 and highest with the NM 100. Consequently in order to run the GTE with biodiesel the fuel system need to be modified to accommodate the extra mass flow of fuel. Operating the engines solely on the biodiesels has its penalty. More fuel will be required for the same power output as against those of diesel or natural gas for the same engine, and more fuel means more money. Presently biodiesel is costlier than both diesel and natural gas. Therefore it is costlier to run the engines on the biodiesels.

IV. Conclusion

The potential of locally sourced J-Oil and N-Oil as prospective fuels for the GTE was investigated. The oils were trransesterfied to biodiesel and the physicochemical properties of the oils and biodiesels evaluated using the American Oil Chemists' Society. The result of the properties was compared with the ASTMB standard while that of vegetable oil was compared with the Pryde's specification for straight vegetable oil (SVO). Though the specific gravity value of the SVOs met the allowable limits the viscosities were rather too high. However transesterifying the oils, reduced these values to the ones that meet the requirement of ASTMB. The specific gravities and viscosity of the biodiesels were further compared with the ASTM D2880-03 GTE fuel oil (NO. 2 GT fuel oil) standard. The specific gravities of the biodiesels met the ASTM D2880-03 limit while the viscosities were found to marginally exceed the maximum viscosity specified. The fuels could be treated with additives or blended with petroleum diesel to improve the viscosities and make them fit for the GTE. Furthermore the fuel flow rate analysis conducted on selected engines at their rated power output revealed increased fuel flow rates over diesel and natural gas. Biodiesel is an environmentally friendly fuel. Its adoption in the fuel mix for the GTE in Nigeria will not only reduce the pressure on fossil fuels but cut down on exhaust pollutant emissions significantly though not without trade-off of increased fuel flow rate. From the forgone discussion, it is obvious that the fuel system of the engines require modification to accommodate the increased fuel flow.

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