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Physiochemical Characterization of Blends of Diesel-like Fuel Produced from Pyrolysis Distillation of Waste Engine Oil

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Abstract

This research is based on the physiochemical (mechanical and chemical) analysis of blends of diesel-like fuel produced from pyrolysis distillation of waste engine oil. The blends considered in this research are D25, D50 and D75. The experimental results obtained for each of the blends were compared to the ASTM standard values for petroleum diesel and biodiesel respectively. It was proved experimentally that the chemical and mechanical properties such as specific gravity, kinematic viscosity, flash point, cloud point, pour point, sulphur content, oxygen content, carbon content, hydrogen content, calorific value and Cetane number of the respective blends of the diesel-like fuel fall within the ASTM standard values for petroleum diesel (D975-18) and biodiesel (D7467-18) respectively. However, it has been experimentally tested that the D75 blend of the diesel-like fuel is more efficient in characterization based on mechanical and chemical properties compared to the D25 and D50 blends respectively. From this research, it was concluded that D25, D50 and D75 blends of diesel-like fuel can be used as an alternative fuel for compression ignition internal combustion engines with little or no engine modification.

Introduction

Coal was the basic type of fuel used in industries; however technological advancements over the years have led to cheaper, easy-to-process, easy-to-transport, easy-to-mine liquid and gaseous fuels called fossil fuel and natural gas that cater for the world's energy needs (Elizabeth, 2008).

Fossil fuel sources (coal, petroleum, natural gas etc.) play a major role in worldwide energy consumption. They power the transportation, agricultural and industrial sectors. However, problems like the depletion of petroleum resources, fluctuating fuel prices, and environmental concerns over the recent years have paved the way for researchers to develop alternate fuel sources that are cheaper and ecologically/environmentally friendly (Fagbemi, 2001).

There are billions of liters of waste engine oil which are thrown away every year in Nigeria and around the world at large. The numbers are expected to increase due to increasing numbers of vehicles. Waste lubricant fuel has multiple benefits utilization of waste energy sources thereby protecting the environment from toxic and hazardous chemicals, reducing dependence on fossil fuels, less petroleum imports thus improving foreign exchange, and inexhaustible source of energy since itlubricates moving parts in a machine and enhancement of regional development and social structure in developing countries. Waste engine oil is an important type of waste lubricating oil, since it will last as long as the engine exists (Orhea, 2010).

Many countries today solely depend on imports to meet their fuel oil requirements and many more will be added in the future as their limited reserves of petroleum deposits get exhausted. The situation is very grave in developing countries like India which imports 70% of the required fuel, spending 30% of its total foreign exchange earnings on oil imports (Bebeteidoh, 2018). Apart from the problem of fast-vanishing reserves and the irreplaceable nature of fossil fuels, another important aspect of their use is the extent and nature of environmental pollution caused by their combustion in vehicular engines. Increasing energy demand and oil depletion situation encourage the development of renewable energy and alternative fuel technology. The pyrolysis process becomes an option of waste-to-energy technology to deliver diesel-like fuel (i.e., a light hydrocarbon with a carbon chain of C_{14}-C_{19}) to replace fossil fuels.

One gallon of waste oil pollutes millionsof gallons of drinking water hence hampering all kinds of aquatic life and the processes of photosynthesis. Waste lubricating oil contains degraded additives, impurities, and residues resulting from the combustion process like PCB (Poly Chlorinated Biphenyls), or PAH (Poly Aromatic Hydrocarbon). Disposal of used oil into the ground has the potential of polluting land, water, crops and even public health.

Diesel is one of the petroleum products, which is used in all kinds of compression ignition engines as a fuel. It is produced from crude oil by various refining processes, which come out from the oil wells. It is assumed that the source of crude oil will be ruined in future, as the demand for petroleum products is growing at a faster rate day by day. Due to the high cost of crude oil, many countries are facing a big amount of import bill for crude oil every year and the economic structure of such countries is not viable enough to withstand the expenditures. This puts an extra burden on its economy. Based on this, possible measures or attempts should be adopted to increase or to find an alternative way for fuel production so that the world at large can survive the situation.

For the smooth functioning of oils are used for lubrication. After a certain period, these used engine oils are taken off as waste oil; these waste oils are not properly disposed of hence affecting aquatic life and the soil significantly. During lubrication, about 20% of the lubricating oil is burnt and the rest 80% is left unburnt with impurities, tiny iron particles due to wear and tire and dirt settled in it. Due to the scarcity of petroleum products, these used or wasted engine oils can be used in engines as diesel-like fuel after undergoing purification and treatment processes. Production of diesel-like fuel from used engine oil involves physical, chemical and blending processes. According to Enweremadu and Rutto (2010), a blended fuel sample of diesel-like fuel is cleaner and contains less harmful products than clear low-sulphur diesel. They also found that the blended fuel had good lubricating properties and the acidity level was below detectable limits. Thus, there is a great scope to utilize these waste-used engine oils in a better way which would help decrease environmental liability, save waste oil disposal fees and reduce the burden of fuel import and scarcity.

Waste engine oil is an organic compound which consists of hydrocarbon, solvents as additives whose main purpose is to increase its viscosity and heavy metal; it also contains soot, polycyclic aromatic hydrocarbons, chlorinated paraffin and polychlorinated biphenyls (Dermibas, 2006).

Pyrolysis Distillation

Pyrolysis is a thermo-chemical decomposition of organic material at elevated temperatures without the participation of oxygen. It involves the simultaneous change of chemical composition and physical phase and is irreversible (Dermibas, 2008). The word ‘Pyrolysis’ is coined from the Greek word pyro meaning ‘fire’ and lysis meaning ‘separating’ hence Pyrolysis is a case of thermolysis and it is most commonly used for organic materials, being, one of the processes involved in charring. The Pyrolysis of wood, which starts at 200–300ºC, occurs for example in fire where solid fuels are burnt or when vegetation comes in contact with lava in volcanic eruptions. In general, Pyrolysis of organic substances produces gas and liquid products and leaves a solid residue richer in carbon content, char. Extreme Pyrolysis, which leaves mostly carbon as the residue, is called carbonation. The process is used heavily in the chemical industry, for example, to produce charcoal, activated carbon, methanol, and other chemicals from wood, to convert ethylene dichloride into vinyl chloride to make PVC, to produce coke from coal, to convert biomass into synthetic gas and biochar, to turn waste into safely disposable substances, and for transforming medium-weight hydrocarbons from oil into lighter ones like gasoline.

Diesel-like fuel is a lighter aromatic acyclic hydrocarbon with a carbon-to-carbon chain ranging from 14-19 whereas fossil diesel is a heavy aromatic acyclic hydrocarbon with a carbon-to-carbon chain ranging from 19 - 24 hence they are unsaturated with a straight carbon-carbon chain (Fuentes, 2007).

This research work is based on comparing the mechanical characteristics/properties of diesel and diesel-like fuel and its blends generated from waste engine oil by Pyrolysis distillation on a multi-purpose compression ignition engine to ascertain their performances as best replacement for fossil diesel since fossil diesel is environmentally unfriendly. These properties are engine torque, engine brake power, brake-specific fuel consumption and brake thermal efficiency.

Materials and Methods

Waste engine oil was collected from an automobile workshop in Port Harcourt, Rivers state, Nigeria for the production of the diesel-like fuel. For this research, the production of diesel-like fuel (i.e.,light-saturated acyclic) hydrocarbon, (C_{14}-C_{19}) from waste lubricating oil is achieved through the following phases:

- Physical phase
- Chemical treatment phase-basicity stage and acidification stage
- Distillation phase

Physical Phase

This phase has to do with the removal of dirt from the waste engine oil and the acidification of the filtered waste engine oil.

The physical phase is categorized into the following phases-filtration and acidification stages.

In the filtration phase, the waste engine oil (SAE-40) of light-duty vehicles gotten from a mechanic workshop is first sieved with a sieve size of about 2-5um to filter the oil from dirt, gums and metal particles settled in it due to wear and tire.

Chemical Treatment Phase

The sieved oil is then added about 7-8% by volume of concentrated sodium hydroxide (NaOH) to quicken sedimentation. The diesel is stirred and allowed to settle for about 2-3 hours after the addition of NaOH after which the oil is decanted and the sludge removed.

Distillation Phase

The physically purified waste engine oil is then poured into the Pyrolysis distillation chamber, stirred for about 30 minutes and allowed to distillate by the application of heat energy as shown in the diagram above.

The distillate is allowed to cool for about an hour after which it is blended. Mechanical and chemical characterization of the blended diesel-like fuels is then tested in the laboratory to obtain characterization data. The data obtained are compared with ASTM standard values for both petroleum diesel and biodiesel.

The respective blends are then tested in a science laboratory in Port Harcourt where their respective physiochemical characterizations are obtained.

The blends of the produced diesel-like fuel considered in this research are D25, D50 and D75.

Results and Discussion

Mechanical and Chemical Characterization of the Produced Diesel-like Fuel

Physical and chemical characterization was carried out on the produced diesel-like fuel on their respective blends. The properties studied are specific gravity, flash point, kinematic viscosity, cloud point, pour point, sulphur content, oxygen content, carbon content, hydrogen content, calorific value and Cetane Number.

The data obtained from the characterization test is tabulated in Table 1.

Table 1: Comparison between the mechanical and chemical properties of the produced blended diesel-like fuels with the ASTM standard recommendations

	Blends of Diesel-like fuel			
Properties	**D25**	**D50**	**D75**	**ASTM Standard (D7467-18)**
Specific gravity (kg/l)	0.86	0.87	0.89	0.88
Kinematic viscosity (mm^2/s)	3.2	3.26	3.28	1.9 to 6.0
Flashpoint (°C)	147	151	154	130
Cloud point (°C)	5	7	9	3 to 12
Pour point (°C)	5.24	5.87	6.94	5 to 10
Sulphur content (ppm)	8.4	8.49	8.58	less than 10
Oxygen content	4	6	11	8
Carbon content (wt. %)	69.4	70	73	100
Hydrogen content	9.4	9.6	9.67	10
Calorific Value (kJ/kg)	39,117	39,450	39,820	37,250-45,620
Cetane Number	52.6	54.6	55.8	52-56

Table 2 below gives the summarized values of the ASTM standards for petroleum diesel and biodiesel respectively.

Table 2: Mechanical and chemical properties of the ASTM recommended standard values for petroleum diesel and bio-diesel.

Properties	ASTM Petroleum Diesel (D975-18)	ASTM Bio-diesel (D7467-18)
Specific gravity (kg/l)	0.85	0.87 to 0.90
Kinematic viscosity (mm^2/s)	3.1	1.9 to 6.0
Flashpoint (°C)	60 to 80	100
Cloud point (°C)	-20	100 to 70
Pour point (°C)	7.10	7.24
Sulphur content (ppm)	8.6	8.64
Oxygen content	8.2	8
Carbon content (wt. %)	87	100
Hydrogen content	9.83	9.81
Calorific Value (KJ/Kg)	45,420	42,120
Cetane Number	55	54

From Table 1, it is clear that some of the properties of the blends of the produced diesel-like fuel considered in this research fell within the ASTM recommended range of values. These properties are specific gravity, kinematic viscosity, pour point, cloud point, and Cetane Number. The flash points of the blends of the diesel-like fuel are 147, 151 and 154 for D25, D50, and D75 respectively, which is slightly higher than the 130 ASTM standard recommended values. The calorific value of the produced blends of diesel-like fuel is slightly higher than the standard value. Oxygen and hydrogen content values are close to the ASTM standard values, while the carbon and sulphur contents of the produced diesel-like fuel blends are lower than the ASTM standard recommendations.

Analysis of the Physiochemical Properties of the Diesel-Like Fuel Blends

Specific Gravity

This is the ratio of the density of the diesel-like fuel blends to the density of the ASTM standard recommended values for petroleum diesel.

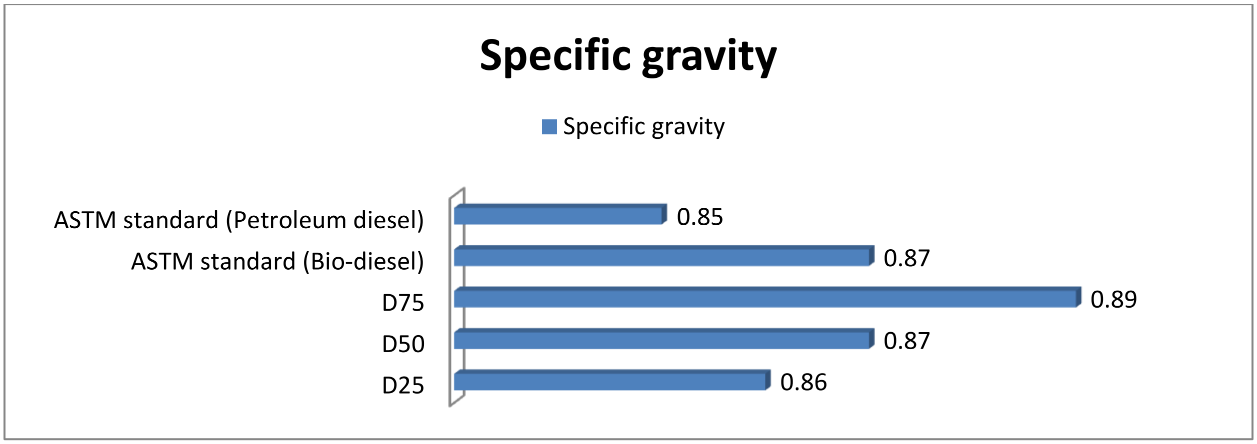

Figure 1: Specific gravity of various blends of diesel-like fuel against ASTM standards of petroleum diesel and biodiesel.

The specific gravity recorded for the produced diesel-like fuel blends is higher than that obtained for petroleum diesel. According to ASTM D975-18, the specific gravity for petroleum is 0.85, while for the blends of the produced diesel-like fuel; we have them as 0.86, 0.87 and 0.89 for D25, D50 and D75 respectively. It is observed that D25 and D50 have a lower specific gravity value. Figure 1 shows a chart of produced blends of diesel-like fuels, ASTM standard value for bio-diesel and petroleum diesel against their various recorded specific gravities.

Kinematic Viscosity

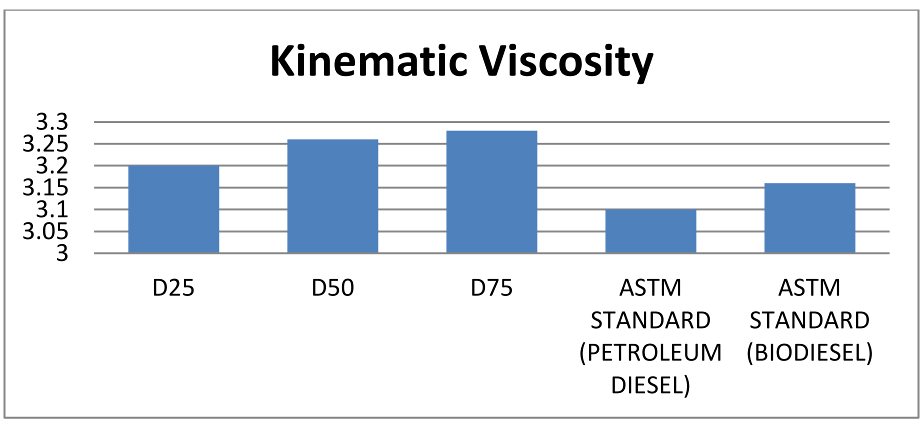

Figure 2: Kinematic viscosity of various blends of diesel-like fuel against ASTM standards of petroleum diesel and biodiesel.

Kinematic viscosity is a measure of a fluid's internal resistance to flow under gravitational forces. It is determined by measuring the time in seconds, required for a fixed volume of fluid to flow a known distance by gravity through a capillary within a calibrated viscometer at a closely controlled temperature.

Figure 2 shows that the blends of the produced diesel-like fuel have higher kinematic viscosity than that of petroleum fuel and bio-diesel fuel. D75 has the highest kinematic viscosity, followed by D50 and lastly by D25.

Carbon Content

Carbon content is the carbon (IV) oxide equivalent that is released through the combustion or oxidation of a fossil fuel, or that is associated with the combustion or oxidation of a fuel used for power generation.

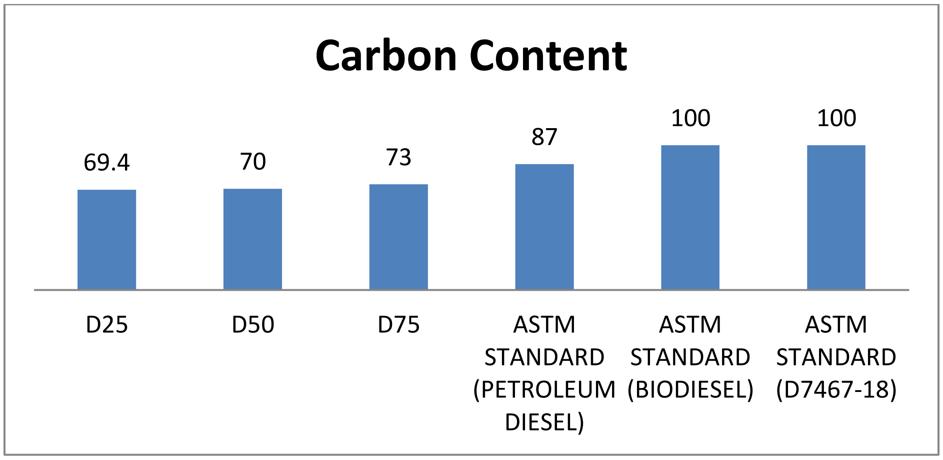

Figure 3: Carbon Content for various blends of diesel-like fuel, ASTM standard for petroleum and biodiesel fuel.

From Figure 3, it is experimentally clear that petroleum diesel reflected the most carbon content when compared to the various blends of the produced diesel-like fuel and the ASTM standard for biodiesel. D75 blend has higher carbon content than the D25 and D50 fuels respectively, but significantly lower than petroleum diesel. The implication of lower carbon content is the reduction of residues which clog the fuel injectors and injection pumps of internal combustion engines.

Cloud Point

The cloud point of a diesel fuel is the temperature below which wax forms giving the fuel a cloudy appearance. This parameter is an important property of the fuel since the presence of solidified waxes can clog filters and negatively impact engine performance.

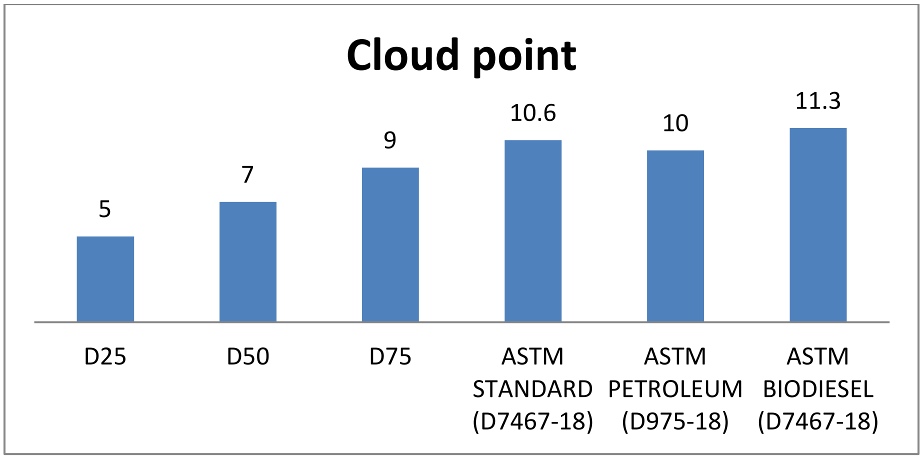

Figure 4: Comparison between cloud points of various blends of produced diesel-like fuels against ASTM standard values for fuels**.**

In Figure 4, it is clear that petroleum diesel depicted a cloud point 10 whereas the blends of diesel-like fuel had 5, 7 and 9 respectively for D25, D50 and D75.

Flash Point

The flash point is the lowest temperature at which a liquid can form an ignitable mixture in air. It means that at this par temperature, the fuel can be ignited or burnt. A flash point does not play a major role in a diesel engine but is quite an important factor in a spark ignition engine. Having a high flash point indicates you have a lower fire hazard when exposed to a high-temperature heat source.

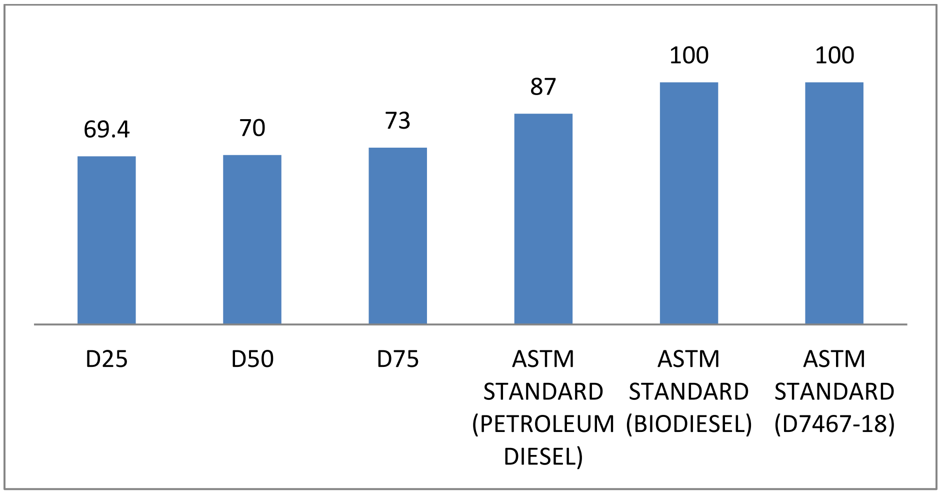

Figure 5: Comparison of flash points of blends of diesel-like fuels with ASTM standard values.

The flash point is the lowest temperature in which a fuel will form a vapour in the air near its surface that will flash or briefly ignite, on exposure to an open flame. The flash point is a general indication of the flammability or combustibility of a fuel.

Figure 5 indicates that the blend of the diesel-like fuels has the highest flash point as compared to the ASTM standard values for petroleum diesel and biodiesel.

Cetane Number

The Cetane Number of a diesel is a quality indicating the ignition properties of diesel fuel relative to Cetane as a standard.

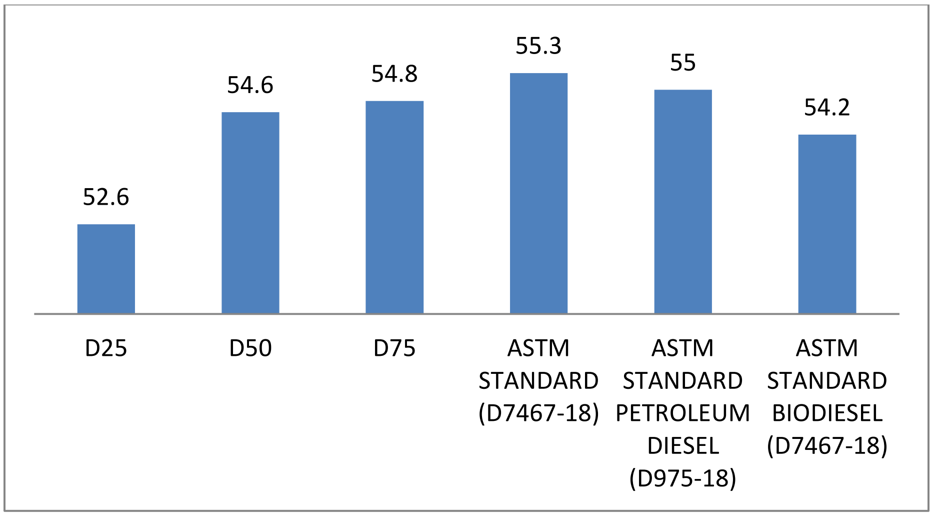

Figure 6: Comparison of Cetane Number of blends of diesel-like fuels with ASTM standard values and ASTM standard values for fossil fuel and biodiesel.

The comparison of the cetane number of the blends of diesel-like fuel with the ASTM standards for fuels is shown in Figure 6 above; the Cetane Number of the blends of the diesel-like fuels are very close to the ASTM standard values for fossil fuel and biodiesel fuel. However, is proven that D75 has a higher cetane number compared to D50 and D25.

Sulphur Content

This is expressed as the amount of sulphur present in diesel. After combustion, sulphur from diesel fuel creates sulphuric acid that causes corrosive wear on the metal surfaces of the engine.

This implies that the lower the sulphur contents of the fuel, the better the performance of the fuel on an engine. From Figure 7, it is clear that D25 will have less corrosive wear compared to D50 and other fuels. However, the sulphur content values of D25, D50 and D75 fall within the ASTM standard values for petroleum diesel and biodiesel.

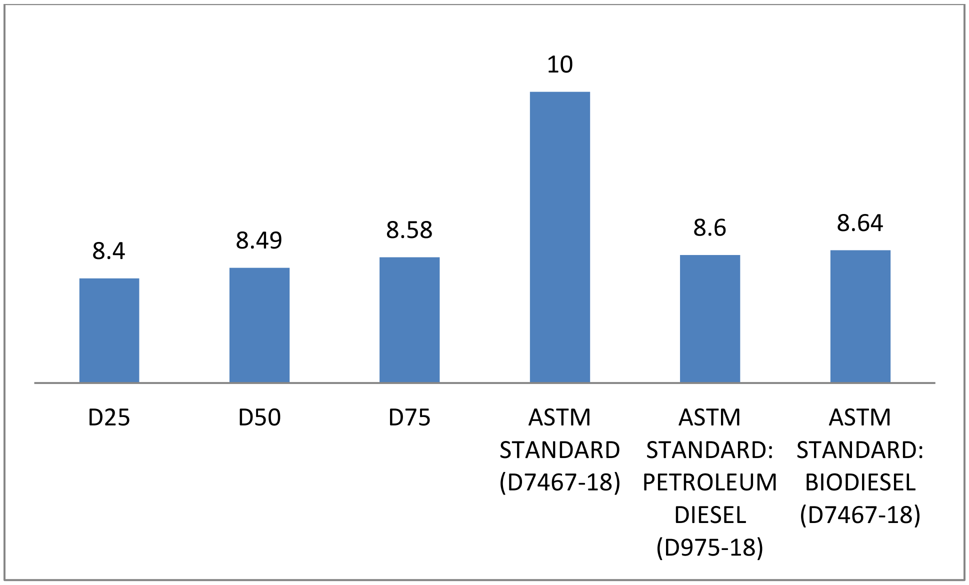

Figure 7: Comparison of Sulphur content of blends of diesel-like fuels with ASTM standard values and ASTM standard values for fossil fuel and biodiesel.

Figure 7 reveals that petroleum diesel has the highest sulphur content compared to the blends of the diesel-like fuel produced through pyrolytic distillation. D75 has the highest sulphur content compared to other blends. However, their sulphur contents are in the same range as the ASTM standard value for all fuels.

Calorific Value

Calorific value is the amount of heat energy released during the complete combustion of a unit mass of fuel. Higher calorific values, give higher engine performance.

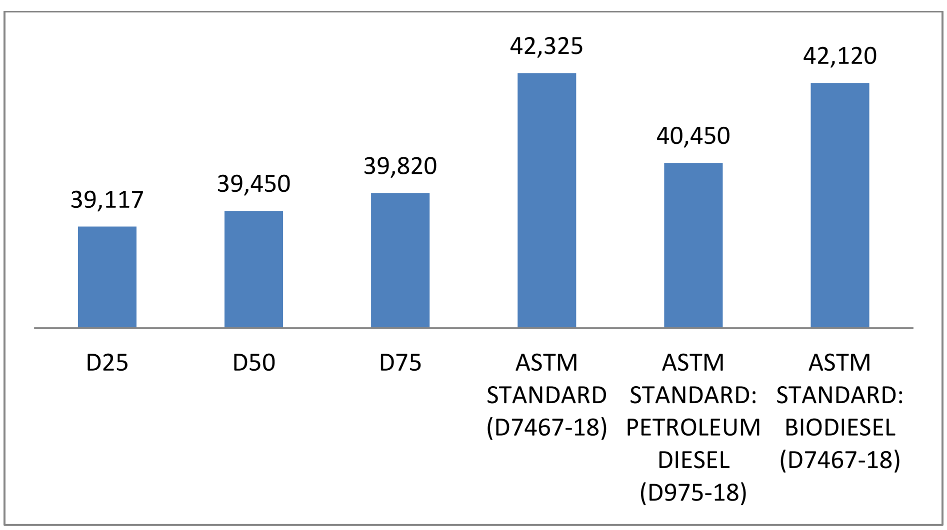

Figure 8: Comparison of Calorific value of blends of diesel-like fuels with ASTM standard values and ASTM standard values for fossil fuel and biodiesel.

The calorific value of petroleum diesel and biodiesel at ASTM standard values are higher than that of the blends of the produced diesel-like fuels. The calorific value of D75 is slightly close to the value of petroleum diesel compared to D50 and D25 respectively. However, the value range of the blends of diesel-like fuels falls within the range values for the ASTM standard values for combustion fuels.

Pour Point

The pour point is the temperature below which the diesel becomes plastic and will not flow. It represents the lowest temperature at which the oil is capable of flowing under gravity. It is one of the important low-temperature characteristics of high boiling fractions. A lower pour point is more desirable.

Of all the blends of the produced diesel-like fuels, D25 is the lowest thus, its pour point is most desirable compared to biodiesel and petroleum diesel.

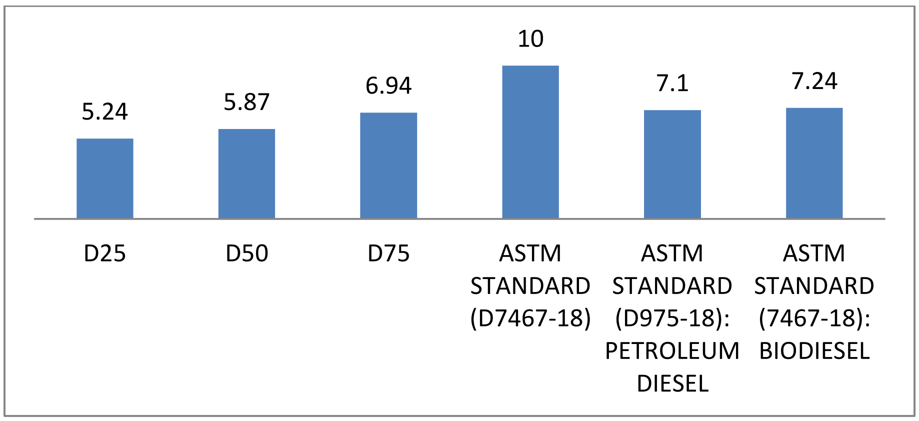

Figure 9: Comparison of pour point of blends of diesel-like fuels with ASTM standard values and ASTM standard values for fossil fuel and biodiesel.

Oxygen content

An increase in oxygen content leads to faster burn rates and the ability of the fuel to burn more fuel at the same time stochiometry (oxygen to fuel ratio). These effects also have the potential to increase the thermal efficiency and specific power output of the diesel engine.

From Figure 10 above, the oxygen content of D75 is closer to the ASTM standard value. The values of D25 and D50 were not close to the ASTM recommendation values for petroleum diesel and biodiesel.

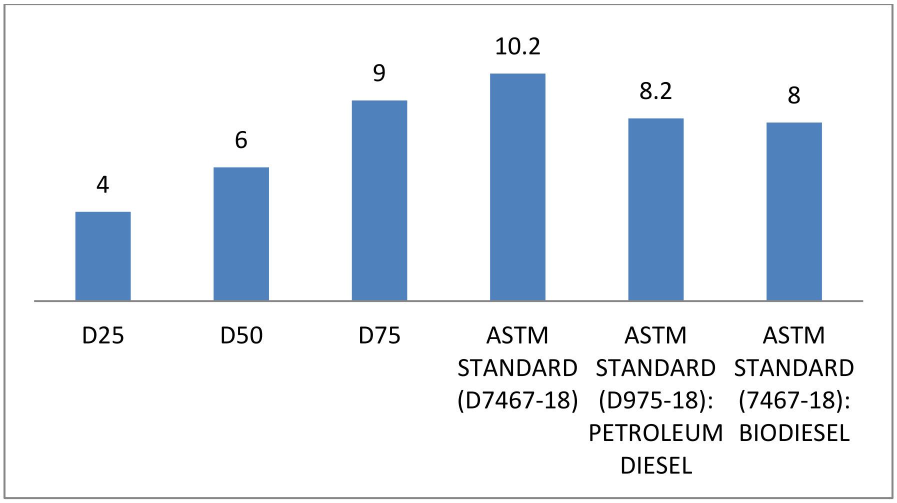

Figure 10: Comparison of oxygen content of blends of diesel-like fuels with ASTM standard values and ASTM standard values for fossil fuel and biodiesel.

Hydrogen content

The heat of combustion of a hydrocarbon fuel is directly affected by its hydrogen content. Hydrogen oxidation liberates more energy than carbon oxidation. Thus, the higher the hydrogen contents of the fuel, the higher the fuel's heat of combustion. In Figure 11 below, it is clear that the hydrogen content of the diesel-like fuels is approximately equal to that of the ASTM standard values for petroleum diesel and biodiesel respectively.

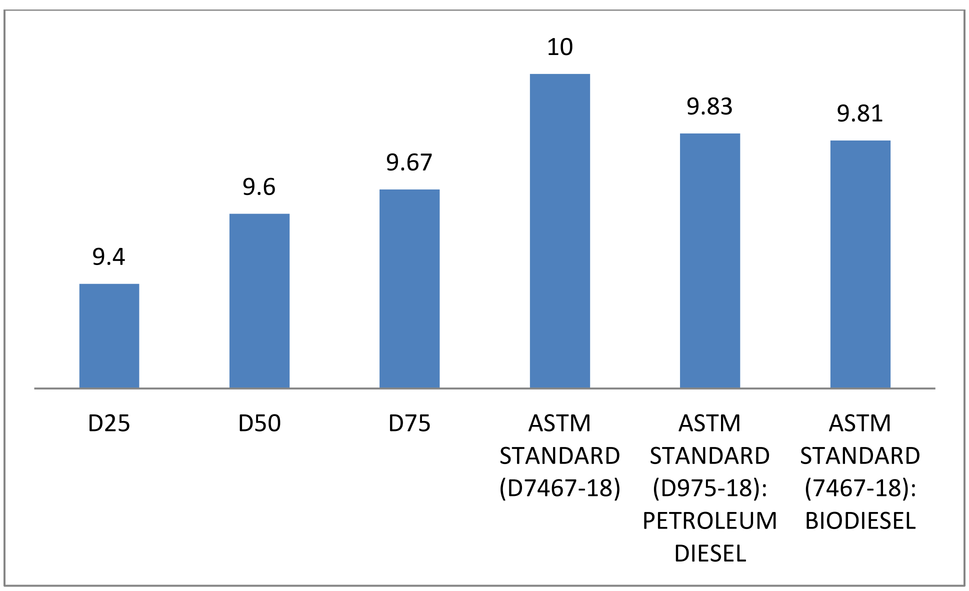

Figure 11: Comparison of hydrogen content of blends of diesel-like fuels with ASTM standard values and ASTM standard values for fossil fuel and biodiesel.

Conclusion

In Nigeria, there is an ever-increasing use of fuels for transportation (land, sea and air) and this has led to a rise in the price of fossil fuel. This high usage of fossil fuels has led to climate change, ozone layer depletion, environmental pollution etc., thus there is a serious demand for a green environment. This demands the use of renewable energy sources for a more sustainable energy solution.

Based on the above findings, this research presents the following conclusions:

- Diesel-like fuel can be produced from pyrolysis distillation of waste engine oil.
- The blends of diesel-like fuel produced revealed better mechanical and chemical properties in line with ASTM recommendation standards compared to fossil fuel and biodiesel.
- The blended diesel-like fuel produced depicted better emission properties than petroleum diesel, hence commercial production should be encouraged.
- Blended diesel-like fuels can be used to drive internal combustion engines with little or no engine modifications.

Furthermore, depending on fossil fuel alone is no longer realistic due to the global depletion of non-renewable energy resources. Its impact on the environment has led to global warming due to ozone layer depletion. The pace for energy conservation and security in the face of an imminent oil shortage is already gathering momentum.

This research work strongly recommends that a lot of studies should be done to suggest approaches tothe conversion of waste engine oil to diesel-like fuels to reduce the cost of production and enhance production efficiency.

References

1. Bebeteidoh, O.L., Makpah, D.E., and Barnabas, A.O. (2018). Physiochemical characterization of B20 biodiesel from Arachis Hypogea Oil as Alternative fuel for marine diesel engine. International Journal of Recent Trends in Engineering and Research, 16(4), 188-196.
2. Orhea A., Recep, Y., and Ayhan D. (2010). Production of diesel-like fuel from waste engine oil by pyrolytic distillation. International journal of applied energy, 86(1), 122-127.
3. Elizabeth J., Chemical characterization of biofuel blends generated from transesterification of groundnut oil. International journal of science, engineering and technology, 54(4),108-116.
4. Enwerenmadu, D.L., and Ruto, M.O. (2010). Internal Combustion engine performance testing of biodiesel blends from castor seed oil. 87 (5), 185-192.
5. Demirbas A. Biodiesel production via non-catalytic SCF method and biodiesel fuel characteristics. Energy Convers Manage 2006; 47: 2271-82.
6. Fuentes M.J, Font R, Gomez –Rico MF, Martin-Gullon I. Pyrolysis and combustion of waste lubricant oil from diesel cars: decomposition and pollutants. J Anal Appl Pyrolysis 2007; 79:215-26
7. Demirbas MF. Pyrolysis of vegetable oil and animal fat for the production of renewable fuels. Energy Educat Sci Technol 2008; 22:59-67
8. Fagbemi L, Khezami L, Capart R. Pyrolysis products from different biomasses: application to the thermal cracking of tar. Appl Energy 2001; 69:293-306
9. Bhaskar T, Uddin M.A, Muto A. Recycling of waste lubricant oil into chemical feedstock or fuel oil over supported iron oxide catalysts. Fuel 2004; 83:9-15.