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# CHARACTERIZATION OF PETROL, ETHANOL AND SPENT ENGINE OIL BLENDS FOR TWO-STROKE SINGLE-CYLINDER SPARK-IGNITION ENGINE

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## Abstract

*This research has provided additional information to conduct performance evaluation of petrol, ethanol and spent engine oil using various mix ratio of sample 0 (98%:00:02%) as control, A (89%:09%02%), B (93%:05%:02%) and C (91%:07%:02%) fueled single-cylinder spark-ignition (SI) engine for power generation and other similar services. Specifically, at load of $0.4kW$, $2353Rpm$, brake power of $0.65kW$, brake mean effective pressure of $254.8kN/m^2$ was obtained. However, carbon-dioxide emission was quite appreciable at 0.7kW load at 5% ethanol blend which produces 21.5%. Emission characterization shows that emission of CO and HC are eco-friendlier when blended with cassava-ethanol, however, due to higher temperature of combustion as the potency of the spent oil is increased, more $NO_x$ are likely to be formed. When the quantity of air supplied and thus, oxygen is completely utilized that is, combustion is stoichiometric, the use of spent oil is advisable for high speed two-stroke engines with fines and other heat dissipation systems modified to handle high temperature, otherwise, operation control systems should be incorporated to restrict the limit of loss of viscosity for the oil to be changed. The presence of lower $CO$ with fuel blend spent oil and ethanol as well as increase in the amount of $CO_2$ emitted with increase in engine load shows the presence of high carbons in the mixture. Hence the use of spent oil and ethanol as blends is on average beneficent to human and vegetation as reported in [25, 29].*

## 1.0 INTRODUCTION

Internal Combustion Engines (ICE), are heat engines in which fuels are combusted inside an enclosure to produce power. In reciprocating type, a piston-cylinder arrangement provides the required enclosure and operation dynamics for the production and transfer of power to the output shaft [1]. Base on their working cycle are classified as four-stroke and two-stroke engines. While four-stroke engines complete a power cycle in two revolution of the crankshaft or in a cycle of four piston strokes (Suction, Compression, Power and Exhaust Stroke), the two-stroke engines complete its power cycle with two strokes of the piston (Compression and Power Stroke) during one crankshaft revolution [1].

Two-stroke engines are largely needed for different mini operations like hand operations in agriculture, building services, aeronautic, among others, due to their higher power to weight ratio [2]. ICEs are believed to stay long enough that necessitate the need for alternative environmentally friendly fuels and re-

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engineering of the engine systems for better performance and lower emission [3, 4, 5]. Thus, has resulted in blending of several fuel of different chemistry which has been tried on alternative engines. The resultant fuel mixture has a different organic structure from the constituents' organic structures. This alteration in organic structure of the resultant blends can have substantial impact on engine performance, safety of thermodynamic operation and the immediate environment. This work focuses on the magnitude of such impact where petrol, ethanol and spent engine oil are blended and used in single cylinder two stroke spark ignition engine, like the Suziiou engine model b T1987 T1400. Engineering Schools have continued to study IC engines to improve their efficiencies on one hand and minimize their negative impacts as well, which is mainly due to their diverse needs in our societies [4].

Lubricating oil is a vital component of engine working fluid [6] used in two-stroke SI engine by "mist lubrication" process [7]. Based on manufactures recommendation vehicles and engine equipment are usually serviced after some specified hours of operation due to contamination from dirt, water, salt, and metal wears. This leads to deterioration of lubricant properties [7, 8] and thus, such oil is called spent or waste engine oil. If undisturbed, the oil settles down at the crankcase and becomes hardened, thereby affecting the crankcase compression ratio. The oil has a carbon molecule of between $C_{15}$ – $C_{50}$. Its chemical constituent depends on the refining process, the crude oil source, engine operation, fuel additives and its resident time in the engine [9, 10]. Spent engine oil constitutes about 73 – 80% weight/weight aliphatic, 11 – 15% monoaromatic, 4 – 8% polyaromatic and 2 – 5% diaromatic hydrocarbon as reported by [10].

Improper disposal or handling of spent engine oil can result to soil and water pollution, and it is reported [10] to slow down thermal degradation processes. However, spent engine oil still contains a large proportion of valuable base oil that may be used to formulate a new lubricant after the undesirable pollutants are removed through recycling process [11]. Ethanol is commonly produced from feedstock with high starch or sugar content. The process of making for example, Manihot esculenta into ethanol involves some steps as presented [12], it starts by milling and liquefaction of cassava to breaking down starch molecules into its building block of glucose molecules using enzymes. This is followed by fermentation which involves conversion of glucose into ethanol using yeast. Then, the content is passed through distillation process to separate the ethanol from other reaction product and inert materials. Finally, the product is blended with petrol to serve as useful fuels in automotive engines. The quantity of starch for ethanol production is dependent on storage temperature. It also degrades with resident time in the storage losing about 5% starch yield during a resident time of 8 months in storage [11]. Availability is a big factor that promotes the tendency of using ethanol as cassava can be grown and harvested throughout the year, thus providing steady supply for ethanol production [11].

In future, cellulosic biomass such as trees and grasses, particularly from agricultural by-products can provide alternative fuel source with near zero emission as they exhaust the carbon dioxide ($CO_2$) present in their production [12]. The chemical formula for Ethanol is $CH_3CH_2OH$. It contains molecules with a hydroxyl group OH bonded to a carbon atom. The oxygen content of this group favors further combustion of gasoline [12]. Typically, the physiochemical properties of interest fuel blends include volatility, research octane number and fuel density, torque, specific fuel consumption, and emission as contained in [1]. The use of biomass as alternative fuel has led to development of flexible fuel vehicle technologies in which ethanol-gasoline blend range as high as $E_{85}$ to $E_{100}$ is achieved. In advanced countries, flexible fuel technologies with high ethanol components is already substantially in use, while in some developing countries like India, $E_{10}$ is mandated on light duty vehicles as short run targets [12].

United Nations foods and agriculture organization (FAO) rates Nigeria as the largest producer of Manihot esculenta with about 34 million tons [13]. Further processing of Manihot esculenta to ethanol will lead to rural employment opportunity [14] and decreasing emission from ICEs. It is ecofriendly as it produces lower CO and HC and influences the ICEs performance with higher evaporation heat, octane number and flammability [15, 16].

## 2.0 MATERIAL SPECIFICATIONS

In the course of this work, Table 1 and Table 2 shows the materials for filtration oft the spent engine oil and the fuel blend laboratory test and the test engine specification.

**Table 1:** Materials

| S/N | Materials | Specification | Description |
|---|---|---|---|
| 1 | Ethanol | 4 liters 0.79gm/cc | Processed from Manihot esculenta |
| 2 | Lubricant | 10 liters | New and Used engine oil |
| 3 | Petrol (PMS) | 4 liters, 0.75gm/cc | Bought from filling station |

| | | | |
|---|---|---|---|
| 4 | Filter paper | 4 pieces of Tissue paper (100 by 120 mm, 2 ply) | Filter spent engine oil |
| 5 | Waste jar | 4 liters | Filter and collect spent oil |
| 6 | Beakers and measuring cylinder | 250 ml | Measuring fuel blends |
| 7 | Plastic Measuring cylinder | 1000 and 100 ml | Fuel and oil measurement |
| 8 | Kegs | 8 pieces of 2.5 liters each | Taking fuel blend samples |
| 9 | Thermometer | 0 ~ 100$^0$C | Temperature reading |
| 10 | Hydrometer | 0.7 ~ 0.75 ml | Determine specific density of the fuel |
| 11 | Chronicle Flask | 250 ml | For storing various blend samples |

**Table 2:** Test engine specification

| S/N | Description | Specification |
|---|---|---|
| 1 | SUZIIOU T1981 Generator engine | Two-stroke single-cylinder SI engine |
| 2 | Number of cylinder / phases | 1/single |
| 3 | Maximum power (P) | 650 VA |
| 4 | Bore mm | 45 |
| 5 | Stroke mm | 40 |
| 6 | Fuel mix ratio | 50: 00: 01 |
| 7 | Starting system | Manual |
| 8 | Net weight | 17.5kg |

## 3.0 METHODS

The chart Figure 1 below shows a graphical presentation of sequence of activities taken in the course of carrying out this experimentation.

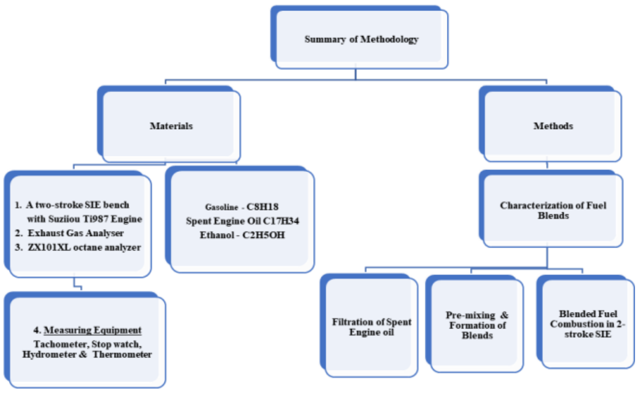



**Figure 1:** Materials and methods flow chart

### 3.1 Characterization of Fuel Blends

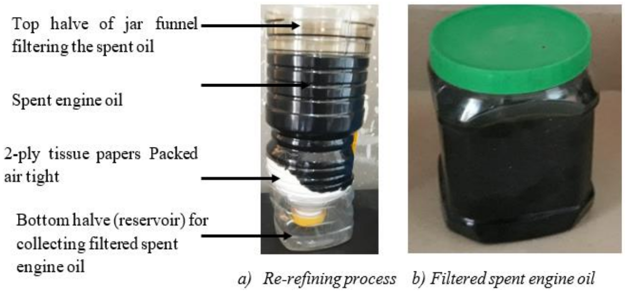
The fuel characterization test was carried out in SIS Laboratory, Lagos, using America Standard Testing Method (ASTM). Five parameters were tested to enable us know the properties of the blended fuel samples, these parameters as stated in Table 3 and results as stated in the Appendix (Table 1A).

**Table 3:** Five parameters tested using standard test methods

| S/N | Test Description | Test Method | Equipment/Procedure |
|---|---|---|---|
| 1 | Mixed oil density | ASTM D1298 [16] | Hydrometer, thermometer and volume correction factor table [18] for corresponding density. |
| 2 | Volatility | ASTM D86 [17] | Distillation bath |
| 3 | Research Octane number | ASTM D2699 [20] | ZX101XL octane fuel analyzer |
| 4 | Motor Octane number | ASTM D2700 [21] | ZX101XL octane fuel analyzer |
| 5 | Particle contamination & Moisture Content | ASTM D4176 [19] | Chronicle flask |

#### 3.1.1 Filtration of spent engine oil

Using the material as listed in Table 1. Filtration of spent engine oil began by using the top of the transversely cut container as funnel and the bottom serves as the reservoir as seen in Figure 2. And at the cover cap, four orifices 5mm were bore in the cover to allow for the filtered spent oil to drain into the reservoir. The funnel was stocked with four pieces of double-ply tissue papers packed air tight to eliminate all forms of voids thus preventing the oil slipping between the tissue papers and the filtration funnel without been filtered. The process was carried out at a temperature of 20°C for proper filtration, as high temperature reduces viscosity and thus, increases the chances of oil slipping through walls [23].




*a) Re-refining process* *b) Filtered spent engine oil*

**Figure 2:** Re-refining process of spent or used engine oil

#### 3.1.2 Fuel blend laboratory test

For the laboratory test, four categories of samples were prepared and labeled as O (0 % ethanol) as control, A (9 % ethanol), B (7 % ethanol) and C (5 % ethanol). Each of the samples has a volume of 250 $ml$. The percentage split is as shown in Table 5. And since we do not intend to make any critical modification on the test engine designs, the percentage volume of ethanol was also limited to maximum of 9 %, because of ethanol volatility and high temperature, and in other for this experiment not to result in damage of this test engine.

The list of apparatus used are as stated in Table 4. Using measuring cylinder, each sample were stored in a cooked chronicle flask. before the laboratory test was carried out to determine the fuel blend samples characteristics which includes; density, volatility, RON, MON, moisture content, particle contamina-tion, appearance, odour and color.

**Table 4:** Laboratory test apparatus/equipment

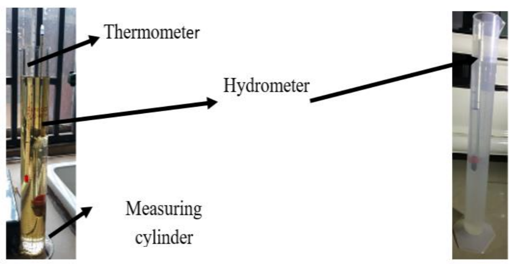
| S/N | Fuel testing Equipment | Specification | Description |
|---|---|---|---|
| 1 | Thermometer | 0 ~ 100 ºC | Reads temperature |
| 2 | Hydrometer | 0.7 ~ 0.75 ml | Reads specific density |
| 3 | Measuring cylinder plastic | 250 and 100ml | For taking fuel samples |
| 4 | Fuel (petrol and ethanol) | 1000 and 250ml respectively | Fuel samples |
| 6 | Calibrated measuring cylinder | 1000ml | As fuel tank |

### *A. Density of petrol, ethanol and spent engine oil:*

Density is a very key factor in determining the price and quality of petroleum products [17], and the ASTM D1298 test procedures [17] was used. This begins with sterilization of each measuring cylinders using each fuel blend, thereafter the measuring cylinders were filled with 250ml of each fuel blend, in mix ratios as specified in Table 5, it was stirred and left for about 12hours to attain homogeneous mixture. The laboratory test then began the following morning for each mix ratio of sample O, A, B and C respectively. They were then allowed to stabilize for about three minutes before gently inserting the hydrometer and readings taken at the point where the products cut the meniscus lines. Similarly, the thermometer was inserted into each fuel samples and the temperature readings were also taken. Same procedures were carried out for each fuel blend samples as shown in Figure 3. These experimental readings for density and temperature are called the observed readings. The petroleum measurement table [19] were used to get the corresponding actual density at 15$^0$C by matching the observed density and temperature accordingly.

**Table 5:** Fuel blend samples Laboratory test mix ratio

| Samples (ml) | Blend Ratio (%) | Petrol Mixed (%) | Petrol Mixed (ml) | Ethanol Mixed (%) | Ethanol Mixed (ml) |
|---|---|---|---|---|---|
| | | | 250 | | |
| O | 98:00 | 98 | 245.00 | 0 | 0.00 |
| A | 93:05 | 93 | 232.50 | 5 | 12.50 |
| B | 91:07 | 91 | 227.50 | 7 | 17.50 |
| C | 89:05 | 89 | 222.50 | 9 | 22.50 |




a) Octane observed density readings, b) Ethanol relative density

**Figure 3:** Observed density readings of fuel samples

And the density of ethanol was computed using [23] density of ethanol ($\rho_E$):

$$\rho_E = \rho_{sg} \ x \ \rho_w \quad (1)$$

Where; $\rho_{sg}$ is the specific gravity (Hydrometer reading), $\rho_w$ is the density of water taken as $1{,}000 \ kg/m^3$

Similarly, density of spent oil is given by [23]:

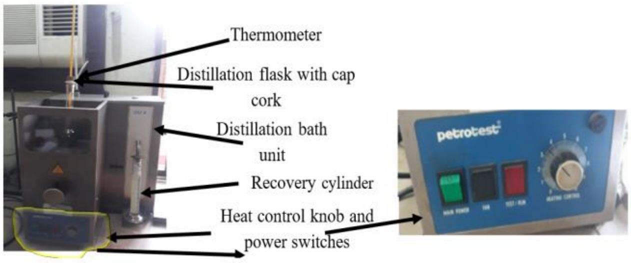
$$\text{Density of spent oil } \rho_o = \frac{m_o \ kg}{v_o \ m^3} \quad (2)$$

Where; The mass $m_o = m_{ocl} - m_{cl}$ being the difference in weight of the beaker when filled with $100 \ ml$ of spent oil and when it is empty. Using the electronic kitchen weight as shown in the Figure 4. $m_{ocl}$ is the mass of the beaker when filled with $100 \ ml$ of spent engine oil in $kg$, $m_{cl}$ is the mass of the empty beaker in $kg$, $v_c$ is the volume of spent engine oil in $m^3$.


**Figure 4:** Determining the density of the filtered Spent Engine oil

### *B. Determination of fuel volatility:*

Among the most important characteristic of fuel is its volatility. Which is the determination of volatile matter present in the fuel such as hydrogen, sulphur and oxygen, because if it's not sufficiently volatile, engines may experience hard starting, especially at low temperature [24]. And one of universally used method in determining volatility is the fuel distillation test method. Using the ASTM (D86) method [18], this involves setting up of the distillation bath as shown in Figure 5. Thereafter, filling of the distillation bath flask with 100ml of fuel blend sample(s), as this introduces the blend sample into the heat chamber. The distillation bath was switched on, and the heat increased from zero 0 to 2.5 using the heat knob control. And the initial boiling temperature (IBT) reading (the time for the first drop from the distillate to occur), noted within 0 ~ 30minutes and the temperature at which 5ml of distillate recovery too noted. Readings were taking at every 10ml until 90ml of the distillates is reached. At 95ml the heat control knob was increased by 0.5, observing the thermometer reading and the maximum temperature reached (this is the temperature reading before temperature drop occurs) called the finial boiling temperature (FBT) as with results as tabulated in Table 1A. This test method measures the percentage of vaporized fuel as temperature is increased. Temperature at which 20%, 50% and 90% fuel vaporize are very critical, as they will determines the cold start capability (especially in cold climate), and the formation of deposits in the engine combustion chamber and fuel-oil dilution [24].




a) Distillation bath nomenclature b) Control switches

**Figure 5:** Fuel volatility test equipment

***C. Determination of particulate contamination and moisture content:***

Knowing the fuel moisture content is very essential, as it will enable us take decisive steps in reducing risk from corrosion, safety problems and infrastructural damage which can arise from unwanted water content. ASTM D4176 [20] test procedure is the standard used in determining free water and particulate contamination in distillate fuels. It involves looking out for any visible water in the fuel, as the fuel should be clear, bright and free from any visible particulate matter. This provides a gross numerical rating of haze appearance [20] as seen in Figure 6.

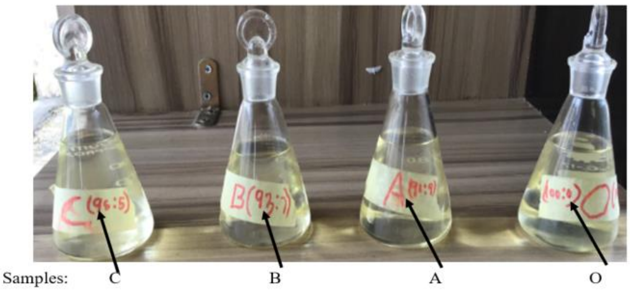



**Figure 6:** Water and particulate contamination check

***D. Research octane number, motor octane number and benzene number***

This is another crucial fuel characteristic, the octane number rating, it's measuring the anti-knock performance of the fuel. ASTM D2699 [21] and ASTM D2700 [22] test procedures were followed, as well as the octane analyzer ZX-101XL machine user manual. This octane fuel analyzer is used to determine the kind of fuel been analyzed. This begins by powering the octane analyzer, it's allowed to boot for about 15 seconds countdown, and ensuring the sample chamber was empty and covered with the light shield. The measure key was pressed to standardize the instrument (self-calibrate), next step instruction as display on the analyzer machine screen where followed at every step. The removal of the light shield from sample chamber, and filled with the fuel blend sample and it placed in the sample chamber, ensuring aligning the stripe alignment on the jar with the left alignment stripe on the instrument and the light shield placed over the jar, the measure switch button was pressed again, after instrument reading, light shield and jar were removed, and the jar rotated to align the stripe on the jar with the right alignment stripe on the instrument before replacing the light shield over the jar, and the measure switch button pressed, allowed to read, thereafter the jar was removed and the chamber covered with the light shield only, the measure switched button pressed and the final results were displayed on the instrument display screen and printed out. Same test process was repeated for fuel blend samples O, A, B and C respectively, and the results as stated in Table 1A.


a) ZX101XL octane analyzer b). Sample holder

**Figure 7:** ZX101XL octane fuel analyser

### 3.1.3 Stoichiometric fuel combustion

As stated by S. McAllister 2011 [26], combustion system consists of various gases and the thermodynamic properties. The control is based on stoichiometric combustion and the quantity of the air to fuel ratio was taken as 14.7, and the stoichiometric relation determined from [27] as:

$$C_{\alpha}H_{\beta}O_{\gamma} + \left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)(O_2 + 3.76N_2) \rightarrow \alpha CO_2 + \frac{\beta}{2}H_2O + 3.76\left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)N_2 \qquad (3)$$

Where, $\alpha, \beta$ and $\gamma$ are the stoichiometric coefficients of carbon, hydrogen and oxygen respectively.

For the blended mixture, the constituent's formation is obtained using their volume fractions and molar mass to determine the energy content and equivalent ratio of the mixture. The individual constituents of Petrol and Ethanol before blending are assumed to have stable formula $C_8H_{18}$ and $C_2H_6O$ respectively [27]. Lubricating oils for automobiles and machines are estimated in several literature's, to have carbon atoms-chain in the range of $C_{17}$ to $C_{24}$, while regular paraffin starts with a carbon chain of $C_{20}$ to $C_{34}$ [28]. In this work, the analysis of new engine oil 5 W − 20 and filtered spent engine oil were based on the lower limit of the carbon-chain values as $C_{17}H_{34}$ and $C_{20}H_{42}$




https://doi.org/10.4314/njt.v43i3.9

respectively [28]. Thus; the fuel combustion stoichiometric becomes using Equation 3;

**Table 6:** Fuel blend samples stoichiometric composition

| Fuel Blend Samples | Chemical composition formula |
|---|---|
| Sample O | $8.18CO_2 + 9.16H_2O + 47N_2$ |
| Sample A | $7.94CO_2 + 8.72H_2O + 46.53N_2$ |
| Sample B | $7.82CO_2 + 8.79H_2O + 45.82N_2$ |
| Sample C | $7.7CO_2 + 8.68H_2O + 45.1N_2$ |
| New engine oil $C_{17}H_{34}$ | $C_{17}H_{34} + 25.5(O_2 + 3.76N_2) \rightarrow 17CO_2 + 17H_2O + 95.88N_2$ |
| Spent engine oil $C_{20}H_{40}$ | $C_{20}H_{40} + 30(O_2 + 3.76N_2) \rightarrow 20CO_2 + 20H_2O + 112.8N_2$ |

## 4.0 RESULTS AND DISCUSSION

This section entails results and discussion of results from the fuel characterization by fuel blend of petrol, ethanol and spent engine oil as stated in Table 4, with samples O (as control), A, B and C with 9%, 7% and 5% ethanol content respectively.

### 4.1 Fuel Blend Characterization

This where determined by testing five parameters as detailed in Table 1A as follows;

#### 4.1.1 Density

***A. Spent engine oil density computation***

Using Equations 1 and 2 the density of spent engine oil and ethanol was computed, results as stated in Table 7.

**Table 7:** Density of fuel blend samples

| Description | Units | Density |
|---|---|---|
| Petrol | $g/ml$ | 0.76 |
| Ethanol | $g/ml$ | 0.81 |
| Spent engine oil | $g/ml$ | 0.79 |
| Density of mixture | $g/ml$ | 0.76 |

***B. Density of ethanol and petrol***

The ASTM D1298 procedures, was used to determine the density of petrol and petrol-ethanol mix ratios for each fuel blend, which were computed and correlating the observed density and temperature with the petroleum measuring table to the actual density, gives the values for each blend as listed in Table 7, which falls within the acceptable range of $(0.72 - 0.78)$ g/ml.

#### 4.1.2 Volatility of the fuel blend

The volatility of fuel is essential in determining the cold start and smooth running of the engine. It is a measure of its tendency or aspiration to burn and it is related to the vapor pressure of the fuel at a given temperature [11]. Thus, the lower the initial boiling point the more it evaporates to mix with ambient air forming combustible charge, hence enhancing cold starting of the engine. The final boiling point (209℃) and residue (0.5%) were flat for all fuel blends as seen in Figure 8 indicates that the same facility can be used for storage and transportation of product [1, 25].

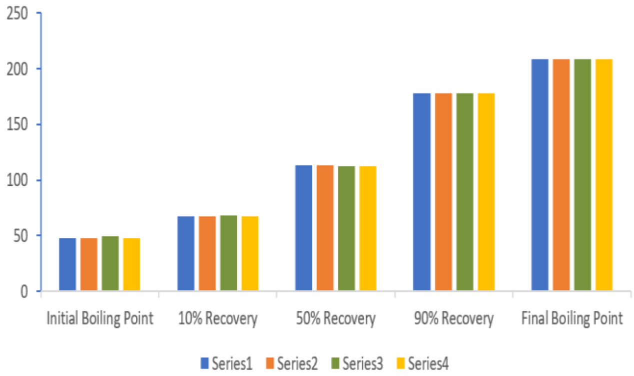



**Figure 8:** Boiling point and percentage recovery of fuel blends

#### 4.1.3 Moisture and particle matter content

Also, by ASTM D4176 visual inspection standard, fuel blend mix samples O, A, B and C appearance, odour, colour and suspended matter characteristics all complied according to specification and no moisture content observed in the fuel samples as seen in Table 1A.

#### 4.1.4 Research octane number and motor octane number content

For better engine and quality performance at low temperature and speed fuel blend sample O has a Research octane number (RON) value (93.1), indicating higher anti-knock performance than others. And the higher motor octane number (MON) value (83.5%) of fuel blend sample A implies a better-quality engine performance at high temperature and speed [23], when compared to other fuel blend sample O (83.2%), B (82.9%) and C (83%) shown below in Figure 9.

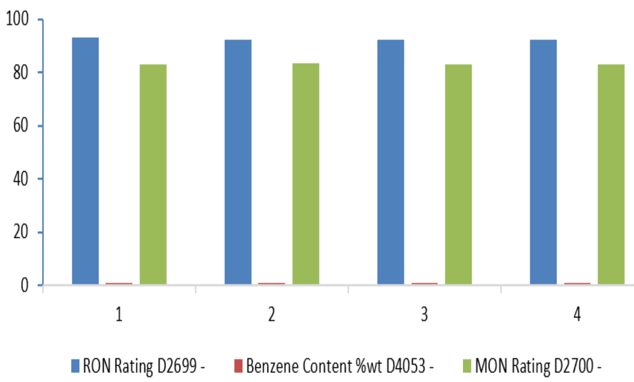



**Figure 9:** RON, MON and Benzene rating

#### 4.1.5 Benzene content

Benzene a faster evaporating drier form of mineral spirit, which can react with other chemicals to form smog [23]. The higher the rating (content) the more the tendency to reacts with other elements to form smog, as this is more likely with fuel blend samples O and A with Benzene content of 1.2% respectively as against fuel blend samples B and C with Benzene content of 1.1% respectively.

#### 4.1.6 Fuel stoichiometric chemical composition

The stoichiometric combustion for various fuel blend samples A, B and C and that of the control mix (sample O) for new and spent engine oil are presented in Table 6. The composition formula shows that new engine oil will emits less $N_2$ (95.88), $CO_2$ (17) and $H_2O$ (17) content compared to spent engine oil with higher $N_2$ (112.8), $CO_2$ (20) and $H_2O$ (20). Further simplification of Equation 3 gives details composition of each fuel mix and the rate at which the blends saturates our environment with exhaust fumes (emission) of $N_2$ $CO_2$ and $H_2O$, which are less with ethanol blended fuel samples A, B and C, when compared to the control fuel sample O of 98% Petrol and new or spent engine oil [29].

## 5.0 SUMMARY AND CONCLUSION

### 5.1 Summary

A two-stroke SI engine test rig with Suziiou engine model Ti987 with specification as stated in Table 2, was used to successfully test the performance and emission characteristics of a fuel blend of petrol, ethanol and spent engine oil. This research covers two-stroke petrol cycle engine, with particular focus on its lubricating oil and ethanol petrol blend in combustion. Furthermore, Crude oil refinery, ethanol production processes and mixed lubrication on spark –ignition engine were discussed. The methodology includes fuel characterization that covers density, fuel vitality, moisture content, octane number among others. The Performance Evaluation include the construction of the test rig and conduction of experiment such as fuel consumption rate, brake power and thermal efficiency. Exhaust Emission determination was carried out during the research.

### 5.2 Conclusion

The conclusion drawn from the research were;

i. It was demonstrated that Ethanol has higher evaporation heat, octane number and flammability, as such, its blend with petrol at 5%, 7% and 9% produced higher torque, better fuel consumption and thermal efficiency as the best blend (Sample C). With various loads of 100 W to 700 W, the system presents adequate performance stability to investigate the basic Engine performance parameters.

ii. This research has provided additional information to conduct performance evaluation of petrol, ethanol and spent engine oil fueled single-cylinder spark-ignition engine for power generation and other similar services using the constructed test rig. Computation of data shows flat values of engine brake power 0.65 kW and the best blend sample C gives higher thermal efficiency as shown in Figure 4.5, higher torque values with increase in load are 100 W (1.72Nm) and 700 W (1.21Nm). Specifically, at load of 0.4 kW, 2353 Rpm, brake power of 0.65 kW, brake mean effective pressure of 254.8 $kN/m^2$ was obtained. However, carbon-dioxide emission was quite appreciable at 0.7 kW load at 5 % ethanol blend which produces 21.5 %.

iii. Emission characterization shows that emission of CO and HC are eco-friendlier when blended with cassava-ethanol, however, due to higher temperature of combustion as the potency of the spent oil is increased, more $NO_x$ are likely to be formed. When the quantity of air supplied and thus, oxygen is completely utilized that is, combustion is stoichiometric, the use of spent oil is advisable for high speed two-stroke engines with fines and other heat dissipation systems modified to handle high temperature, otherwise, operation control systems should be incorporated to restrict the limit of loss of viscosity for the oil to be changed. The presence of lower CO with fuel blend spent oil and ethanol as well as increase in the amount of $CO_2$ emitted with increase in engine load shows the presence of high carbons in the mixture. Hence the use of spent oil and ethanol as blends is on average beneficent to human and vegetation.

## APPENDICES (A)

**Table 1A:** Fuel blend laboratory test results (by Synergy Inspection Services Ltd. Apapa, Lagos)

| SN | Characteristics | Units | Methods | | Specifications | Results | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | ASTM | IP | | Class O | Class A | Class B | Class C |
| 1 | Appearance | | | | Clear and Bright | Clear and Bright | Clear and Bright | Clear and Bright | Clear and Bright |
| 2 | Odour | | | | Merchantable (M) | M | M | M | M |
| 3 | Color | Visual | | | | Undyed | Undyed | Undyed | Undyed |
| 4 | Moisture Content | | D4176 | | Nil | Nil | Nil | Nil | Nil |
| 5 | Suspended Matter | Visual | | | Nil | Nil | Nil | Nil | Nil |
| 6 | Density PMS @ $15^0C$ | | D1298 | 160 | 0.720-0.780 | 0.758 | 0.758 | 0.764 | 0.758 |
| 7 | Distillation | | D86 | 123 | - | - | | | |
| 8 | Initial Boiling Point | $^0C$ | " | " | Report | 48 | 48 | 49 | 48 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 9 | 10% Recovery | " | " | " | " | 67 | 67 | 68 | 67 |
| 10 | 50% Recovery | " | " | " | " | 113 | 113 | 112 | 112 |
| 11 | 90% Recovery | " | " | " | " | 178 | 178 | 178 | 178 |
| 12 | Final Boiling Point | " | " | " | 210 Max | 209 | 209 | 209 | 209 |
| 13 | Recovery | %v/v | " | " | 97 Min | 98.5 | 98.5 | 98.5 | 98.5 |
| 14 | Recovered @ $70^0C$ | " | " | " | 10 Min | 12 | 12 | 11 | 11 |
| 15 | Recovered @ $1250^0C$ | " | " | " | 50 Min | 60 | 60 | 60 | 60 |
| 16 | Recovered @ $180^0C$ | " | " | " | 90 Min | 92 | 92 | 92 | 92 |
| 17 | Residue | " | " | " | 2 Max | 0.5 | 0.5 | 0.5 | 0.5 |
| 18 | Ethanol Content | " | D5845 | - | Nil | Nil | Nil | Nil | Nil |
| 19 | Sulphur Content | %wt | D4294 | 336 | 0.10 Max | - | | | |
| 20 | RON | Rating | D2699 | - | 91 Min | 93.1 | 92.5 | 92.5 | 92.4 |
| 21 | Benzene Content | %wt | D4053 | - | 2 Max | 1.2 | 1.2 | 1.1 | 1.1 |
| 22 | MON | Rating | D2700 | - | | 83.2 | 83.6 | 82.9 | 83 |
| 23 | RVP | psi | 394 | | 9 Max | | | | |

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