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Determination of Physicochemical Properties of Electric Transformer Oil Extracted from Selected Plant Seeds in Nigeria

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Abstract: *This research work was undergone to extract oils from selected plant (Jatropha, Moringa and Castor) seeds and as well as to carry out the physicochemical analysis of the extracted oils so as to determine whether they are can be used as transformer oil. For the study, seeds of five plants (Jatropha, Moringa, Castor, Cotton and Shea) were selected. The oils were extracted from the powdered seeds with the aid of Soxhlet extractor using n-hexane as solvent and cold press method. The extracted oils were collected and purified for the characterization. The physicochemical parameters of the oils were determined using appropriate methods. It was found that for all the oil samples, their dielectric strengths (25.18±0.07kv for Jatropha oil, 24.65±0.13kv for Moringa and 24.32±0.13kv for castor oil) were very close to the standard dielectric strength limits set by ASTM. The values of the free fatty acid of all oil samples assessed were found to be within the range of 0.01 – 0.08mgKOH set by ASTM. Meanwhile the values of the physicochemical parameters obtained for Jatropha, Moringa and Castor seed oils showed that these oils can serve as transformer oils if they are well refined*.

Key Words: **Transformer, Extraction, Plant, Seed, Oil**

1. INTRODUCTION

Transformer oil, also known as insulating oil is oil that is stable at high temperatures and has excellent electrical insulating properties [1]. It is used in oil-filled transformers, some types of high-voltage capacitors, fluorescent lamp ballasts, high-voltage switches and circuit breakers to insulate, suppress corona and arcing, and to serve as a coolant [2]. Therefore, it must have high dielectric strength, thermal conductivity, and chemical stability, and must keep these properties such as flash point 140 °C or greater, pour point −30 °C or lower, dielectric breakdown voltage 28 KV (RMS) or greater, when held at high temperatures for a long period [3].

Transformer oil is most often based on mineral oil, but alternative formulations with better engineering and environmental properties are growing in popularity [3].

Mineral oil like synthetic alkanoates is usually effective as transformer oil, but it is highly flammable, so that, if a leak occurs in a transformer, fire outbreak can easily start. Therefore, transformer oil is required to be a less flammable [4]. Transformer oils experience electrical and mechanical stresses during operation, this leads to gradual changing in the physical-chemical properties of the oil, thereby render it ineffective for its intended purpose after a long period [5]. Due to these challenges faced, there is a need for researchers to continuously search for the best alternative in terms of cost and suitability. In this regard, there is a need to harness nature like plants for possible extraction of suitable oils that can serve as transformer oil of high quality.

1.1 Materials and Methods

1.1.1 Materials:

The plant seeds (jatropha, moringa and castor seeds) were sourced from Kure market, Minna. The seeds were treated and ground into fine particles and prepared for extraction [6].

1.1.2 Extraction

Oils were extracted from the powdered seeds with the aid of Soxhlet extractor using n-hexane as solvent and cold press method. The extracted oils were collected and purified for the characterization. About 300 cm^3 of n-hexane was poured into a round bottom flask. 10 g of the seed sample was placed in a thimble and then inserted in the center of the extractor. The soxhlet was heated to 40 - 60 Oz. When the solvent is boiling, vapour was rising through the vertical tube into the condenser at the top. The liquid condensate was then dripping into the filter paper thimble in the centre. The extract was seeping through the pores of the thimble and filled the siphon tube, where it was flowing back down into the round bottom flask. This was allowed to continue for 30 min. It was then removed from tube, dried in the oven, cooled in the desiccators and weighed again to determine the amount of oil extracted. Further extraction was carried out at 30 min intervals until the sample weight at further extraction and previous weight became equal. The experiment was repeated by placing another 10 g of the sample into the thimble again. The weight of oil extracted was determined at each 30 min internal. At the end of the extraction, the resulting mixture containing the oil was heated to recover solvent from the oil [7].

1.1.3 Characterization

The extracted samples were analyzed for quality parameters as follow:

Free fatty acid (FFA): 25 cm^3 of ether was mixed with 25 cm^3 of ethanol in a 250 cm^3 beaker. The mixture was then mixed with 10 g of oil sample in a conical flask and a few drops of phenolphthalein was added. The mixture was titrated with 0.1 mol dm^{-3} NaOH to a dark pink colour end point with consistent shaking. The volume of 0.1 mol dm^{-3} NaOH (*V*) was noted and used to calculate the free fatty acid as follows:

$$\text{Free fatty acid (FFA)} = \frac{Vo}{Wo}$$

$\frac{Vo}{Wo}$ = 82 - 100, where 100 cm^3 of 0.1 mol dm^3 NaOH= 2.83 g of oleic acid;

$$Wo = \text{sample weight; Acid value} = \text{FFA} - 2.$$

Dielectric Strength: This test was carried out by placing 10 cm^3 each of oil samples in a constant fixed volume beaker to be placed in a Foster Transformer. An electric current passed through the oil sample until the circuit breaker goes off and flow of current is stopped. The voltage at which this occurs was the breakdown voltage or dielectric strength. This process was repeated twice for each sample and average result was recorded.

The Specific Gravity: The specific gravity was determined using a specific gravity bottle. The bottle was properly cleaned and dried in an oven at about 60°C. The weight of the empty bottle was recorded, after which the empty bottle was filled with the oil sample and properly covered, then, the weight was taken, and then the weight of the bottle filled with deionized water was also taken. The equation below was used to calculate the specific gravity:

$$\text{Specific gravity} = \frac{(Wo - W)}{(W1 - W)}$$

where W = weight of empty bottles, Wo = weight of the bottle and oil content, W1 = Weight of bottle and water content.

Viscosity: The viscosity of the extracted oil samples was determined using a Cannon-Fenske 1972 – B50. 50 cm^3 was carefully introduced into the reservoir to avoid gas bubbles. The viscometer was placed in a water bath to allow measurements to be obtained at different temperatures between 20°C and 60°C. The measurement of viscosity involves measurement of the time taken for a fixed volume of the liquid to flow through a narrow capillary and a multiplication by the calibration constant [3].

$$\text{Viscosity (V)} = c \times t$$

Where: V = Viscosity in (mm^2/s or cSt), t = time in seconds, c = viscosity tube constant

Saponification value: The saponification value of the extracted oil sample was determined by weighing 2 g of the oil sample into a conical flask to which 25 cm^3 of 0.1 mol dm^{-3} ethanoioc potassium hydroxide was added, stirred and allow to boil gently for 60 minutes. A reflux condenser was placed on the flask containing the mixture and a few drops of phenolphthalein indicator was added to the warm solution, titrated with 0.5 mol dm^{-3} HCl to the disappearance of the pink colour of the indicator. The same procedure was repeated for the other samples and a blank. The expression for the saponification value (*SV*) is given by:

$$SV = \frac{56.1N\,(Vo - Vi)}{m}$$

Where: *Vo* = the volume of the solution used for the blank test, *Vi* = the volume of the solution used for the determination, N = Actual normality of HCl used and *m* = mass of the sample.

Iodine value: To determine he iodine values of the sample, 0.4 g of the sample was weighed into a conical flask and 20 cm^3 of carbon tetra chloride was added to dissolve the oil. Then 25 cm^3 of Dam reagent was added to the flask using a safety pipette influenced chamber. A stopper was placed and the content of the flask was vigorously swirled before the flask is placed in the dark for 2 h and 30 min. At the end of this period, 20 cm^3 of 10 % aqueous potassium iodide and 125 cm^3 of water were added and the mixture was titrated with 0.1 mol dm^{-3} sodium-thiosulphate solution until the yellow colour almost disappeared. A few drops of 1% starch indicator were added and the titrations continue by adding thiosulphate drop-wise until blue coloration disappears after vigorous shaking. The same procedure was used for the blank test and for other samples. The iodine value (*IV*) is given by the expression:

$$IV = \frac{12.69c\,(V1 - v2)}{m}$$

Where: c = concentration of sodium thiosulphate used, V1 = volume of sodium thiosulphate used for the blank, V2 = volume of sodium thiosulphate used for the determination, m = mass of the sample.

Flash point was carried out in the laboratory by applying the Closed Cup Method using the Pensky-Marten flash point tester at 0 – 400 °C.

Pour point was carried out using an ice bath, test tubes and a thermometer. The apparatus was set up such that the test tubes containing the oil samples are stuck in the ice bath and periodically checked at intervals of 3°C for flow characteristics, The temperature at which oil sample starts to coagulate was taken as pour point, while the temperature at which wax first becomes visible was the cloud point.

Determination of the Oil Densities was carried out by according to the method used by [7].

pH value:- The pH of the oil samples was determined by using pH meter.

Sulphur Content:- 5 cm^3 of the sample was placed in a ceramic crucible and put in a high frequency induction furnace and ignited to form SO_2, which was then being measured by the Infrared Detector.

2.0 RESULTS AND DISCUSSION

2.1 Results

The results of the density of all the plant seed oils analyzed with its standard values are presented in Figure 2.1. From the results, moringa oil obtained has the lowest value ($0.52\pm0.40g/cm^3$) of density, followed by jatropha oil whose density is ($0.72\pm0.50g/cm^3$), while the highest density is obtained in Shea oil density of $0.91\pm0.20g/cm^3$. All the oils have its densities to be within the range of the standard values (0.55 – $0.89g/cm^3$) except Shea oil whose density is slightly higher than the highest standard value.

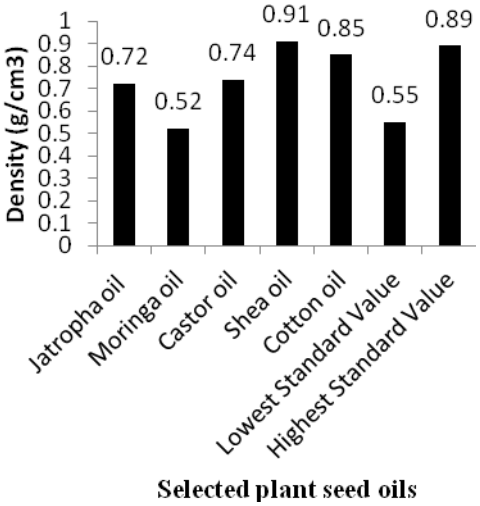

Figure 2.1: Result of Densities of the Plant Seed Oils

The results of the viscosity of all the plant seed oils analyzed with its standard values are presented in Figure 2.2. From the results, Shea oil has the highest value ($9.98\pm0.50mm^2/s$) of viscosity, followed by castor oil whose viscosity is ($8.1\pm0.12mm^2/s$), while the lowest viscosity is obtained in moringa oil with viscosity of $1.8\pm0.02mm^2/s$. All the oils have their viscosities to be less than the lowest standard value ($9.3mm^2/s$.) except Shea oil whose viscosity ($9.98\pm0.50mm^2/s$) is within the range of the standard values.

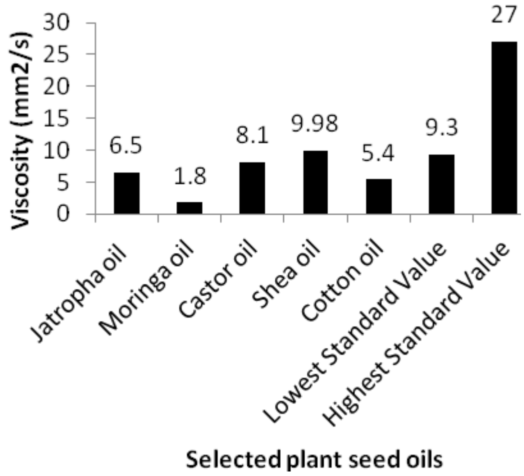

Figure 2.2: Result of Viscosities of the Plant Seed Oils

The results of flash point of all the plant seed oils assessed with its standard values are presented in Figure 2.3. From the results obtained, castor oil has the lowest value (132 ± 1.50^0C) of flash point; while the highest flash point ((231 ± 2.50^0C) was obtained in Shea oil. Only the Jatropha oil has its flash point being within the range of the standard values (140 – 155^0C).

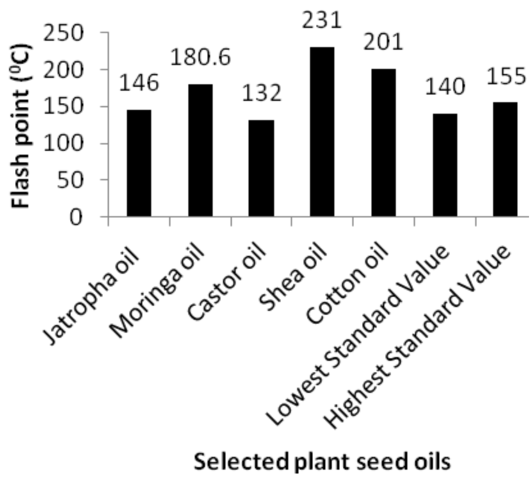

Figure 2.3: Result of Flash Points of the Plant Seed Oils

The results of acid number obtained from all the plant seed oils analyzed with its standard values are presented in Figure 2.4. From the results, all the oils have their acid number to be above the range of the standard values. The lowest acid number ($2.12\pm0.08mgKOH/cm^3$) is obtained from the castor oil while the moringa oil has the highest acid number of $4.47\pm0.12mgKOH/cm^3$.

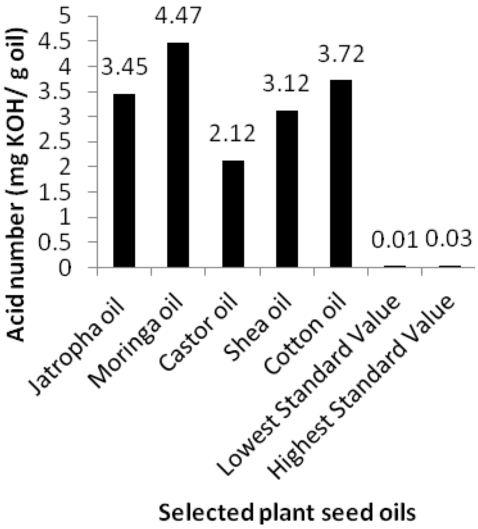

Figure 2.4: Result of Acid Numbers of the Plant Seed Oil

The results on the dielectric strength of all the plant seed oils evaluated with its standard values are presented in Figure 2.5. From the results, jatropha and cottonseed oils have their dielectric strengths (25.18±0.07kv and 25.81±0.09kv respectively) to be within the range of the standard values (25 – 40 kv) the lowest dielectric strength value (23.24±0.12kv) was obtained from Shea oil while the highest dielectric strength value (25.81±0.09kv) is obtained in cottonseed oil.

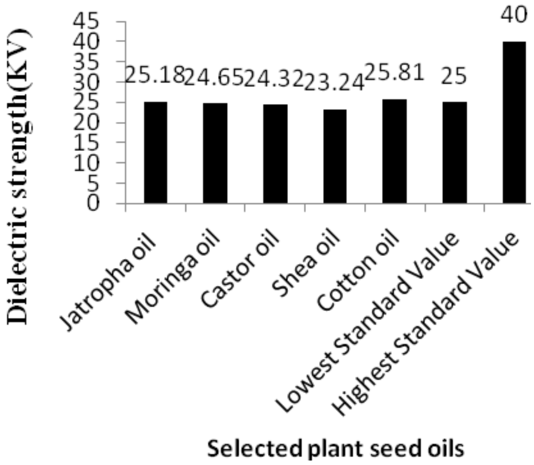

Figure 2.5: Result of Dielectric Strengths of the Plant Seed Oils

The results of pour point (^{0}C) of all the plant seed oils analyzed are presented in Figure 2.6. From the results, castor oil has the lowest value of 1.15± 0.10^{0}C, while the highest pour point of 8.00±0.30 ^{0}C is obtained in Shea oil. The pour points of jatropha, moringa and cottonseed oils were 4.00±0.01^{0}C, 2.00±0.15^{0}C and 6.50±0.60^{0}C respectively. The order of increase in pour points of the assessed seed oils is as follows; castor oil<moringa oil<jatropha oil<cotton seed oil<Shea oil. There are no specific standard values of the pour point of these oils

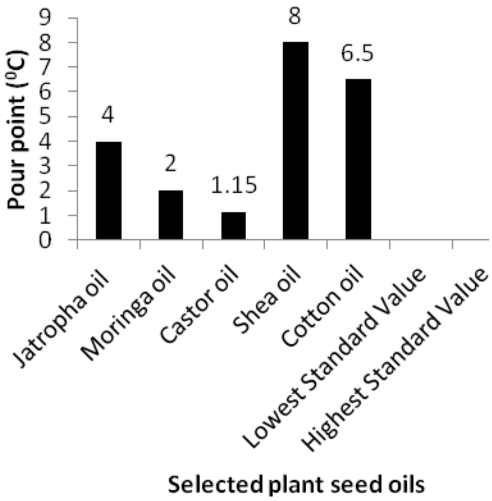

Figure 2.6: Result of Pour Points of the Plant Seed Oils

The results of pH values of all the plant seed oils analyzed with its standard values are presented in Figure 2.7. From the results, cottonseed oil has the lowest value of pH of 5.40±0.12, while the highest pH value (6.00±0.75) is obtained from castor seed oil. All the oils have their pH values to be within the range of the standard values (5.5 – 8.2).

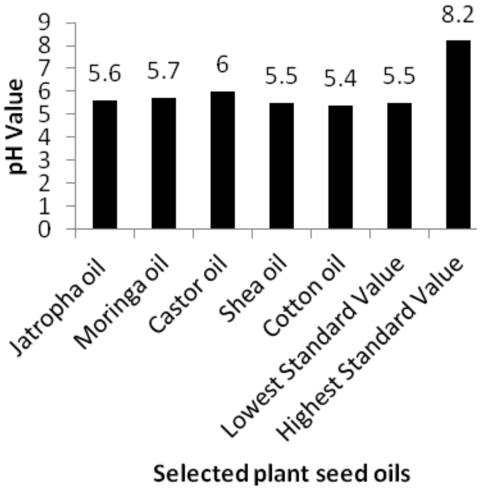

Figure 2.7: Result of pH Values of the Plant Seed Oils

The results of the specific gravity of all the plant seed oils analyzed with the standard values are presented in Figure 2.8. From the results, moringa oil obtained has the lowest value (0.82±g/cm^3) while the highest specific gravity (0.94±0.12) is obtained from Shea oil. All the oils have their specific gravities to be lower than the lowest standard value

(0.89) except Shea oil whose specific gravity (0.94±0.12) is slightly higher than the highest standard value (0.91).

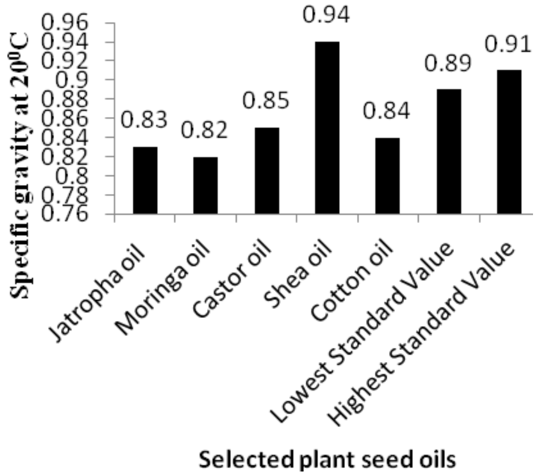

Figure 2.8: Result of Specific Gravities of the Plant Seed Oils

The results of sulphur contents of the plant seed oils studied and their standard values are presented in Figure 2.9. From the results, moringa seed oil has the lowest value (8.00±0.50wt %) of sulphur content, while the highest sulphur content of 11.00±0.80wt % is obtained for Shea oil. All the oils have their sulphur contents to be within the range of the standard values (7 – 15wt %).

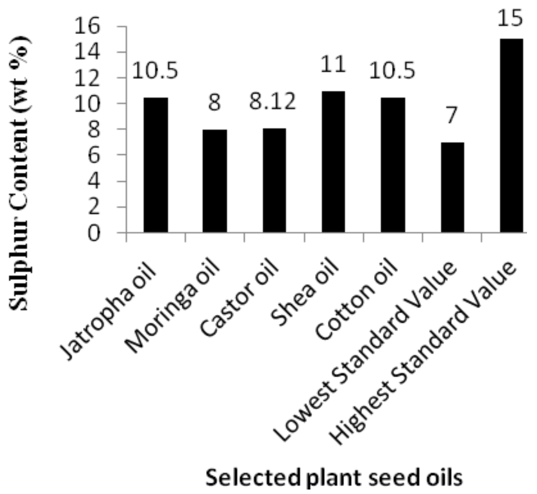

Figure 2.9: Result of Sulphur Contents of the Plant Seed Oils

The results of iodine values of all the plant seed oils evaluated and the standard values are presented in Figure 2.10. From the results, castor seed oil has the lowest value (9.31±0.20g/100g oil) of iodine value, while the highest iodine value (103.30±0.25g/100g oil) is obtained for jatropha seed oil. The castor, Shea and cotton oils have their iodine values to be below the lowest standard value 55g oil. But jatropha and moringa seed oils have their iodine values to be within the range of standard values (55 – 120g/100g oil).

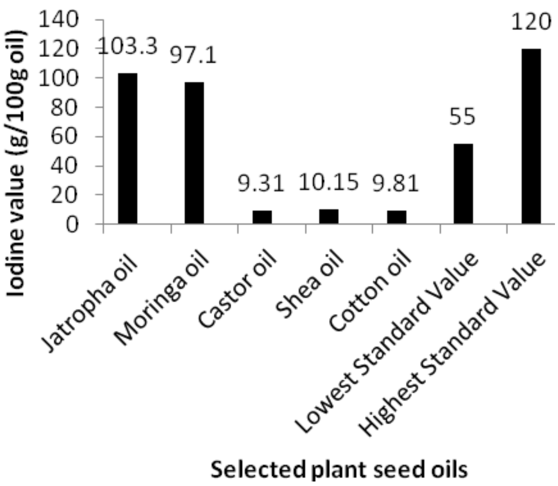

Figure 2.10: Result of Iodine Values of the Plant Seed Oils

The results of the saponification values obtained in all the plant seed oils analyzed with its standard values are presented in Figure 2.11. From the results, castor oil has the highest value of 268.31±0.20mgKOH/g oil, followed by Shea oil whose saponification value is (261.30±6.70mgKOH/g oil), while the lowest saponification value of 232.51±0.43mgKOH/g oil is obtained in moringa oil. Castor, Shea and jatropha oils have their saponification values to be higher than the highest standard value (244mgKOH/g) while moringa and cotton oils have their saponification values to be within range of the standard values (150 - 244 mgKOH/g)

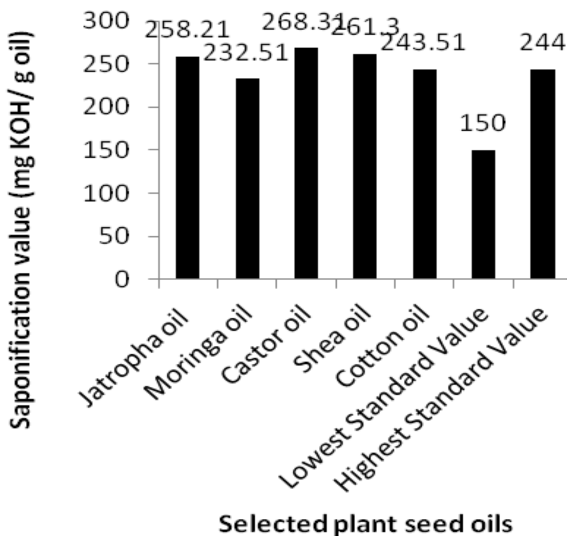

Figure 2.11: Result of Saponification Values of the Plant Seed Oils

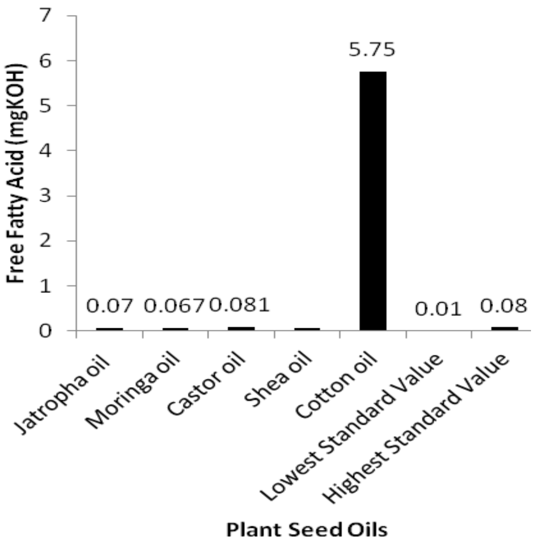

Figure 4.11: Result of Free Fatty Acid Values of the Plant Seed Oils

2.2 Discussions

The iodine values (103.30±0.25g/100g for jatropha oil, 97.11±0.51g/100g for moringa oil, 9.31±0.20g/100g for castor oil, 10.15±0.20g/100g for Shea oil and 9.81±0.72g/100g for cotton oil) of the plant seed oils analyzed in this study were found to be below the standard range of 55 – 120 g/100g set by [8] for transformer oil. The iodine value of jatropha oil in this study was below 105 g/100g, 101.7 g/100g and 112.4 g/100g reported by [9], [10] and [11] respectively, but higher than the value (98.89 g/100g) reported by [12], while the iodine value of moringa oil was found to be higher than the values 69.45g/100g and 66.83g/100g reported by [5] and [13] respectively. Castor seed oil has its iodine value (9.31±0.20g/100g) to be below the values 83.67g/100g and 84.50g/100g obtained from [14] and [2] respectively but higher than 1.061g/100g reported by [15]. The iodine value (10.15±0.20g/100g) of Shea oil obtained in this study was found to be lower than 59.50g/100g, 36.60g/100g and 54.14g/100g reported by [4], [16] and [17]. Cotton seed oil has its iodine value (9.81±0.72g/100g) to be below the value (94.70g/100g) obtained from [1]. Hence, jatropha and moringa seed oils in this study have their iodine values to be within the range value of transformer oil.

The results of saponification values of the plant seed oils assessed were present in the Figures 2.10. However, the saponification values (232.51±0.43mgKOH/g and 243.51±2.15mg/KOH/g) of moringa and cottonseed oils respectively, were within the range of 150 – 244mg KOH/g set by [8] for transformer oil. The saponification values (258.21±5.30mgKOH/g, 268.31±0.20mgKOH/g and 261.30±6.70mgKOH/g) of jatropha, castor and Shea seed oils respectively were above the standard values set by [8]. The saponification value (232.51±0.43mgKOH/g) for moringa seed oil is higher than the values 186.67mgKOH/g and 178.11mgKOH/g reported by [6] and [13]. While Shea oil has its saponification value (261.30±6.70mgKOH/g) also to be higher than the values 190, 192.15 and 197.40mgKOH/g obtained from [4], [16] and [17] respectively. The respective saponification values for jatropha seed oil (199, 166, 195 and 180.6mgKOH/g) reported by [9], [12], [10] and [11] were found to be below the value (258.21±5.30mgKOH/g) obtained in this study. The cotton seed oil has its saponification value of 243.51±2.15mgKOH/g to be above the value (189mgKOH/g) reported by [1] while castor oil analyzed has its saponification value of 268.31±0.20mgKOH/g to be greater than the values 182.9 and 164.50mgKOH/g obtained by [2] and [14] but lower than 327.40mgKOH/g reported by [15]. All the plant seed oils studied if well refined can be used as transformer oil in terms of saponification.

The pH values of the plant seed oils (5.40±0.12 – 6.00±0.75) obtained in this study were presented in figure 2.7. The pH (5.60±0.20, 5.70±0.13, 6.00±0.75 and 5.50±0.10) of jatropha, moringa, castor and Shea seed oils respectively, were found to be within the ranges of 5.5 – 8.2 set by [8]. Cotton seed oil has it pH of 5.40±01.2 to be above the pH of 4.82 reported by [1].

The sulphur contents of plant seed oil samples studied indicated that levels of sulphur, which ranged from 8.00±0.50wt% of moringa seed oil to 11.00±0.80wt% for Shea oil had regular variations and were found to be within the permissible limits 7 – 15wt% set by [8]. Figure 2.5 shows the values of dielectric strengths of the plant seed oils assessed in this study. From this figure, the results showed that dielectric strengths (25.18±0.07kv and 25.81±0.09kv) of the jatropha and cotton oil samples, respectively, were within the permissible limits (25 – 40kv) set by [8], while moringa, castor and Shea oil samples have their dielectric strengths of 24.65±0.13kv, 24.32±0.13kv and 23.24±0.12kv respectively to be lower than the limits set by [8].

However, figure 2.12 in this study showed that the free fatty acid values of all the plant seed oil samples investigated were within the set limits of 0.01 – 0.08mgKOH by [8] except cotton seed oil sample whose free fatty acid value of 5.75±0.50mgKOH was above the standard limits by [8]. The free fatty acid (0.071±0.80mgKOH) of jatropha oil sample in this study was found to be below the values 1.8mgKOH and 3.08mgKOH reported by [9] and [12] respectively. Moringa oil sample has its free fatty acid of 0.067±0.50mgKOH to be lower than 0.83mgKOH obtained by [13]. Meanwhile, the free fatty acid values (3.4mgKOH and 7.21mgKOH) for castor oil reported by [2] and [15] respectively were found to be 42 and 89 times of the value obtained in this study. Cotton oil sample analyzed has its free fatty acid value to be the same as the value (5.75mgKOH) reported by [1].

The values of specific gravity in all the oil samples studied varied from 0.82±0.13 (moringa seed oil) to 0.94±0.12 (Shea oil sample) as shown in figure 4.8. There were regular variations of specific gravities among the plant seed oil samples. The specific gravity value (0.82±0.13) of moringa oil sample was lower than the values 0.91 and 0.88 reported by [5] and [13] respectively. Jatropha oil sample has its specific gravity of 0.83±0.12 to be lower than 0.92 obtained by [9] and [10]. Shea and cotton seed oil samples in this study have their specific gravities of 0.94±0.12 and 0.84±0.04 to be lower than 0.91 and 0.92 reported by [4] and [1] correspondingly. This study, however, revealed that the values of specific gravity in all the oil samples studied were lower than the permissible limits of 0.89 – 0.91 set by [8] except Shea oil sample, which had the specific gravity of 0.94±0.12 above the standard range.

The values of acid number in all the plant seed oils assessed varied from 2.12±0.08mgKOH/g (castor oil) – 4.47±0.12mgKOH/g (moringa seed oil) (Figure 2.4). The acid number of all the oil samples assessed in this studied was much higher than the limits 0.01 – 0.03mgKOH/g set by [8]. The study showed that 3.72±0.51mgKOH/go acid number obtained from cotton seed oil was found to be lower than 11.50mgKOH/g recorded by [1] for cotton seed oil. In this study, the acid number (3.45±0.12mgKOH/g) of jatropha seed oil was slightly lower than the value reported by [9] but very low compared to the values 38.2mgKOH/g and 26.75mgKOH/g obtained by [10] and [11] correspondingly. The acid number (3.12±0.45mgKOH/g) of Shea oil in the present study was found to be lower than the values (3.62mgKOH/g, 3.18mgKOH/g and 11.17mgKOH/g) reported by [4], [16] and [17] respectively, while castor seed oil has its acid number of 2.12±0.08mgKOH/g to be lower than 4.9mgKOH/g and 14.42mgKOH/g achieved by [2] and [15] respectively, but higher than the value (0.41mgKOH/g) reported by [14].

In general the viscosities of the oil samples varied according to the following trend moringa oil<cotton seed oil<jatropha oil<castor seed oil<Shea Oil (Figure 4.2). Viscosity of Shea oil of 9.98±0.50mm^2/s was found to lower than the standard limits of 9.3 – 27mm^2/s set by [8] while the viscosities of the other plant seed oils were below the standard limits set by [8]. The respective viscosities (17mm^2/s, 36.28mm^2/s and 40.40mm^2/s) of jatropha oil samples obtained from previous studies carried out by [9], [12], and [10] were found to be higher than 6.50±0.12mm^2/s gotten for this study. However, Shea oil has it viscosity of 9.98±0.50mm^2/s to be lower than 39.98mm^2/s obtained by [4] but higher than 2.6mm^2/s reported by [16]. Meanwhile, moringa seed oil has it viscosity of 1.80±0.02mm^2/s to be lower than 57mm^2/s reported by [13]. Also, the viscosity (74mm^2/s) of cotton seed oil reported by [1] is found to be almost 14 times of the value (5.40±0.12 mm^2/s) obtained from this study.

The results of flash points obtained from this study as presented in figure 4.3 show that the flash points of 180.60±0.50^{0}C, 231.00±2.50^{0}C and 201±2.50^{0}C for Moringa, Shea and cottonseed oils respectively, were greater than the limits of 140 - 155^{0}C set by [8], while the flash point of 146±2.50^{0}C for jatropha seed oil is found to be within the standard limits set by [8]. The flash point of 132±1.50^{0}C for castor oil obtained in this present study was found to lower than the limits set by [8]. The flash point of 171^{0}C for Shea oil reported by [4] was found to lower than the value (231.00±2.50^{0}C) obtained in this study.

The values of pour points obtained from this study as shown in figure 2.6, show that among the plant seed oils assessed, Shea oil has the highest pour point of 8.00± 0.30^{0}C, while the lowest pour point of 1.15±0.10^{0}C was recorded for castor seed oil. However, the pour points of all the seed oils evaluated were found to be higher than the standard limits of -8 – (-6) set by [8]. Meanwhile, the pour point (8.00± 0.30^{0}C) of Shea oil in the study is higher than the value (3^{0}C) reported by [4].

The values of density of all the plant seed oils assessed varied from 0.52±0.40g/cm^3 for moringa oil to 0.91±0.20g/cm^3 for Shea oil as shown in figure 4.1. The densities of all the oil samples assessed in this work were found to be within the standard limits (0.55 – 0.89 g/cm^3) set by [8], except the density of moringa oil which was lower than the standard limits by [8]. Shea oil has its density to be higher than the standard range by [8].

3. CONCLUSIONS

From the results obtained from this work, most of the physio-chemical parameters such as free fatty acid, sulphur content, iodine value, specific gravity, pH, dielectric strength, density of the jatropha, moringa and castor oils studied were found to be similar or close to the established standards of transformer oils. While, the parameters of the Shea and Cotton seed oils were either below or above the limits established foe transformer oil. Thus, those plant seed oils whose physiochemical parameters were found to close or within the established standards might be considered or taken as transformer oils

Hence, the physicochemical properties of jatropha, moringa and castor seed oils have been outlined. The above mentioned oils were very unique with appropriate characteristics and likely to recommend for suitable industrial usage as transformer oil, but need to be properly refined to required standards.

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