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Suitability Assessment of Physical Properties of Common Edible and Inedible Oils as A Substitute for Conventional Mineral Transformer Oils in Nigeria

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ABSTRACT

As a result of climate change, the global trend is to find alternatives to petroleum-based products which are non-renewable in nature and hazardous to the environment in the event of spillage. Seed oils obtained from edible and inedible oils could be exploited as a possible alternative based on the fact that they are renewable and environmentally friendly. This research work aimed at investigating the potential of alternative sources of oil (natural esters) as a substitute for conventional mineral transformer oil. The physical properties of four different natural oils, which include palm oil supernatant, soybean, thevetia peruviana and jatropha oil, were studied in the course of the research. The laboratory analysis was carried out to determine specific gravity, flash point, fire point, pour point and kinematic viscosity. The materials used include oil samples, thermometer, Karl Fischer titrator, beakers, reagents, etc. The tests were carried out using basic laboratory procedures conforming to ASTM standards. Statistical analysis was carried out using SAS package and the means were separated using Duncan's multiple range test. The result revealed that the specific gravity of all the natural oils except Palm oil supernatant were below the maximum stipulated value when compared to the conventional oil, while kinematic viscosity, flash, fire and pour points of the natural oils were below the recommended values as they were in unrefined states. Also, the widely acclaimed Soybean oil had values lesser than Jatropha oil, Palm oil supernatant and Thevetia peruviana oil thereby strengthening the potentials of these oils as substitutes for mineral oil if improved on. It could be concluded from this research work that natural oils in their unrefined states have lesser physical properties potential in substituting for mineral oils as transformer oil. It is therefore recommended that further studies should be carried out on improving the physical properties of these oils in order to strengthen their potential as substitute for mineral oil.

Keywords: Edible oil, inedible oil, mineral oil and transformer.

INTRODUCTION

Transformers are one of the most critical equipment in power transmission and distribution system. To achieve efficient operation of these transformers, there is need of effective insulating medium and cooling medium with better characteristics. Petroleum based mineral oil has been used as electrical insulation medium and heat exchanging medium in transformers over many decades. It was mostly used due to their easier availability, low cost and good dielectric and thermal characteristics (McShane, 2002).

Insulating oils are part of electrical insulation system of most electrical equipment and often perform additional functions such as cooling and lubrication, therefore stable high-quality properties are desired (Eissa, Abdallah & Taman, 2011). Transformers and circuit breakers make up the largest single user of electrical insulating liquids (Duval and Rouse, 1994). Whereas mineral transformer oil is petroleum based, vegetable oil is agricultural plant based. Vegetable oils are broadly divided into two classes: Synthetic Esters and Natural Esters (McShane, 2002). Due to poor biodegradability, negative environmental impacts and other factors, there is an increasing drive to find alternatives to traditional mineral oil (Oommen, 2002), (Lakrari, El Moudane, Hassanain, Ellouzi, Kitane, & Alaoui Ei Belghiti, 2013), (Azis and Mohtar, 2013). Natural esters are possible alternatives because they are biodegradable, renewable and have higher flash and fire points (Martin, Khan, Dai & Wang, 2006).

Vegetable and seed oils (natural esters) have been utilized as insulators since oil-filled transformers were invented (Lewand, 2004). However, they were considered unsuitable and replaced by mineral oil due to their low oxidative stability, higher viscosity and pour points amidst other factors (Spohner, 2012; Lewand, 2004). This is compensated for in recent times by usage of fluid additives, modern transformer design practices and modification (McShane *et al*., 1999). The interest to develop natural ester dielectric liquids was rekindled in the early 1990s (Lewand, 2004) and by the late 1990s, they have been commercially available for use in distribution transformers (Luksich, 2004).

According to (Duval and Rouse, 1994) there are basically three ways of categorizing properties of insulation oil viz: Chemical properties (refractive index, molecular weight, acidity, water content); Physical properties (relative density, flash point, pour point) and Electrical properties (dielectric breakdown strength, oxidation stability, and fire point). For the purpose of this work physical properties of natural oil were tested in selected edible and inedible seed oils so as to ascertain their suitability for possible replacement of the conventional mineral oils.

MATERIALS AND METHODS

The following seed oils were purchased off-shelf: Palm oil, 2 local brands of Soybean oil (Grand and Sunola), Palm oil supernatant "ogere epo" and Palm kernel oil. Thevetia Peruviana was mechanically extracted and Jatropha oil was chemically extracted. The samples were subjected to AC Breakdown Voltage test to strike out unlikely samples. Soybean oil, Palm oil supernatant (ogere epo), Jatropha oil and *Thevetia peruviana* oil having passed the preliminary test were then analysed in the laboratory for specific gravity, flash point, fire point, pour point and kinematic viscosity. Each property was tested for 3 times and an average value found.

DETERMINATION OF SPECIFIC GRAVITY (ASTM D1298-12)

Specific gravity is a measure of the weight of oil compared to the weight of water. If oil has a high density, water present would float on the oil instead of remaining at the bottom of the transformer, thereby reducing the effectiveness of the oil. Hence, low specific gravity is desired. The specific gravity was determined thus:
An empty beaker was weighed and value denoted as W1. 10ml of distilled water at 25C was poured into the beaker and weighed with value denoted as W2. 10ml of oil sample was poured into the beaker after it was emptied of water and dried. Weight of beaker + oil was denoted as W3. Specific gravity was calculated.

DETERMINATION OF FLASH POINT (ASTM D92-12B)

Flash point value is the temperature at which the dielectric insulating liquid gives off sufficient vapour to ignite in air. It is one measure of the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions. Thus a high flash point is desirable to ensure safety in operation and reduce the risk of fire hazards. The following procedure was used to determine the flash point.
50ml of oil was measured into a 250ml conical flask with rubber cork containing a Thermometer and placed on a heating mantle. The flask and its content were heated at a controlled rate to decompose the oil to point of evolution of the volatiles, with a flame being passed over the surface of the sample at regular intervals of 5min. The temperature measured by the thermometer at a point at which a flash appears at any point of the surface of the sample is taken as the flash point.

DETERMINATION OF FIRE POINT (ASTM D92-12B)

Fire point is the lowest temperature at which dielectric insulating liquid continues to burn in air after it has been ignited. Like flash point, a high fire point is desirable to ensure safety in operation and reduce the risk of fire hazards. The fire point was determined using the following procedure.
50ml of oil was measured into a 250ml conical flask with rubber cork containing a Thermometer and placed on a heating mantle. The flask and its content were heated to decompose the oil to point of evolution of the volatiles which proceeds so rapidly that continuous combustion occurred.i.e. a fire. The temperature at which continuous combustion occurred was taken as the fire point.

DETERMINATION OF POUR POINT (ASTM D97)

Pour point is defined as an index of the lowest temperature to which the oil may be cooled without seriously limiting the degree of circulation. It is important and, perhaps, critical in low temperature applications. Pour point was determined thus:
5ml of oil was drawn into a capillary tube tied to a negative thermometer, placed in a 250ml beaker containing distilled water and immersed together in a water bath for controlled heating. The temperature at which oil just begins to move downward due to its weight was taken as Pour point.

DETERMINATION OF KINEMATIC VISCOSITY (ASTM D445-12)

Viscosity is the measure of fluid friction. The viscosity of oil is important for cooling and lubricating. Therefore, the lower the viscosity of a dielectric insulating liquid the better its performance would be.
Kinematic viscosity, ν, was determined by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer. The oil samples were put into the viscometer one at a time. With the sample

flowing freely, the time required for the advancing ring of contact to pass from the first timing mark to the second was measured in seconds to within 0.1 s and the measurementrecorded. Kinematic viscosity was calculated:
where t = measured time of flow and C = viscometer constant

RESULTS AND DISCUSSIONS

Table 1: Physical Properties of the natural oils as analysed

Samples	Specific gravity	Flash point (^{O}C)	Fire point (^{O}C)	Pour point (^{O}C)	Kinematic Viscosity (cSt)
ASTM D 6871–03(2008) Transformer oil	≤ 0.96	≥ 140	≥ 300	≤ -10	≤ 15
Soybean oil Ave.	0.9285	55.7	128.1	5.6	4.133
Palmoil Supernatant Ave.	0.9792	56.6	131.67	6.0	4.633
Jatropha oil Ave.	0.9483	57.033	135.53	6.233	4.933
Thevetia oil Ave.	0.9251	56.233	130.83	5.833	4.033

Table 2: Statistical separation of means of the physical properties of the natural oils in comparison with ASTM acceptable limits

Sample	Specific Gravity	Flash Point (^{O}c)	Fire Point (^{O}c)	Pour Point (^{O}C)	Kinematic Viscosity (Cst)
Soybean Oil	0.92850^{D}	55.700^{E}	128.100^{D}	5.60^{D}	4.133^{D}
Palmoil Supernatant	0.97923^{A}	56.600^{C}	131.667^{C}	6.00^{B}	4.633^{C}
Jatropha Oil	0.94833^{C}	57.033^{B}	135.533^{B}	6.23^{A}	4.933^{B}
Thevetia Peruviana Oil	0.92507^{E}	56.233^{D}	130.833^{C}	5.83^{C}	4.033^{D}
ASTM D6871 Transformer Oil	0.96000^{B}	140.000^{A}	300.000^{A}	10.00^{E}	15.000^{A}

The result in Table 2 revealed the following about the selected physical properties of the natural oils in comparison with ASTM recommended values:
Specific gravity- All the oil samples were significantly different to each other. Also, Palm oil supernatant has a mean above the ASTM 6871 stipulated maximum value while the remaining oil samples have means below it.
Flash point- All the oil samples were significantly different to each other. Also, all oil samples have means below the ASTM 6871 stipulated minimum value with Jatropha oil the closest to it and palm oil supernatant in that order.
Fire point- This physical property also followed the same trend as flash point, as the ASTM 6871 stipulated minimum value was significantly superior to the oil samples having value that doubled the values of the natural oils. It is also

worthy of note that Jatropha oil exhibited potential that is next to ASTM value while Palm oil supernatant and Thevetia peruviana oil were not significantly different from each other.

Pour point- The values obtained revealed a different trend in that the ASTM 6871 stipulated minimum value was given as negative value, while all the natural oil had positive values. All oil samples were significantly different from each other, with Jatropha oil again the closest to the ASTM value followed by palm oil supernatant. It is important to note that pour point is a function of the starting lowest temperature it is started from and the climatic condition of the region.

Kinematic viscosity- All the oil samples were again statistically significantly different from each other. Also, all oil samples have means below the ASTM 6871 stipulated minimum value with Jatropha oil the closest to it followed by Palm oil supernatant.

CONCLUSION

The study established the possibility of the use of natural oils as a substitute for conventional mineral transformer oil with Jatropha oil and palm oil supernatant having a higher potential if subjected to refining processes such as degumming. This is because mineral transformer oil is a highly refined mixture of various compounds.

It is also worthy of note that of all oil samples, Soybean oil had values lesser than Jatropha oil, Palm oil supernatant and Thevetia peruviana oil thereby strengthening the potentials of these oils as substitutes for mineral oil if improved on.

RECOMMENDATIONS

It could be recommended from this study that other properties (chemical and electrical) should be considered to ascertain the suitability of Jatropha oil, Palm oil supernatant and Thevetia peruviana oil as likely substitutes for conventional mineral transformer oil.

Alternatively, they can be considered for applications with less stringent requirements such as biodiesel and lubrication.

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