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INVESTIGATION OF THE SUITABILITY OF PALM OIL AND PALM KERNEL OIL FOR USE AS INSULATING OIL IN HIGH VOLTAGE TRANSFORMERS

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ABSTRACT
*Insulating fluids play different roles in high voltage Engineering. They can be used as transformer oil and also for impregnated tapes. Mineral oils have been widely used as insulating oil in transformers, but their negative impact on the environment and disposal problems with used oil have prompted researchers to direct their focus onto biodegradable and renewable insulating materials. Palm oil (**Elaeis guineensis)** and palm kernel **(Elaeis guineensis)** oils were tested under controlled temperature for their suitability in high voltage insulation. The test results showed that the oils are suitable for use as transformer oil, in low voltage transformers. However, the oils are best suited for use in tropical regions because of their poor pour point.*
Keywords: Suitability; Palm Oil; Palm Kernel Oil; Insulating; High Voltage Transformers

Introduction
Transformer oil or insulating oil is oil that is stable at high temperatures and has excellent electrical insulating properties. Transformer oil's primary functions are to insulate and cool a transformer (IEC, 1995). It must therefore have high dielectric strength, thermal conductivity, and chemical stability, and must keep these properties when held at high temperatures for extended periods. Mineral oil is generally effective as transformer oil, but it has some serious disadvantages, of which the worst is its high flammability. If a transformer leaks mineral oil, it can easily ignite fire (Gill, P 2009). Mineral oil is also an environmental contaminant, and its insulating properties are rapidly degraded by even small amounts of water.

In order to overcome the environmental issues and other problems posed by the use of mineral oils as insulating oil in transformers, researchers started to look out for alternative sources for insulating oils. The latest insulating oil implementation is vegetable oil-based fluid which is known as the most potential source to replace the mineral oil because of its biodegradability characteristics. They are nontoxic, more biodegradable and less flammable than mineral oils (CIGRE, 2008). The vegetable oils that will be used in this paper include oil palm (**Elaeis guineensis) and** palm kernel **(Elaeis guineensis) oils.**

These oils will be subjected to different tests to ascertain their suitability for use as insulating oils in high voltage transformers. Some of the tests that will be carried out include:

- The flash points
- The pour points
- The breakdown voltages
- The moisture content of these oils (humidity)
- The effect of aging
- The dielectric dissipation factor

The chemical structures of these vegetable oils are shown in the figure below:

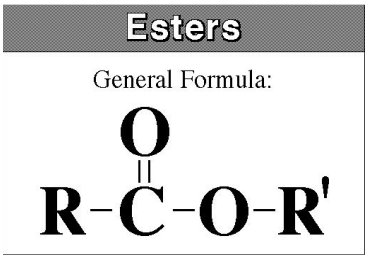


Fig 1: General Structure of an ester molecule.

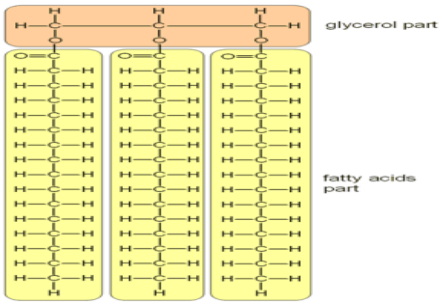


Fig 2: The structure of a vegetable oil molecule

R and R^1 represent alkyl groups. The two oxygen atoms bonded to the carbon atom constitute the functional group. The remaining carbon atoms could be long chains of carbon molecules (complex) or as simple as these in the Fig 1. The general formula and the esterification process (Production of Esters, RCOOH) is the equilibrium reaction between a carboxylic acid and alcohol (R1OH). Water (H2O) is the by-product.

$RCOOH + R^1OH \longrightarrow RCOOR^1 + H_2O.$

Esters can be extracted from palm nuts, soybeans, groundnuts, coconut oil etc.

Table 1.0: Extraction Process of Palm oil and Palm kernel oil

Source	**Process**	**Type of oil**
Palm fruits	• Sterilized at 130℃, pound to release the fruits • Squeeze to extract the oils by hand	Palm oil
Palm kernel	• Crush the nuts with digester • Produce liquid (oil and water through screw process) • Free the oil from water through centrifugation and vaccum drying	Palm kernel oil

Table 2: Comparison between mineral oil, palm oil and palm kernel oil

Criteria	**Mineral Oil**	**Palm oil and Palm kernel oil**
Source	Produced from petroleum crude.	Produced from plants
Environmental Properties	Contains compounds that do not readily biodegrade. It may also contain traces of carcinogen.	Highly biodegradable, non-toxic, does not contain petroleum, silicone or halogens
Transformer performance	Does not slow down the standard insulation aging rate; requires special and expensive processing to dry out paper insulation	It is proven to slow down the aging rate of the insulation system, resulting in an increase in expected life of a transformer by decades, also promotes automatic dry-out of paper insulation.
Leaks and Spills	Some bacteria have the ability to absorb these toxic oils and synthetically convert it into a food items. It could be formed by hybridization for more than one type of bacteria found in nature. This could possibly cause a large number of exchanges between different genes to reach the desired qualities to produce a new type of bacteria that do not exist in nature. Harmful to crops and aquatic lives.	(i)Relatively rapid biodegradation may eliminate the need for environmental awareness related to find new complicated dynamic processes to curb eco-concerns during spills. (ii) are not harmful to crops and aquatic lives
Fire-risk	Catches fire more easily leading to higher probability of transformer fires	Reduces the frequency and impact of transformer fires, virtually eliminates sustained fires
Utility cost	Smaller investment leads to shortened life of transformer and diminished economic returns increases liability.	Up front investment promotes transformer life and leads to longer-term economic benefits

2.0 Tests

I. Pour and Flash Points

The pour and flash points of the oil samples are shown in table 3.

Table 3: Pour and Flash Points of oil Samples

S/N	Sample type	Parameter	
		Pour point (·C)	Flash Point (·C)
1	Transformer oil	Below 0·	270
2	Palm oil	30	304
3	Palm kernel oil	30	346

It should be noted that pour point of any oil is the temperature at which the oil begins to freeze. It is desired that pour point of transformer oil need to be low (Ushakov, Klimkin, and Korobeynikov, 2007). This is because, at a very low temperature, the oil will become a gel. The pour point is the temperature at which transformer oil will just flow under the prescribed conditions. Pour point is a useful measure of how transformer oils will perform under low temperatures, especially when it is required to cold start a transformer under very low temperature conditions. Natural esters have a higher pour point than mineral oil, typically in the range -15 to -25°C

(Organisation of Economic cooperation and Development,2008), but tests have shown successful cold start down to -30°C. Also, flash point is the lowest temperature at which oil can evaporate to form an ignitable mixture in air or combustible concentration of gas. Flash point is very vital for it signifies the chances of fire hazard. The higher the flash point, the better the oil to be used for insulation and cooling of transformers.

II. Aging Test or Peroxide Value

In order to obtain peroxide values of oil samples, accelerated stress were applied to the samples up to the point of wear. Values were recorded and shown in table 4:

Table 4: Peroxide values (Aging test) of oil sample

S/N	Sample type	Peroxide value (MgE/kg)			
		4 days	14 days	20 days	30 days
1	Transformer oil	1.0	3.0	6.0	8.0
2	Palm oil	10.0	16.0	28.0	30.0
3	Palm kernel oil	6.0	9.0	12.0	15.0

Peroxides play a central role in the degradation of oil. Like all organic matter, oil is constantly under threat of degradation by peroxidation, i.e., auto-oxidation by atmospheric oxygen brought about by radical chain reactions of organic peroxides. A low peroxide value increases the suitability of the oil for a long-time storage due to a low level of oxidative and lipolytic activities. Refining of oils can result in considerable decrease of peroxide value of various oils.

III. Moisture Content

Moisture content is the amount of moisture or water contained in the insulating oil. This can vary with the method of processing. The presence of moisture in any insulating oil reduces its dielectric strength. Moisture in transformer oil makes it less thick with a lower boiling point. Moisture content is a direct proportionality to transformer oil aging (Ezechukwu, Olisakwe and Nnebe, 2014). Also, the paper insulation is adversely affected by moisture in transformer oil. Tests were carried out to determine the moisture content at certain temperatures.

1g of the specimen was used as sample for the test.

Let weight of petridish and oil sample before drying = W_1

Weight of petridish& sample after drying = W_2

Weight of Moisture = W_1-W_2

% Moisture Content = $\frac{Weight\ of\ moisture}{weight\ of\ Specimen}$x 100

i.e % Moisture Content = $\frac{W_1-W_2}{W_1-W_p}$ x 100

Where W_p = weight of petridish

Table 5: Released Moisture (%) at different temperature.

S/N	Sample Type	Temperature (·C)					
		10	30	50	100	150	200
1	Transformer oil	Nil	Nil	Nil	32.30	29.11	25.30
2	Palm oil	Nil	Nil	Nil	27.88	21.84	18.20
3	Palm kernel oil	Nil	Nil	Nil	12.65	11.83	2.00

IV. Dielectric Strength (Voltage Breakdown) Test.

The dielectric strength is determined by taking note of the voltage at which sparks occur between two electrodes immersed in oil and a specific gap between them. Low level of dielectric strength shows presence of moisture and may be other conducting substances in the oil (Crime, 1988).

Equipment Used:

Oil tester
Model-(OTS60PB) oil tester set.
Spherical electrode gap = 2.5mm
Ambient Temperature: 30·C
Method of Testing [BS 148 (1984)]

Samples were de-moisturized through heating. Electric heating was employed to avoid contamination by carbon(iv)oxide. Six tests were done on each sample and the average was recorded as shown below.

a) Sample 1- Palm oil
   Temperature = 70·C
   Average breakdown voltage = 51kv
   Standard deviation (σ) =9.60
   Dielectric loss factor (tanσ) =0.17
b) Sample 2- Palm kernel oil
   Temperature = 70·C
   Average breakdown voltage = 51kv
   Standard deviation (σ) =10.19
   Dielectric loss factor (tanσ) =0.18
c) Sample 3- Transformer (Mineral)oil
   Temperature = 70·C
   Average breakdown voltage = 37kv
   Standard deviation (σ) = 1.15
   Dielectric loss factor (tanσ) =0.02

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Table 6: Summary of all results

S/N	Sample type	Average breakdown voltage at 70·°C (kv)	% moisture expelled at 150.C	Pour point (.C)	Flash Point (.C)	Peroxide value (30 days)
1	Transformer oil	37	29.11	Lower than 0·C	270	8.0
2	Palm oil	51	21.84	30	304	30.0
3	Palm kernel oil	51	11.83	30	346	15.0

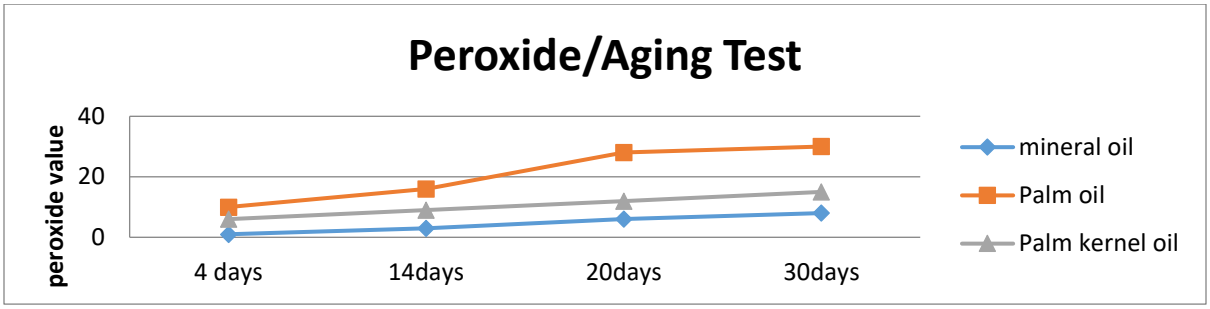


Fig. 3A.Peroxide value.

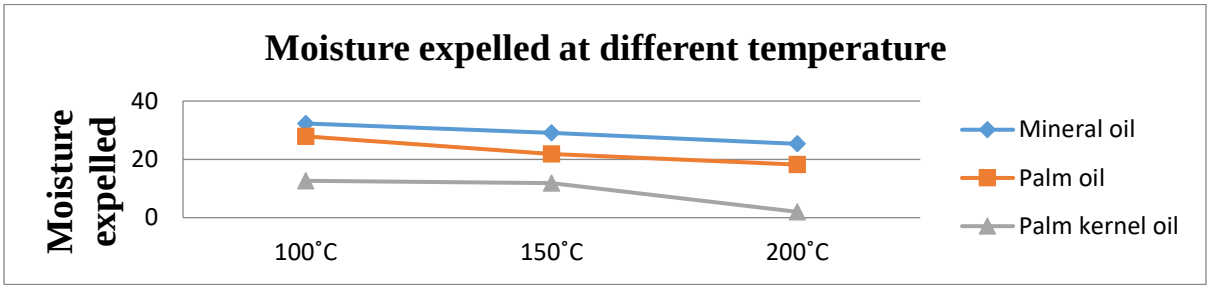


Fig. 3B: Expelled moisture at different temperatures

Analysis of Results

From table 6, it is seen that the pour point for palm oil and palm kernel oil are the same which is 30˚C, while that of transformer (mineral) oil is below 0·C. That means that palm oil and palm kernel oil cannot flow below 30˚C. They can be used in the zones where the ambient temperature is above 30˚C. The results show that palm oil and palm kernel oil are safer in areas with high temperature since their flash points are higher than transformer (mineral) oil. The dielectric strength of palm oil, palm kernel oil and transformer (mineral) oil are 51kv,

51kv and 37kv respectively which is a good property of transformer oil.

Recommendations/Conclusion

The dielectric strength and other properties of palm oil and palm kernel oil were investigated. Both oils can be used for impregnated tapes for cables and others. The oils can be used on high voltage systems because of their high breakdown voltages. Both oils are biodegradable and can be easily obtained in Nigeria at affordable cost. They cannot pose any danger to crops and aquatic lives at spillage. Palm oil and palm kernel oil can be refined further to improve on their qualities.

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