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Palm Oil As An Alternative Dielectric Transformer Coolant

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ABSTRACT
Palm Oil is in abundant supply in Benue State in particular and Nigeria in general. But it is ironical to note that this commodity has only found limited use in the kitchen and cosmetic industries This paper deals with the use of Palm oil as an alternative dielectric coolant for distribution level transformers. The research is consequent upon the obvious importance of transformers in electrical power supply networks and the present realization that the existing method of cooling falls short of specifications. Most importantly, is the inability of mineral and petroleum oils to comply with environmental regulation Laws. In order to verify the suitability of Refined bleached and deodorized Palm oil as an alternative dielectric transformer coolant, a detailed investigations of dielectric properties - like dielectric dissipation factor tan □, relative permittivity $□_r$, humidity content and breakdown strength under AC stress were carried out. Relevant parameters, with respect to electrical and dielectric properties, are water content and oil temperature as well as field strength and frequency. Results obtained are compared to conventional mineral oil based insulating fluid Shell Diala D. The comparison shows that properties of refined bleached and deodorized Palm oil are better than mineral oil Shell Diala D particularly the breakdown voltage and the humidity content, the dielectric dissipation factor and relative permittivity also satisfy operation requirements. Based on results obtained from this work, it is recommended that a practical refined bleached and deodorized Palm oil based dielectric coolant can be incorporated into transformer insulation systems in the electricity distribution networks with little or no modifications.

KEYWORDS: Breakdown Voltage, Loss Tangent, Dielectric, Mineral oil, Refined bleached and deodorized palm oil, Ageing time, Relative Permittivity, Humidity.

I. INTRODUCTION

Oil is used as an insulator and coolant in transformers and by monitoring its condition the transformer's overall health is determined. The oil fills up various spaces between turn to turn, layer to layer, coil to coil, phase to phase, and phase to ground in a transformer and serves as electrical insulation. Because of easy circulation, oil also plays an important and effective role in heat dissipation and hence cooling of transformer, apart from its functioning as insulation.

Among all of the transformer components, the insulation system plays a significant role in the transformer life, because most of transformer failures were caused by insulation problems according to the statistics of transformer failures in USA from 1997 to 2001 [1].

There are two basic transformer insulation types, solid and liquid. Solid insulation can be made of paper, pressboard, epoxy, and wood. Among them, kraft paper is widely used as solid insulation in the transformer, which is made from unbleached softwood pulp.

Oil insulation provides two main purposes in the transformer operation, as the insulation material and the cooling medium. There are several requirements for transformer insulating oil [2]:

a.) To act as a coolant with the main task of absorbing the heat from the core and winding, then transmitting it to the outer surface of the transformer. At higher temperatures the viscosity of the oil decreases, thus facilitating the circulation of the oil.

b.) To insulate different parts at different electrical potential. Oil makes a good contribution to transformer insulation by penetrating into and filling the spaces between wound insulation layers;

II. Mineral Oil

Mineral oil is a mixture of different kinds of hydrocarbon compounds (naphtenic C_nH2_n, such as cyclohexane C_6H_{12}, paraffin C_nH_{2n+2}, such as hexane C_6H_{14}, and aromatic C_nH_n, such as benzene C_6H_6). The proportions of the contents of the individual components depend on the composition of the starting petroleum and, for example, most prized naphthenic transformer oils can be obtained only with the certain types of petroleum.

III. Vegetable Oil

Vegetable oil basically consists of triglycerids, naturally synthesized by esterification of the tri-alcohol, called glycerol, with three fatty acids. The fatty acids are composed of linear hydrocarbon chains ended by a carboxylic function. These molecules have an even number of carbon atoms (typically from 8 to 22 in triglycerids) and the chain can be saturated or mainly mono-, di- and tri-unsaturated. Stearic acid is an example of a saturated fatty acid. Its raw formula is HOOC–(CH2)16–CH3 and it is symbolized by the expression C18:0, where the two numbers correspond to the numbers of carbon atoms and unsaturated bound(s) in the molecule, respectively. The nature of the fatty acid components of triglycerides plays an important role in determining the physico-chemical properties of bio-oil.

IV. Extraction

Ester oil can be extracted from palm fruits or seeds using different processes. The starting point in the production of vegetable oil based dielectric fluid is the vegetable seeds from trees. After the separation of solid matter, the oil is treated with special solvents to remove unwanted components. Bleaching is usually done by clay filter presses, which further purifies the oil. Deodorization by steam removes volatiles that produce odours. The RBDP oil varies in electrical purity over a wide range, from marginal to impure; with conductivities ranging from 5 to 50 pS/m. For transformer use, it is desirable to have conductivity of 1 pS/m or below [3].

Figure 1: Raw palm kernel fruits

V. Investigation

The accelerated thermal aging process is arranged for approximately 140 hours at an aging temperature of between 20°C - 140°C. According to [4, 5] data from aging test shows that 20hours of overload represents a year of useful life of a transformer.

In order to select the best raw material for electro-technical applications, measurements of the main properties of RBDPO were compared with the VDE 03070 and IEC 60296 standards requirements for insulating mineral oils [6]. As no specific international standards exist for vegetable oils yet, the applicability of this specification was assumed.

The IEC 60296 has the following requirements for new insulating oils as specified:

- Breakdown voltage
- Dielectric loss factor
- Relative Permittivity
- Humidity content

The experiments followed the following methods:

a. Breakdown voltage measurement based on IEC 60296;
b. Dielectric losses measurement based on IEC 60247;
c. Relative permittivity measurement based on IEC 60247;
d. Humidity measurement;

VI. Dielectric breakdown voltage U_B

Breakdown voltage at power frequency is the most important value with respect to insulation ability of a liquid. Furthermore, it is a criterion sensitive to impureness by water as well as particles like fibres and soot.

Measurements of the electrical AC strength were carried out with spherical calotte electrodes at 2.5 mm gap distance. Breakdown voltage was determined by applying *50 Hz* AC voltage to the electrodes, starting from 0 and raising with 2 kV/s increase rate up to breakdown. U_B, is the average of 6 single voltage rises.

Between the respective measurements there was 2 minutes break, in which a magnet stirrer was used to remove gaseous and solid decomposition products out of the electrode gap, which were caused by the breakdown of oil, thereby assuring statistical independence.

Power-frequency voltage strength of an insulating liquid is primarily affected by temperature. A result of investigations depending upon temperature is given in Figure 2.

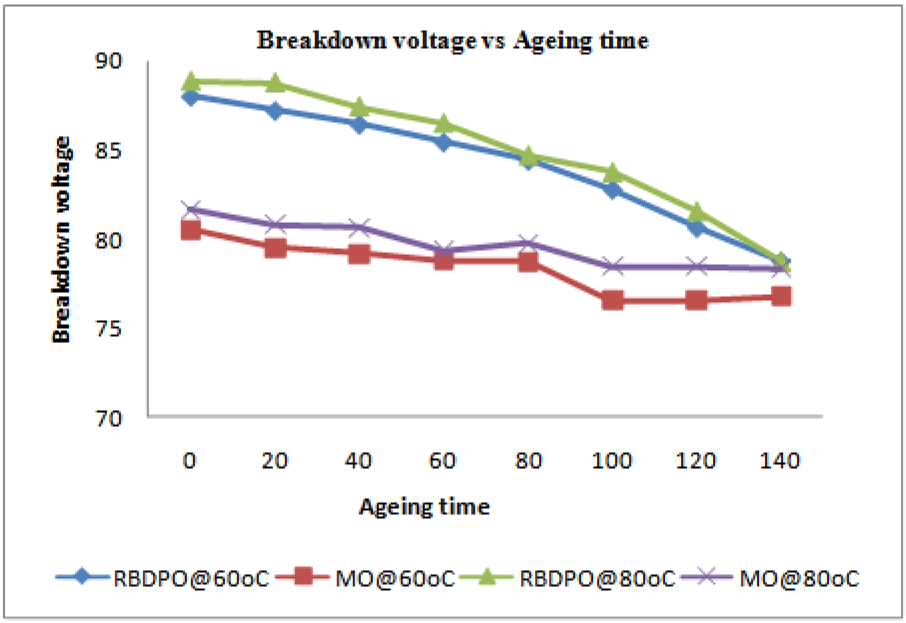


Figure 2: Graph of Breakdown Voltage vs Ageing Time

The BDV of mineral oil (MO) was 81.65kV @ the beginning of the period and decreased steadily to 76.80kV at the end of the period.

The initial BDV value for RBDPO was 88.87kV which is clearly higher than mineral oil at the same temperature; it then decreased to 78.78kV at the end of the period. The result shows a similarity between mineral oil (MO) and refined bleached and deodorized palm oil (RBDPO). This is because transformers perform optimally between 60°C -80°C [7]

The requirement of the VDE 03070 standard regarding breakdown voltage is BDV >50kV. The measurement result shows that RBDPO fulfils the requirement of the IEC/VDE regulation [8, 9].

VII. Dielectric dissipation factor Tan δ

The tan δ results of both types of oil along the aging time are calculated from the mean of two consecutive measurements for each temperature. The value of tan δ was determined using the loss factor measurement bridge.

The value of tan δ is strongly temperature dependent. The IEC 60247Standard requirement for new insulation oils tan δ to be ≤ 0.005 at a temperature of 90°C. From a comparison of the graphs we can infer different trends for both types of oil. RBDP Oil has a tan δ value of 0.003 even at 100°C, which also clearly fulfils the requirement of IEC 60247 [10].

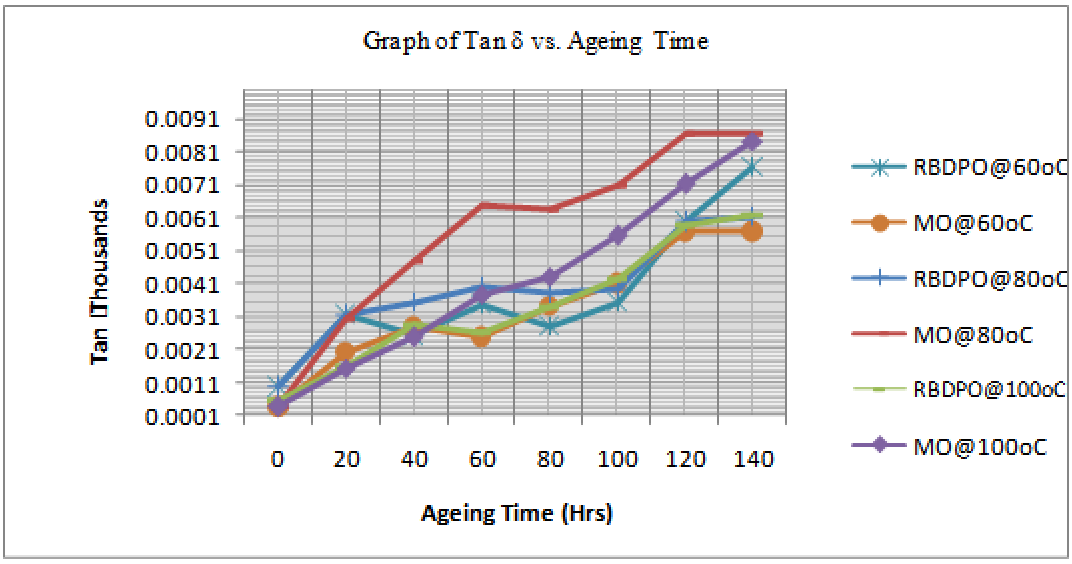
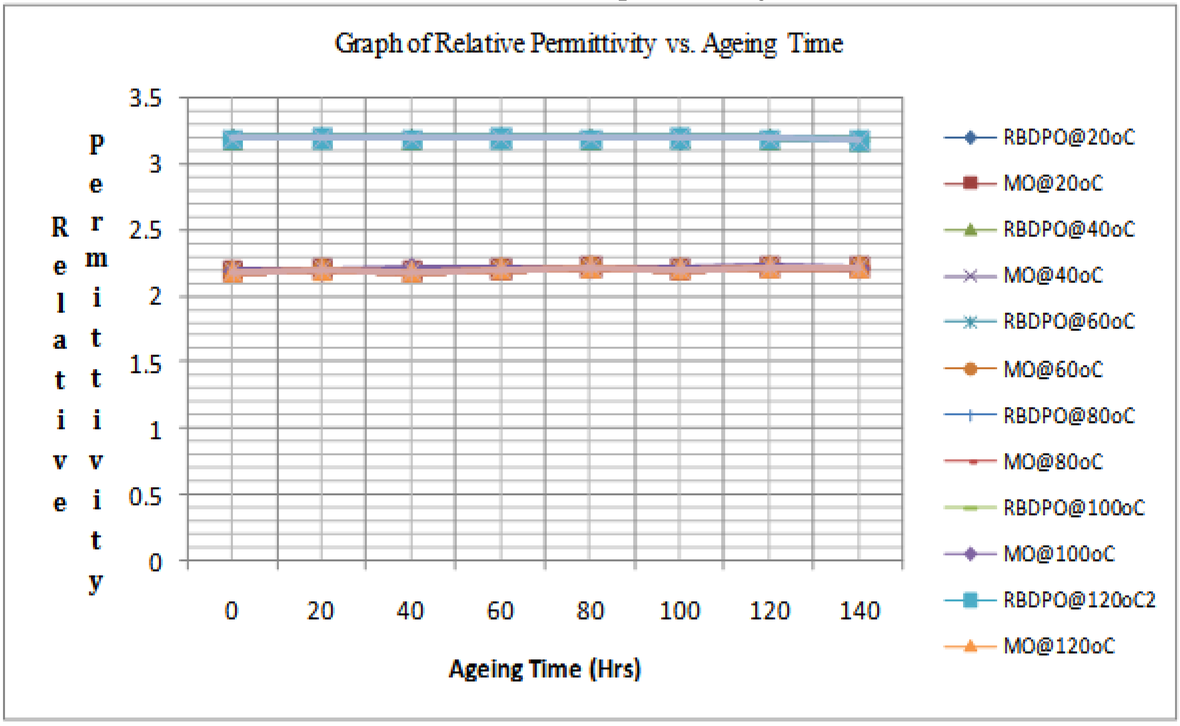


Figure 3: Graph of Tan **δ** vs Ageing Time

It was also observed that the both types of oil exhibited almost similar characteristics at the different ageing times. A rising dissipation factor is an indication of oil ageing or contamination. The dissipation factor is strongly influenced by polar components and is therefore a very sensitive parameter.

VIII. Relative permittivity



The relative permittivity values of both types of oil along the aging time are calculated from the mean of two consecutives measurements for each applied temperature. Actually the measurement itself only determined the capacitance of the test object, the relative permittivity (ε_X) was calculated as the ratio of capacitance of the cell filled with the oil (C_x) and capacitance of the cell with air as the dielectric (C_a). All data are measured at different temperatures from 20°C to 140°C.
Figure 4: Graph of Relative permittivity vs Ageing Time

The relative permittivity results for both types of insulating oil are apparently stable during the accelerated aging process at different temperatures. Based on the graphic illustration, it is clearly seen that ε_X values for mineral oil is lower than RBDP oil. It can be concluded that the relative permittivity of insulating oil is not affected by the accelerated aging process.

IX. Humidity content

The humidity values of mineral oil and RBDPO along the aging time are presented in Figure 5. The humidity test was conducted at the optimal temperature of 100°C.

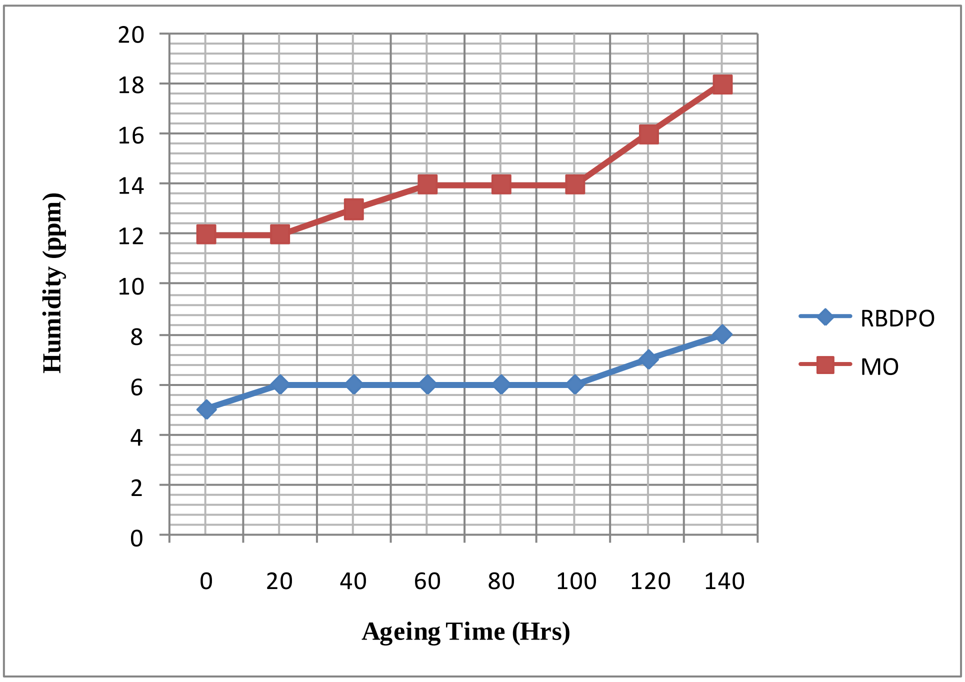


Figure 5: Graph of Humidity vs. ageing time for Mineral Oil and RBDPO

The graph shows that the initial humidity value of mineral oil was relatively higher than RBDP oil. Along the accelerated aging process, the humidity value of mineral oil increased steadily until it reached the maximum at the end of aging process. The condition was almost similar to RBDP oil, but the humidity value did not significantly increase but was fairly stable until the end of accelerated aging process.

X. Conclusion

The dielectric properties of RBDP Oil and mineral oil (Shell Diala D) insulating oil widely used in distribution level transformers were investigated. The dielectric strength of transformer oil is defined as the maximum voltage that can be applied across the fluid without electrical breakdown. The dielectric breakdown voltage of RBDPO is in the range of 90kV. As per IEC60296, transformer-insulating oil must have a dielectric breakdown voltage of 50 kV. Investigations show, that influencing factors on electrical properties of conventional insulating oil Shell Diala D are also qualitatively valid for RBDPO. In many properties this oil was similar to mineral oil. especially the *50* Hz breakdown voltage of RBDPO is sufficiently higher than MO.
The relative permittivity of RBDPO was around 3.2 while it was around 3.1 for mineral oil. Since there is no significant difference in the two values, no special modification is required for the construction of vegetable oil based transformer.

Since transformer oils are designed to provide electrical insulation under high electrical fields, any significant reduction in the dielectric strength may indicate that the oil is no longer capable of performing this vital function. Some of the things that can result in a reduction in dielectric strength include polar contaminants, such as water, and other impurities. The DIN/VDE standard requires for new insulation oils tan δ to be ≤ 0.005 at a temperature of 90°C , the test result shows that RBDP Oil has a tan δ value of 0.003 even at 100°C, which also clearly fulfils the requirement of IEC 60247.

Nowadays, it is increasingly important that dielectric fluids provide a better balance between high functional performances *versus* low environmental impacts. Inside transformers, a stable, chemically inert fluid having good thermal and dielectric properties is needed. Outside (for instance in the event of release), the fluid should become environmentally benign by being non-toxic and readily biodegradable.

In this frame, the agricultural commodity oils, used mainly in food products, are not only widely available, but, unlike mineral oil, are derived from renewable resources. They are biodegradable and do not contribute significantly to the net greenhouse gases released to the atmosphere.

The inherent environmental performance, fire safety and chemical and electrical properties of natural vegetable oil and ester based dielectric coolants are advantageous. The insulating and coolant liquid presented in this research work, specifically formulated from conventional crop plants products for use in tank sealed distribution transformers, offers an interesting alternative to mineral oil-filled transformers.

XI. Recommendation

Based on results obtained from this work, it is recommended that a practical vegetable oil based dielectric coolant can be incorporated into transformer insulation systems in the electricity distribution networks with little or no modifications.

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