Comparison of the Effect of Condensed Moisture on the Breakdown Voltage and Dissipation Factor (tan δ) of RBDPO as an Alternative Transformer Coolant

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Abstract- In this study, an investigation was carried out to evaluate the effect of condensed moisture on refined bleached and deodorized palm oil as an alternative dielectric transformer coolant. Dielectric response measurements were carried out temperatures of between 20°C to 140°C. The breakdown voltage and dissipation factor (tan **δ**) of the oil samples were systematically investigated under the influence of moisture and results compared using ASTM, VDE and IEC standard procedures. Owing to comparable results in the RBDPO and mineral oil (Shell Diala D) studied, it is suggested that treated vegetable oils is a suitable alternative to mineral oil.

Index Terms- Breakdown voltage, Dissipation factor (tan δ), Mineral oil (Shell Diala D*)*, RBDPO*,*

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 three main purposes in the transformer operation [2];

i. To act as a coolant with the main task of absorbing heat from the core and windings, then transmitting it to the outer surface of the transformer.

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

iii. To minimize the evaporation losses, the oil volatility should remain low. Oil temperature in service should be maintained below its flash point.

Accelerated thermal ageing

The Arrhenius law is a mathematical empirical law which concerns the influence of temperature on the velocity of chemical reactions. According to this rule, reactions are generally dependent on temperature and the following relation expresses the reaction time:

$$t = A \exp^{\frac{B}{T}}$$

Where:
t = Time
T = Temperature
A and B = Experimental constants which are based on the reacting materials, reaction conditions and the system of units.

Meshkatoddini *et al*. [3]concluded that accelerated ageing tests have been accomplished on pressboard by Montsinger during a 70 week period at temperatures ranging from 70-110°C, by Dakin during 100 weeks at temperatures of 100-135°C, by Shroff during 16weeks at temperatures of 110-140°C, by Moser during 57 weeks at temperatures of 90-135°C and again by Moser during 3 weeks at temperatures of 145-190°C and finally by Oommen during one week at temperatures of 120-180°C. All these experiments have proved the validity of the Arrhenius law for the degradation phenomena in the insulation study of pressboard.

Requirements for Insulating Oils

The capability of electrical systems and devices in which insulating materials are used, depends to a high degree on the insulating ability of the materials used. The insulating ability may vary depending on the type and quality of these oils; this means that for the construction of electrical devices the thickness of insulation varies with the quality of the oil used.

The requirements for insulating oils are specified by international standards, these standards represent minimal requirements that have to be fulfilled by insulating oils.
In DIN 57310 / VDE 0310 the following requirements of new insulating oils are specified:

- breakdown voltage
- dielectric loss factor
- density
- kinematic viscosity
- resistance against aging
- ignition point neutralization
- number corrosive sulphur
- purity and appearance

II. EXPERIMENTAL SETUP

The sample bottles and the test cell were cleaned by following the standard procedure established by IEC 60156 [4]

Sample Preparation

In this experiment, RBDPO and mineral oil (Shell Diala D*)* were used as samples. In order to observe the effect of water on the insulating liquid, 1ml of distilled water was added to both oil types per sample prepared. The use of distilled water is analogous to the water that condenses in an actual power transformer during service [5].

The Breakdown voltage measurement was based on VDE 03070/ IEC 60296; [6] and the Dielectric losses measurement was based on IEC 60247; [7].The samples arrangement inside the oven is shown in Figure1

Figure 1: Photo of oil samples in the oven for accelerated aging process

The accelerated thermal ageing process is arranged for approximately 140 hours at an ageing temperature of between 20°C - 100°C.

Figure 2:Breadkdown test set for oils

Determination of breakdown voltage

According to standard IEC 60156 insulating liquid - determination of the breakdown voltage at power frequency, there are several procedures that should be followed:

The breakdown test set up for oils is illustrated in Figure 2 and the description of the setup is explained below:

First voltage application is started approximately 5 min after completion of the filling and there should be no air bubbles which are visible in the electrode gap. The applied voltage uniformly increases from zero at the rate of 2 kV/s ± 0.2kV/s until breakdown occurs.
The measurements are carried out until 6 breakdowns on the same cell filling have occurred, allowing a pause of at least 2 min after each breakdown before reapplication of voltage or until there are no gas bubbles present within the electrode gap.

The final result is calculated from the mean value of the 6 breakdowns in kV.

In order to get an accurate result, IEC 60475 gives the additional requirement for the final result that the range of the measurement results must not exceed 10% of the mean value.

Determination of dielectric losses (tan δ)

The dielectric dissipation factor (tan δ) measurement in this project follows the standard IEC 60247 procedure including preparation of measurement tools.
The design of the test cell was slightly modified to reduce the complexity. Figure 3 shows a picture of the test apparatus.

Figure 3: Tan δ test cell

This test cell consists of two main parts, high voltage (HV) and low voltage (LV) electrodes. All electrodes are made of stainless steel that qualifies for its high heat resistance. The cover on the top of the LV electrode is made of epoxy as an insulator and equipped with a potential guard which is put inside it. The potential guard has a function to minimize the effect of any leakage current on the measurement. Two additional parts, the small hole in the cover of LV electrode and a long air junction pipe connected on the side of HV electrode, are intentionally designed in order to ensure that no air is trapped inside the test cell after it is filled with the oil sample. The test cell was measured with empty condition and a capacitance value of 133.58 pF and 3.60×10^{-4} of tan δ value at 600 V applied voltage were measured.

The tan δ in insulating oil can be measured using the Schering Bridge and other related equipment. The balance condition and the capacitance value are observed by the Tettex C_tan δ bridge.

The test cell is connected in parallel to a standard capacitor C_n at the HV side which has a nominal value of 100 pF. It also connects to a balanced detector Tettex at the LV side.

The test cell and oil samples are measured at ambient temperature. The test cell should be rinsed at least three times with a portion of the oil sample. The filling process of oil samples is carefully done to minimize air bubbles.

The test ac voltage should be applied to the liquid within the electric stress between 0.03kV/mm- 1kV/mm. The applied voltages are slowly increased to the test voltage, and then tan δ value can be determined from an adjustment of the Schering bridge variable (capacitance, resistance).

The final result is calculated as the mean of two consecutives values for tan δ, and agrees to within 0.0001 plus 25% of the higher value of two values being compared.

III. RESULTS AND DISCUSSION

Dielectric breakdown voltage U_B

The results of dielectric breakdown voltage measurements are presented in Figure 4

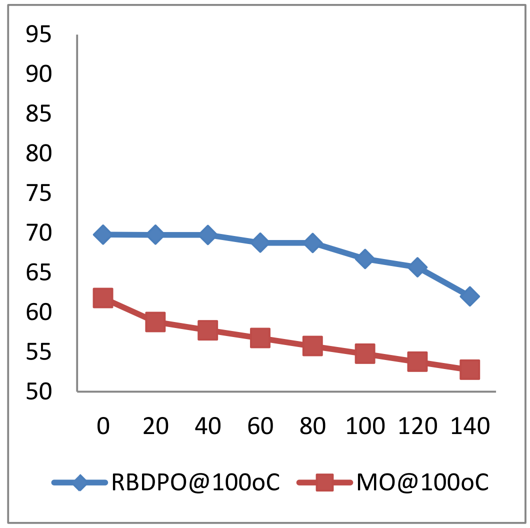

Figure 4: Breakdown Voltage vs. Ageing Time

Figure 4 shows a steady decrease in the BDV of both oils, when this result is compared with an earlier work done by Obande [8], it will be observed that due to the inclusion of water the BDV of both oils never exceeded 70kV and 62 kV respectively.

Dielectric dissipation factor Tan δ

The results of dielectric dissipation factor Tan δ measurements are presented in Figures 5

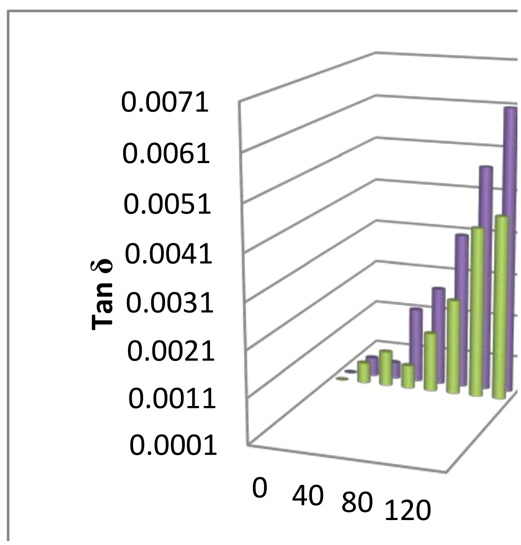

Figure 5: Graph of Tan δ vs. Ageing Time

The tan δ results of both types of oil along the ageing time were 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. IEC 60247standard requires for new insulation oils tan δ to be ≤ 0.005 at a temperature of 90°C. The graph shows an increase of tan δ which is an indication that the presence of contaminants like water can considerably increase the value of tan δ this again is in agreement with Obande [8]. 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.

IV. CONCLUSION

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 voltages of the oil samples showed a decrease along the accelerated ageing process but were within the required range as per IEC60296 and VDE 03090 which stipulates that transformer-insulating oil must have a dielectric breakdown voltage of ≥50kV.
The measurements of tan δ showed an increase along the accelerated ageing process which implies that the presence of moisture in the oil samples is responsible for this increase.
The result clearly shows that if RBDPO is properly treated to remove moisture, it can be used as a transformer coolant.

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