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Effect of Proper Treatment on Mineral Oils

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ABSTRACT

For over a century, a transformer act as a crucial part of the high voltage system. This also acts as an energy alteration device that is used to step-up and step-down voltage for power distribution from power generation to the consumers. Maintaining a transformer is important since a single mistake can lead to a vast amount of problems in a high voltage system in terms of cost. Thus, nowadays, many researchers study the important parts of a transformer, making it to function more effective. One of the studies involves improving treatment in the insulation medium of transformers to improve its function and performance. Here, the focus of this experiment was to study the effect of proper treatment on mineral oil in terms of electrical properties as an insulator in the transformer. The drying process was the main concern in this experiment. Parameters such as AC breakdown voltage, Tan Delta value, Raman measurement, resistivity, and relative permittivity were particularly measured. Origin software was used to analyze the data obtained from the experiment. The results expected from the experiment is that the proper preparation plays the role in tuning the AC breakdown voltage.

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1. INTRODUCTION

For the past few years, electricity demand has been drastically increasing due to economic development and an increase in population. This causes an increase in demand for a longer lifespan for the transformer. The reliable and efficient operation of the electrical power transformer significantly depends on its insulation characteristics, as it constitutes the major portion of the transformer failure. The insulating oil plays a crucial role in the power transformer lifespan as it performs both the insulation as well as coolant function. Since 1892, petroleum-based oil which is mineral oil has been used as a primary insulating medium. The benefits obtained by its properties which are good ageing behaviour, low viscosity, ready availability, and low cost were the reason that it is used more commonly than other types of oil (Wang *et al*., 2018). Despite having many advantages, mineral oil also has its weakness such as being highly flammable and non-renewable (Jacob *et al*., 2020).

One of the alternatives for improving the transformer oil is through dispersing of nanomaterials in transformer oil that helps in developing new types of insulating nanofluids (Lv *et al*., 2014; Suhaimi *et al*., 2020a). Nanofluid is a good insulator due to its nanoscale dimension material with a wide range of classes that has a larger relative surface area which improves heat transfer abilities and improves the stability of the suspensions (Yu & Xie, 2012). According to the research that has been done with the addition of nanoparticles, the conclusion that has been achieved is the AC breakdown voltage increased slightly above that of the mineral oil (Minea, 2019). Research presented by Naddaf and Heris states that the nanofluid using the multi-wall carbon nanotubes causes an increase in electrical conductivity as the volume of the concentration increase (Naddaf & Zeinali Heris, 2018; Wong & De Leon, 2017). Besides enhancing the electrical properties of mineral oil through the addition of Carbon Nanotube particles, proper preparation also needs to be considered as it could cause a great influence on the conductivity (Suhaimi *et al*., 2020b). Presence of polar particles such as sludge, sediments, varnish, water molecule, and resin cause the insulating properties to deteriorate. According to the research paper, moisture in the oil can reduce the insulating ability of the oil at high load and high-temperature periods leading to dielectric breakdown due to the oil absorbing the moisture (Paper, 2011).

In this study, the electrical properties of the mineral oil have been concerned with observing the resulting pattern of the proper preparation with a variable type of test.

2. METHODS

Figure 1 shows the flowchart of the overall experiment conducted in the Laboratory using the equipment provided.

For preparation, mineral oil provided by Hyrax company was used. 500 mL was used for the drying process by using the vacuum oven (VO200 Memmert) which is then indicated by heated mineral oil while 500 ml of ageing mineral oil without undergoing any preparation which indicate as raw mineral oil. The drying process was carried out using the vacuum oven VO200 Memmert to dry the ageing mineral oil at the temperature of 60°C for 24 hours. The ageing mineral oil was dried personally to prevent the moisture from the other fluids being absorbed by mineral oil. This can change the characteristics of the ageing mineral oil. Finally, the mineral oil was left at room temperature before the AC breakdown test was taken place.

The AC breakdown voltage test was carried out according to the IEC 60156 standard by using the BAUR DTA 100C tester. 400 mL of ageing mineral oil was inserted inside the test vessels carefully to prevent any formation of gas bubbles and stirred after each breakdown for two minutes using the magnetic stirrer to make sure the oils have equal distribution

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between the electrodes. The testing data was collected in ten cycles (six measurements every one cycle) with the different distances of electrode gap. The distance between the electrodes in the test vessels was set at 2.5 and 3.5 mm, in which the thickness gauge was set at NO 15SM. The test was carried out using a mushroom shape electrode with the applied frequency of 50 Hz. The process was then repeated with the 400 mL of raw ageing mineral oil.

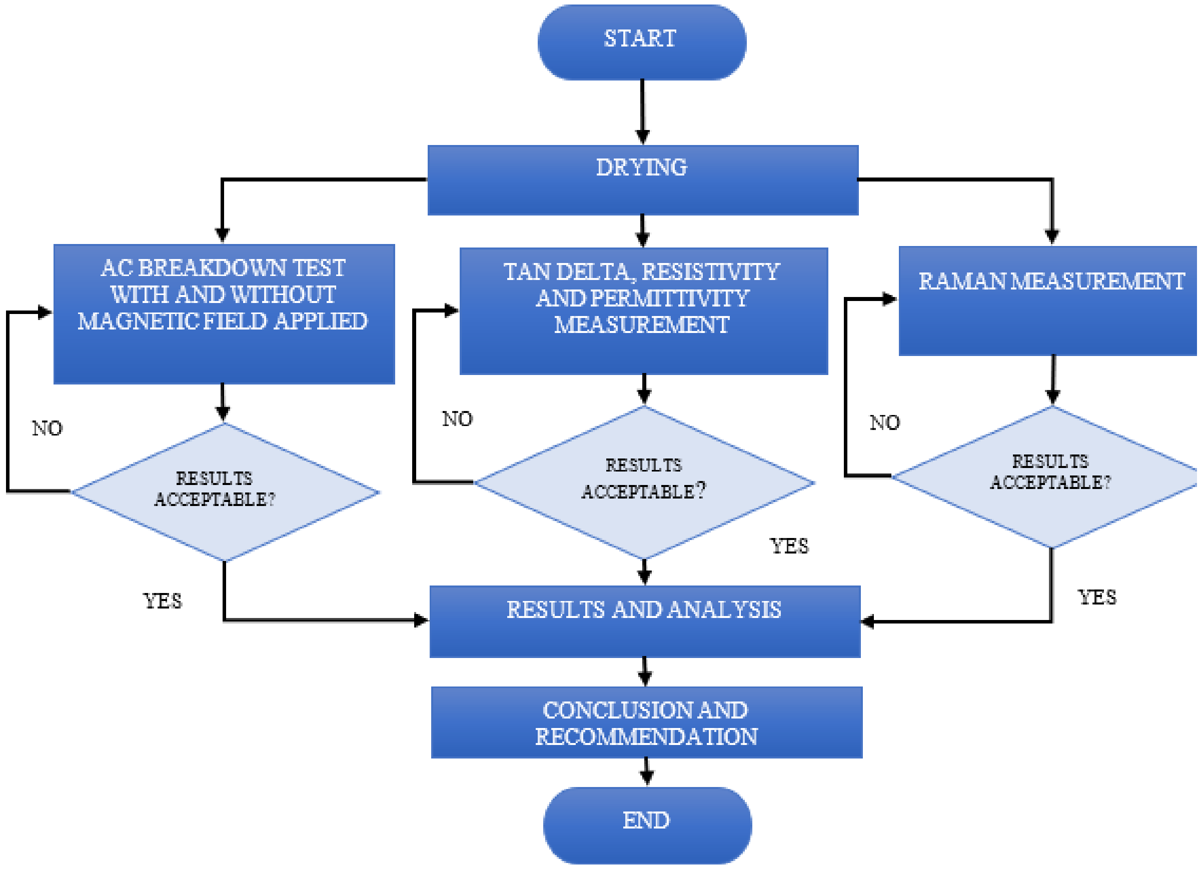

Figure 1. Flowchart for the overall experiment.

The combination of automatic oil test cell heater AOCH-06 and ADTR-2K Plus was used to measure the tan delta, permittivity, and resistivity of the ageing mineral. The cell electrode was created with a spherical bottom design made with stainless steel 316 with Teflon spacers, consisting of three terminal configurations with a dimension of 90 x 195 mm. Automatic oil test cell heater AOCH-06 was used to heat the oil test cell. While handling the test cell, it is necessary to make it free from other substances as possible. Acetone was used to make sure it dry and clean before the test was conducted. 20 mL of heated ageing mineral oil was used inside the test cell. Then, it continued with 20 mL of raw ageing mineral oil. The temperature was set to 30°C with an increment of 10°C and stopped at 100°C.

In this study, Raman measurement was used to characterize materials and crystal structure or crystallinity of ageing mineral oil. Generally, the Renishaw Raman instrument consisted of an inVia confocal Raman microscope, a combination/ hybrid system, a portable Raman analyzer, Renishaw's WiRE (Window-based Raman Environment) software for analysis and data acquisition. This study also used control of Raman data, providing users with dedicated data processing and analysis option. Other accessories were adaptable to the Raman system to suit user's requirement.

Origin software is used to analyze the data obtained from the experiment. Origin software is a software used to design specifically for plotting and analyzing quantitative data. Using the data obtained from the experiment, origin software gives the capabilities in plotting and curve-fitting. The results produced were discussed and thus the conclusion was made based on the most suitable concentration of nanoparticle and the presence of a magnetic field in the insulation medium for transformers. The experiment was made based on the objective that must be achieved to give the best result in producing the insulating medium for the transformer.

3. RESULTS AND DISCUSSION

3.1 AC breakdown voltage

The average of the AC breakdown voltage with a different gap of electrode and cycles is present in **Figures 2** and **3**.

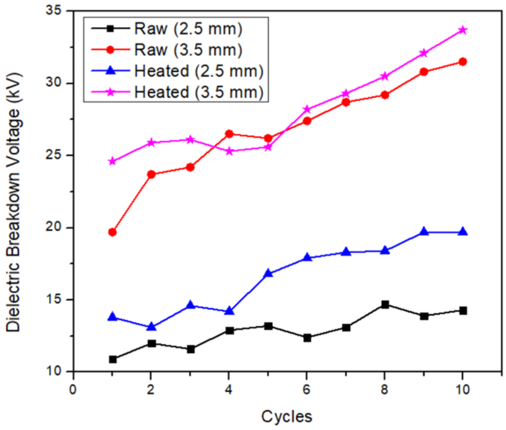

Figure 2. Dielectric breakdown voltage versus cycles.

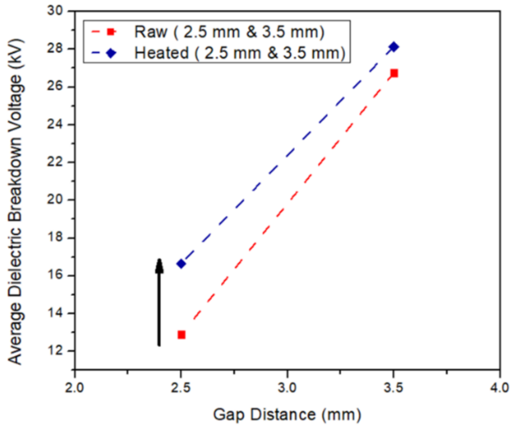

Figure 3. Average dielectric breakdown voltage versus gap distance.

Raw means without proper preparation of ageing mineral oil and Heated means undergoing a drying process. The highest breakdown voltage for 10 cycles of each electrode gap at 2.5 mm of raw is 14.7 kV, 2.5 mm of heated is 19.7 kV, 3.5 mm of raw is 31.5 kV and 3.5 mm of heated is 33.7 kV. **Figure 3** shows the average value of 10 cycles for breakdown voltage versus gap distance. Increasing the electrode gap results in increasing the AC breakdown voltage. This result can be related to the space charge or by the retardation effect of the particles by the adsorption of the particles to the electrodes when migrating to the

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place of maximum electric stress. In this experiment, the value of AC breakdown voltage of 3.5 mm is very promising for this experiment for further studies.

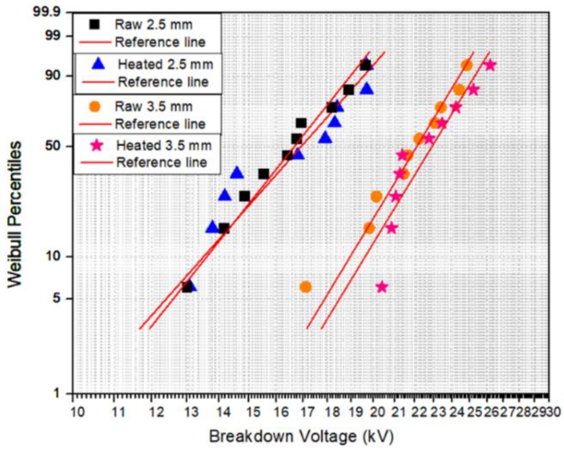

Figure 4. Weibull percentiles versus breakdown voltage.

From the result obtained, the data fitted using the Weibull Distribution Analysis are shown in **Figure 4**. This is to detect the probability of AC breakdown voltage for both samples (heated and raw). The Weibull percentiles that were taken for this experiment are 50 and 90%. The value obtain are presented the **Table 1**.

Table 1. Data obtain for Weibull percentiles of 50 and 90% in breakdown voltage.

	Breakdown Voltage (kV)			
Weibull Percentiles	**Raw (2.5 mm)**	**Heated (2.5 mm)**	**Raw (3.5 mm)**	**Heated (3.5 mm)**
50%	16.6547 kV	17.1204 kV	22.1598 kV	22.7883 kV
90%	19.0716 kV	19.7365 kV	24.4146 kV	25.3455 kV

Based on **Table 1**, the probability for 50 and 90% of AC breakdown voltage are compared. For 50 and 90% in breakdown probability, the breakdown voltage for heated with a 3.5 mm electrode gap was 22.7883 and 25.3455 kV, which is the highest compared to others. Proper preparation and gap distance influence the breakdown voltage.

3.2 Tan delta, permittivity, and resistivity

The value of relative permittivity slightly decreased with increasing temperature (as shown in **Figure 5**). Dielectric permittivity refers to a molecule polarized by an electric field in the dielectric material. At a higher temperature, the polar molecule heat movement is aggravated, causing molecules in the oil to move and vibrate which contributes to a decrement in polarization. **Figure 6** shows the tan delta result for both raw and heated ageing mineral oil with the increasing temperature. For tan delta, it is desirable to have the dissipation factors as low as possible due to the low resistivity component of the current, which indicates high resistive insulation. The resistivity drastically decreased with the increasing temperature as shown in **Figure 7**. The high resistivity indicates good insulation and low resistivity. This means bad insulation as resistivity to be used and to measure the resistance of a given size of a specific material to conducting electricity. A high resistivity value reflects the low presence of free ions and low concentration of conductive contamination.

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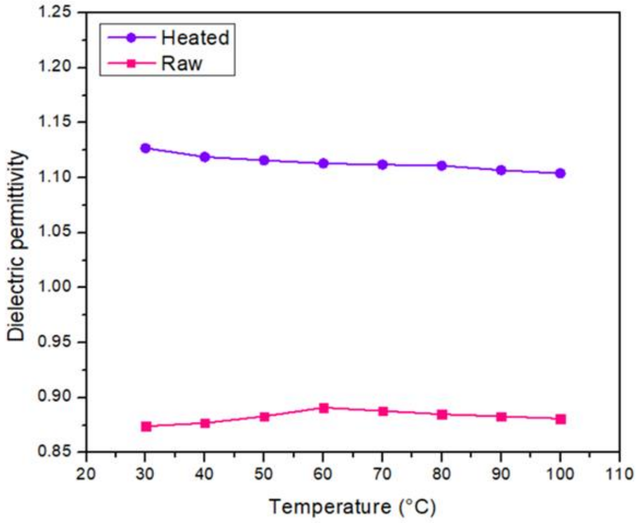

Figure 5. Dielectric permittivity versus temperature.

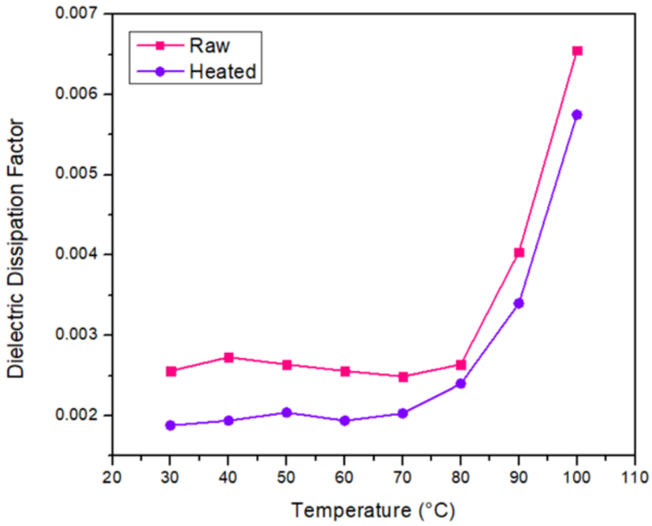

Figure 6. Dielectric dissipation factor versus temperature.

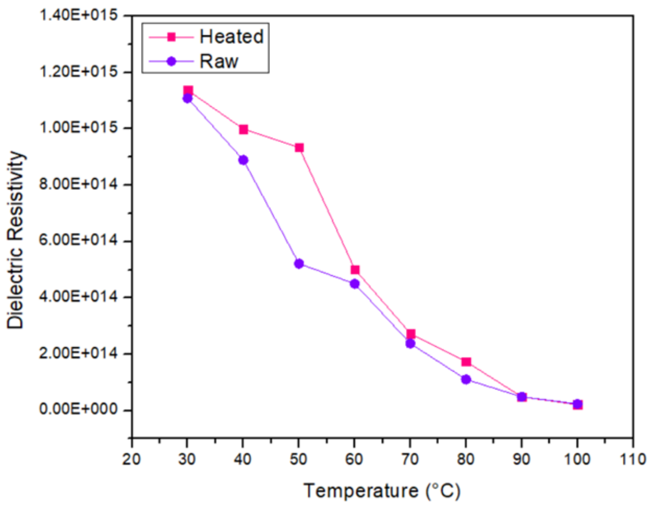

Figure 7. Dielectric resistivity versus temperature.

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3.3 Raman measurement

Figure 8 shows the Raman spectrum light intensity plots (count) versus the Raman shift of oil heated and raw.

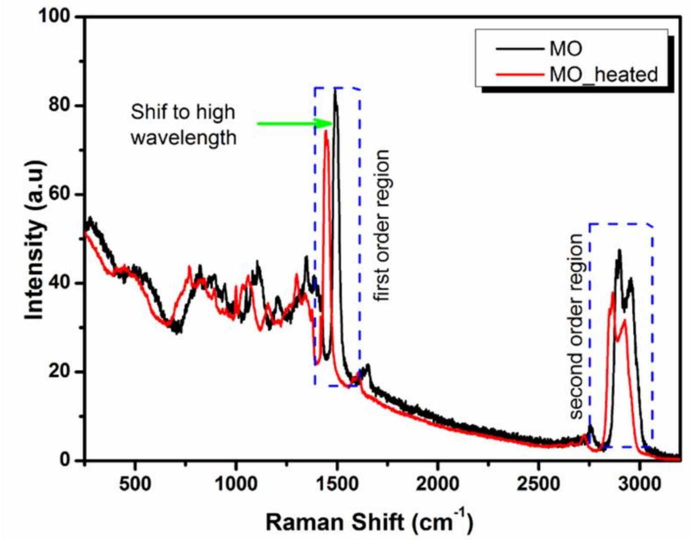

Figure 8. Intensity versus Raman shift.

Both samples have almost similar chemical structures regarding the peaks and pattern in **Figure 8**. Referring to the Raman spectra of the first order and second order region, it is analyzed that the peak of the oil sample after the drying process is reduced compared to raw which has less crystalline or an improper arrangement of atoms in the lattice. This explains that the higher the value of the intensity ratio, the lower the breakdown voltage. D-peak with the highest value of intensity verifies the presence of the oxygen functional groups in the samples. By reflecting the structural distribution, the samples that undergo the drying process have the lowest intensity which suggests the structure of the molecule is stable and believed in having good electrical properties.

4. CONCLUSION

Based on the experiment that has been carried out, the electric properties of mineral oil have been systematically studied. Improvement of mineral oil properties of AC breakdown has been implemented with different treatments and different gap distances. The measurement of parameter concern related to the tan delta, resistivity, permittivity and Raman contributes to explaining the AC breakdown behavior. The value of AC breakdown voltage is increase with the increasing electrode gap and proper preparation. The value of tan delta increases proportionally to the temperature while the value of resistivity is inversely proportional to temperature. The higher the resistivity, indicates the best the insulation properties. The best use of Raman measurement is to indicate the chemical structure of the mineral oil. As for the conclusion, it is concluded that the heated ageing mineral oil with the 3.5 gap distance is the best option for insulation oil in this project. As the presence of foreign particles reduces the breakdown voltage due to an increase in electron avalanche activity.

5. ACKNOWLEDGMENT

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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