The effect of semi-conductive and non-conductive nanoparticles in sunflower oil based insulation

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Abstract: Following the improvement of technology, more and more alternatives are introduced to improve the insulation material and one of them is the nanotechnology. Research had been done which confirm the enhancement of the transformer oil upon adding nanoparticles in term of dielectric strength, viscosity, relative permittivity and others. In this research, semi-conductive (ZnO) and non-conductive (ZrO\textsubscript{2}) nanoparticles with weigh to volume ratio of 0.05g/l are added to the sunflower oil based insulation and the effects are observed. The relative permittivity of added ZnO is higher compare to ZrO\textsubscript{2} in mineral oil. The situation is opposite as ZrO\textsubscript{2} yield higher permittivity with sunflower oil. In term of breakdown voltage, the addition of ZnO shows a better dielectric strength compare to ZrO\textsubscript{2}. The kinematic viscosity is also increase when both nanoparticles are added in which ZnO contributes a higher value.

1. Introduction

Mineral oil as a non-biodegradable natural source is composed from middle range of petroleum-derived distillates. It is able to withstand high voltages while keeping transformer in stable performance. However, the possibility of polynuclear aromatic hydrocarbons in mineral oils get exposed into environment during explosion had raised the concern on its usage. Not to mention the non-biodegradable properties that brings negative effect to environment and human health. Since then, research on alternative transformer insulating oil had been done where vegetable oils been one of most suitable replacement considering its properties. Vegetable oils are made up of different triacylglycerols that can be naturally obtained from seeds or flowers [1]. High biodegradable and low toxicity properties of vegetable oils are environment friendly compared to mineral oil. The presence of high concentration of unsaturated fatty acids however affects the stability of the oils that prone to oxidation [2].The introduction of nanofluids as transformer oil is then developed to obtain better dielectric and thermal characteristic. The general process of creating nanofluids is mixing the nanoparticles with the base fluid of transformer. The introduction of adding nanoparticles to the base fluid of transformer oil had been reported elsewhere before [3-5]. The size and properties of nanoparticles are believed to improve the dielectric strength and thermal conductivity. There are different properties of nanoparticles available in the market which can be classified as conductive, semi-conductive and non-conductive type. Both types of nanoparticles may have different result when added to the base fluid. This leads to the comparative study on the effect of adding these types of nanoparticles into transformer oil.

2. Experiment Methods

The experiment method is classified into 3 stages which are preparation of nanofluids, electrical and physical property tests and aging process.
Preparation of Nanofluids

Two different base oils that were mineral oil and sunflower oil were used. A semi-conductive nanoparticle, zinc oxide (ZnO) and a non-conductive nanoparticle, zirconium dioxide (ZrO$_2$) were prepared and mixed into mineral oil and sunflower oil respectively to obtain the nanofluids. In this research, the nanofluids were prepared using two-step method as this method is preferable for oxide particles and provide higher stability with less agglomeration. In order to obtain 0.05 g/l nanofluids, 0.015 g of nanoparticles was measured and added into every 300 ml of base oil. The mixture solution were then stirred for 10 minutes before undergoes sonication process by using an ultrasonicator. These samples were set to undergo sonication process for one hour long with amplitude of 30%. Molecular sieve is then added into all samples at the final step to eliminate the moisture content. Figure 1 shows the processes involved during the preparation of nanofluids.

![Figure 1: Two step methods.](image)

Electrical and Physical property test

Three different experiments were conducted which include permittivity test, breakdown strength test and viscosity test. The data collected can be used to compare the properties between different nanofluids and pure base oil. Parallel plate test is performed to determine the relative permittivity and dissipation factor of the transformer oil in accordance to ASTM D150 standard [6]. The test was performed at room temperature using a liquid sample electrode.

The breakdown voltage of the nanofluids is tested using an oil tester in accordance with IEC60156 standard. The electrodes should be a 36mm diameter stainless steel spherical or hemispherical 25mm radius with 2.5mm gap between the two electrodes. The rate of voltage rise was set to 2kV/second. An approximate of 300ml sample fluid is then used to completely drain the electrodes for the testing process. Viscosity test was performed to measure the resistance of the transformer oil to flow. This is important as lower viscosity can circulate quicker to dissipate the heat in the transformer oil. This test basically utilizes a viscometer tube to discover the kinematic viscosity of sample fluids based on the ASTM D445 standard. The viscometer is moved to into a holder and place in a constant temperature water bath and measurement was performed at 40 °C [7].

Aging Process

The aging process took place in a fan oven at 90 °C for a week. The beakers were covered to minimise the moisture effect in the nanofluids. All aged samples went through similar electrical and physical tests and compared back to the result of the fresh samples.

3. Result and Discussion

Relative permittivity

The relative permittivity of the oil samples is retrieved from an average of 5 times runs per samples. Figure 2 and figure 3 illustrate the relative permittivity for mineral oil based samples and sunflower oil based samples with or without nanoparticles based on the frequency supplied from the impedance analyser.
From Figure 2, it seems that the MO F has the highest average relative permittivity at 1.54 while the MOZR A has the lowest relative permittivity around the average of 1.23. Another trend that can be observed is that all the fresh mineral oil based samples tend to have higher relative permittivity compare to their aged samples. According to Figure 3, the trend is similar for sunflower based oil samples. The SF F tops the list with average relative permittivity at 1.94 where SFZO A has the lowest score than the other sunflower oil based samples at around 1.39.

Further zoom to the power frequency range around 50 to 60 Hz in Figure 4 and Figure 5 shows the consistency of relative permittivity of both mineral and sunflower based oil samples. The MO F and SF F with the higher relative permittivity could cause by the moisture content due to the absence of ultrasonication process compare to other samples. The ultrasonication process indirectly heat up all the samples for one hour period and moisture content should be lower. The higher the moisture content in oil, the relative permittivity will also increase accordingly [8].

Theoretically, the presence of nanoparticles should have contributes to higher relative permittivity due to their inner polarization. However, the reducing relative permittivity of nanofluids obtained from this experiment goes against the theory. This could happen because of the semi-conductive and non-conductive nanoparticles are used in the experiment which is not easily charged and polarized compared to conductive nanoparticles. The interfacial zone in nanofluids has the intermolecular forces keeping molecules from each other. Hence, the affected and aligned layers form two layers within nanoparticles causing it harder to be polarized [9].
**Dissipation Factor**

By focusing at 50 Hz in figure 4, MOZR F has the highest dissipation factor while MOZO F has the lowest dissipation factor. The similar pattern is obtained in figure 5 for sunflower based oil samples where SFZR F and SFZO F possess the highest and lowest dissipation factor at 50 Hz respectively.

![Figure 4: Dissipation factor of mineral based oils versus power frequency.](image)

![Figure 5: Dissipation factor of sunflower based oils versus power frequency.](image)

**Breakdown Voltage**

Generally, all those oil samples did manage to achieve around the minimum breakdown strength which is 30 kV for high-voltage transformers that have its rating above or equal 230 kV. Based on figure 6, the breakdown voltage of mineral oil based sample shows some improvement with the adding of ZnO nanoparticles. The breakdown voltage only increases by 1.35 kV of MOZO F over MO F. On the other hand, MOZR F shows no improvement and possesses lower breakdown voltage than MO F. The main possibility for this scenario is perhaps the preparation process which may include some impurities. Any moisture content or impurities appear in the oil could also contribute to the partial discharge within the oil that will lower down the breakdown strength of the insulating fluids.

The SFZO F in figure 7 has the highest breakdown voltage among all others sunflower oil based samples which is 81.4 kV. The lowest goes to SF F which goes against the study made by Jilani et al where sunflower oil had its breakdown voltage 34% higher than mineral oil [10]. The SF A achieved a better breakdown voltage than the SF F. This probably means that the moisture content is still high in the fresh sunflower oil sample compare to those aged samples which had been place into oven...
during aging process. The more convincing factor is due to the SF F had not been treated with molecular sieve.

From both figure 6 and figure 7, it can be easily seen that sunflower oil based samples has higher breakdown voltage strength compare to mineral oil. According to Y. Bertrand et al, vegetable oils tend to have higher water saturation limits compare to mineral oil. Since the water limits is dependent on relative humidity, 200 ppm absolute moisture of vegetable oil has its relative humidity at 26.7% which is equivalent absolute moisture of 10 ppm in mineral oil [11]. Therefore, the breakdown strength is generally higher for vegetable oil.

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure6.png}
\caption{Breakdown voltage of mineral oil based samples.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure7.png}
\caption{Breakdown voltage of sunflower oil based samples.}
\end{figure}

**Viscosity**

Figure 8 shows the kinematic viscosity of mineral oil based samples after multiplying the efflux time with the viscometer constant. The trend is similar at which all the aged samples tend to have higher kinematic viscosity compare to the fresh samples. This can be explained by the altering chemical bonds of the samples during aging process where heat is applied [12]. MOZO A has the highest kinematic viscosity at 11.9972 cst while the MOZR F and MOZR A have the lowest kinematic viscosity at 8.2902 cst and 9.7393 cst respectively. The result for mineral oil with added zirconium dioxide is affected by the preparation process that probably not evenly mixed.

In figure 9, the SFZO A is at the top the list with 38.418 cst whereas the fresh sunflower oil possesses the lowest kinematic viscosity among all sunflower oil based samples. Therefore, a short conclusion is done here where ZnO contributes more on higher viscosity than ZrO$_2$. When two graphs put side by side, it can be seen that the sunflower oil has higher kinematic viscosity than mineral oil. However, in accordance with IEC 60296, the upper limit for insulating oil’s viscosity is 12 cst at 40°C. Therefore, all the operating insulating fluids in transformers are mainly mineral oil.
4. Conclusion

Several conclusions could be drawn from the research:

- **ZrO\textsubscript{2}** has better performance with lower relative permittivity and dissipation factor in mineral oil while ZnO is in favour for sunflower oil.
- In terms of breakdown strength, the addition of ZnO into mineral oil and sunflower oil produce the highest breakdown voltage among all. However, the breakdown voltage of MOZO F is not significantly increase over the MO F although it possesses highest breakdown voltage. ZrO\textsubscript{2} on the other hand when added into mineral oil see some decrements in breakdown voltage. For sunflower oil, ZrO\textsubscript{2} has different response where it did improve the breakdown voltage of the sunflower oil.
- Mineral oil with ZrO\textsubscript{2} produce lower kinematic viscosity than ZnO. When both nanoparticles are dispersed into fresh sunflower oil, the ZnO is in favour over zirconium dioxide as it has lower kinematic viscosity. However, after aging the samples, the kinematic viscosity of SFZO A increase much more than SFZO A.

From the observed experiments, the application of nanofluids possess minor enhancement and still lack of stability. The vegetable oil which is presume to be an alternative to the existing mineral oil as the transformer oil also lack of stability although its superior breakdown strength over mineral oil. Therefore, more in depth study should still be carried on to investigate and determine the most suitable dispersants to enhance the vegetable oil in overall dielectric properties.

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