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Determining Electrical Properties of Different Type of Mineral Oil Mixtures

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Abstract

This paper is written to show comparison between the naphthenic mineral oil with namely olive oil and sunflower oil in the context of voltage breakdown as insulating transformer oil. Olive oil is known to have been tested as alternative oil for transformer insulation and sunflower oil is a new oil being tested in this paper.The oils are mixed within certain ratios in order to determine the withstand breakdown voltages. The relationship of the breakdown voltages are also tied with the viscosity of the mixtures, and the mixture of oils are also exposed to ageing test and of tan-delta balancing test. All test follow IEC60156 standard test procedure for liquid insulation test. The mixtures were compared to the existing mineral oils and the findings will be discussed.

Keywords*: vegetables oils mixture, olive oil, sunflower oil, naphthenic mineral oil, breakdown voltage*

1. Introduction

The main purpose of insulation is to limit the conductivity of electricity. A transformer is an equipment that needed to be insulated, as a transformer is a device which transfers energy between two or more circuits through electromagnetic induction. A transformer normally use oil based insulation to insulate the transformer from electrical live parts, and also to cool down the transformer to avoid overheating.

There is an increasing trend to switch from mineral oil to vegetable oil as vegetable oil is much more environment friendly and has biodegradable properties [1]. As mention by Hosier, Gu, Chotchuangchutchavel, and Vaughan in their research paper, they mentioned that after the thermal ageing of the vegetable oils, the oils will increase in viscosity and will exhibit a high AC breakdown strength and low conductivity [2]. D. Martin et al in 2006, tested esters by comparing to mineral oil and they found out that esters have a higher flash points and fire points making esters much more suitable for transformers [3].

Khan, Mossain and Arosh conducted their research and their findings shows that the breakdown voltages of soybean oil, palm oil, mustard oil being compared with mineral oil shows it is applicable up to low voltage appliances [4].

This paper mainly focused on the AC breakdown voltage of the mixtures, ageing test of the mixture, tan-delta test and the relationship of viscosity of the mixture with breakdown voltage.

There are four main objectives of this study. The objectives are:

1. To determine whether viscosity affects breakdown voltage
2. To determine the best mixture of vegetable oil and mineral oil as transformer oil insulation
3. To determine the effects of ageing towards the performance of the oil
4. To determine the effects of used mineral oil and new batch of mineral oil in terms of performance.

2. Research Method

Generally naphtha based oils are easily oxidized compared to the paraffin based oil, but in terms of sludge, the waste product of oxidation, the naphtha based oil sludge is much more soluble compared to the paraffin based oil. It will not precipitate the base on the ventilation cooling system unlike paraffin base oil, as the sludge is not soluble and tends to precipitate at

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the bottom of the transformer, obstructing the cooling system of the transformer. The mineral oil that is chosen for this paper research is naphthenic based mineral oil. There will be two sets of mineral oil that are used in the test which is used mineral oil and a brand new mineral oil of the same brand.

Two types of vegetables oil being tested are sunflower oil and olive oil. Both are chosen due to easy excess and availability. Olive oil are known to be tested around as alternative oil for transformer insulation and sunflower oil is a new based oil being tested in this paper.

The experiments and research done were based on IEC60156 standards [5]. The main software that was used during the research is the High Voltage software WGMSWINthat is available in the High Voltage Laboratory in University Technology MARA, UiTM, Shah Alam, Selangor. IEC60156 is the standard procedure set by the IEC on the method of Determination of Breakdown VoltageTest Method for Liqiud Insulation. IEC60156 dictates that the distance of gap between copper electrodes should be a minimum of 2.5 mm with tolerance of 1%. The gap chosen in this research was 3.5 mm. The WGMSWIN High Voltage software can interact with a computer and the data obtained can be recorded and stored in Excel files.

Starting of the experiment requires the sample preparation. The sample preparation will be divided into three sets, which is SET A is for voltage breakdown test and tan-delta test. Set B mainly focused on the ageing test and finally Set C is the viscosity test. SET A was then be sub-divided into groups which were mixtures between 2 different vegetable oils, and 2 different sets of mineral oils in different ratios of mixtures. The mixture of each set was mixed atspecific percentage ratio as represented in Table 2.0. Each set of oil mixture was tested at initial voltage of 5kV and the voltage was increased by 1kV at an interval of 1 minute until it reached breakdown. The steps were repeated until a certain trend was achieved or the oil was then unable to withstand any breakdown anymore.

Table 1. Set A percentage mixture of oils

OIL MIX	SET A1	SET A2	SET A3
OO+FMO	25%+75%	50%+50%	75%+25%
OO+UMO	25%+75%	50%+50%	75%+25%
SO+FMO	25%+75%	50%+50%	75%+25%
SO+UMO	25%+75%	50%+50%	75%+25%
OO	100%	-	-
SO	100%	-	-
FMO	100%	-	-
UMO	100%	-	-

Abbreviation for ALL tables:

(i) OO = olive oil
(ii) SO = sunflower oil
(iii) FMO = fresh mineral oil
(iv) UMO = used mineral oil

For the dissipation test, the oils were exposed to 5kV and using the tan-delta measuring machine, the values of the power factor (PF) and tan-delta *(Tan δ)* were obtained when the status had reached balanced state.

Dissipation factor test *(Tan δ)* and power factor test were conducted to determine the quality of the oil being tested, whether it is contaminated or whether it is a good insulation. The lower the power factor and Tan δ, the lower is the contaminants in the oil, the better is the oil as an insulating liquid.

Oil mixtures for aging test are represented in the Table 2. The table showed the percentage of mixtures used for ageing test, in which each samplewas exposed to constant voltage for 1 hour, and after 1 hour of exposure at half of initial breakdown voltage, it will be tested and exposed to 3 fold of the testing voltage to determine at which level will breakdown occurs.

Oil mixtures in Set C were used for the viscosity test and the mixtures are shows in the Table 3. The test was conducted in the Geological Laboratory in the Chemical Engineering Faculty.

Table 2. Set B Percentage oil mixture

OIL MIX	SET B1	SET B2
OO+FMO	25%+75%	75%+25%
SO+FMO	25%+75%	75%+25%

Table 3. Set C Percentage oil mixture

OIL MIX	PERCENTAGE
OO	100%
FMO	100%
OO+FMO	75%+25%
OO+UMO	75%+25%

The high voltage experimental setup to test for breakdown voltage of the samples are shown as Figure 1 and Figure 2.

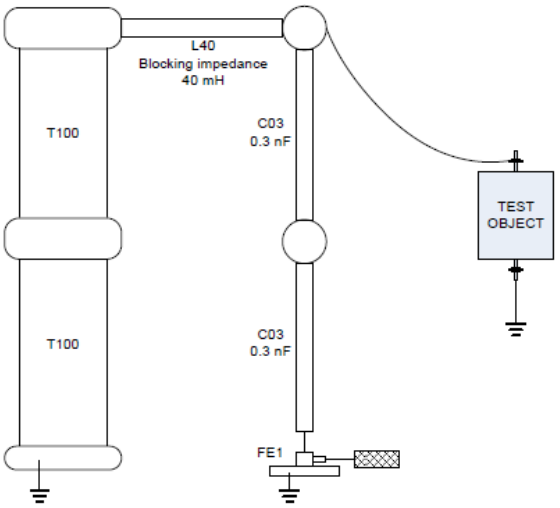

Figure 1. Testing Circuit with Earth Point

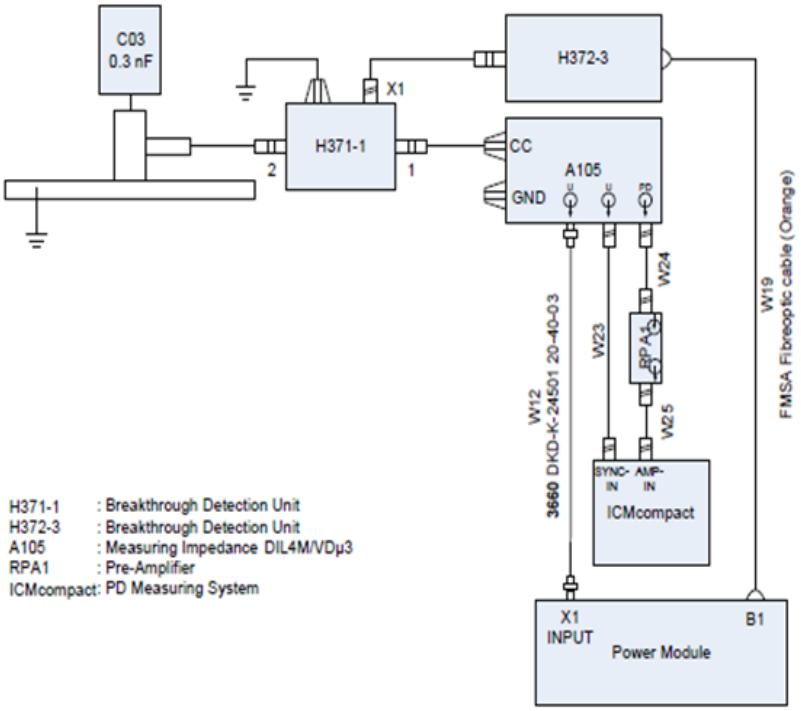

Figure 2. Measuring Circuit

3. Results and Analysis

3.1. Voltage Breakdown

Figure 3 showed the voltage breakdown and comparison between used mineral oil (UMO) and fresh mineral oil (FMO) with the mixtures of olive oil (OO) in the solution with different percentage of mixtures. As it can be seen that in mixtures of 25% of olive oil and 75% of mineral oil, the FMO mixtures fared slightly better voltage breakdown value compared to UMO with average of 6.72kV and 5.65kV respectively. At 50% of mixtures, again the FMO fared much better compared to UMO mixtures with average voltage breakdown of 22.92kV compared to 6.89kV of UMO. In the 75% of OO and 25% of MO, the result was quite different with UMO mixtures having a better average breakdown voltage compared to FMO with UMO gaining 23.3kV and FMO 16.62kV. In general, the blue line graph showed a much better result, which was the mixtures of OO and FMO with overall average value of breakdown voltage of 15.42 kV compared to a value of 11.95 kV for OO and UMO mixtures.

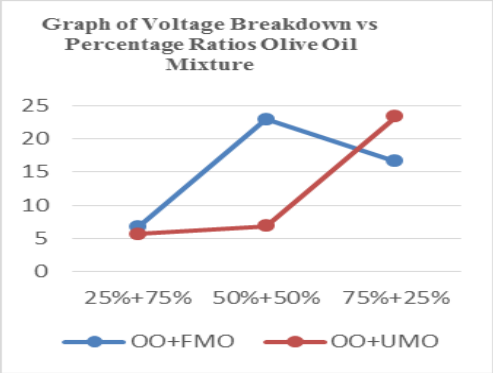

Figure 3. Graph comparing Fresh Mineral Oil and Used Mineral Oil Performance with Olive Oil

Figure 4 on the other hand showed the average breakdown of mixtures of sunflower oil (SO) and the fresh mineral oil (FMO) and used mineral oil (UMO). At 25% of SO and 75% MO, the average breakdown voltages were almost similar, with a small margin of difference with FMO being 5.69kV and UMO with 6.37kV. In the 50% mixture of SO and MO, there was a significant difference with FMO gaining a higher value at 16.84kV and UMO with 12.94kV. When at the 75% SO and 25%MO, the difference between FMO and UMO was also by a little margin with 17.56kV and 18.08kV respectively. Thus, FMO mixtures can be concluded to be better than the UMO mixtures as the overall average values of breakdown voltages for FMO mixtures was 13.36 kV, whereas that of UMO mixtures was 12.46 kV.

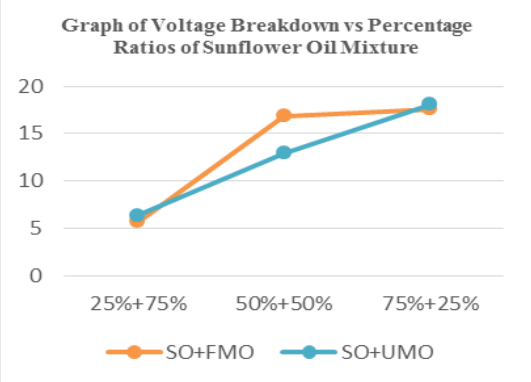

Figure 4. Graph comparing Fresh Mineral Oil and Used Mineral Oil Performance with Sunflower Oil

Figure 5 showed the average breakdown voltage of purely 100% of each type of oil being tested. It can be seen that olive oil (OO) has a better average breakdown with 22.15kV, followed by the sunflower oil (SO) with 11.14kV. Both the fresh mineral oil (FMO) and used mineral oil (UMO) came at almost the same average breakdown voltage of 6.1kV and 6.21kV respectively.

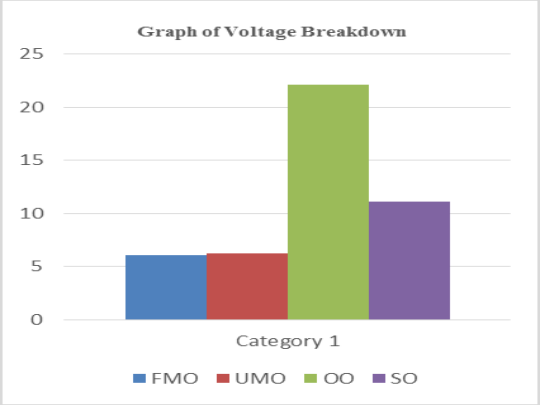

Figure 5. Graph comparing all types of oil in 100% Mixture

In Figure 6, it can be seen that in 75% of MO mixtures, the mixtures were all clustered at almost at the same point around 6kV, at 50% of mixture with vegetable oils; the OO+FMO perform the best, followed by SO+FMO, SO+UMO and finally OO+UMO. At 25% of MO mixtures, almost all were clustered at one point also around 17kV except for OO+UMO. The graphs showed that higher percentage of vegetable oils in the mixtures will produce higher breakdown voltage.

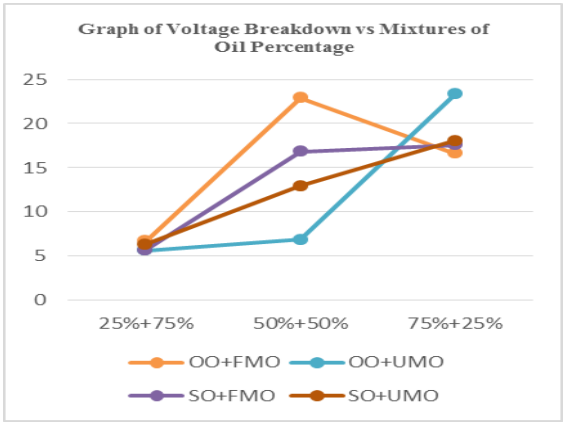

Figure 6. Graph comparing of all the mixtures of oil

3.2. Dissipation Test (Tan δ)

Figure 7 shows the values of power factor (in percentages, %) and the tan delta *(Tan δ)* (in percentages, %) of the olive oil mixtures with the minerals oil. It can be gathered that at 25% of OO and 75%MO, the power factor (PF) of FMO was higher at 11% compared to UMO at 4.06%. The tan delta test also showed that FMO was higher in FMO with 12% and UMO with 4.13%. As for 50% of OO and 75% of OO mixtures, both FMO power factor were rated at 3.48% and 1.778% respectively and their tan delta were at 3.58% and 1.778% respectively. It can be

seen that mixtures of olive oil (OO) with fresh mineral oil (FMO) gives higher values of power factor as well as tan delta. The values of power factor can be said to be the same as expected.

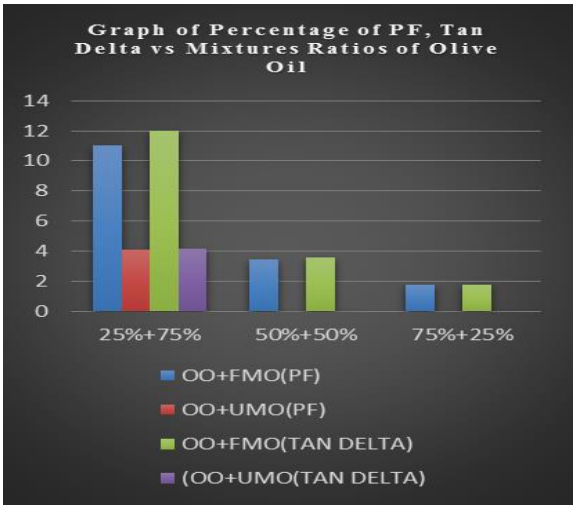

Figure 7. Graph comparing the different type of mineral oil with olive oil in terms of percentage of Power Factor (PF) and Tan Delta *(Tan δ)*

Figure 8 showed the mixture percentage of sunflower oil in 25%, 50% and 75% with MO.The graphs showedthat the power factor (PF) of FMO were at 67.15%, 12.18%, and 3.22% respectively and the tan delta were at 74.8%, 11.96%, and 3.16% respectively. For the UMO, the Power factor was at 2.83%, 1.69%, and 1.18% respectively and the tan delta was at 2.93%, 1.68%, and 1.19% respectively. From the chart, it can be seen that the mixture of sunflower oil and fresh mineral oil yield a greater percentage on both power factor and tan delta compared to used mineral oil and sunflower oil mixtures.

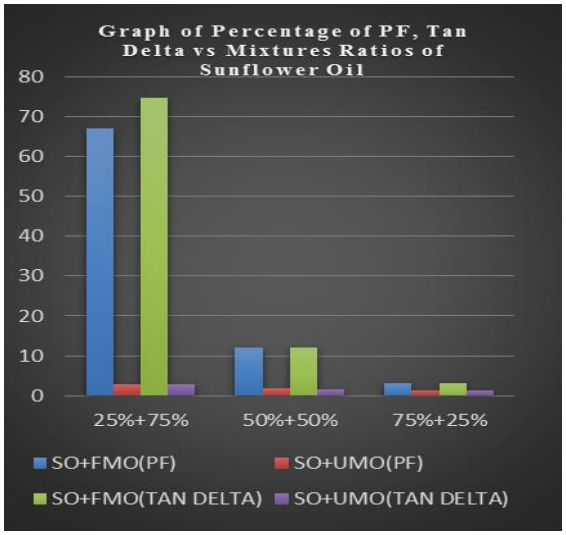

Figure 8. Graph comparing the different type of mineral oil with sunflower oil in terms of percentage of Power Factor (PF) and Tan Delta *(Tan δ)*

Addition of vegetable oils with naturally low values of tan delta and power factor to used mineral oils can be seen to have reduced the values of tan delta and power factor of the mixtures, showing that adding vegetable oils (OO or SO) to used mineral oil (UMO) can actually improved the electrical properties of UMO to have very low losses as indicated by the low values of tan delta and power factor.

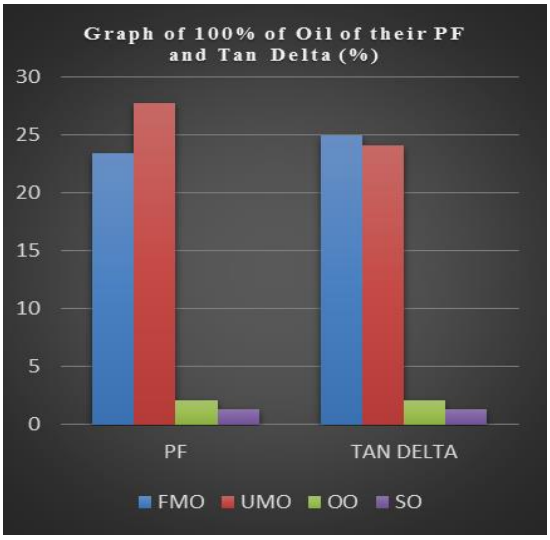

Figure 9. Graph comparing all types of oil of their power factor (PF) and their tan delta *(Tan δ)* value

Graph in Figure 9 showed the relationship of 100% of different types of oil in their performance of the power factor and the tan delta. It showed that the used mineral oil (UMO) have the highest power factor percentage of 27.69%, followed by fresh mineral oil (FMO) with 23.41%, olive oil (OO) 2.07% and lastly sunflower oil (SO) with 1.33%. For the tan delta test, the trend was slightly different, with FMO topping the chart with tan delta of 24.88%, UMO with 24.06%, OO with 2.06% and lastly SO with 1.32%.

Power Factor value or the Tan δ are used to determine the quality of the oil. As mention by Gray I.A.R 2008, the acceptable level of power factor for new oil is as low as 0.05 or 5%. A high power factor in an oil showed the oil had been contaminated or it has deteriorated. All the graphsabove showedthat, OO and SO both have low power factor which means it is within the safe range to operate, whereas both the mineral oils have a very high power factor and it is not recommended to use them on its own [6]. It is also proven that a low PF in mixtures have a significant result towards the breakdown voltage values. Both SO and OO of 75% mixtures with mineral oil have a high breakdown voltage values.

The values of power factor and tan delta for all samples were in the same order of strength as expected. However, it can be seen that OO and SO have very low values of power factor and tan delta, showing that they have very good insulating properties. These properties can explain the low values of power factor and tan delta for UMO mixtures in Figures 7 and 8.

3.3. Viscosity Test

The viscosity test was done in the Chemical Engineering Faculty Laboratory, UiTM, Shah Alam, Malaysia. From the bar chart in Figure 10, it can be seen that 100% of olive oil being tested at the constant speed of 600rpm for 3 minutes, the viscosityobtain was 60.2cP (centipoise) which is equivalent to SI Unit for viscosity of 60.2mPa.s (milipascal-second). This was the highest value of viscosity compared to other set tests. 1Pa.s is equivalent to $1Ns/m^2$ [7]. For the following set of tests on the fresh mineral oil, FMO, its viscosity was obtained at 12.4cP or 12.4mPa.s. This was the lowest value amongst the four samples. The other two mixtures are olive oil and fresh mineral oil at mixtures of 25%UMO+75%OO and 25%FMO+75%OO. The viscosity values were almost identical, which are 44.5cP and 42.8cP.

From the findings, it was observed that liquid with high viscosity tend to have a high level of breakdown voltage. Both mixtures with high viscosity exhibit a voltage breakdown higher than 10kV compared to low viscosity liquid such as FMO.

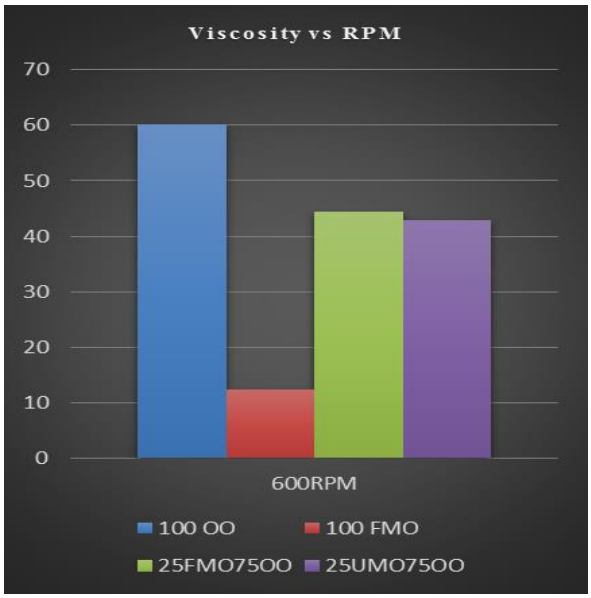

Figure 10. Graph of viscosity value (mPa.s)

4. Conclusion

Pure olive oil (OO) was found to have a better average breakdown voltage at 22.15kV, followed by pure sunflower oil (SO) at 11.14kV. The results of the research also showed that olive oil mixtures with naphthenic oil have a better performance compared to similar mixtures of sunflower oil. Comparing to the pure naphthenic mineral oil, the mixtures of vegetables oil performed better in term of voltage breakdown. The best ratio of fresh mineral oils and olive oil was at 50% equal whereas for sunflower oil was at 75%SO+25%FMO. The mixtures of OO and FMO had an overall average value of breakdown voltage of 15.42 kV compared to a value of 11.95 kV for OO and UMO mixtures. FMO+SO mixtures can be concluded to be better than the UMO+SO mixtures as the overall average values of breakdown voltages for FMO mixtures was 13.36 kV, whereas that of UMO mixtures was 12.46 kV. It can be concluded that higher percentage of vegetable oils in the mixtures will produce higher breakdown voltage.

OO and SO have very low values of power factor and tan delta, showing that they have very good insulating properties.

Addition of vegetable oils with naturally low values of tan delta and power factor to used mineral oils can be seen to have reduced the values of tan delta and power factor of the mixtures, showing that adding vegetable oils (OO or SO) to used mineral oil (UMO) can actually improved the electrical properties of UMO to have very low losses.

Viscosity affects the breakdown voltage level. Liquid with high viscosity can tolerate a higher level of voltage before breakdown, as discussed.

Finally it can be concluded that a high voltage breakdown of oil is influenced by the different percentage of mineral oil with vegetable oils, the higher percentage of vegetable oil in the mixtures will provide higher breakdown voltage.

Acknowledgement

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