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Research paper

Electrical Performance of Palm Oil and Rice Bran Oil as Transformer Insulating Liquid

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Abstract

This paper presents a study on the Palm oil (PO) and Rice Bran oil (RBO) as alternatives to transformer oil. The nature of biodegradability, environmental friendly and easy availability makes these oils a suitable replacement for liquid insulation in transformer. Comparative studies of AC breakdown voltage between these two oils were investigated using two different electrode configurations with a gap distance of 2.5mm. This experimental works was done according to the IEC 60156. The statistical analysis was used to find the withstand voltage and evaluate breakdown probability for both oils. The results indicated that the breakdown voltages of PO and RBO are comparable to each other under different configurations. The Weibull distribution determined the withstand voltage at 1% for RBO are higher than PO even though the average of PO is slightly higher compared to RBO.

Keywords: *Insulation oil; Palm oil; Rice bran oil; AC breakdown; Weibull distribution; Withstand voltage.*

1. Introduction

Natural esters are one of the potential alternatives to replacing non-biodegradable mineral oils in transformer oil. This is because of their significant fire safety characteristic, sustainability, non-hazardous and biodegradable in nature. Besides that, their superior thermo-physical and enhance dielectric opening its use as a transformer oil property. Natural ester oil consists of total fat classified as saturated fatty acids, mono unsaturated and poly unsaturated fatty acids. This fat acid concentration determines the range of natural ester oil behavior [1, 2].

Thus, the natural ester oils must in good condition before being used in transformer. The application of natural ester oils as transformer oil is required to meet the electrical properties criteria such as AC breakdown voltage, lightning impulse voltage and switching impulse voltage before it can be applied in the transformer. AC breakdown voltage is the most and common electrical properties that need to be fulfilled. The AC breakdown voltage also used to measure the transformer oil condition. A lot of experiments have been carried out by researchers recently to compare the breakdown voltages and characteristics of natural esters oils. Among the types of vegetable oils considered for potential application as dielectric insulating fluid in transformers are PO and RBO. Initial study shows that, RBO has comparable performance to other natural esters [3, 5-6].

Viscosity for natural esters plays an important role in determining the power of an oil used. Viscosity mainly depends on fatty acid content. Oil with lower content of poly unsaturated fatty acid has higher viscosity. Most of oil with higher poly unsaturated fatty acid has lower viscosity among investigating oil samples. Uniform distribution of saturated fatty acid and monounsaturated fatty acid in vegetable oil samples lead to medium range of viscosity [4, 6].

Currently, there are still less studies that have been carried out to examine the electrical performances of RBO with consideration on different electrode configurations. Therefore, RBO is selected in this experiment to study the effect of different electrode configurations on AC breakdown voltages. The PO is used as a comparison in this study. The scale effect probability of AC breakdown voltage of RBO ad PO were represent using the Weibull distribution function.

2. Experimental Description

The samples used in this study were PO and RBO. RBO and PO were obtained from readily available cooking oil products in the market. Figure 1 shows the different on physical color of RBO and PO. Table 1 shows the composition of fatty acids and viscosity of RBO and PO of the samples. Oil with high content of unsaturated fatty acids will have an excellent viscosity performance [9]. Thus, in this study RBO has better viscosity than PO, which translates to better cooling performance for transformer application. Nevertheless, the obtainable content of vitamin E has no noteworthy significance on the performances of breakdown voltages data and analysis below.

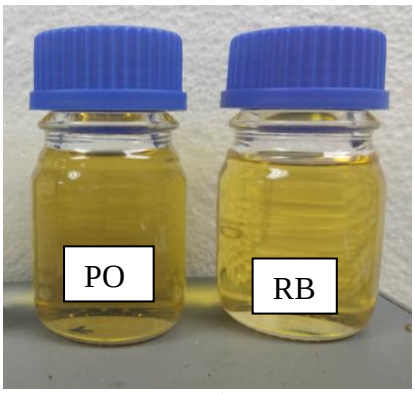

Fig. 1: Sample of PO and RBO

Table 1: Fatty Acids and Vitamin E contents of RO

Properties	PO	RBO
Saturated fatty acid (g)	45.4	22
Monounsatureated fatty acids (g)	43	38.3
Polyunsaturated fatty acids (g)	11.6	4.7
Vitamin E (mg)	4.4	1
Viscosity (pa/s)	0.069	0.06

The " as-received" PO and RBO samples were firstly filtered three times using a Thermo Fisher Nalgene membrane filter with a pore size of 0.2 µm. After being filtered, the oil samples were dried, degassed and dehydrated in a Memmer vacuum oven at temperature of 85 ºC under 500 Pa for 48 hours. The oil samples were then rested at ambient temperature for a further 24 hours under vacuum before tested for AC breakdown voltage. These steps are needed in order to make sure that the influence of impurity present in the sample and moisture content in the sample is minimized.

The AC breakdown test was performed using BAUR DTA 100C with a maximum output voltage of 100 kV. Horizontal uniform configurations of mushroom to mushroom and sphere to sphere electrodes with 2.5mm gap distance were set up in a cubic glass with a volume of 400ml according to IEC 60156 standard. Figure 2 illustrates the equipment used for the AC breakdown test. The rate of rise voltage was set at 2 KV/s and fixed initial standing time of 5 minutes before voltage applied. The time interval was set at 2 minutes. A total 50 reading of breakdowns was obtained for each sample.

Fig. 2: AC breakdown tester (BAUR OIL –DTA 100C)

3. Results and Analysis

3.1. Electrodes configuration effect on breakdown voltage

The average 50 breakdown voltage shows in Figure 3. From the figure, there is no significant difference of 50% breakdown voltage between PO and RBO. The differences are 0.04% and 0.18% for mushroom and sphere electrodes respectively. This is belief due to the viscosity of both samples is almost identical as shown in Table 1. From the results, PO and RBO structures and characteristics are not much influenced on the AC electrical breakdown voltage. However, the different electrode shapes play a role for the AC breakdown voltage. In this case, sphere to sphere configuration observed higher average about 18% (different 17kV) compared to mushroom-mushroom configuration. The breakdown voltage with different electrode shape almost same under small gap [7]. This different is might be due to mushroom-mushroom electrode produces quasi uniform electric field as compare to sphere-sphere electrode which produces uniform electric field hence. Quasi uniform electric filed will cause lower breakdown voltage than uniform electric filed.

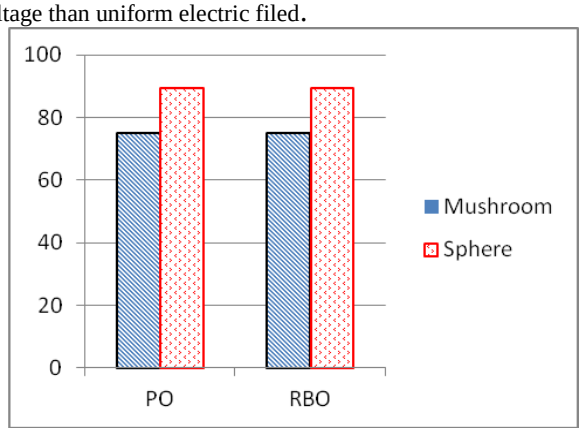

Fig. 3: 50% of breakdown voltage at 2.5mm gap distance under Sphere and Mushroom electrodes

The scattered of the AC breakdown voltages for PO and RBO is shown in Figure 4. Even though PO has higher average breakdown voltage, RBO scattered on both electrode configuration shows more evenly than PO. This shows that, RBO has uniform distribution compared to PO. Besides that, due to less fatty acids content in RBO and the less viscous will help the AC breakdown voltage of RBO distributed evenly. This finding agreed by previous researcher which states that liquids with low viscosity will have a good and forced natural convection [1-2, 8]. A significant positive result of reducing the viscosity of natural ester oil which might improve its characteristic.

3.2. Determination of withstand and 50% breakdown voltage

Withstand voltage is critically important for the design of power transformer insulation. The Weibull distribution is usually used to fit the breakdown voltages and the withstand voltage can be deduced based on the fitted curve. The Weibull statistic method is based on a stability postulate [10]. The weak-link theory gives the breakdown probability Weibull distribution *F (x)* is given in as follows:

$$F(x) = 1 - e^{-(\frac{x}{\beta})\alpha} \quad (3)$$

where α is the shape parameter and β is the scale parameter.

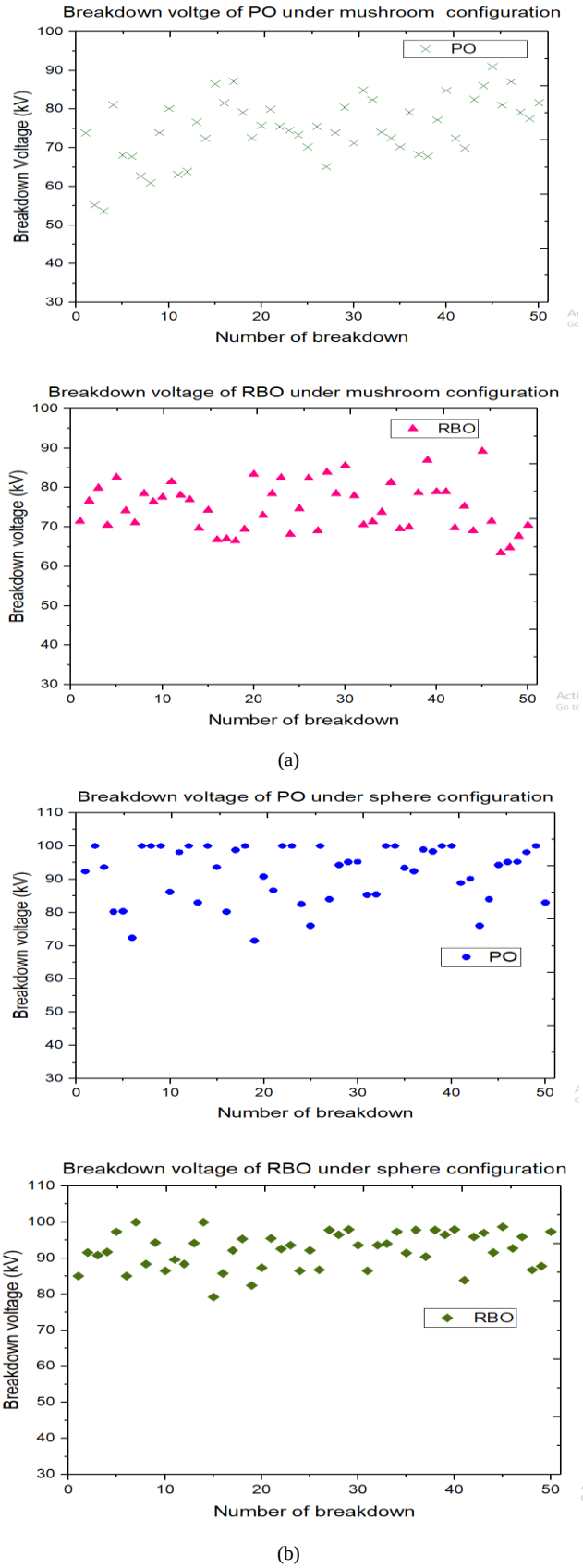

Fig. 4: Scattered data of breakdown voltage at 2.5mm gap distance of (a) Mushroom electrodes and (b) Sphere electrodes

The breakdown voltage data were compiled using Weibull distribution function according to different electrode configuration. Based on Figure 5(a), Weibull distribution fitted well for PO at all probabilities under mush-mushroom electrode. However, for RBO, the Weibull distribution predicted lower breakdown voltages up to 10% probabilities. Figure 5(b) shows the Weibull fitted for sphere-sphere electrodes for both PO and RBO. As we can see from the figure, the Weibull distribution fitted well for both PO and RBO breakdown voltage data.

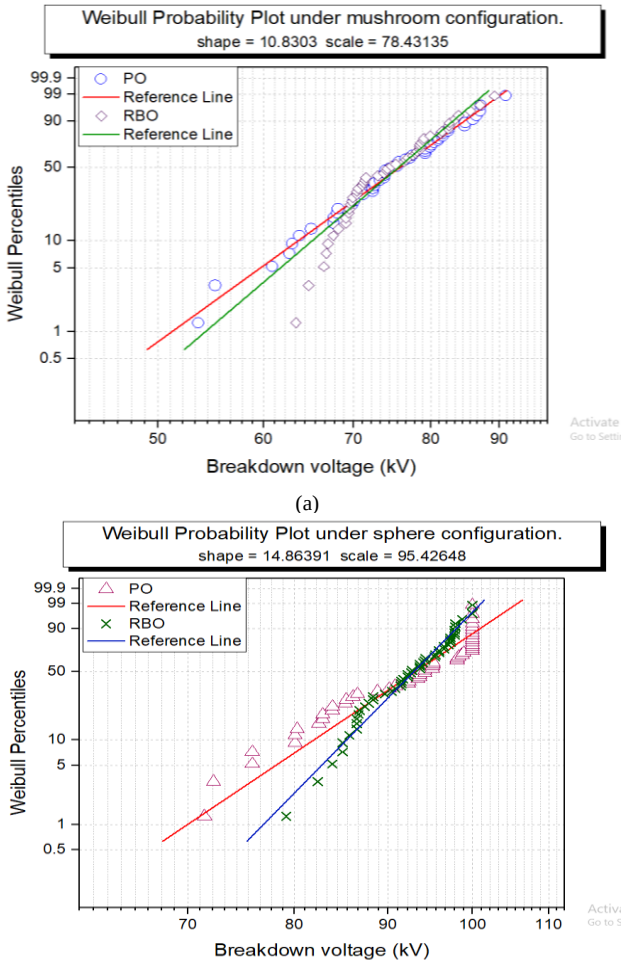

Fig. 5: The Weibull fitting for RBO and PO under (a) mushroom configuration and (b) sphere configuration

Table 2 indicates the breakdown probabilities for both oils at 2.5mm gap. The 50% breakdown voltage of PO and RBO as closed to each other which is consistent with the conclusion previously drawn. The withstand and 50% breakdown voltages of sphere-to-sphere configuration is higher than mushroom-to-mushroom configuration for both samples which is greed with experimental results. At 1% withstand voltage, RBO predicted higher breakdown voltage compare to PO with percentage of difference of 6% and 10% for mushroom-mushroom and sphere-sphere respectively.

Table 2: 1% and 5% Breakdown Voltage of PO and RBO

Electrodes Configuration	Breakdown Probabilities (%)	Breakdown Voltage (kV)	
		PO	RBO
Mushroom	1	51.28	54.30
	50	75.79	75.74
Sphere	1	70.07	77.05
	50	93.40	93.10

4. Conclusion

AC breakdown voltages of the PO and RBO for transformer insulation liquid in two different electrode configurations were investigated. The results indicated that AC breakdown voltage for PO and RBO are comparable to each other. Furthermore, sphere-to-

sphere electrodes produce higher breakdown voltage than mush-room-to-mushroom electrode configuration. Overall, PO and RBO are considered as has good breakdown voltage strength and can replaced currently non-biodegradable insulating transformer oil. The Weibull distributions were used to fit the experimental data and for most of the cases, the distribution fitted well with the data. The 50% breakdown voltages of the PO and RBO are close to each other and agreed with the results in this study for both electrode configurations, the withstand voltage of RBO is higher than PO for all the electrode configurations.

Acknowledgment

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