Study on Breakdown Voltage for Vegetable Oils with Additive TiO$_2$

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Article Info	ABSTRACT

High voltage power transformers commonly used petroleum-based mineral oil for cooling and insulation purposes. Researchers are looking for suitable vegetable oils as alternatives to mineral oil to be used as transformer oil. The alternative vegetable oils are biodegradable, non-toxic and environmentally friendly. They may require some processing and modification to improve some of their properties to ascertain their safe use in power and distribution transformers as well as in high voltage equipment. This paper presents a study on the AC breakdown voltages of Palm Oil (PO) and Coconut Oil (CO) with presence of an additive. PO and CO are chosen as they are locally produced oils in Malaysia and easily obtained. The type of additive used in this study is Titanium dioxide TiO$_2$. TiO$_2$ nanoparticles was added into PO and CO at volume concentration of 0.1% to 0.5%. The effect of different gap distance of electrode 1.5mm, 2.5mm and 3.5mm was studied. The temperature of oil is controlled at 30°C. This paper provides a comparative assessment of breakdown properties through experimental investigation of PO and CO before and after the additive is added according to ASTM D1816 standard. From the experimental result, the PO have slightly higher breakdown voltage compared to CO. From all oil sample data recorded, it can be concluded that the breakdown voltage had increased to the increase in gap distance of electrode under presence of TiO$_2$.

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1. INTRODUCTION

High voltage transformer commonly used petroleum-based mineral oil for cooling and insulation purposes. It has been used extensively for more than a hundred years [2]. The petroleum-based mineral oil is non-biodegradable and can infect soil and water if serious spills occur. Moreover, petroleum-based mineral oil is going to run out. Therefore biodegradable oils are introduced to replace petroleum-based mineral oil, such as vegetable oils, to overcome this problem [3].

Test on different characteristics and types of palm oil (PO) and coconut oil (CO) had been carried out on chemical, electrical and physical properties [4]–[7]. According to the studies, PO and CO may be appropriate to meet the principle requirements and shown that they are similar to other type of vegetable oils.

Investigations during the last recent period have shown that conductive nanoparticles can be dispersed in transformer oils to form nanofluids. Well-dispersed nanoparticles can increase the breakdown voltage of the oil under power frequency and lightning impulses. They also increase the inception voltages for partial discharge [8] There are three groups of additives which may be divided into, namely, conducting

nanoparticles (Fe3O4, Fe2O3, ZnO, SiC), semiconducting nanoparticles (TiO2, CuO, CuO2) and insulating nanoparticles (Al2O3, SiO2) [9].

In this study, investigations will be conducted regarding the breakdown voltage analysis of vegetable oils under presence of an additive with different gap distance of the electrodes. The vegetable oils that will be used are PO and CO. The objective of this project is to study the effect of additive TiO2 with different electrode gap spacing on electrical properties of PO and CO. The presence of partial discharges is also recorded.

2.   RESEARCH METHOD

This section explains the experiment setup for breakdown voltage test using standard mushroom electrode arrangement. The apparatus required for measurement of liquid breakdown, description of equipment used for breakdown test and experimental procedure for conducting the liquid breakdown voltage are discussed.

This project began with the review of the past research on the biodegradable insulation oils. All the relevant information were collected and summarized. The collected information were about the breakdown voltages of biodegradable oils with presence of additives.

In the second step, the samples for conducting the experiment was prepared. The samples were PO and CO. The additive Titanium (IV) Oxide was added into the PO and CO samples with different volume concentration. The experiment results before and after the additive was added were recorded and analyzed.

The results obtained from the experiments were used to analyze the trend of the breakdown voltage for the two types of liquid dielectrics. The relationship of breakdown voltage under presence of additive with the different gap distances in two types of liquid dielectrics were compared and discussed.

2.1. Test Material

The oil samples for this project was already defined which were PO and CO. The samples were used to test the effect of additives at different percentages of addition with different gap distance of electrode from 1.5mm, 2.5mm and 3.5mm on the breakdown voltage of the oils. The test cell used in this study is shown in Figure 1.
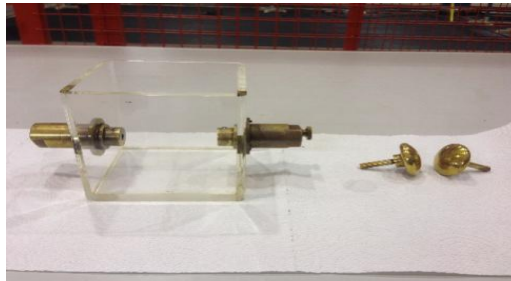

Figure 1.Test cell sample

$$X_d^{(G)} = X_d^{(G-1)} + \alpha \oplus \text{Levy } (\beta) \tag{10}$$

Where X_d is the population and α is a step size for updating new solution.

$$X_{d,new} = \begin{cases} X_d + rand(X_{r1} - X_{r2}) if\ RN < P_a \\ X_d \quad otherwise \end{cases} \tag{11}$$

Where X_{r1} and X_{r2} are random solutions withdrawn from the population.

$$X_D = \begin{cases} X_{d,new} \quad if\ Fitness(X_{d,new}) < Fitness(X_d) \\ X_d \quad otherwise \end{cases}, d = 1, ..., N_p \tag{12}$$

Where $X_{d,new}$ is a new solution at the same nest d.

In the last stage, MOCSA will perform a selection process. During the selection process, all fitness function were normalized before calculating the multiobjective fitness (F_T). If new fitness, F_T value is better than old F_T, the new fitness value will be updated as a new nest. Otherwise, it will go back to generate Cuckoo randomly. The selection process can be represented by (12). The value of fitness obtained need satisfy with the various constraints in economic dispatch problem. The number of nest is set to 20 and the best fitness value obtained will be compared with the best value of G_{best}.

2.2. Nanofluids Preparation

Nanofluid samples were prepared by adding additive with different volume of concentration into PO and CO through ultrasonic treatment.

The concentration of Titanium (IV) Oxide, TiO2 in oil samples were in the range of 0.1%, 0.2%, 0.3%, 0.4% and 0.5%. The oil samples were left for 24 hours before the experiment was carried out to avoid the influence of small microbubbles created during ultrasonic processing. The process of nanofluids preparation is shown in Figure 2. There were thus ten samples of nanofluids that were used to test the effect of additive with different gap distance of electrode on the breakdown voltage of oil.

The nanoparticles powder was weighted by using digital analytical electronic balance. The weighing samples of conductive nanoparticles are determined by the following formula [12]:

$$W(nm) = \frac{\rho(nm)xV(oil)xPVF(nm)}{100} \qquad (1)$$

where,
  W(nm): weight of nanoparticles (g)
  ρ(nm): density of conductive nanoparticles (g/cm^3)
  V(oil): volume of oil (ml)
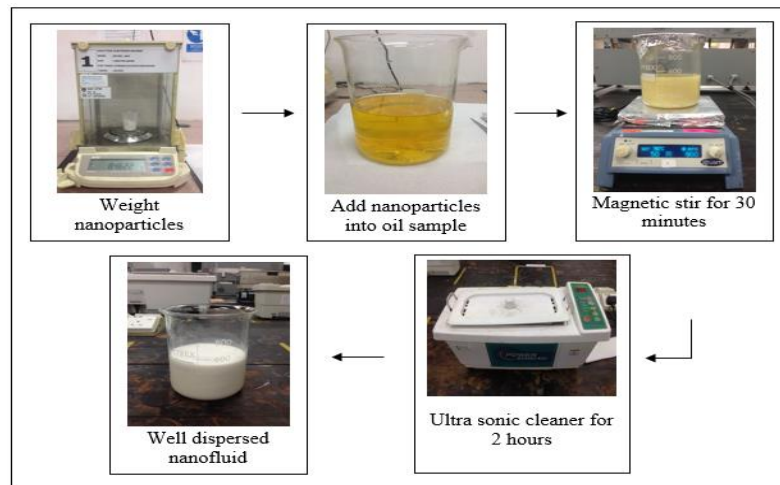 PVF(nm): volume fraction of nanoparticles (%)

Figure 2. Process of nanofluids preparation

The samples need to withstand a stirring treatment to disperse the aggregations of nanoparticles. It is worthy to say that this method was able to break the aggregations as reported in [13]-[16]. Figure 2 shows the steps in preparation of the samples before they were ready for the voltage breakdown test. The heat-stir equipment used to disperse the nanoparticles was the third important step. The equipment was set to 60oC and 900 rpm of stirring speed. A magnetic stirrer was used to disperse the nanoparticle. Each sample took 30 minutes to undergo the treatment.

After the heat-stirrer treatment, the samples were placed in ultrasonic cleaner to extract and remove any bubble, moisture and gases that emerged during the stirring treatment. The samples were left in the ultrasonic cleaner for 2 hours at 50oC [13].

2.3. Preconditioning of Test Oil and Nanofluid Samples

In order to investigate the effect of additive with different gap distance of electrode on the breakdown voltage of oils, the measurements were done at controlled constant temperatures. The temperature

was controlled at 30°C. Infrared laser thermometer was used to measure the temperature and to make sure the temperature of each sample before the start of each experiment was 30°C. Preconditioning process shown in Figure 3.
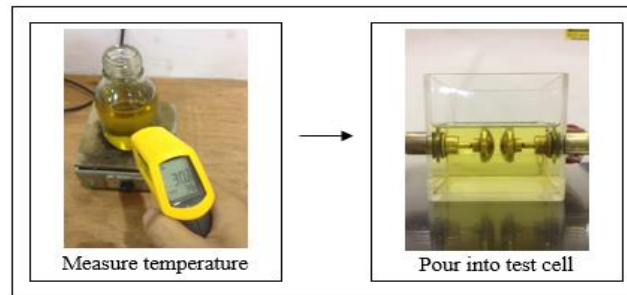

Figure 3. Preconditioning process

2.4. Breakdown Voltage

Figure 4 shown the breakdown voltage was tested by using a Megger automatic tester that is in compliance with ASTM D1816 standard. In this paper, the mushroom electrodes were used with gap distance of 1.5mm, 2.5mm and 3.5mm with 500 ml volume of oil samples.
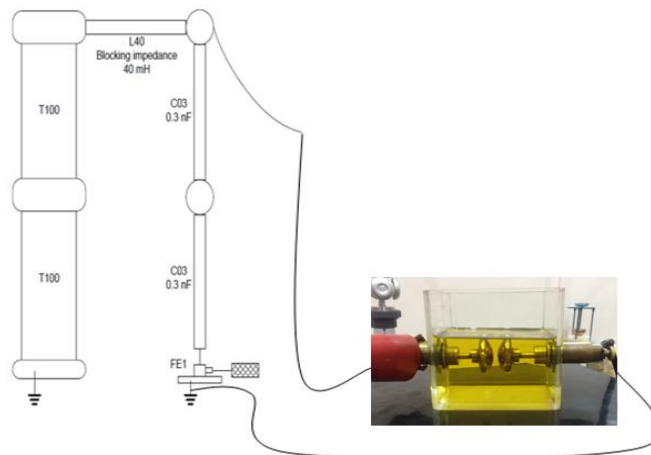

Figure 4. Testing Circuit with Earth Point

2.5. Partial Discharge

A partial discharge (PD) is defined as a localized electrical discharge which partially bridges the insulation between electrodes, such as a discharge in a bubble within a liquid dielectric [18]. Usually the way of quantifying the apparent charge of PD is in picocoulombs (pC). A limiting value of 50 pC that was specified in the apparatus standard is the usual criterion for passing or failing a PD test. The ICM compact is used for the measurement of these PD quantities in measuring circuit according to IEC 60270.

3. RESULTS AND ANALYSIS

From the data taken from the experiment, the average breakdown voltage was calculated. The breakdown voltages of PO and CO under different concentration of TiO2 and gap distance of electrode are shown in Table 1.

Table 1. AC Breakdown Voltage After TiO2 Was Added to Samples

Sample	Conc of TiO$_2$ (%)	Electrode Gap Distance (mm)					
		1.5	2.5	3.5	1.5	2.5	3.5
		Average Breakdown Voltage BDV(kV)			Average Partial Charges (pC)		
PO	0	22.3	29.9	34.4	59.4	56.3	50.4
	0.1	26.2	34.2	37.1	48.4	45.5	38.4
	0.2	28.5	35.7	40.0	46.5	40.2	34.7
	0.3	32.1	36.5	40.0	37.2	32.1	20.3
	0.4	35.3	39.2	40.0	29.6	24.8	20.7
	0.5	38.3	40.0	40.0	23.3	19.6	19.1
CO	0	19.5	27.9	31.7	48.8	45.3	40.1
	0.1	23.1	33.9	36.3	32.3	30.4	26.9
	0.2	25.7	34.4	39.1	36.1	34.6	25.2
	0.3	31.2	35.8	40.0	30.7	27.3	25.0
	0.4	35.0	38.3	40.0	25.5	22.2	20.9
	0.5	37.2	40.0	40.0	24.2	21.4	20.3

*Conc.= Concentration, BDV= Breakdown Voltage, pC = picoCoulomb

The data from the above table can be interpreted by using graphs as shown in Figure 5, 6 and 7:
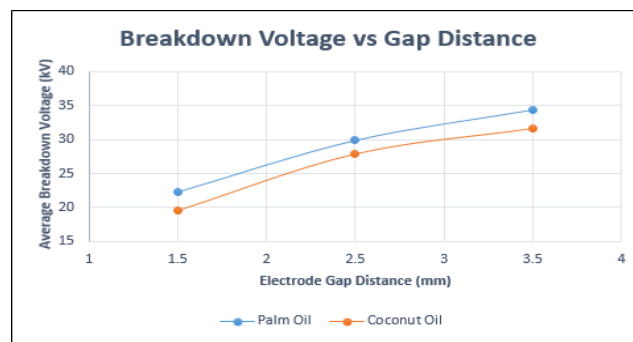

Figure 5. Characteristic of breakdown voltage of PO and CO under different gap distance of electrode before TiO2 is added

Figure 5 shows the characteristic of AC breakdown voltage versus different electrode gap distance between PO and CO before TiO2 is added. It can be shown that the breakdown voltage of PO and CO increases almost linearly as electrode gap distance increases. It is generally accepted that the gap spacing effect on dielectric strength is an essentially complex phenomenon [19]. It shows that the AC breakdown voltage of PO is higher than CO with zero percent concentration of TiO2.
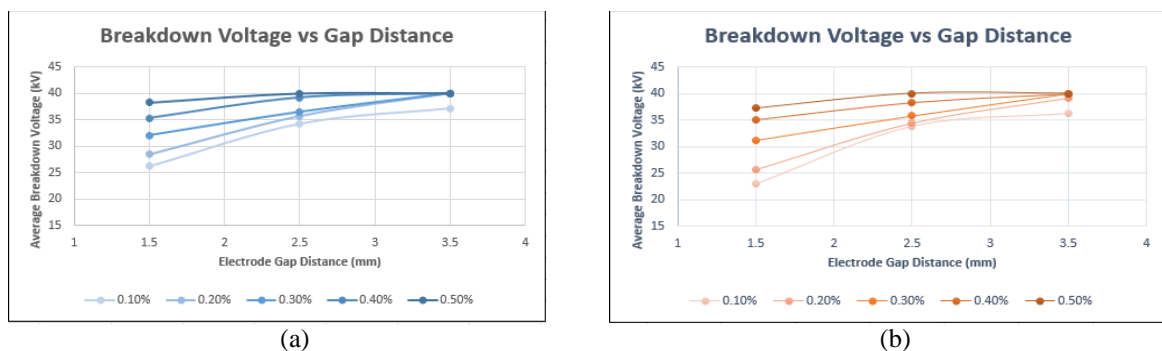

Figure 6. Characteristic of breakdown voltage of a) PO and b) CO under different gap distance of electrode after TiO2 is added

The value of apparent charges of PD has small drooping characteristic to the gap distance of electrode as shown in Figure 7.
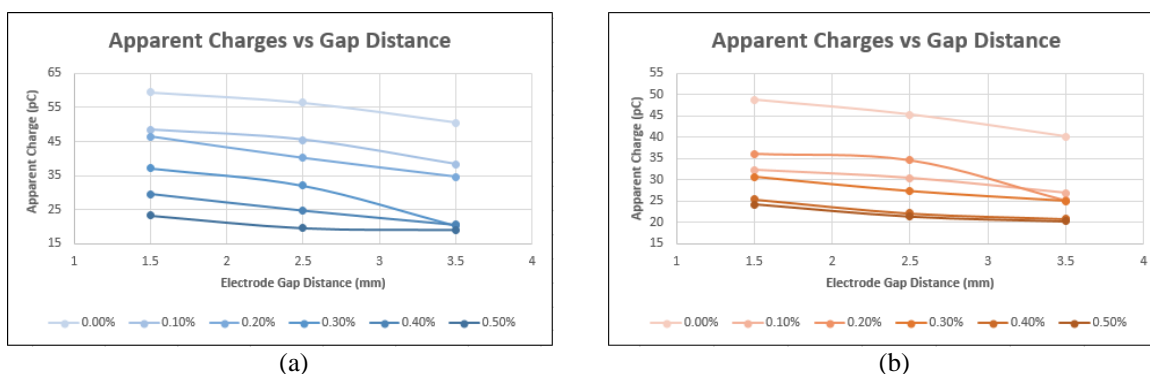

Figure 7. Characteristic of apparent charges of PD for a) PO and b) CO under different gap distance of electrode before and after TiO2 is added

Higher number of apparent charges occurred in PO compared to CO at 1.5mm, 2.5mm and 3.5mm gap due to variations in local field distribution nearby high voltage electrode. It is because PO has higher viscosity than CO, therefore the process of dispersion of bubbles and space charge density becomes slow.

4. CONCLUSION

The breakdown voltage of PO, and CO is measured using AC voltages system with different gap distance of 1.5mm, 2.5 mm and 3.5mm sphere gap under presence of additive TiO2 from 0.1% to 0.5% concentration. The AC breakdown test is controlled at 30oC and the value of partial discharge is also recorded.

From the experimental result, the PO have just slightly higher breakdown voltage compared to CO, in other words, there is no significant diiference between PO and CO, both can be said to have similar properties. From all oil sample data recorded, it can be concluded that the breakdown voltage had increased to the increase in gap distance of electrode under presence of TiO2.

In addition, for PO and CO, it is considered that, the TiO2 can improve the AC breakdown voltage as the concentration increases, the breakdown voltage also increases. The AC breakdown voltage for PO has reached the maximum breakdown limit at concentration of 0.5% at 2.5mm gap which gave the highest voltage breakdown at 40Kv, while CO, the AC breakdown voltage has reach the breakdown limit also at concentration of 0.5% at 2.5mm which gave the same highest voltage breakdown at 40kV.

Apparent charges of PD decreases as the gap distance of electrode increase with an increasing volume of concentration TiO2. It shows that TiO2 can decrease the deteriorioation of insulation in the transformer. PD prevention and detection is crucial to ensure reliable, long-term operation of high voltage equipment used by electric power utilities.

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