Influence of Electrode Geometry on the Lightning Impulse Breakdown Voltage of Palm Oil

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***Abstract*— This paper presents a study of lightning impulse breakdown voltage of palm oil under needle/plane and needle/sphere electrode configurations. All tests were carried out at gap distance of 25 mm under both positive and negative polarities. Two types of palm oil and mineral oil were used in this study. The results show that the different electrode geometry has significant impact on the lightning impulse breakdown voltage. It was found that needle/plane geometry has lower breakdown voltage than needle/sphere. The voltage polarity also showed some influence on the lightning breakdown voltage for all fluid samples. Comparing both positive and negative polarities, the percentage of difference between all samples is much higher under needle/plane electrode configuration which can be up to 43%. The positive mean lightning breakdown voltage of palm oil is comparable with the mineral oil.**

Keywords—electrode geometry, lightning impulse breakdown voltage, palm oil, transformer

I. INTRODUCTION

Over the past few years, vegetable oils have attracted increasing attention and have been considered as dielectric insulating fluids in transformers due to their better environmental performance and higher fire safety. Palm Oil (PO) is one of the common vegetable oils that have been introduced as potential alternative for the conventional Mineral Oil (MO). Lately, a numbers of studies have been carried out on PO in different properties such as AC, lightning breakdown performances, thermal properties, ageing and viscosity [1-6]. However, only few studies have investigated the lightning breakdown performance of PO for different electrode geometry under non-uniform field.

The shape of discharge figures is one of the sources of information on the liquid breakdown mechanism which can be affected by different electrode geometry [7]. Different electrode geometry determines the strength of electric field at the head of propagation channel thereby influences its propagation velocity and finally the electric strength of fluids [7]. Besides, the shape of discharge is sensitive to changes in applied voltage, voltage polarity, gap distance, and properties of liquid which will affect the fluids breakdown strength [7].

Lightning impulse test is one of the important characteristics for dielectric insulating fluid. Previous studies have reported that the negative lightning impulse breakdown voltages of PO are higher than positive breakdown voltage under non-uniform field [8, 9]. According to an investigation in [10], the results showed that the different electrode configurations have significant impact on breakdown voltage. Needle/plane geometry which had the most divergent electric field resulted in the lowest breakdown voltage compared to needle/sphere and U-type electrode configurations.

In this work, different types of electrode configurations were used to determine the influence of electrode geometry on lightning impulse breakdown voltages under non-uniform field. The mean breakdown voltages were obtained and compared between PO and MO under both positive and negative polarities at a gap distance of 25 mm.

II. EXPERIMENTAL DESCRIPTION

A. Test Sample

The lightning impulse breakdown tests were carried out on two different samples of PO and one sample of MO. Refined, bleached and deodorized palm olein was used in this study and was obtained from readily available cooking oil products in the market. The properties of PO samples are shown in Table 1. All PO samples have almost similar composition of saturated, polyunsaturated and monounsaturated fats. The main difference is in the composition of vitamin A and vitamin E. Only POA sample has vitamin A and very low content of vitamin E, while POB has higher vitamin E content. The ratio of the saturated and unsaturated fat for PO is around 4:6.

TABLE I. FAT CONTENTS OF ALL SAMPLES

Contents (In every 100 ml)	Samples	
	POA	POB
Saturated fat (g)	45.4	43
Poly-unsaturated fat (g)	11.6	14
Mono-unsaturated fat (g)	43	43
Vitamin E (mg)	4.4	75
Vitamin A (μg)	264	-

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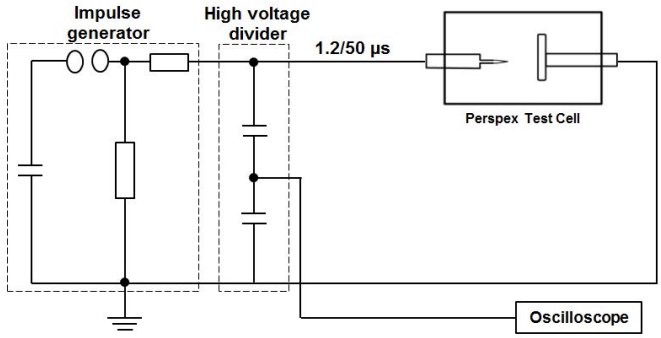
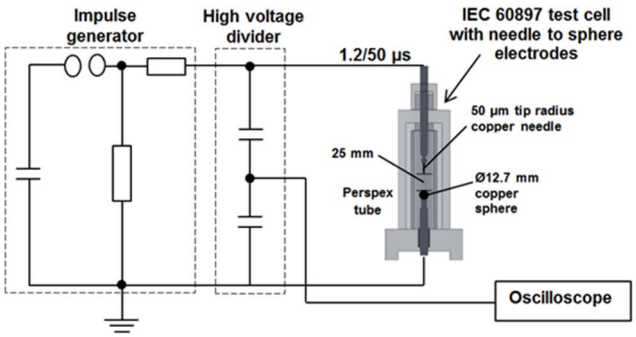
B. Experimental Setup

The test cell configuration for the lightning breakdown voltage test is illustrated in Figure 1(a) and (b). A 2-stages TERCO impulse generator acts as a supply voltage to the test cell. The oil samples were filled into the designed test cell and were tested for the lightning breakdown voltages. The non-uniform field tests were carried out based on needle-plane and needle-sphere electrodes. The needle electrode was made from copper, with the tip radius having curvatures of 50 µm. The diameter of the grounded copper plane and sphere are 50 mm and 12.7 mm respectively. All tests were carried out using rising voltage method at gap distances of 25 mm.



(a)



(b)

Fig. 1. Lightning impulse test configurations for (a) needle/plane and (b) needle/sphere.

The average streamer velocity, v_a before breakdown can be calculated based on streamer stopping length, l_a and propagation time, t_a according to Equation (1). The average streamer velocity, v_b after breakdown can also be calculated based on Equation (2) where d is the gap distance and t_b is the time to breakdown.

$$v_a = l_a / t_a \quad (1)$$

$$v_b = d / t_b \quad (2)$$

III. Result and Data Analysis

A. Electrode Geometry

The positive and negative mean lightning breakdown voltages for both samples PO and MO under needle/plane and needle/sphere electrode configurations are tabulated in Table II. The mean lightning breakdown voltages of all samples at different electrode geometries are compared as shown in Fig 2 (a) and (b). Under positive polarity, the difference between both configurations is quite significant with percentage different of 43% and 40% for PO and MO, respectively. For negative mean lightning breakdown voltage, the different between the two configurations are only 27% for PO and 38% for MO.

The results show that the needle/plane electrode configuration exhibits lower lightning breakdown voltages as compared with needle/sphere electrode configuration and this is consistent with the finding by [10]. Needle/plane geometry which has more divergent electric field caused lower breakdown voltage compared to needle/sphere geometry [10].

TABLE II. Breakdown Voltages under Different Electrode Configuration

Samples	Positive breakdown voltages (kV)		Negative breakdown voltages (kV)	
	Needle/Plane	Needle/Sphere	Needle/Plane	Needle/Sphere
POA	65	111	92	124
POB	62	109	93	128
MO	69	115	120	195

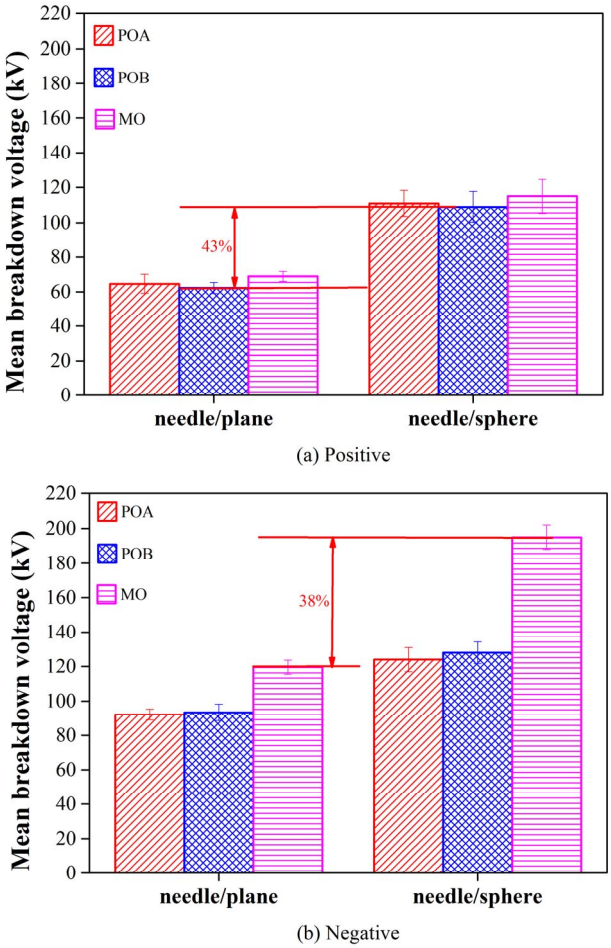


Fig. 2. Mean lightning breakdown voltages of PO and MO at different electrode geometries under (a) positive and (b) negative polarities.

B. Voltage Polarity

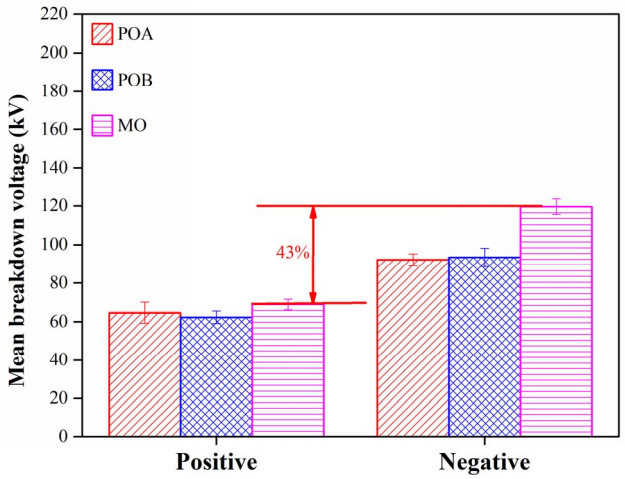
The histograms in Fig. 3(a) and (b) generally indicate higher mean lightning breakdown voltages of PO and MO under negative polarity compared to positive polarity. For needle/plane electrode configuration, the percentage difference between negative and positive polarity for PO and MO are 33% and 43% respectively. For needle/sphere

electrode configuration, the difference between both polarities for MO is quite significant with 41% percentage difference while for PO the difference is only 15%. The results also suggest that there is more influence of voltage polarities on the breakdown voltages for all samples under needle/plane electrode configuration compared to needle/sphere.

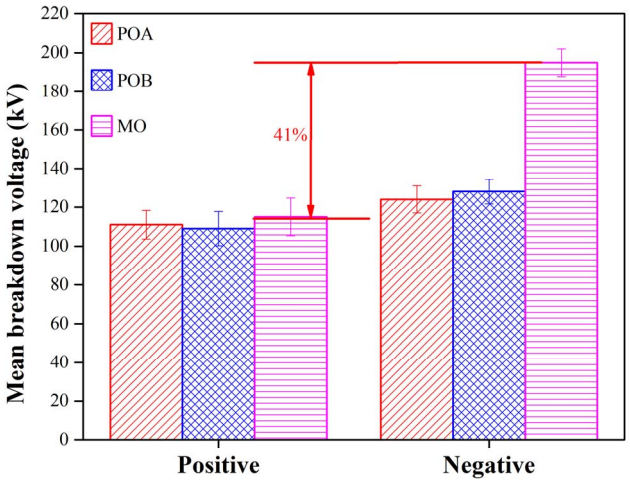
It was observed that MO has the highest mean breakdown voltage at both electrode geometry and voltage polarities. Under positive polarity, all three samples show quite comparable mean breakdown voltages with MO where the highest percentage of different is 10%. However, the negative mean breakdown voltages of both PO are much lower than MO where the highest percentage of different can be up to 36%. The space charge and different chemical structure of PO and MO have impact on the polarity effect of the lightning impulse breakdown voltage [7].

C. *Streamer Breakdown Velocity*

The streamer breakdown velocities of all samples under different electrode configuration are tabulated in Table III. At breakdown voltage, positive streamer velocities for both configurations are higher than negative streamer. For example, the streamer velocity of POA is 1.6 km/s for positive and 1.0 km/s for negative. Similar trends are observed for both POB and MO. The results also show that MO has the highest streamer velocity under both positive and negative polarities as compared with PO.



(a) Needle/plane



(b) Needle/sphere

Fig. 3. Mean lightning breakdown voltages of PO and MO at both positive and negative polarities under (a) needle/plane and (b) needle/sphere.

TABLE III. STREAMER BREAKDOWN VELOCITY UNDER DIFFERENT ELECTRODE CONFIGURATION

Samples	Positive streamer velocity (km/s)		Negative streamer velocity (km/s)	
	Needle/Plane	Needle/Sphere	Needle/Plane	Needle/Sphere
POA	1.6	1.5	1.0	1.2
POB	1.5	1.4	1.1	1.1
MO	1.9	1.8	1.5	1.6

IV. CONCLUSION

The most obvious finding to emerge from this study is the different electrode configuration does have an impact on the lightning breakdown voltages. With a fixed length of gap distance, breakdown voltage is expected to decrease at more divergent electric field. This study has shown that needle/plane geometry which has more divergent electric field produced lower lightning breakdown voltage compared to needle/sphere geometry. Voltage polarity also one of the factors that can affect the lightning breakdown voltage where the positive lightning impulse breakdown voltages for all samples are always lower than the negative polarity. The highest percentage of difference between all samples can be up to 43%. The positive lightning breakdown voltages of both PO are comparable with MO where the percentage of difference only 10%. The composition of the saturated/unsaturated fats and vitamins of the PO show no significant effect on the lightning breakdown voltages.

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