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Lightning Impulse Breakdown Voltage RBDPO with the Presence of Metallic Particles Under a Uniform Electric Field

(Kegagalan Voltan Impulse Kilat terhadap RBDPO dengan Kehadiran Zarah Logam di bawah Medan Elektrik)

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ABSTRACT

The performance of liquid insulation in power transformer is vulnerable to particles, especially the metallic particles. This paper presents the experimental study on the effect of metallic particles on the palm oil (PO) as dielectric insulating fluid under lightning impulse breakdown voltage. The type of PO used in this study is refined, bleached and deodorized Palm Oil (RBDPO) Olein. Two different types of metallic particles (copper and iron) with different concentrations (clean, low, medium, and high) were studied. The lightning impulse test has been carried out according to IEC 60897 standard and under the influence of a uniform electric field. For the comparative purpose, similar test has been carried out with mineral oil (MO). The presence of metallic particles reduces the average lightning impulse breakdown voltage of MO and PO but shows less significant effect to MO. This is because the streamers in the PO propagate faster and further than in the MO at the same voltage level. Hence, causing the breakdown voltage of PO lower than MO. Under negative lightning impulse, the breakdown voltage of MO is slightly higher than RBDPO. From the study, the increment of the number of particle level contamination will reduce the lightning impulse breakdown voltages of the PO.

Keywords: Mineral oil; palm oil; metallic particles; lightning impulse breakdown voltage; uniform field

ABSTRAK

Prestasi penebat cecair yang digunakan di dalam pengubah kuasa terdedah kepada zarah, terutamanya zarah logam. Kajian ini menjalankan eksperimen mengenai kesan zarah logam pada minyak sawit (PO) sebagai cecair penebat dielektrik di bawah voltan kerosakan impuls kilat. Jenis PO yang digunakan dalam kajian ini adalah jenis Olein yang ditapis, diluntur dan dinyahbau (RBDPO). Dua jenis zarah logam yang berbeza (tembaga dan besi) dengan kepekatan yang berbeza (bersih, rendah, sederhana, dan tinggi) dikaji. Ujian impuls kilat telah dilakukan mengikut Standard IEC 60897 dan di bawah pengaruh medan elektrik yang seragam. Untuk tujuan perbandingan, ujian yang sama telah dilakukan dengan minyak mineral (MO). Kehadiran zarah logam mengurangkan voltan kerosakan impuls kilat terhadap MO dan PO tetapi kurang signifikan terhadap MO. Ini kerana streamer dalam PO menyebar lebih cepat dan lebih jauh daripada pada MO pada tahap voltan yang sama. Oleh itu, ia menyebabkan voltan kerosakan PO lebih rendah daripada MO. Di bawah dorongan kilat negatif, voltan kerosakan MO sedikit lebih tinggi daripada RBDPO. Dari kajian tersebut, kenaikan jumlah pencemaran tahap zarah akan mengurangkan voltan kerosakan impuls kilat PO.

Kata kunci: Minyak kelapa sawit: impulse kilat; penebat cecair;minyak sayur

INTRODUCTION

MO has been used as the liquid insulation in power transformer over 100 years [1]. Nevertheless, due to the environment issue regarding the quality of mineral oil such as, it could have severe contamination to the environment if a spill occurs, alternative liquid insulations are analyzed [2][3]. Many researches have been carried out to look at the alternative sources for insulating oil. Vegetable oil such as palm oil is one of the alternative liquids to be considered for replacing the MO [4]. From recent studies, it is proven that PO is renewable, environmental friendly to others, and has higher fire points which ensure more safety in service operation of transformer [5][6]. Besides that, if there is a case of leakage, PO is said to be a highly biodegradable and non-toxicity insulation oil which ensure low harm to the environment. There are different types of PO that can be obtained from the palm nut which is the Crude Palm Oil (CPO), Refined, Bleach and Deodorized Palm Oil (RBDPO) and Palm Kernel Oil (PKO). RBDPO is the most studied among other POs [6][7].

Palm oil shows promising results in AC breakdown tests. Particles play an important role in the performance of the insulating oil inside the transformer. Copper, iron, and aluminum particles are the main metallic particles that exist in the insulating oil while carbon, cellulose fiber, and dust are for the non-metallic particles [8]. Mostly, all the metallic particles originate from winding and core of the transformer. The contaminant of metallic particles will affect the insulating oil inside the transformer during the installation and operation process. The particle concentration are one of the key factors influencing the breakdown strength of insulating oil [9]. An impurity bridge will be formed under the electric fields of converter transformer within the insulating oil which can cause discharge in insulating oil [10]. Based on the previous study, the presence of a conductive contaminant in insulating oil will gather at a high electric field region of the transformer and cause the insulation strength of the MO to decrease, so that the breakdown voltage will also reduce [9]. The different breakdown voltage of insulating oil can also be seen by different concentration of metal particles [11]. Particles are common contaminants that influence the insulating performance of insulating oil. CIGRE working group WG 12.17 presented a significant number of power transformer failures attributed to particles [11]. Many consequences show that the dielectric strength is affected by metallic particles over insulating particles [12]. The relationship between the lightning impulse voltage and type of metallic particles use is studied.

The performance of biodegradable oil were conducted previously under uniform and non-uniform field [13][14] [15]. But, until now there is still less information that can be obtained in the lightning impulse breakdown voltage performance of PO especially with the presence of metallic particles [6]. It is essential to consider the impact of metallic particles on the lightning impulse breakdown voltage of the PO as an insulating fluid in transformer due to increasing interest in transformer application. Therefore, this paper aims to investigate the effect of metallic particles on RBDPO under uniform electric field lightning impulse breakdown.

METHODOLOGY

SAMPLE PREPARATION

The lightning impulse breakdown test in this study is carried out using two types of sample which are PO and MO as shown in Figure 1. The cooking oil products which is RBDPO Olien type is used in this research as the type of PO. It can be obtained in the market. This oil was processed through three refinement procedures, which is degumming, bleaching, and deodorizing. Hyrax (M) Oil Sdn Bhd is the supplier for the MO used for this experiment.

FIGURE 1. The sample of palm oil and mineral oil

To get clean sample, the "as received" oil sample were filtered through a membrane filter by using Thermo Fisher Nalgene unit with a pore size of 0.2 µm. The process was repeated for three cycles [16] as shown in Figure 2.

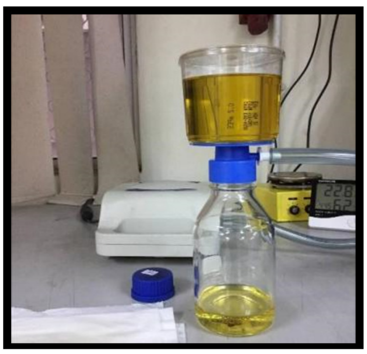

FIGURE 2. Filtration process

After the filtering process, the clean sample were dried out and de-gassed in a Memmert Vacuum Drying Oven at less than 5 mbar and 80˚C for 48 hours as shown in Figure 3. After that, a further 24 hours were given for the samples to cool down to ambient temperature [6]. The samples were kept in fixed glass holders and prepared for use. The sample through the above procedures are called "clean" samples.

FIGURE 3. Drying process

Next, the experiment conducted involves the presence of metallic particles on lightning impulse breakdown voltage, the clean samples were artificially contaminated by adding different metallic particles which are iron and copper. The particle concentration was measured by volumetric concentration. The weight of metallic particles-in per 2000 mL of insulating oil used in this study were 1.8 g, 12.5 g, and 21.4 g, thus representing three different volumetric concentrations, which is 0.01%, 0.07%, and 0.12%, respectively. Then, the particle samples were blended into the liquid by a magnetic stirrer for at least 15 minutes to ensure even distribution of particles in liquids.

LIGHTNING IMPULSE BREAKDOWN VOLTAGE TEST

Lightning impulse breakdown voltage test normally used are rising up- voltage method, up-and-down method, and multiple level methods. In this research study, a rising up-voltage method with negative polarity is being utilized under the uniform electric field. At the high voltage laboratory, a Samgor 8-stage impulse generator with the output voltage of 800 kV and energy of 4 kJ will be utilized as a source voltage to produce standard lightning waveform 1.2(±30%)/ 50(±20%) µs.

Figure 4 shows a test cell configuration for lightning impulse breakdown voltage test. A Samgor 8-stage impulse generator with the output voltage of 800 kV and energy of 4 kJ was utilized as a source voltage to produce standard lightning waveform 1.2(±30%)/ 50(±20%)µs. The negative polarity lightning impulse was utilized in this study. The oil tests were filled into the outlined test cell and tested for the lightning breakdown voltages. To scale down the high voltage, the high voltage divider was used before it can be measured within the input range of the measurement equipment without getting damaged [17].

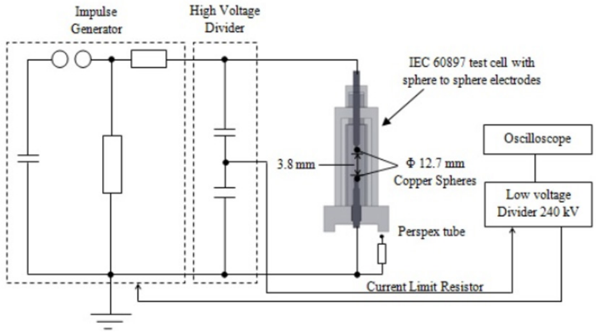

FIGURE 4. Test configuration for lightning impulse [17]

A perspex transparent cylindrical test cell with a volume of 2000 ml containing a vertical spherical electrode was used for the experiments as shown in Figure 5. The test cell was fabricated according to the dimensions recommended by IEC 60897. To generate a uniform electric field, sphere to sphere electrodes were used. The electrodes were made from copper with a diameter of 12.7 mm. In this study, the electrode gap was set at 3.8 mm.

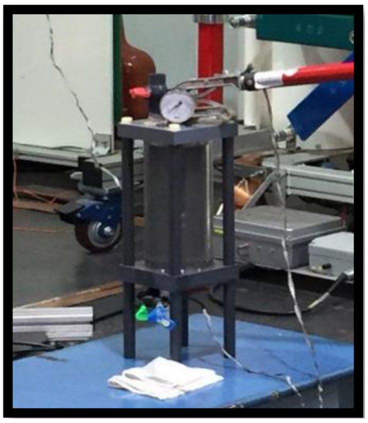

FIGURE 5. Cylindrical test cell

For the lightning impulse breakdown test of insulation oil, the rising up-voltage method is adopted from IEC 60897 and ASTMD300 [18]. The initial voltage is set and the voltage level was increased by 5 kV step voltage, until the breakdown occurs [17]. The time interval after the breakdown and next test was set at 3 minutes to 5 minutes for the oil samples to recover in order to obtain more uniform breakdown voltages. A total of 15 breakdown voltages were recorded for each type of oil.

RESULTS AND DISCUSSION

Figure 6 shows the average lightning impulse voltage of MO and PO. From Figure 6, MO has the highest average breakdown voltage with 240.8 kV for the gap separations of 3.8 mm. The result obtained from this experiment is quite similar to the results found in the literature [13], where the mean value for breakdown voltage of clean MO (GeminiX) under lightning impulse with 3.8 mm is 243.9 kV. The average breakdown voltage for PO under clean condition shows the mean value of 208.6 kV.

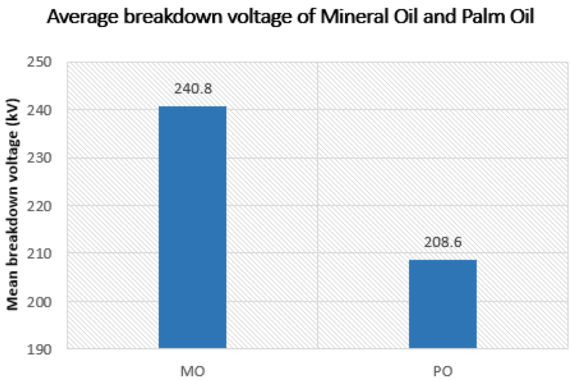

FIGURE 6. Average breakdown voltage of insulating oils under clean condition

As can be seen in the result, MO has better breakdown voltage than PO for similar conditions. Similar results were also found in the literature [13], which state that the mean value for breakdown voltage of clean PO (Midel 7131 and FR3) under lightning impulse with 3.8 mm is 208.8 kV and 202.8 kV. The reason why this condition happens is due to streamer propagation in PO is different from MO. Based on the literatures [13], the streamers in the vegetable oil propagates faster and further than in the mineral oil at the same voltage level. Hence, causing the breakdown voltage of PO lower than MO. The breakdown voltage under uniform field is rather difficult, as there is a large component of initiation time that limits the streamer velocity.

The average lightning impulse breakdown voltage of RBDPO and MO under contamination of iron particle is summarized in Figure 7. From the figure, it can be found that the mean breakdown voltage of MO at 0.01% contaminated level is the highest with 124.85 kV followed by 0.07%, 118.49 kV and lastly 0.12% is 108.68 kV. When iron particles increase, the breakdown voltage will reduce significantly. For PO, the mean breakdown voltage at 0.01% contaminated level is the highest with 121.85 kV followed by 0.07% with 111.81 kV, and lastly 0.12% with 106.21 kV. The increasing in particles reduced the breakdown voltage, respectively. Using clean samples as the baseline, the percentage of voltage drop from clean sample to the sample with 0.01% iron particles are 92.9% and 71.2% for both MO and PO, respectively. For ratios of 0.07% and 0.12%, the average voltage do not significantly drop for MO and PO. The average breakdown voltage for MO with 0.07% iron particles is 118.5 kV and for 0.12% iron particles in MO is 108.7 kV. Whereas for PO, the average voltage for 0.07% and 0.12% iron contamination are 111.8 kV and 106.2 kV, respectively. The percentage of voltage drop between 0.01% to 0.12% for MO is less than 15%. For PO, the voltage drop among different ratios is around 14.7%. From previous study, the worst case of percentage reduction of PO was about 20% compared to MO [19].

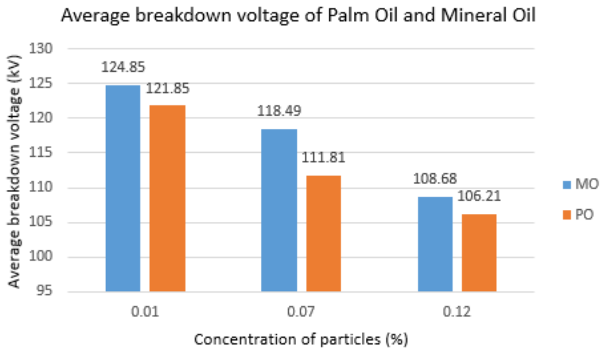

FIGURE 7. Average breakdown voltage of insulating oils with different concentration of iron particle

Figure 8 shows the average lightning impulse voltage of MO and RBDPO under contamination of copper particle. From Figure 8, it can be found that the mean breakdown voltage of MO at 0.01% contaminated level is the highest with 116.1 kV followed by 0.07% with 99.5 kV, and lastly 0.12% with 92.9 kV. When copper particles increase, the breakdown voltage will reduce significantly. For PO, the mean breakdown voltage at 0.01% contaminated level is the highest with 107.02 kV followed by 0.07% with 94.4 kV, and lastly 0.12% with 81.7 kV. The increasing in particles reduced the breakdown voltage respectively. Same as previous study, the clean sample is used as the baseline. The percentage of voltage drop from clean sample to the sample with 0.01% copper particles are 107% and 94.9% for both MO and PO, respectively. Like the iron particles, the average voltage do not significantly drop for MO and PO for ratios of 0.07% to 0.12%. The average breakdown voltage for MO with 0.07% copper particles is 99.5 kV and for 0.12% copper particles in MO is 92.9 kV. Whereas for PO, the average voltage for 0.07% and 0.12% copper contamination are 94.4 kV and 81.67 kV, respectively. The percentage of voltage drop between 0.01% to 0.12% for MO is less than 25%. For PO, the voltage drop among different ratios is around 31%.

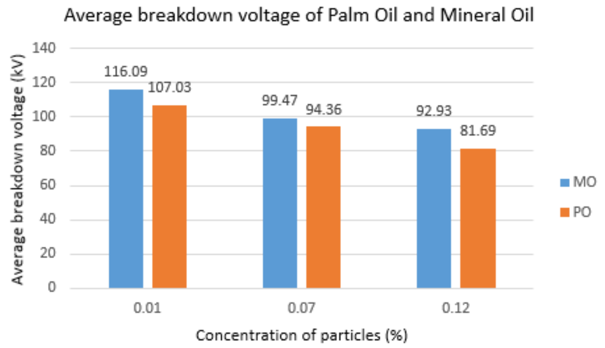

FIGURE 8. Average breakdown voltage of insulating oils with different concentration of copper particle

Figure 9 and Figure 10 show the lightning impulse breakdown voltage of MO and PO that had been contaminated with different particles. As can be seen in Figure 9, the breakdown voltage of MO contaminated with iron particles has higher breakdown voltage compared to MO contaminated with copper particles. As the particle concentration of insulating oil is large, the interaction between particles is obvious because particles concentrate in a region of strong electric field due to the electric force, thus leading to an increase of the local particle concentration. The difference between the iron particles and copper particles are due to the difference in their conductivity. Copper particles have high conductivity to induce charge on the two sides of particles as compared to iron particles, thus making the copper particles to have a lower breakdown voltage compared to iron particles. It also promotes the formation of impurity bridges which will reduce the breakdown voltage. It also can be concluded from these figures that the effect of copper particle on the breakdown strength of MO is higher than iron particles when using the same volumetric concentration.

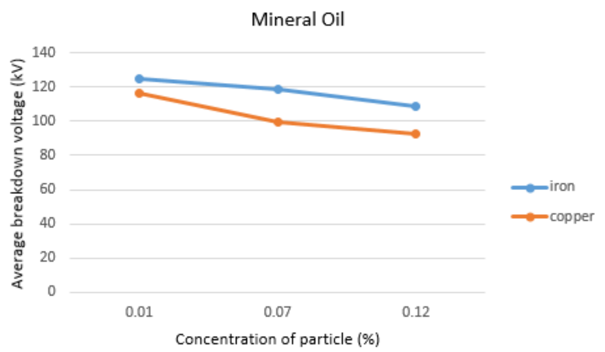

FIGURE 9. Average breakdown voltage of MO with different particle

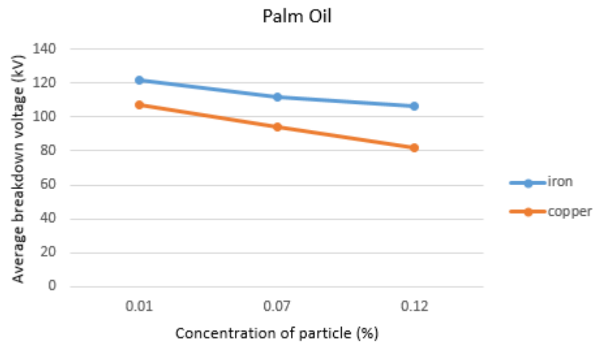

FIGURE 10. Average breakdown voltage of PO with different particle

In order to find the breakdown strength of the oils, the normal distribution is normally used to plot the experiment data. The plot of normal distribution of this study can be seen in Figure 11, 12 and 13. Figure 11 shows the normal probability plot for the lightning impulse breakdown voltage of PO and MO. This normal distribution is used to compare the sample of data of PO and MO to an expected normal distribution using the mean and standard deviation calculated from the data obtained. The gradient of trend-line of the PO is less than the gradient line of MO which indicates that the lightning impulse breakdown voltage of PO is more dispersed. From the figures, the normal distribution is fitted well with the experimental data for both MO and PO. From this distribution, the withstand voltage can be deduced from the probability of 1%, 50%, and 90%.

From Figure 12 and 13, it can be seen that all the data fit nicely with normal distribution in all cases. From the probability plotting, we can extract the 1% and 90% probability of breakdown voltage for both oils. The lowest breakdown voltage that can be experienced by the oil is 1% probability, while a breakdown voltage that is confirmed to happen is at 90% probability. . These two values are important for a transformer designer to design the structure of the transformer.

As estimated using the Gaussian distribution, the breakdown voltage of the insulating oils at 1% probability of failure is given in Table 1 and 2. It consist of the results for 1%, 50%, and 90% of lightning impulse voltage of insulating oils. It is found that 50% probability breakdown voltage of MO and PO reduced moderately as the particle concentration increase. Copper particles have affected the breakdown voltage of PO as it gives the lowest breakdown voltage at 1% probability of failure with 68 kV at 0.12% volumetric concentration. For both MO and PO, it states that 1% probability of breakdown voltage reduced gradually with the increasing of volumetric.

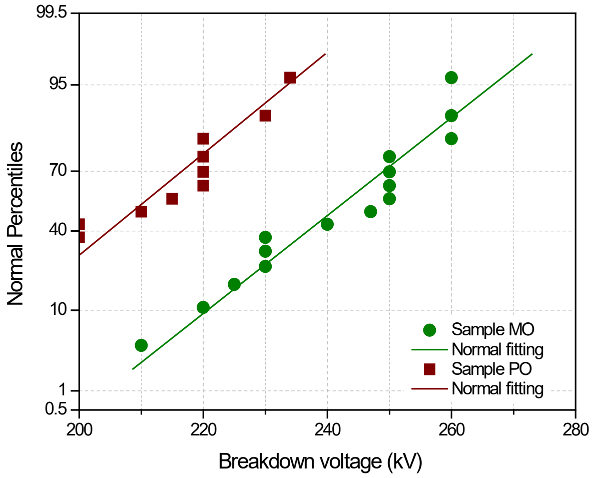

FIGURE 11. Normal probability plot for lightning impulse breakdown for sample MO and sample PO.

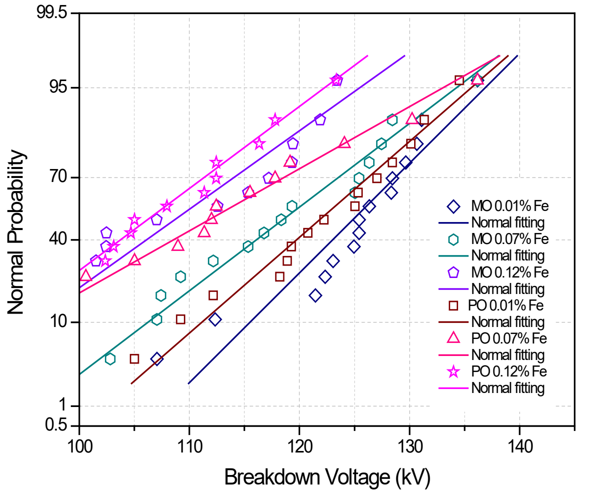

FIGURE 12. Normal probability plot for the lightning impulse breakdown voltage of insulating oil with different concentration of iron

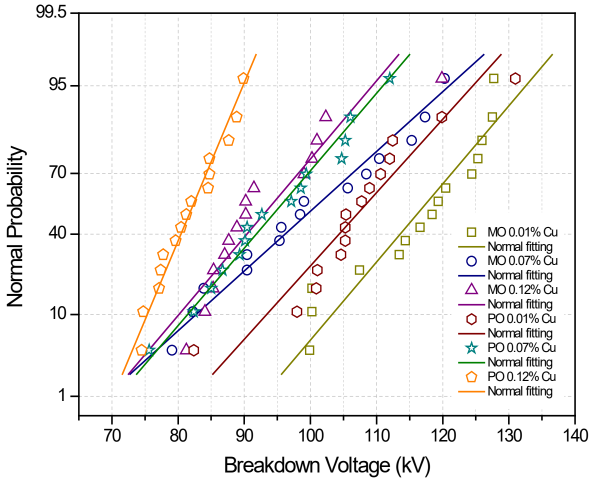

FIGURE 13. Normal probability plot for the lightning impulse breakdown voltage of insulating oil with different concentration of Copper

TABLE 1. Breakdown voltage of insulating oils at 1%, 50%, and 90% probability of failure using normal distribution for iron contamination

Breakdown probabilities (%)	Lightning impulse breakdown voltage (kV) of insulating oils					
	Mineral Oils			Palm Oil		
	0.01%	0.07%	0.12%	0.01%	0.07%	0.12%
1	106	101.81	93.17	100.01	84.74	81.39
50	125.43	118.34	107.04	122.23	112.01	105.01
90	132.09	128.92	122	132.34	131.23	118.79

TABLE 2. Breakdown voltage of Insulating oils at 1%, 50%, and 90 % Pprobability of Ffailure using normal distribution for copper contamination

Breakdown probabilities (%)	Lightning impulse breakdown voltage (kV) of insulating oils					
	Mineral Oils			Palm Oil		
	0.01%	0.07%	0.12%	0.01%	0.07%	0.12%
1	90	77.09	76.25	80.37	73.62	68
50	118.4	98.45	90.23	105.39	92.66	81.25
90	128.53	117.88	104.34	120.88	107.08	88.86

CONCLUSION

A study of lightning impulse breakdown voltage under influence of iron and copper particles for PO and MO was done in this paper. PO can be used as an insulating oil based on the average of breakdown voltage of 208.6 kV that fulfills the minimum breakdown voltage for transformer oil in service. It can be concluded that under current testing setup, the lightning impulse performance under a clean condition of the PO is comparable with MO. The experimental results in this paper show that metallic particles will significantly reduce the dielectric strengths of liquid. Copper has the biggest influence in both MO and PO because it has the highest conductivity as compared to the iron. Only conductive particles affect the breakdown because these polarize instantaneously and cause breakdown, whereas non-conductive ones do not have sufficient time to have an effect. The effect of metallic particles is more severe than the non-metallic particles on the dielectric strength of transformer liquid. The motion of metallic particles in PO is much slower than MO in AC breakdown, but faster in the lightning impulse breakdown which probably explains why the breakdown strengths of MO are higher than PO in the presence of metallic.

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DECLARATION OF COMPETING INTEREST

None

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