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Partial Discharge Behaviour within Palm Oil-based Fe_2O_3 Nanofluids under AC Voltage

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Abstract. In this work, comparison studies of partial discharge (PD) behaviours within palm oil-based Fe_2O_3 nanofluids under AC voltage were performed. The samples were prepared with different weight percentage of Fe_2O_3 nanoparticles; LC (Low Concentration), MC (Medium Concentration) and HC (High Concentration) in order to investigate the „electron trapping" effectiveness, their discharge withstand capability, discharge numbers, magnitude and Phase Resolved Partial Discharge (PRPD) patterns under high voltage stress. The results indicate that the presence of Fe_2O_3 nanoparticles with LC enhances the withstand characteristics of palm oil against PD.

1. Introduction

Nowadays, nanofluids have attracted a wide interest due to their superior performance and engineering impact. This leads to the trend of researches to conduct the studies on the characteristics and suitability of nanofluids in various fields especially in high voltage engineering for power transformer application. The combination of natural ester and nanotechnology for example, may produce dielectric nanofluids with higher breakdown strength, prone to ageing process and biodegradable. This could replace the usage of mineral oil in power transformer in future.

Generally, natural ester such as palm oil can be synthesized to several derivatives with different molecular structure and physiochemical properties. In fact, the differences would provide different performance and characteristics as insulation purpose. For example, increasing the length of the side branches of chemically modified alkyl ester of palm kernel oil possess an excellent breakdown strength compared to mineral oil [1]. Partial discharge activities are also hindered in the larger molecular structure with double bonds in hydrocarbon and extra energy is needed to break the chemical bonds under the same electric field [2].

Partial discharge (PD) is defined as a localized electrical discharge, which partially bridges between electrodes inside the insulation system. The measurement of PD behaviour is merely important for assessment on insulation quality or as an early diagnostic before the insulation failure. Therefore, the objective of this work is to compare the PD behaviours of palm oil-based Fe_2O_3 nanofluids with different range of concentration level. The experimental results present the partial discharge inception voltage (PDIV), partial discharge numbers, phase resolved partial discharge (PRPD) patterns and morphology analysis.

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2. Experimental Method

2.1. Material selection

The natural ester used in this study is Refined Bleached Deodorized Palm Olien (RBDPO), which is high in dielectric strength [3]. The nanoparticles of Fe_2O_3 were obtained commercially from Sigma Aldrich in the form of nanopowder with physiochemical properties as shown in Table 1. All the materials were dried through vacuum chamber to remove the impurities and moisture.

Table 1. Physiochemical properties of Fe_2O_3 nanoparticles

	Ferum Oxide, Fe_2O_3
Type	Conductive
Size	50 – 100 (nm)
Density	5.17 (g/cm^3)
Electric Conductivity	1 x 10^4 - 1 x 10^5 (S/m)
Relative Dielectric Constant	80
Relaxation time constant	7.47 x 10^{-14} (s)

2.2. Nanofluids preparation

The Fe_2O_3 nanoparticles in all formulation samples were dispersed by ultrasonication in two-step method. The weight percentage and amount of Fe_2O_3 in each nanofluid samples are tabulated in the Table 2.

Table 2. Palm oil-based Fe_2O_3 nanofluids formulation samples

Unit	Concentration level			
	Null (Pure)	Low (LC)	Medium (MC)	High (HC)
Weight percent (%)	0.0	0.1	10	100
Amount (g/L)	0.0	0.01	0.1	1.0

After the sonication, all samples were dried again in the vacuum chamber to remove the micro bubbles during the mixing process and then stored inside the bottle for experimental purpose as shown in Figure 1. The variations of colours indicate the concentration of Fe_2O_3 nanoparticles in the sample.

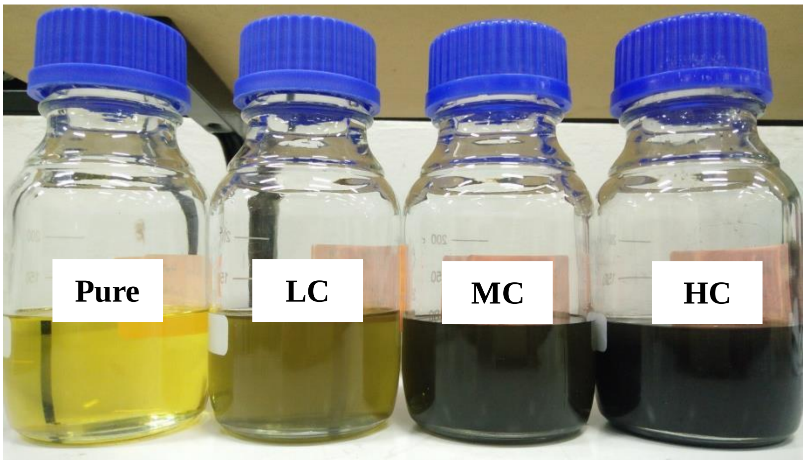

Figure 1. Snapshot of palm oil-based Fe_2O_3 nanofluids sample

2.3. Partial discharge measurement setup

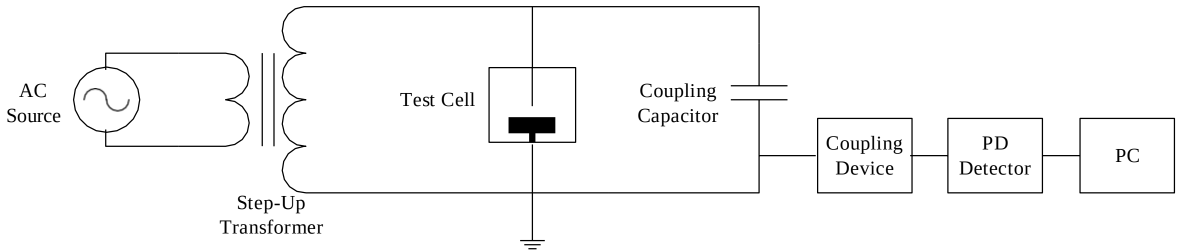

Figure 2. Experimental setup for PD measurement

Figure 2 shows the experimental setup used for the PD measurement. The test setup includes a HVAC supply (100/0.22 kV, voltage rating), measuring impedance (coupling device which is equivalent to RLC circuit), a coupling capacitor (1 nF), PD detector and a test cell which contains the sample. In order to initiate PD, a high voltage AC supply was connected to the needle electrode with curvature radius of 10 µm and 10 mm gap distance to the plane electrode (grounded). The voltage rise was controlled to have a rate of rise around 1 kV/s. Every single PD event captured was then transmitted to a personal computer via optic cable for further analysis.

3. Result and discussion

This section presents how the concentration of Fe_2O_3 nanoparticles influences the PD activities within the samples.

3.1. Partial discharge inception voltage

The results of PDIV are shown in Figure 3 and it clearly indicates the increment of inception voltage of LC sample compared to the pure sample. The result also shows slightly reduction of inception voltage for MC and HC samples respectively. PDs were initiated when the electric field at the tip of needle exceeds the dielectric breakdown strength of the samples due to ionization of surrounding at tangential needle to the ground electrode. Thus, for LC sample, the electron trapping effect due to the existence of nanoparticle prevents the charge mitigation and consequently increases the inception voltage. This was also reported by several researchers when low concentration of conductive nanoparticles was dispersed in mineral oil [4-5]. However, the inception voltage decreases for MC and HC due to the electron trapping effect is deteriorated when the Fe_2O_3 nanoparticle concentration increases. Similar trends were observed in PD histograms and PRPD patterns.

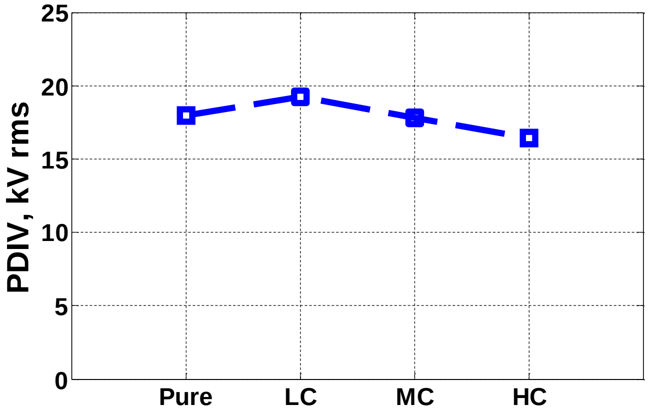

Figure 3. Partial discharge inception voltage (PDIV) result

3.2. Partial discharge numbers

In order to compare PD behaviours from various samples, the applied voltage were constantly set at 20 kV and higher than their PDIV level. Figure 4 shows the histogram of PD at 0 – 360 phase degree within positive and negative cycles of the applied voltage. At positive cycle, LC sample shows the lowest number of PD and increases with the increasing Fe_2O_3 concentration. This is due to the "electron trapping" effect that is associated with the applied electric field when Fe_2O_3 nanoparticle was dispersed in the palm oil. The nanoparticles induce the trapping and de-trapping process of charge carrier due to the differences of dielectric constant in a medium [6-7]. However, in high concentration of Fe_2O_3 nanoparticles, the trapping effect deteriorates due to the agglomeration of nanoparticles. At negative cycle the LC still dominant to maintain the lowest number of PD events. From the PD activity at negative cycle, it is also revealed that in larger surface area of negative electrode permits higher ionization process and produces more deterioration of liquid dispersion, which consequently produces more PD activities. In overall, the total number of PDs is higher in HC due to the 'bridging electron' effect is more dominant than 'electron trapping'.

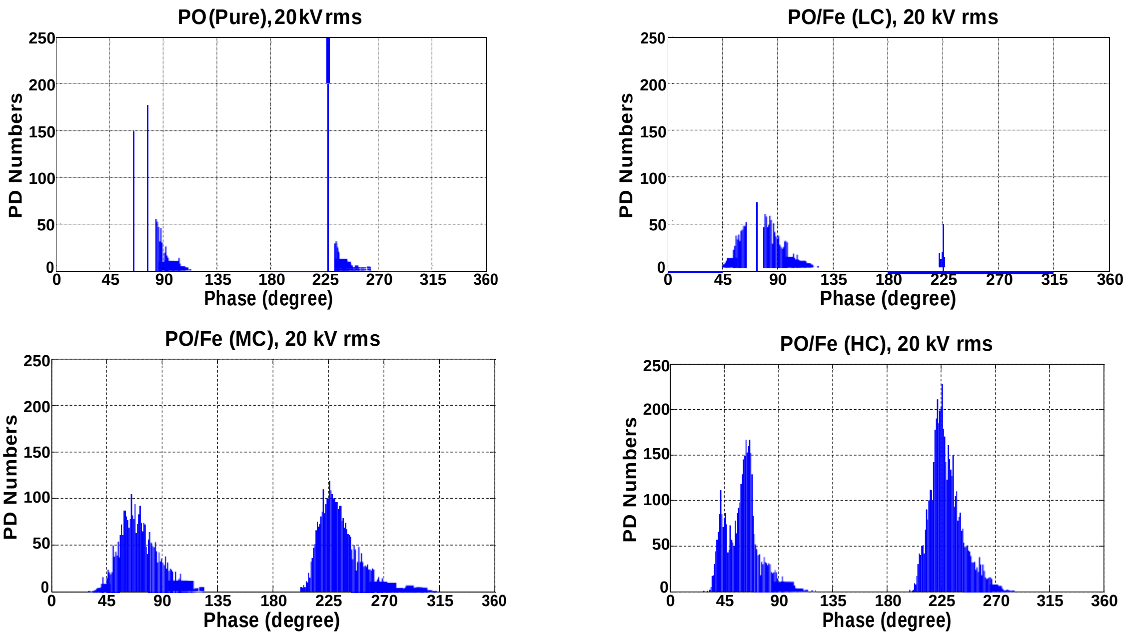

Figure 4. PD histogram with phases measured from samples

3.3. Phase resolved partial discharge pattern

The Phase Resolved Partial Discharge (PRPD) patterns have been widely used in high voltage system diagnostic to analyse the insulation condition [8]. Typical PRPD patterns obtained for pure, LC, MC, and HC with 3000 cycle of 20 kV rms of applied voltage are presented in Figure 5. The PRPD patterns show the PD charge magnitude and phase of all obtained pulses during the measurement. Referring to Figure 5, the PRPD pattern for pure sample is not symmetrical while the PD charge magnitude at positive cycle is much higher than negative cycle. The unbalanced geometry of the positive and negative electrode contributes to the asymmetrical shape of PD corona generation in the pure sample [9]. On the other hand, the PRPD patterns for nanofluids samples are generally equal. When the electron avalanche escapes from the trapping position, their velocity is higher, resulting in higher PD magnitude.

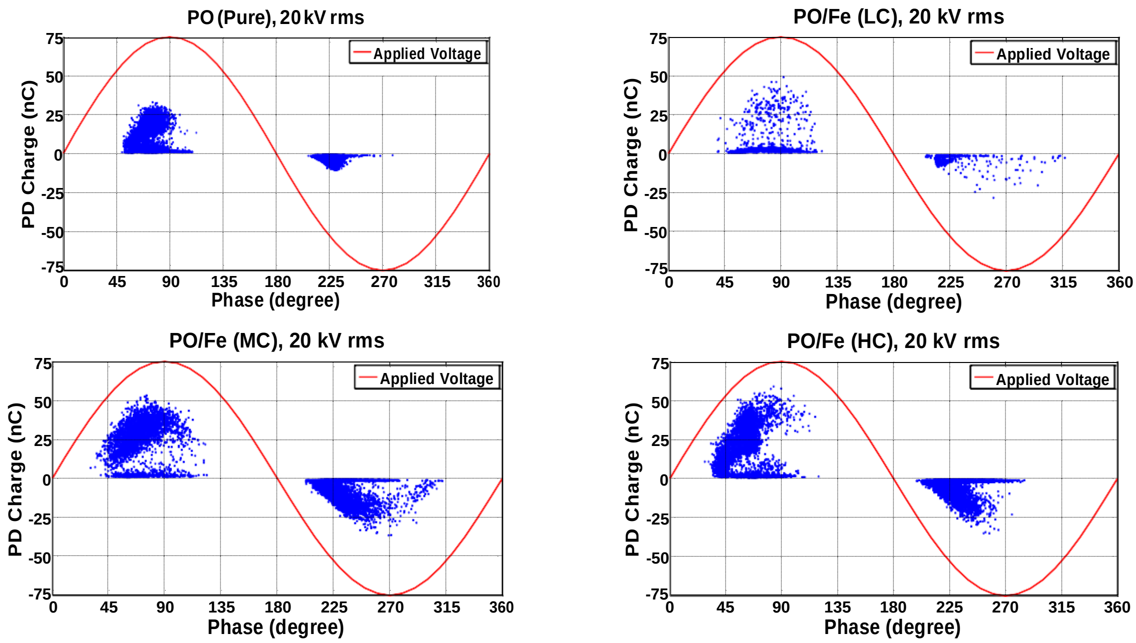

Figure 5. PRPD patterns measured for various samples

3.4. Morphology analysis

The morphology analysis was used to reveal extra information on how PD activity is affecting the nanofluids sample after 3000 cycles of applied voltage. Within the cycles, only in HC sample shows black layer developed within the surface area of the ground electrode. This is due to the bombardment of high velocity electron on the negative electrode, which could degrade the dispersion stability of palm oil-based Fe_2O_3 nanofluids. Hence, the Van der Walls force between particles deteriorates and leads to the sedimentation process that was obviously observed in HC sample. In fact, identical process happens on solid insulation when it was exposed to corona discharge [10]. Figure 6 shows the ground electrode condition after PD activity in PO/Fe (HC) sample. Figure 6 shows ground electrode condition after PD activity in PO/Fe (HC) sample.

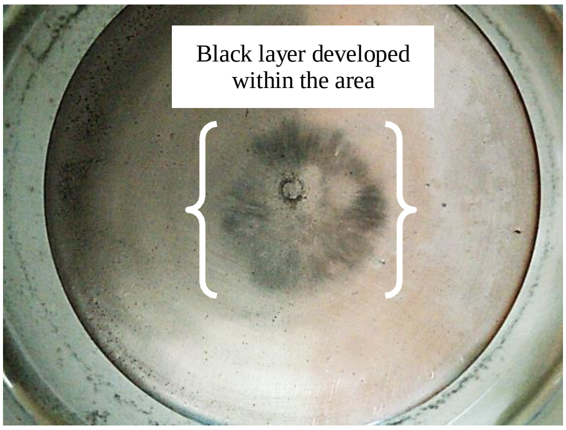

Figure 6. Ground electrode condition after PD activity in PO/Fe (HC) sample.

4. Conclusions

In conclusion, the PDIV withstand characteristic of palm oil is enhanced when the low concentration (LC) of Fe_2O_3 nanoparticles was dispersed in the liquid-based and performs the 'trapping' effect. However, it will deteriorate if the concentration exceeds certain limit. The PD charge magnitude is higher in the nanofluid samples compared to the pure sample. This is due to the accelerated velocity of the electron after escaping from the 'trapping' effect. The bombardment of high velocity electron avalanche will produce electrical ageing and therefore degraded the nanofluids stability. This effect can be investigated by performing the morphology analysis on the ground electrode after PD activities.

5. Acknowledgments

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