

# Investigation of the Electrical Properties of Palm Oil (PO) Under Magnetic Field Applied and Concentration Doping of Semiconductor Particles in Transformer Application

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**Abstract.** This paper presents a study investigating the potential use of Palm Oil (PO) as a transformer insulator medium by exploring its dielectric properties. The study includes evaluating the ac breakdown, tan delta test, and Raman measurement to assess the impact of doping various concentrations (0.01%, 0.1%, 0.2%, 0.4%, and 0.5%) of Silicon (Si) particles and the influence of a magnetic field (0.01T) on PO's electrical properties. The results indicate that the dielectric properties of PO can be enhanced to make it suitable for transformer oil applications. This matter was proven when the doping of 0.1% Si particle with PO has the highest voltage breakdown value compared to the mixture with other Si concentrations. Hence it is higher than pure PO. Furthermore, it has been observed that the voltage breakdown of all samples is higher when a magnetic field is present, in contrast to the samples without any magnetic field applied. It's worth noting that the specific relationship between the magnetic field and voltage breakdown may vary depending on the material properties and experimental setup. However, further research is required to address additional crucial factors such as thermal stability, compatibility with transformer materials, and oxidation susceptibility of palm oil, ensuring its suitability as an effective insulator medium.

## Introduction

The demand for sustainable and environmentally friendly insulating materials has led to an exploration of alternative options for transformer insulators in transformer applications. The insulator in a transformer is a material or component that separates and isolates different parts of the transformer, preventing the flow of electrical current between them. It helps to maintain electrical safety and efficient operation by providing insulation, dissipating heat, and offering mechanical support. The insulator ensures that the transformer functions properly by keeping the conductive components apart and protecting them from external factors, contributing to its overall performance and reliability [1-2]. One potential candidate is Palm Oil (PO), a renewable resource abundant in tropical regions. This paper aims to investigate the dielectric properties of PO to assess its suitability as a transformer insulator medium. The dielectric properties play a critical role in determining the electrical performance and reliability of insulating materials [3-4].

The aim of the investigation is to focus on evaluating the ac breakdown, tan delta, and Raman measurements to examine the effects of doping different concentrations of silicon particles and the

influence of a magnetic field on the electrical properties of PO. The potential enhancements in the dielectric properties of PO, addressing factors such as voltage breakdown strength, energy dissipation, and molecular structure also been systematically studied. However, it is important to consider additional aspects such as thermal stability, compatibility with transformer materials, and the oxidation factor of palm oil to ensure its suitability as a practical and efficient insulator medium. By investigating these parameters, this study aims to contribute to understanding PO's potential as a transformer insulator and provide insights into further research and development in this field.

### Experiment Methodology

Figure 1 illustrates the progress and procedure conducted in this study. The experimental procedure commenced with the meticulous preparation of the samples. This involved the implementation of various steps including filtering, doping, sonication, and drying, all aimed at enhancing the dielectric properties of palm oil through the incorporation of a specific concentration of semiconductors. A total of eight samples were prepared for the experiment. Once all the necessary preparations were completed, the focus shifted to conducting the AC breakdown test on the nanofluid solutions, both with and without the application of a magnetic field. The test was performed multiple times, with repetition as deemed necessary until achieving an acceptable and reliable outcome. Subsequently, measurements of resistivity and permittivity were carried out, followed by the Raman measurement phase, which was initiated once satisfactory results were obtained from the preceding tests. With the completion of all the experiments, meticulous organization and analysis of the gathered data and results ensued, culminating in the formulation of conclusive findings and relevant recommendations.

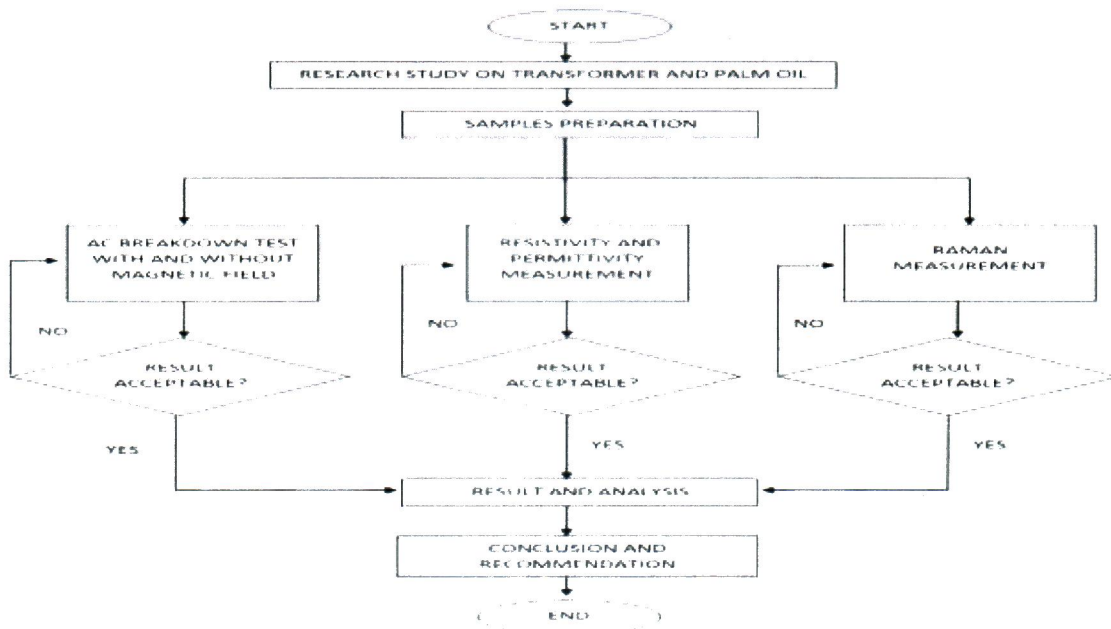


Figure 1: Illustrate the flowchart of the experiment.

### Samples Preparation

There are many different types of samples used in this experiment. Therefore, many process are required to be implemented to get the samples. The easiest way to understand the process for the sample's preparation can be done by referring to Figure 2. A total of eight samples are used in this experiment which consists of Pure Palm Oil (P PO), Filtered Palm Oil (F PO), Filtered Dried Palm Oil (FD PO), and a mixture of five (0.01%, 0.1%, 0.2%, 0.4%, 0.5%) different concentrations of Silicon (Si) with PO.

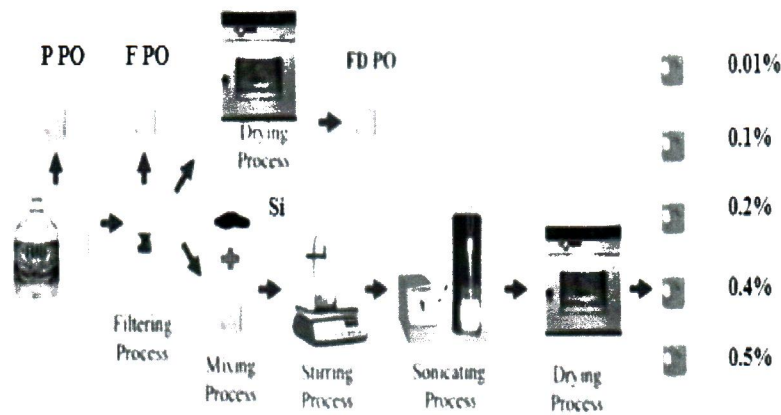


Figure 2: The step of samples preparation

### Result and Analysis

The analysis of the experimental data offers valuable insights into the behavior of Palm Oil (PO) as an insulating medium, specifically in relation to AC breakdown voltage and the influence of a magnetic field. The observed patterns and conclusions derived from the data contribute to the broader understanding of PO's performance characteristics in transformer applications. These findings have significant implications for the utilization of PO as an effective and sustainable insulating medium in various electrical applications. Moreover, the study aids in the advancement of techniques, guidelines, and standards for optimizing the use of PO, thereby promoting its practical implementation and fostering environmentally friendly practices in the electrical industry.

According to the findings presented in Table 1, the sample Si PO (0.1%) exhibited the highest voltage breakdown value of 50.92 kV/s when a magnetic field was applied, while the lowest value of 3.33 kV/s was observed for Si PO (0.5%) without a magnetic field. The results, as illustrated in Table 1 and Figure 3, indicate that the dielectric properties of PO can be improved through various treatments such as filtering, drying, and sonicating with nanoparticles. Notably, the pattern shows a progressive increase in voltage breakdown values, starting from 17.27 kV/s for P PO, 22.3 kV/s for F PO, and reaching 37.95 kV/s for FD PO. This suggests that the removal of moisture and unwanted substances from the oil contributes to enhanced electrical properties [4-6].

Table 1: The average AC Voltage Breakdown test of each samples.

	P PO	F PO	FD PO	Si PO (0.01%)	Si PO (0.1%)	Si PO (0.2%)	Si PO (0.4%)	Si PO (0.5%)
No Magnet	17.27	22.3	37.95	25.6	45.73	16.27	4.52	3.33
With Magnet	24.02	28.67	41.1	27.03	50.95	21.92	4.77	3.58

Additionally, it is observed that the voltage breakdown values of Si PO (26.6 kV/s) are lower than those of FD PO. The highest value is achieved at a specific concentration of nanoparticles before a decline is observed with further increases in Si concentration, indicating the importance of nanoparticle dosage for enhancing the dielectric properties of PO. Furthermore, the impact of a magnetic field (0.01T) on the dielectric properties of PO is evident in Figure 3, where all samples subjected to a magnetic field (orange) exhibit higher voltage breakdown values compared to samples without a magnetic field (blue). These findings provide valuable insights into the optimization of PO's dielectric properties for practical applications.

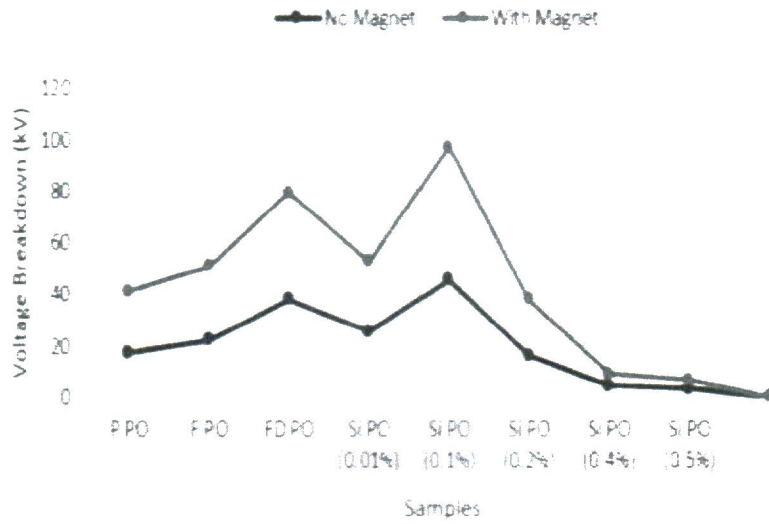


Figure 3: Graph pattern of the average AC Breakdown test.

By measuring the tan delta, it is possible to detect changes in the dielectric properties of the material over time. An increase in the tan delta value suggests a decrease in the insulation quality, indicating the presence of factors that contribute to energy loss, such as moisture, contaminants, or degradation products. Conversely, a low tan delta value indicates good insulation performance, with minimal energy dissipation. The relative resistivity and permittivity of all oil samples can be determined from this test. Table 2 shows the range value of permittivity, resistivity, and tan delta for commonly used transformer oils.

Table 2: Range of transformer oil permittivity, tan delta, and resistivity.

Temperature (°C)	25
Permittivity ( $\epsilon$ )	2.2 - 2.5
Tan Delta ( $\sigma$ )	0.005
Resistivity (M $\Omega$ m)	300 - 350

Transformer oil undergoes various electrical tests to assess its insulation properties and ensure its suitability for use in transformers. Three important parameters tested are resistivity, permittivity, and tan delta (dissipation factor). Resistivity refers to the oil's ability to resist the flow of electrical current and maintain its insulating properties. Typical standard values for resistivity range from 300 to 350 megohm-m (M $\Omega$ m) at 25°C. Permittivity, which measures the oil's ability to store electrical energy, typically falls within the range of 2.2 to 2.5 at 25°C. A lower Tan Delta value, which indicates lower energy loss in the oil, is desired. A typical tan delta value for transformer oil is below 0.005 at 25°C[6].

These standard values help determine the electrical performance and insulating capability of transformer oil. They serve as reference points for assessing the quality and reliability of the oil. By meeting or exceeding these standard values, transformer oil ensures effective electrical insulation, reduces power losses, and maintains the overall efficiency of the transformer. However, it's important to note that specific standards of resistivity, permittivity or even tan delta may vary depending on one organization of countries. Therefore, as guidelines or references to determine which values are the most suitable to be used, it is recommended to refer to applicable industry standards such as IEC and ASTM.

The dielectric properties of P PO, F PO, and FD PO were evaluated by examining the values of permittivity ( $\epsilon$ ), tan delta ( $\sigma$ ), and resistivity ( $\rho$ ) at different temperatures. Based on Table 3, the

permittivity values ranged from 2.155  $\epsilon$  for 25°C P PO to 1.473  $\epsilon$  for 85°C FD PO. A higher relative permittivity indicates a greater ability to withstand higher voltages, making it desirable for efficient and compact insulation systems [7-8].

Table 3: The result of resistivity, permittivity, and tan delta test for P PO, F PO, and FD PO.

<b>PURE PALM OIL (P PO)</b>				
<b>Temperature (°C)</b>	<b>25</b>	<b>45</b>	<b>65</b>	<b>85</b>
<b>Permittivity (<math>\epsilon</math>)</b>	2.155	2.067	2.046	1.993
<b>Tan Delta (<math>\sigma</math>)</b>	0.003	0.00949	0.01359	0.02671
<b>Resistivity (<math>\Omega\text{m}</math>)</b>	7.180T	2.042T	1.147T	632.9G

<b>FILTERED PALM OIL (F PO)</b>				
<b>Temperature (°C)</b>	<b>25</b>	<b>45</b>	<b>65</b>	<b>85</b>
<b>Permittivity (<math>\epsilon</math>)</b>	2.025	1.839	1.492	1.88
<b>Tan Delta (<math>\sigma</math>)</b>	0.0031	0.00532	0.00672	0.0478
<b>Resistivity (<math>\Omega\text{m}</math>)</b>	75.36G	62.90G	62.66G	909.8G

<b>FILTERED DRIED PALM OIL (FD PO)</b>				
<b>Temperature (°C)</b>	<b>25</b>	<b>45</b>	<b>65</b>	<b>85</b>
<b>Permittivity (<math>\epsilon</math>)</b>	1.557	1.532	1.522	1.473
<b>Tan Delta (<math>\sigma</math>)</b>	0.005	0.0043	0.0077	0.0265
<b>Resistivity (<math>\Omega\text{m}</math>)</b>	12.26T	70.41T	33.14T	20.18T

Moreover, the tan delta values, of 25°C P PO had the lowest value (0.003  $\sigma$ ) and 85°C F PO had the highest value (0.0478  $\sigma$ ). A lower Tan Delta value indicates efficient insulation performance with minimal energy losses. It signifies that the insulation material is effectively preventing the leakage of electrical energy. On the other hand, higher Tan Delta values suggest insulation degradation or issues that can compromise the effectiveness of the insulation. It implies that the insulation material is experiencing increased energy losses and may not be providing optimal electrical insulation [9].

Regarding resistivity, as shown in Table 3, for 45°C FD PO exhibited the highest value of 70.41 T  $\Omega\text{m}$ , indicating its superior ability to resist electrical current flow compared to other samples. High resistivity is desirable for insulating materials as it ensures effective electrical isolation and prevents current leakage [10-12].

## Conclusion

In conclusion, pure palm oil alone is not suitable for use as a transformer insulator due to its poor insulating properties. However, studies have shown that through appropriate experimentation, its dielectric properties can be enhanced, making it a potential substitute for mineral oil in transformer applications. Insulating materials used in transformers require high dielectric strength, thermal stability, and chemical resistance to withstand high voltage and temperature conditions and prevent breakdown. The addition of filtering, drying, and other treatments to palm oil has been found to improve its AC breakdown strength, making it a promising option for insulation purposes.

Furthermore, the application of a magnetic field to the insulating medium can further enhance its AC breakdown strength. The magnetic field helps restrict the formation and growth of discharge channels called streamers, which can lead to electrical breakdown. By confining the charged particles

involved in the streamer process, the magnetic field makes it more challenging for the discharge to propagate, requiring a higher electric field strength for breakdown to occur. This finding highlights the potential of magnetic fields as a means to improve the dielectric properties of insulating materials and enhance their performance in electrical applications.

Additionally, it is crucial to consider the concentration of nanoparticles when doping the oil sample to enhance its dielectric properties. In the case of our study, a silicon concentration of 0.1% in palm oil yielded satisfactory voltage breakdown values, while other concentrations resulted in a degradation of breakdown strength. Exceeding a certain threshold of nanoparticle concentration, such as silicon, can increase the oil's conductivity, transitioning it from an insulator to a conductor. This transition is undesirable as it can lead to electrical leakage. Therefore, careful control of the nanoparticle concentration is necessary to achieve optimal enhancement of dielectric properties without compromising insulation performance.

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