UNIVERSITI PUTRA MALAYSIA

BREAKDOWN CHARACTERISTICS AND DIELECTRIC PROPERTIES OF PALM OIL AND COCONUT OIL BASED TiO_2 NANOFLUIDS

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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November 2016

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The increasing concerns on environmental issues have led to the introduction of vegetable oils such as Palm Oil (PO) and Coconut Oil (CO) as potential candidates for alternative dielectric insulating fluids for mineral oil. Even though the overall performances of these oils are comparable with other types of vegetable oils, some improvements can be carried out especially on their electrical properties. Extensive electrical examinations need to be conducted on these PO and CO at laboratory level in order to determine its feasibility for practical application in transformers.

This work presents an examination on the electrical properties of PO and CO under the presence of a semi-conductive nanoparticle, Titanium (IV) Oxide (TiO_2). Refined, Bleached and Deodorized Palm Oil (RBDPO) Olein was used in this study, whereas the volume concentrations of TiO_2 used are from 0.001% to 0.050%. Investigation on the effects of a surfactant, Cetrimonium Bromide (CTAB) was also carried out. Transmission Electron Microscope (TEM) was used to examine the morphology of RBDPO and CO based TiO_2 nanofluid. Moreover, AC and lightning breakdown voltages, dielectric dissipation factor, relative permittivity and resistivity measurements were taken whereas the withstand voltages for AC and lightning were statistically evaluated through Weibull distribution.

This study found that the AC breakdown voltages of the RBDPO and CO can be increased through introduction of TiO_2 without CTAB where the highest percentages of increments are 17.2% and 22.7% respectively. The AC breakdown voltage of RBDPO and CO based TiO_2 nanofluid can however decrease with introduction of CTAB. The effect of TiO_2 on the lightning breakdown voltages of RBDPO and CO under both fields is quite small for samples with or without CTAB where the highest percentages of increments are 9.2% and 11.3% respectively. The dielectric dissipation factors and resistivity of RBDPO and CO based TiO_2 nanofluid are significantly affected by the presence of CTAB whereas TiO_2 has no significant effect on the relative permittivity of RBDPO and CO for samples with and without CTAB. The statistical analysis reveal that the AC breakdown voltages at 1% probability for RBDPO and CO have experienced a

significant improvement after the introduction of TiO_2 regardless with or without CTAB where the highest percentages of increments are 63.9% and 36.8% respectively. On the other hand, TiO_2 has small effect on improving the lightning breakdown voltages at 1% probability under non-uniform field regardless with or without CTAB. Significant improvements of the lightning breakdown voltages at 1% probability under quasi uniform field are found for samples with CTAB.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

CIRI-CIRI PECAHAN VOLTAN DAN SIFAT-SIFAT DIELEKTRIK TERHADAP MINYAK KELAPA SAWIT DAN MINYAK KELAPA BERASASKAN BENDALIR NANO TiO_2

Oleh

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Kebimbangan semakin meningkat mengenai isu-isu alam sekitar yang telah membawa kepada pengenalan minyak sayuran seperti Minyak Kelapa Sawit (PO) dan Minyak Kelapa (CO) sebagai calon yang berpotensi sebagai alternatif cecair penebat dielektrik untuk menggantikan minyak mineral. Prestasi keseluruhan minyak ini boleh dibandingkan dengan lain-lain jenis minyak sayuran, beberapa penambahbaikan boleh dijalankan terutamanya pada sifat-sifat elektrik mereka. Pengujian elektrik yang meluas perlu dijalankan ke atas PO dan CO diperingkat makmal untuk menentukan kelayakan untuk digunakan secara praktikal di dalam alat ubah.

Kajian ini membentangkan pengujian sifat-sifat elektrik ke atas PO dan CO di bawah kehadiran TiO_2. RBDPO Olein telah digunakan dalam kajian ini, manakala jumlah kepekatan TiO_2 yang digunakan adalah dari 0.001% kepada 0.050%. Pengujian mengenai kesan bahan permukaan iaitu CTAB juga telah dijalankan. TEM telah digunakan untuk mengkaji morfologi RBDPO dan CO berasaskan bendalir nano TiO_2. Selain itu, pecahan voltan arus ulang-alik dan kilat, pengukuran faktor pelesapan dielektrik, ketelusan relatif dan kerintangan telah dijalankan manakala pecahan voltan arus ulang-alik dan kilat dianalisis melalui taburan Weibull.

Kajian ini mendapati bahawa pecahan voltan arus ulang-alik untuk RBDPO dan CO boleh diperbaiki melalui pengenalan TiO_2 tanpa kehadiran CTAB di mana peratusan tertinggi kenaikan masing-masing adalah 17.2% dan 22.7%. Pecahan voltan arus ulang-alik untuk RBDPO dan CO berasaskan TiO_2 bendalir nano boleh berkurangan dengan pengenalan CTAB. Kesan TiO_2 pada pecahan voltan kilat untuk RBDPO dan CO di bawah kedua-dua medan ini agak kecil untuk sampel dengan atau tanpa CTAB di mana peratusan tertinggi kenaikan masing-masing adalah 9.2% dan 11.3%. Faktor pelesapan dielektrik dan kerintangan untuk RBDPO dan CO berasaskan TiO_2 bendalir nano secara ketara dipengaruhi oleh kehadiran CTAB manakala kehadiran TiO_2 mempunyai kesan yang besar ke atas ketelusan relative untuk RBDPO dan CO dengan kehadiran dan ketidakhadiran CTAB. Analisis statistik menunjukkan bahawa pecahan voltan arus

ulang-alik pada 1% kebarangkalian untuk RBDPO dan CO telah mengalami peningkatan yang ketara selepas pengenalan TiO_2 tidak kira dengan atau tanpa kehadiran CTAB di mana peratusan tertinggi kenaikan masing-masing adalah 63.9% dan 36.8%. Sebaliknya, TiO_2 mempunyai kesan kecil kepada peningkatan pecahan voltan kilat pada 1% kebarangkalian di bawah medan yang tidak sekata tanpa mengira kehadiran atau ketidakhadiran CTAB. Peningkatan yang ketara telah ditemui untuk pecahan voltan kilat pada 1% kebarangkalian di bawah medan sekata untuk sampel yang mempunyai CTAB.

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I certify that a Thesis Examination Committee has met on 25 November 2017 to conduct the final examination of Shamsul Fahmi Mohd Nor on his thesis entitled "Breakdown Characteristics and Dielectric Properties of Palm Oil and Coconut Oil Based TiO_2 Nanofluids" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

%	Percentage
α	Scale Parameter
β	Shape Parameter
+	Increment
–	Decrement
ρ	Density of Nanoparticles
ºC	Celsius
µs	Micro Second
AC	Alternating Current
ASTM	American Society for Testing and Materials
Al_2O_3	Aluminium Oxide
C	Carbon
CuO	Copper (II) Oxide
Cu_2O	Copper (I) Oxide
CO	Coconut Oil
CPO	Crude Palm Oil
CTAB	Hexadecyl Trimethyl Ammonium Bromide
CTAB	Cety Trimethyl Ammonium Bromide
CTAB	Centrimonium Bromide
cSt	Centistokes
DDF	Dielectric Dissipation Factor
Fe_2O_3	Maghemite
Fe_3O_4	Magnetite
g	Gram
g/cm^3	Gram per Cubic Centimetre
g/mL	Gram per Millilitre
GC	Gas Chromatography
GΩm	Giga Ohm Metre
Hz	Hertz
IEC	International Electrotechnical Commission
ISO	International Standards Organization
J/kg.K	Joule per Kilogram Kelvin
kV	Kilovolt
kV/mm	Kilovolt per Millimetre
kV/s	Kilovolt per Second
mm	Millimetre
mgKOH/g	Milligram Potassium Hydroxide per Gram
MPOB	Malaysia Palm Oil Berhad
M-U.S. fat	Monounsaturated Fat
nm	Nanometre
ppm	Parts per Million
P-U.S. fat	Polyunsaturated Fat
PKO	Palm Kernel Oil
PO	Palm Oil
PVP	Polyinylpyrrolidone
RBDCO	Refined, Bleached and Deodorized Coconut Oil
RBDPO	Refined, Bleached and Deodorized Palm Oil
RCO	Refined Coconut Oil

s	Second
SDS	Lauryl Sodium Sulfate
SiO_2	Silicon Dioxide
S. fat	Saturated Fat
S/m	Siemens per Metre
Std. dev	Standard deviation
TiO_2	Titanium (IV) Oxide
TEM	Transmission Electron Microscopy
V	Voltage
V/mm	Volt per Millimetre
V.A	Vitamin A
V.E	Vitamin E
VCO	Virgin Coconut Oil
VDE	Verband der Elektrotechnik
Vn	Volume of Nanoparticles
Vo	Volume of Oil-based
Vc	Volume of Concentrations
W/m.k	Watt per Metre Kelvin
x	Measured Breakdown Data
ZnO	Zinc Oxide

CHAPTER 1

INTRODUCTION

1.1 Background

Most transformers in the power system network are oil-filled type. Among the main functions of the oil include to insulate between components, to dissipate the heat generated from the core/winding and to act as information carrier for condition-monitoring purposes [1–4]. For more than a century, mineral oils have been widely used as dielectric insulating fluids in transformers due to their excellent electrical properties. They are derived from petroleum crude stock from buried and decayed vegetable matter or by action of water on the metal carbides [5, 6]. However, there are several issues associated with the characteristics of mineral oils. Mineral oils are non-biodegradable, have low flash/fire points and could cause serious contamination issues in the presence of a leakage [7].

Due to the increasing concern on environment and safety, alternative fluids for mineral oil are currently being sought. Among the possible fluids considered for transformers application include vegetable oil. It is derived mainly from glycerol and fatty acids known as triglyceride [8]. Vegetable oil is biodegradable, non-toxic and has high flash/fire points [8–10]. There are a number of studies that have been carried out on different types of vegetable oils which include soy, rapeseed and sunflower oils. The studies cover on different aspects such as ageing characteristics, fault diagnosis based on dissolved gas analysis and breakdown mechanisms [12–16]. Apart from esters, Palm Oil (PO) and Coconut Oil (CO) are other types of vegetable oil considered for transformers insulation [11, 17, 18]. Most of the PO and CO are food grade type and have almost the same characteristics as esters. There are a number of studies previously that have been carried out to examine its physical and chemical properties such as viscosity, acidity and oxidation stability, together with its electrical properties such as AC breakdown voltage, dissipation factor and partial discharge [19–24].

Nowadays, nanotechnology provides exciting new possibilities to enhance the electrical and thermophysical properties of oils [29–32]. The technology has been applied in various fields such as biomedical industry, mechanical and aerospace engineering fields [29, 33, 34]. A number of studies have also been carried out to improve the performance of dielectric insulating fluids through the introduction of nanoparticles such as Magnetite (Fe_3O_4), Maghemite (Fe_2O_3), Zinc Oxide (ZnO), Aluminium Oxide (Al_2O_3), Silicon Dioxide (SiO_2) and Titanium (IV) Dioxide (TiO_2) [35–39]. Most of these nanofluids studies are mainly on mineral oil and also covers on the electrical performance and dielectric properties [40, 41]. There are also a number of studies that have been carried out on vegetable oils through the introduction of nanoparticles which covers also different aspects such as AC and lightning breakdown voltages and thermal ageing [42, 43]. With the current interest of green technology application in transformers, there is a need to expand the application of nanoparticles to other types of vegetable oils such as PO and CO.

1.2 Problem Statement

Mineral oils have been widely used due to their excellent electrical properties, however there are issues associated with mineral oil such as non-biodegradable, have low flash/fire points and could cause serious contamination issues in the presence of a leakage [7]. Therefore, vegetable oils have been introduced as possible alternatives for dielectric insulating fluids in transformers due to their environmental friendliness. PO and CO are among the vegetable oils that are currently being considered for transformer application. Current studies on PO and CO show that the performances are comparable to commercial esters applied in transformers [11, 44]. Among the issues associated with PO and CO are the AC breakdown voltages is slightly lower than mineral oil, low resistivity and high dielectric dissipation factor [25–28, 109]. The current nanotechnology provides a good platform for improvement of the electrical properties of PO and CO. In recent years, a number of studies have been carried out to improve the electrical, physical and chemical performances of other types of vegetable oils such as AC and lightning breakdown voltages, dielectric properties, flash/fire points, viscosity and acidity through introduction of various types of nanoparticles [42, 43, 45–47]. However, before the PO and CO based nanofluids can be further explored for potential application in transformers, there are several issues that need to be considered:

1. Refined Bleached and Deodorized Palm Oil (RBDPO) and CO are chosen as a candidate for application of nanoparticles since these oils have good electrical performances and ageing properties based on a number of previous studies.
2. Considering the importance of AC breakdown voltage for insulation design and condition monitoring, the breakdown characteristics under AC voltages of RBDPO and CO under presence of nanoparticles is still not known.
3. On the other hand, lightning breakdown voltage is among the important parameters for insulation design. It is also important to consider the lightning breakdown voltages of RBDPO and CO based nanofluids under good and worst scenarios which can be represented through quasi and non-uniform fields, however there is no study have been conducted to examine the performances of lightning breakdown voltages for RBDPO and CO based nanofluids under both fields.
4. In addition, the dielectric properties such as dielectric dissipation factor, resistivity and relative permittivity are important to indicate any irregularities that occur in the oils. Currently, there is no information can be obtained on the effect of nanoparticles on the dielectric properties of RBDPO and CO.
5. The application of nanoparticles in oils is associated with surfactant mainly to improve the stability as well as to reduce the aggregation. Considering this fact, it is important to evaluate the overall performance and its mechanisms of RBDPO and CO based nanofluids with introduction of surfactant.
6. Overall, there is still lack of knowledge on the electrical properties of RBDPO and CO under presence of TiO_2 and Centrimonium Bromide (CTAB). It is anticipated through measurements such as the AC and lightning breakdown voltages and dielectric properties, the properties of RBDPO and CO based TiO_2 nanofluids can be further learned for the benefits towards further studies in the future and it would beneficial knowledge to the asset engineer and management.

1.3 Research Aim and Objectives

The main aim of this study is to investigate the breakdown characteristics and dielectric properties of RBDPO and CO based TiO_2 nanofluids with and without CTAB. In order to achieve the aim of this research, a number of objectives are outlined as follows:

1. To investigate the AC breakdown voltages of RBDPO and CO based TiO_2 nanofluids with and without CTAB and its mechanisms.
2. To evaluate the lightning breakdown performances of RBDPO and CO based TiO_2 nanofluids with and without CTAB under quasi and non-uniform fields.
3. To examine the characteristics of dielectric dissipation factor, resistivity and permittivity of RBDPO and CO based TiO_2 nanofluids with and without CTAB.

1.4 Scope and Limitations of the Project

The scope and limitations of the project are outlined as follows:

1. This research only considers only one type of nanoparticles, namely TiO_2.
2. The volume concentrations of TiO_2 under study are from 0.001% to 0.050%.
3. The surfactant considered in this research is only CTAB at volume concentration of 0.02%.
4. This research focuses on the AC and lightning breakdown voltages, dielectric dissipation factor, relative permittivity and resistivity of RBDPO and CO based TiO_2 nanofluids.

1.5 Contribution of the Research

1. The knowledge derived regarding the effect of the various concentrations of TiO_2 with and without CTAB on the electrical properties of RBDPO and CO based TiO_2 nanofluids can be further applied in future research and development in relation to the practical application in transformers.
2. The analysis of the AC and lightning breakdown voltages of RBDPO and CO based TiO_2 nanofluids can be utilized for insulation design. Coupled with information from its thermal performances, a comprehensive design of transformers can be carried out.
3. The characteristics of dielectric dissipation factor, resistivity and relative permittivity of RBDPO and CO based TiO_2 nanofluids can be used as a condition monitoring reference for application in transformers in the future.

1.6 Thesis Outline

This thesis is divided into 5 chapters. A summary of all of the chapters presented in this thesis is as follows:

Chapter 1 Introduction
This chapter introduces the background and the problem statement of this study. Also describes the research aim and objectives, together with the scope, the limitations and the contribution of the research, are also elaborated.

Chapter 2 Literature Review
This chapter provides a detailed overview of the insulation materials in transformers and a brief introduction of nanoparticles and surfactant in dielectric insulating fluids. The synthesis process of nanofluids are described along with the most recent studies on mineral oil and vegetable oil based nanofluids.

Chapter 3 Methodology
This chapter describes the properties of oils and characteristics of nanoparticles and surfactant are also explained, followed by the steps to prepare the all oil samples. The detailed explanation of AC and lightning breakdown voltages and dielectric properties measurement are also presented.

Chapter 4 Results and Discussion
This chapter investigates the electrical properties on the AC and lightning breakdown voltage, as well as the dielectric properties of RBDPO and CO based TiO_2 nanofluids with and without CTAB. The AC and lightning breakdown voltages result were analysed using statistical analysis to determine the withstand voltages.

Chapter 5 Conclusions and Recommendations
This chapter summarises and concludes the main findings in this research. It also provides the recommendations for future works on electrical properties of RBDPO and CO based TiO_2 nanofluids with and without CTAB.

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