DIELECTRIC STRENGTH AND VISCOSITY OF PALM OIL BASED NANOFLUIDS FOR LIQUID INSULATION IN POWER TRANSFORMER

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MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

2018

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A thesis submitted
in fulfilment of the requirement for the degree of Master of Science
in Electrical Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this thesis entitled "Dielectric Strength and Viscosity of Palm Oil Based Nanofluids for Liquid Insulation in Power Transformer" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering .

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Supervisor Name : Assoc. Prof. Dr. Hidayat Bin Zainuddin

Date :……………………..…

DEDICATION

To my beloved parent, wife and kid

ABSTRACT

The liquid insulation system of high voltage oil-immersed transformers is involved in this thesis. Until now, mineral insulation (MI) oils are typically used in high voltage oil-immersed transformers because of their excellence in dielectric strength and cooling performance. However, MI oils are non-renewable and non-sustainable sources. This has led scientists and researchers to formulate alternative insulation liquids such as natural ester insulation (NEI) oils to replace MI oils. Palm fatty acid ester (PFAE) is one of the ester types of insulation oil and the alternative oil to replace MI oils. This PFAE oil was developed in 2006 by Lion Corporation as insulation oil for transformer applications which have several advantages compared to MI oils i.e. good biodegrability, excellent performance in insulation and cooling medium. Nowadays, nanotechnology is one of the most important research fields especially in electrical insulation system due to the increasing demand for the electrical power in the world. Therefore, adding the nanoparticles is one of the approaches used by researchers to improve the performance of liquid insulation also known as nanofluids. The use of nanofluids in insulation system give more benefit in terms of insulation performance, design and power capacity of transformer. Based on this premise, the objectives of this research is to formulate PFAE oil-based nanofluids by dispersing three types of nanoparticles (i.e. conductive, semi-conductive and insulating nanoparticles) into PFAE oil. The potential of these nanofluids as insulation liquids is validated based on its Alternating Current (AC) breakdown voltage and viscosity. In sample preparation of PFAE oil-based nanofluids, four specific procedures must be followed i.e. weighing, homogenizer treatment, vacuum oven and moisture removal treatment process. The AC breakdown voltage was measured which complies with the specifications of the ASTM D1816 and the viscosity of the oil samples was measured according to ASTM D445 and ASTM D2983. The findings from the AC breakdown voltage suggested that the PFAE oil-based conductive nanofluid has the highest dielectric strength enchancement at weibull probability of 63.2 % with a value of 50.57 % relative to that for virgin PFAE oil. Besides that, the histogram for this nanofluids is skewed to the left, whereby most of the data fall within a range of 45 – 49 kV. In terms of heat transfer, the PFAE oil-based insulating nanofluid has the lowest viscosity compared to the other oil samples, particularly at 60 ^{o}C, based on viscosity values. Both of these parameters (AC breakdown voltage and viscosity) are crucial to designers of high voltage equipment and systems. In conclusion, the effects on breakdown voltage is more significant compared to the viscosity when nanoparticles are added into the PFAE oil.

ABSTRAK

Sistem penebat cecair bagi pengubah minyak-tenggelam voltan tinggi didedahkan dalam tesis ini. Sehingga kini, penebat minyak mineral (MI) kebiasaannya digunakan dalam pengubah minyak-tenggelam voltan tinggi kerana ianya sangat baik dalam kekuatan dielektrik dan keupayaan penyejukan. Walau bagaimanapun, minyak MI adalah sumber yang tidak boleh diperbaharui dan tidak lestari. Hal ini menyebabkan ramai saintis dan penyelidik mengkaji penebat cecair alternatif seperti penebat minyak semulajadi ester (NEI) untuk menggantikan minyak MI. Asid lemak kelapa sawit ester (PFAE) merupakan salah satu penebat minyak jenis ester dan minyak alternatif untuk menggantikan minyak MI. Minyak PFAE ini telah dibangunkan pada tahun 2006 oleh Lion Cororation sebagai minyak untuk aplikasi pengubah yang mempunyai beberapa kelebihan berbanding minyak MI iaitu tahap pereputan yang bagus, sangat baik dalam penebatan dan media peyejukan. Pada masa kini, teknologi nano merupakan salah satu bidang penyelidikan yang terpenting terutamanya dalam sistem penebatan elektrik yang disebabkan permintaan elektrik yang semakin meningkat untuk kuasa elektrik dunia. Oleh itu, menambah nanopartikel adalah salah satu kaedah yang digunakan oleh ramai penyelidik untuk meningkatkan prestasi penebat cecair yang dikenali sebagai cecair nano. Penggunaan cecair nano dalam sistem penebat memberi banyak manfaat dari segi prestasi, reka bentuk dan kapasiti kuasa bagi pengubah. Berdasarkan pernyataan ini, objektif kajian ialah untuk merumuskan PFAE berasaskan cecair nano dengan menyebarkan tiga jenis nanopartikel (iaitu konduktif, separuh konduktif dan penebat nanopartikel) ke dalam minyak PFAE. Potensi cecair nano sebagai penebat cecair disahkan berdasarkan voltan pecah tebat arus ulang alik (AU) dan kelikatan. Dalam penyediaan sampel cecair nano, empat langkah khusus mesti diikuti iaitu penimbangan, rawatan homogenisasi, ketuhar vakum dan rawatan penyingkiran kelembapan. Voltan pecah tebat (AU) diukur dengan mematuhi spesifikasi ASTM D1816 dan kelikatan diukur berdasarkan ASTM D445 dan ASTM D2983. Penemuan yang dicadangkan daripada voltan pecah tebat (AU) ialah minyak PFAE berasaskan cecair nano konduktif mempunyai peningkatan kekuatan dielektrik yang paling tinggi iaitu pada kebarangkalian Weibull 63.2 % dengan nilai 50.57 % berbanding minyak PFAE dara. Selain itu, histogram bagi cecair nano adalah condong ke kiri, yang mana kebanyakan data berada pada julat 45 – 49 kV. Dari segi pemindahan haba, minyak PFAE berasaskan cecair nano penebat mempunyai kelikatan yang rendah berbanding sampel minyak lain, terutamanya pada 60 ^{o}C, berdasarkan nilai kelikatan. Kedua – dua parameter ini (voltan pecah tebat (AU) dan kelikatan) adalah penting kepada pereka peralatan voltan tinggi dan sistem. Kesimpulannya, kesan terhadap voltan pecah tebat adalah lebih ketara berbanding dengan kelikatan apabila nanopartikel ditambah ke dalam minyak PFAE.

ACKNOWLEDGEMENTS

Alhamdulillah thanks to ALLAH, for giving me the strength to complete this thesis through the help of various parties either directly or indirectly. I would like to take this opportunity to express my sincere acknowledgement to my supervisor, Assoc. Prof. Dr. Hidayat Bin Zainuddin and co-supervisor, Ir. Imran Bin Sutan Chairul from the Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for their essential supervision, support and encouragement towards the completion of this thesis.

I would also like to thank to Ir. Sharin Bin Ab Ghani from Faculty of Electrical Engineering for his advice and suggestions that significantly helped in my work. Special thanks to Research Acculturation Grant Scheme (RAGS) Kementerian Pendidikan Malaysia (RAGS/1/2014/TK03/FKE/B00055), MyBrain15 program and Universiti Teknikal Malaysia Melaka for the opportunity to pursue my master study as well as the financial sponsorship.

I would also like to thank to Mr. Mohd Wahyudi Bin Mohd Hussain and Mr. Norhisham Bin Abu Seman (Assistant Engineers from the UTeM High Voltage Engineering Research Laboratory (HVERL)), Mrs. Rusni Binti Abdullah and Mr. Azrul Syafiq Bin Mazlan, (Assistant Engineers from the Chemical and Tribology Laboratory, Faculty of Mechanical Engineering), for their assistance and efforts in all the lab works. A big thank you to the entire college members for meaningful helps, discussions, and opinions while performing the work in this research project.

Special thanks to my mother, Mrs. Zainab Binti Abdullah and beloved father, Mr. Mohamad Bin Teh for moral supports in completing this research. To my beloved wife, Mrs Siti Norzulaiha Binti Asrin and my little children, Muhammad Umar Zahran, thank you for your supports and motivations until the end of this research project.

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Al_2O_3	-	Aluminum oxide
CO_2	-	Carbon dioxide
CuO	-	Copper (II) oxide
Cu_2O	-	Copper (I) oxide
exp	-	Exponential
Fe_2O_3	-	Iron (III) oxide
Fe_3O_4	-	Iron (II,III) oxide
g/cm^3	-	gram per cubic meter
g/L	-	gram per litre
kPa	-	kilopascal
kV	-	kilovolts
kV/s	-	Kilovolts per second
mg/kg	-	milligram per kilogram
mg	-	Milligrams of potassium hydroxide per gram KOH/g
min	-	minute
mL	-	millilitre
mm	-	millimetre
mm^2/s	-	millimetre square per second
mPa.s	-	millipascal seconds

nm	-	nanometer
Pa	-	Pascal
PPM	-	Part per million
Psi	-	Pound per square inch
$PVF_{(nm)}$	-	The particles volume fraction of the nano material
SiC	-	Silicon carbide
SiO_2	-	Silicon oxide / silica
TiO_2	-	Titanium oxide / Titania
$V_{(oil)}$	-	The volume of oil
$W_{(nm)}$	-	The quantity of nano material
ZnO	-	Zinc oxide
b	-	Intercept
g	-	Gram
j	-	The sequence of data
m	-	Slope
η	-	Scale parameter
ρ	-	Correlation coefficient
$\rho_{(nm)}$	-	The density of nano material
wt	-	Total mass of the solution
β	-	Shape parameter
$F(x)$	-	The probability of the AC breakdown voltage
M_a	-	Mass of nanoparticles
M_b	-	Mass of insulating oil
MF_a	-	The mass fraction of nanoparticles

N	-	The number of data
%	-	Percent

LIST OF ABBREVIATIONS

AC	-	Alternating Current
ASTM	-	American Society for Testing and Materials
BDV	-	Breakdown Voltage
BN	-	Boron Nitrade
CN	-	Conductive Nanoparticles
CPO	-	Crude Palm oil
IEC	-	International Electrotechnical Commission
IEEE	-	Institute of Electrical and Electronics Engineers
HV	-	High Voltage
IN	-	Insulating Nanoparticles
KFC	-	Karl Fischer Coulometer
LPG	-	Liquefied Petroleum Gas
MI	-	Mineral Insulation
MO	-	Mineral Oil
MR	-	Median Rank
NEI	-	Natural Ester Insulation
OECD	-	Organisation for Economic Co-operation and Development
OLTC	-	On-Load Tap Changers
PFAE	-	Palm Fatty Acid Ester

PKO	-	Palm Kernel Oil
RBPO	-	Refine Blenched Palm Oil
RBDPO	-	Refine Blenched Deodorized Palm Oil
SN	-	Semi-conductive Nanoparticles
VO	-	Vegetable Oil

LIST OF PUBLICATIONS

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