UNIVERSITI PUTRA MALAYSIA

AN EXAMINATION ON THE AGEING PERFORMANCE OF PALM OIL AND COCONUT OIL WITH CONSIDERATION ON THE PRESENCE OF INSULATION PAPER

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By

NUR AQILAH BINTI MOHAMAD

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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AN EXAMINATION ON THE AGEING PERFORMANCE OF PALM OIL AND COCONUT OIL WITH CONSIDERATION ON THE PRESENCE OF INSULATION PAPER

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Mineral Oil (MO) has been a major type of dielectric insulation fluid in transformers. However, due to the increasing tight regulations on safety and environment in recent years, a number of studies have been carried out to explore an alternative fluid for MO. Palm Oil (PO) and Coconut Oil (CO) have been introduced as a suitable candidate for transformers application. Before these oils can be applied in-service, several assessments such as ageing performance need to be carried out at laboratory level in order to determine the feasibility of these oils for practical application.

There are two sets of laboratory accelerated ageing experiments were carried out. The first part involved are the ageing of oil at 85 ºC and 115 ºC under open condition. The second part examined the ageing of oil with the presence of insulation paper and high moisture content at 90 ºC, 110 ºC and 130 ºC. The properties of three different variations of RBDPO and one sample of CO were measured and analysed through AC breakdown voltage, dielectric properties, physicochemical properties and tensile strength of paper. Finally, the degradation rates of paper aged in RBDPO and CO were analysed based on the Weidmann model.

Only resistivity of RBDPO and dielectric dissipation factor of CO show a clear reduction trends throughout the ageing duration while other electrical properties of these oils remain almost unaffected by the ageing under open condition. The effect of oxidation is not apparent on RBDPO and CO since the viscosities remain almost unchanged and the acidities remain low throughout the ageing duration. There are no clear trends of moisture that can be observed for both RBDPO and CO. Under sealed condition, the AC breakdown voltages and relative permittivities of RBDPO, CO and MO are not significantly affected by the ageing. There is no significant changes on the resistivities of CO and MO while for RBDPO, it decrease as the ageing progresses. Only the dielectric dissipation factor of CO shows a clear reduction trend. The acidities of RBDPO and CO remain at low level and within the range of MO. The moistures in RBDPO and CO reduce as the ageing progresses. The trends of moisture in paper for RBDPO and CO at different temperatures are the same as MO. With no significant on most of the electrical

properties, RBDPO and CO have a bright opportunity to be applied either in free breathing or hermetically sealed transformers. The reductions of Tensile Index (TI) of RBDPO and CO are not severe in MO and maintain at value higher than 50% retention of TI. Based on Weidmann model, the ageing rate of paper aged in RBDPO and CO could be 2.02 lower than MO. This property is one of the encouraging outcomes for RBDPO and CO especially on extending the operation life of transformers. An advantage is gain where the effect of oxidation on the RBDPO and CO can be minimized.

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

KAJIAN TENTANG PRESTASI PENUAAN TERHADAP MINYAK KELAPA SAWIT DAN MINYAK KELAPA DENGAN PERTIMBANGAN KEHADIRAN KERTAS PENEBAT

Oleh

NUR AQILAH BINTI MOHAMAD

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Minyak Mineral (MO) merupakan sejenis cecair penebat dieletrik yang utama di dalam alat ubah. Walau bagaimanapun, disebabkan oleh peningkatan peraturan yang ketat terhadap keselamatan dan alam sekitar, beberapa kajian telah dijalankan untuk mencari satu cecair alternatif sebagai pengganti MO. Minyak Kelapa Sawit (PO) dan Minyak Kelapa (CO) telah diperkenalkan sebagai minyak yang sesuai untuk aplikasi alat ubah. Beberapa kajian perlu dijalankan sebelum minyak ini dapat digunakan dalam perkhidmatan, contohnya kajian terhadap prestasi penuaan yang dijalankan di makmal untuk mengetahui keupayaan minyak ini secara praktikal.

Terdapat dua eksperimen penuaan telah dijalankan. Bahagian pertama melibatkan penuaan minyak pada suhu 85 °C dan 105 °C dalam keadaan terbuka. Bahagian kedua melibatkan kajian penuaan minyak dengan kehadiran kertas penebat dan kandungan kelembapan yang tinggi pada suhu 90 °C, 110 °C dan 130 °C. Tiga jenis RBDPO dan satu sampel CO telah dikaji dalam kajian ini. Sifat-sifat RBDPO dan CO diuji dan dianalsis melalui AC pecahan voltan, ciri-ciri dielektrik, sifat-sifat fizik kima. Akhir sekali, kadar degradasi penuaan kertas dalam RBDPO dan CO telah dianalisis berdasarkan model Weidmann.

Dalam keadaan terbuka, RBDPO dan CO menunjukkan kadar penurunan pada kerintangan dan faktor pelesapan dielektrik, manakala tiada perubahan ditunjukkan oleh sifat-sifat elektrik yang lain. Kesan pengoksidaan tidak jelas terhadap RBDPO dan CO. Hal ini kerana, tiada perubahan pada kelikatan RBDPO dan CO dan keasidan kekal rendah sepanjang tempoh penuaan. Kelembapan RBDPO dan CO tidak menunjukkan kadar yang jelas. Dalam keadaan tertutup, AC pecahan voltan dan ketelusan relatif RBDPO dan CO tidak terjejas oleh penuaan dan corak yang sama terdapat pada MO. Tiada perubahan yang besar ke atas kerintangan CO dan MO. Akan tetapi, kerintangan RBDPO menurun selepas penuaan. Hanya faktor pelesapan dielektrik CO menunjukkan kadar penurunan yang jelas. Keasidan RBDPO dan CO kekal pada tahap yang rendah dan berada dalam julat MO di akhir tempoh penuaan. Dengan tiada kesan terhadap sifat-sifat elektrik, RBDPO dan CO mempunyai peluang

yang cerah untuk digunakan sebagai alat ubah terbuka ataupun tertutup. Selepas penuaan, kelembapan dalam RBDPO dan CO berkurang. Pada suhu yang berbeza, kadar kelembapan dalam kertas penebat untuk RBDPO dan CO adalah sama seperti MO. Penurunan TI kertas untuk RBDPO dan CO tidak teruk berbanding MO dan kekal pada nilai lebih tinggi 50% daripada nilai asal TI. Berdasarkan model Weidmann, didapati kadar penuaan kertas dalam RBDPO dan CO lebih rendah 2.02 daripada MO. Sifat ini membuatkan RBDPO dan CO boleh memanjangkan jangka hayat alat ubah disamping kesan oksidasi terhadap RBDPO dan CO boleh dikurangkan.

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I certify that a Thesis Examination Committee has met on 29 January 2016 to conduct the final examination of Nur Aqilah binti Mohamad on her thesis entitled "An Examination on the Ageing Performance of Palm Oil and Coconut Oil with Consideration on the Presence of Insulation Paper" 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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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

^{o}C	Degree Celsius
Ω/m	Resistivity per meter
µm	Micro meter
A/m^2	Amperes per square meter
AC	Alternating Current
ASTM	American Society for Testing and Materials
BS EN	British Standard European Norm
C	Carbon
C-C	Carbon to Carbon
CO	Coconut Oil
CPO	Crude Palm Oil
cSt	Centistokes
DGA	Dissolved Gas Analysis
DP	Degree of Polymerization
g/ml	Gram per Milliliter
GC	Gas Chromatography
HCO	Hydrogenated Coconut Oil
Hz	Hertz
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standards Organization
KF	Karl Fischer
kJ/mole	Kilo Joule per Mole
kN/m	Kilo Newton per Meter
kP	Kilo Pascal
kV	Kilo Voltage
LCO	Liquid Coconut Oil
mm	Millimetre
MO	Mineral Oil
MPOB	Malaysia Palm Oil Berhad
M-U.S fat	Mono-unsaturated fat
PFAE	Palm Fatty Acid Ester
PH	Power of Hydrogen
PKO	Palm Kernel Oil
PKOAE	Palm Kernel Alkyl Ester
PO	Palm Oil
ppm	Part per Million
PTFE	Polytetrafluoroethylene
P-U.S fat	Poly-unsaturated fat
RBDCO	Refined, Bleached and Deodorized Coconut Oil
RBDPO	Refined, Bleached, Deodorized Palm Oil
RCO	Refined Coconut Oil
S. fat	Saturated fat
SVM	Stabinger Viscometer
TS	Tensile strength
TI	Tensile Index
UV	Ultraviolet
UTM	Universal Testing Machine

V/m	Volt per meter
V.A	Vitamin A
V.E	Vitamin E
VCO	Virgin Coconut Oil
VDE	Verband der Elektrotechnik

CHAPTER 1

INTRODUCTION

1.1 Background

Oil and paper insulations are among the important parts in transformers. Failure in these materials might cause different types of faults such as electrical breakdown, short circuit, overheating and arcing which in turn lead to transformers damage [1]. The main function of the oil is to act as a cooling medium by absorbing the heat from the winding and core and transmit it to the outer surface of transformers [2]. Besides that, it is used to act as an electrical insulation at different electrical potentials by penetrating and filling the spaces between the insulation paper layers [3]. Meanwhile, paper is used to protect the winding section, turn and lead of transformers against electrical breakdown and short circuit.

Mineral Oil (MO) is known as the common dielectric insulation fluids used in transformers and it has been proven to be effectively used in-service for many years. MO has excellent dielectric and good cooling properties [4]. Despite the excellent performance of MO, it is non-biodegradable and could potentially contaminate the soil/waterways if serious spillages take place which trigger the research on examining the potential alternative of this oil [5, 6].

In recent years, vegetable based oils have been identified as potential candidates for application in transformers. Vegetable oils are biodegradable, non-toxic and have high fire/flash points that ensure more safety in-service [7-9]. There are a significant number of studies that have been carried out to investigate the performances of vegetable oils by looking into its basic properties, ageing behaviours under different conditions, electrical properties which included the AC/lightning breakdowns under different conditions as well as its mechanisms and its in-service capabilities [7-17].

Among the types of vegetable oils considered as a dielectric insulation fluids, are Palm Oil (PO) and Coconut Oil (CO). PO and CO are among the highest produced vegetable oils in Asian countries. The largest production of PO in Asian countries is dominated by Indonesia with 51%, followed by Malaysia with 42% and others with 7% [18, 19]. For CO, the largest production is dominated by Indonesia with 51%, Philippines with 37%, Sri Lanka with 4.92%, Thailand with 3.26%, Vietnam with 2.57% and Malaysia with 0.01% [19-21]. PO and CO are also been identified as among the sustainable vegetable oils in the market [20].

Several tests have been carried out to examine the suitabilities of PO and CO as dielectric insulation fluids in transformers. Currently, most of the studies on PO and CO mainly focus on their basic properties which cover on various parameters including

electrical properties, physicochemical properties and lightning breakdown performances [10, 16, 17, 22-28]. There are still remain several characteristics of PO and CO that need to be investigated and one of them is the thermal ageing studies.

Thermal ageing is known as one of the important aspects in studies on transformers. This is due to the fact that transformers are subjected to ageing while in-service which can be accelerated by the heat, loading and environmental factors such as moisture, temperature and oxygen [29]. Ageing of transformers could also lead to the generation different types by-products such as moistures, acids, gases and furanic compounds. Some of these by-products such as moistures and acids could in turn degrade the lifetime of insulation fluids and papers and affect the overall performances and reliabilities of transformers [30].

1.2 Problem statement

MO has been used as dielectric insulation fluids in power transformers for decades. MO is preferred due to excellent dielectric properties and cooling medium. However, it is known that the existence of MO in the world has been depleted and probably it will not occupy our needs in future. Besides that, MO is non-biodegradable oil and could potentially contaminate the soil/waterways if serious spillages take place. Alternate sources for insulating fluid are being considered to overcome the sustainable and environmental issues. Vegetable oils such Refined, Bleached and Deodorized Palm Oil (RBDPO) and CO offer suitable alternatives for MO. It is biodegradable, non-toxic, has high fire/flash points which ensure more safety in service and environmental friendly. There are however several aspects that need be addressed before these new vegetable oils qualify to be used as dielectric insulation fluids in-service.

1. It is anticipated that most of the un-aged oil could satisfy the minimum requirement for dielectric insulation fluids in transformers.
2. However, since transformers in-service could be subjected to heat and multiple environmental parameter, the oil could be subjected to ageing. The chemical properties of the oil may change and its performances could be affected by the presence of ageing by-products such as moisture and acids.
3. Without proper mitigation, this could lead to failure which could be costly. Therefore, considering the application of new dielectric insulation fluids such as vegetable oils in transformers, it is crucial to first examine its ageing performances at laboratory level.
4. There are several known issues with some of the types of the vegetable oils and one of them is the poor ageing performances in presence of air.
5. One of the practical solutions for this issue is to use these types of vegetable oils in hermetically sealed transformers. Among the solutions would be involved with modification of the conventional free breathing transformers which is traditionally filled with MO.
6. Regardless of this issue, some of the types of vegetable oils are proven could slow the ageing rate of the paper through its hydrolytic and water scavenging mechanisms. This finding provides a needed advantage for promoting application of vegetable oils in transformers. Nevertheless, there are still a few aspects in this area that need further investigation such as the ageing

performances of vegetable oils and paper in the presence of high moisture content.

7. Most of the types of vegetable oils that have been examined previously have different chemical structures than RBDPO and CO. Considering these factors and the lack of knowledge in this area for RBDPO and CO, a study is needed to examine its ageing performance under different conditions.

1.3 Research aim and objectives

The aim of this research is to examine the ageing performances of RBDPO and CO under open and sealed conditions with consideration on the presence of insulation paper. In order to achieve the aim of this research, several objectives have been identified as follows:

1. To examine the effect of ageing under open condition on the electrical and physicochemical properties of RBDPO and CO.
2. To evaluate the properties of RBDPO and CO in the presence of insulation paper under sealed ageing condition and high moisture content.
3. To assess the degradation of insulation paper aged in RBDPO and CO based on tensile strength measurement and analyse its ageing rate.

1.4 Scope of work

The scope and limitations of this research work are as follows:

1. This research considers the electrical and physicochemical properties of RBDPO, CO and MO with and without insulation paper under accelerated thermal ageing at various ageing time periods.
2. This research focuses on the tensile strength/tensile index of insulation paper under RBDPO, CO and MO after being subjected to thermal ageing.
3. This research evaluates the performances of the ageing properties using the kinetic degradation model of insulation paper impregnated in RBDPO, CO and MO.

1.5 Contributions of the research

1. The knowledge on the characteristics of RBDPO and CO under open and sealed ageing conditions can be used for manufacturers to decide whether to design either free breathing or hermetically sealed transformers for application of these oils.
2. The physicochemical properties of RBDPO and CO, especially on viscosity and acidity, can be used to determine whether the RBDPO and CO should be added with an oxidation inhibitor before it can be applied as dielectric insulation fluids in transformers.

3. The knowledge on the strength of the paper aged in RBDPO and CO and its ageing rate can be used for assessment of the life and condition of transformers filled with these oils in the future.

1.6 Thesis outline

This thesis consists of five chapters, which cover the introduction, literature review, methodology, results and discussion and finally conclusions and recommendations for future work.

Chapter 1 Introduction
This chapter describes introduction of this research along with the problem statement, research aim and objectives, scope of work, limitation and contributions of the study.

Chapter 2 Literature review
This chapter discusses various aspects on the ageing of insulators used in transformers. The latest knowledge on ageing mechanisms, ageing accelerators and ageing by-products are summarised in order to access the ageing conditions of insulation in transformers. Besides that, the previous ageing studies were also discussed in this chapter.

Chapter 3 Methodology
This chapter presents the procedure of ageing materials. It describes the pre-processing materials and the detailed procedures of ageing. Electrical and physicochemical measurements of insulation fluids are discussed, together with the measurements for the tensile strength of insulation paper.

Chapter 4 Results and Discussion
This chapter discusses the final results of the research. This includes the ageing assessment of RBDPO and CO based on their electrical and physicochemical properties. This chapter also discusses the ageing assessment of insulation paper under RBDPO and CO based on moisture and tensile strength.

Chapter 5 Conclusion and Recommendations
This chapter summarizes and concludes this research. At the end of this chapter, recommendations for future work on ageing assessment of the RBDPO and CO filled transformers are given.

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