UNIVERSITI PUTRA MALAYSIA

AC BREAKDOWN VOLTAGE PERFORMANCE OF REFINED, BLEACHED AND DEODORIZED PALM OIL AND MINERAL OIL IN THE PRESENCE OF MULTIPLE CONTAMINATIONS

MUHAMMAD SAFWAN BIN SHUKRI

ITMA 2021 12

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By

MUHAMMAD SAFWAN BIN SHUKRI

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

June 2021

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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June 2021

Chair : Norhafiz Azis, PhD
Institute : Advanced Technology

Refined Bleach and Deodorized Palm Oil (RBDPO) is one of the alternatives considered for Mineral Oil (MO) for possible application in transformers. It is biodegradable, environmentally friendly and non-toxic. In addition, the electrical performances of dried and filtered RBDPO is comparable with MO. Currently, there is only few studies that have been carried out to examine the effect of individual contaminants i.e. moisture, copper and cellulose particles on the AC breakdown voltage of RBDPO under separate experimental works. Systematic comparison of the individual contaminants under the same experimental setup is quite important to obtain overall overview of the effects on the AC breakdown voltage of RBDPO. Furthermore, there is no study that has been carried out to examine the combined contaminants impact on the AC breakdown voltage of either MO and RBDPO.

This study aims to examine the effect of individual and combined contaminants i.e. moisture, copper and cellulose particles on the AC breakdown voltages of RBDPO. MO was also examined on this study for comparison purpose. The first study examined the effect individual contaminant on the AC breakdown voltage of RBDPO and MO. The particles to oils weight ratios were set to various weight. Next, the AC breakdown voltage of RBDPO and MO were investigated in the presence of combined contaminants. The total particles to oils weight ratios were set at various weight and at different levels of moisture. Finally, statistical analyses utilizing normal, Weibull and lognormal distribution functions were carried out to evaluate the AC breakdown voltage performances of RBDPO and MO under the influence of either individual and combined contaminants.

It is found that moisture has significant impact on the AC breakdown voltage of RBDPO and MO. The AC breakdown voltage of RBDPO experiences significant reduction at higher level of moisture as compared to MO. Under low moisture content,

the sudden reductions on AC breakdown voltage patterns for both RBDPO and MO in the presence of copper particles are quite similar. Meanwhile, the AC breakdown voltage reduction of RBDPO occurs at higher number of cellulose particles as compared to MO. On the contrary, the increment of number of cellulose particles could lead to the AC breakdown voltage increments of RBDPO and MO at medium and high moisture levels. The presence of higher weight ratio of copper is more dominant as compared to cellulose particles on the reduction of AC breakdown voltages for both RBDPO and MO. Based on the Anderson-Darling test, Weibull distribution has been found to be the suitable to represent most of the data on this study. Hence, the prediction on the AC breakdown voltages for RBDPO and MO has been developed. The estimated AC breakdown voltage based on Weibull equation is mostly has percentage difference of less than 5% as compare to the measured AC breakdown voltage for RBDPO and MO whereby the highest percentage difference is 20.83%.

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

PRESTASI PECAHAN VOLTAN AC TERHADAP MINYAK KELAPA SAWIT YANG DIHAPUS, DIPUTIHKAN DAN MENGHILANGKAN BAU DAN MINYAK MINERAL DENGAN KEHADIRAN PELBAGAI KONTAMINASI

Oleh

MUHAMMAD SAFWAN BIN SHUKRI

Jun 2021

Pengerusi : Norhafiz Azis, PhD
Institut : Teknologi Maju

Minyak Kelapa Sawit yang Dihapus, Diputihkan dan Menghilangkan Bau (RBDPO) adalah salah satu alternatif kepada Minyak Mineral (MO) yang boleh dipertimbangkan untuk kemungkinan aplikasi dalam alat ubah atau "transformer". Ia boleh terbiodegradasi, mesra alam dan tidak beracun. Di samping itu, prestasi elektrik RBDPO yang telah melalului proses pengeringan dan tapisan adalah setanding dengan MO. Pada masa ini, hanya ada beberapa kajian yang telah dilakukan untuk mengkaji kesan kontaminasi individu seperti kelembapan, zarah tembaga dan zarah selulosa terhadap pecahan voltan AC bagi RBDPO yang dilakukan dalam kerja eksperiman yang berasingan. Perbandingan yang sistematik bagi setiap kontaminasi di dalam satu kerja eksperimen yang sama adalah sangat penting untuk mendapatkan gambaran keseluruhan kesan pada pecahan voltan AC bagi RBDPO. Tambahan pula, tidak ada kajian yang dilakukan untuk memeriksa kesan gabungan beberapa kontaminasi pada pecahan voltan AC sama ada pada MO atau RBDPO.

Kajian ini bertujuan untuk mengkaji kesan kontaminasi individu dan gabungan bebrapa kontaminasi iaitu terdiri daripada kelembapan, zarah tembaga dan zarah selulosa pada pecahan voltan AC bagi RBDPO. MO juga diperiksa dalam kajian ini untuk tujuan perbandingan. Kajian pertama adalah mengkaji kesan kontaminasi individu terhadap pecahan voltan AC bagi RBDPO dan MO. Nisbah berat zarah terhadap minyak masing-masing ditetapkan kepada beberapa kategori berat. Seterusnya, kesan pecahan voltan AC bagi RBDPO dan MO disiasat dengan kehadiran gabungan beberapa kontaminasi. Nisbah penuh berat zarah terhadap minyak ditetapkan kepada beberapa berat pada tahap kelembapan yang berbeza. Akhir sekali, analisis statistik menggunakan fungsi taburan normal, Weibull dan lognormal dijalankan untuk menilai prestasi pecahan voltag AC bagi RBDPO dan MO di bawah kehadiran kontaminasi individu dan gabungan beberapa kontaminasi.

Hasil kajian mendapati bahawa kelembapan mempunyai kesan yang signifikan terhadap pecahan voltan AC bagi RBDPO dan MO. Pecahan voltan AC bagi RBDPO mengalami penurunan yang ketara pada tahap kelembapan yang tinggi berbanding dengan MO. Di bawah kandungan lembapan yang rendah, corak pecahan voltan AC bagi RBDPO dan MO di bawah kehadiran zarah tembaga agak serupa. Sementara itu, pengurangan pecahan voltan AC bagi RBDPO berlaku pada bilangan zarah selulosa yang tinggi berbanding dengan MO. Sebaliknya, kenaikan bilangan zarah selulosa boleh menyebabkan kenaikan pecahan voltan AC bagi RBDPO dan MO pada tahap kelembapan sederhana dan tinggi. Kehadiran nisbah berat tembaga yang lebih tinggi lebih dominan berbanding dengan zarah selulosa dalam mempengaruhi pengurangan pecahan voltan AC untuk kedua-dua RBDPO dan MO. Berdasarkan ujian Anderson-Darling, staburan Weibull didapati sesuai untuk mewakili sebahagian besar data kajian ini. Oleh itu, ramalan pecahan voltan AC bagi RBDPO dan MO telah dilakukan. Anggaran pecahan voltan AC berdasarkan persamaan Weibull mempunyai majoriti peratusan yang kurang daripada 5% berbanding pecahan voltan AC yang diukur untuk RBDPO dan MO di mana perbezaan peratusan tertinggi adalah 20.83%.

ACKNOWLEDGEMENTS

Alhamdulillah, thanks to Allah S.W.T, for giving me strength and ability to complete my Master study.

First and foremost, I would like to express my deep and sincere gratitude to my supervisor, Assoc. Prof. Dr. Norhafiz Aziz for all of his aspiring and guidance in helping me throughout finishing my study. Without his assistance and dedicated involvement in every step throughout the process, this study would have never been accomplished. I would also want to express my grateful to my co-supervisors Assoc, Prof Dr. Jasronita Jasni and Prof. Dr Robiah Yunus for their advice and encouragement along the way of my study.

Most importantly, I cannot thank you enough to who in one way or another contributed in the completion of my study especially to my senior Dr. Nur Aqilah and to all members from the Advanced Lightning, Power and Energy Research Center (ALPER) and Institute of Advanced Technology (ITMA).

Not to forget my grateful appreciation to the university that has provided me with such facilities and services. The assistance and convenience given have been very helpful in order for me to complete my study.

Lastly, I owe my loving thanks to my parent and my siblings for their support. Without their encouragement and understanding, it would have been hard for me to finish my study.

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:

Norhafiz bin Azis, PhD
Associate Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Jasronita binti Jasni, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Robiah binti Yunus, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 October 2021

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This is to confirm that:

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Signature:	______________________
Name of Chairman of Supervisory Committee:	Assoc. Prof. Ir. Dr. Norhafiz Azis

Signature:	______________________
Name of Member of Supervisory Committee:	Assoc. Prof. Dr. Jasronita Jasni

Signature:	______________________
Name of Member of Supervisory Committee:	Prof. Dr. Robiah Yunus

TABLE OF CONTENTS

LIST OF TABLES

voltage of MO at low moisture levels based on Weibull distribution

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternating Current
AD	Anderson-Darling
ASTM	American Society for Testing and Materials
ATR	Attenuated Total Reflection
C	Carbon
CDF	Cumulative Distribution Function
CIGRE	International Council on Large Electric Systems
cm-1	Centimetre power–1
CPO	Crude Palm Oil
cSt	Centistokes
DC	Direct Current
FTIR	Fourier-transform Infrared Spectroscopy
g	Gram
g/ml	Gram per Mililiter
IEC	International Electro-technical Comission
kV	Kilo Voltage
mg KOH/g	Miligrams of Potassium Hydroxide per Gram
ml	Mililiter
mm	Millimeter
mN/m	Mili Newton per Meter
MO	Mineral Oil
MPOB	Malaysia Palm Oil Berhad
NE	Natural Ester
OH	Hydroxide

PFAE	Palm Fatty Acid Ester
PKO	Palm Kernel Oil
PO	Palm Oil
ppm	Part per Million
RBDPO	Refined, Bleached and Deodorized Palm Oil
SE	Synthetic Ester
VDE	Verband der Elektrotechnik
VO	Vegetable Oil
μm	Micro meter
˚C	Degree Celsius

CHAPTER 1

INTRODUCTION

1.1 Background

Among the main insulation materials in transformers is Mineral oil (MO). It has an excellent electrical insulation and cooling properties and it acts as an information carrier to determine the condition of transformers [1]. It has been extensively used for decades due to its good performance on providing the necessary insulation to transformers [2-3].

However, MO has several issues related to the low fire/flash points and moisture tolerance [4-6]. It has poor biodegradability and it could cause contamination issues if serious spills occur in the soils and waterways [2]. In addition, MO is non-renewable source [3]. Recently, the interests on environmental considerations in electrical industries are increasing which prompt for serious efforts to seek the alternatives for MO.

Several types of Vegetable Oil (VO), for examples, sunflower oil, rapeseed oil, coconut oil and palm oil have been identified as viable alternatives for MO whereby extensive laboratories experimental works and in-services testing have been carried out [7]. Those VO are biodegradable, non-toxic and have higher flash points compared to MO which ensure safety in transformer [8-9].

Among many types of VO, Palm Oil (PO) have been considered as alternative of MO for dielectric insulating liquid application [10]. Different types of POs which can be categorized into two main groups which are Crude Palm Oil (CPO) and Palm Kernel Oil (PKO) have been investigated of which promising results have been obtained [11]. Refined, Bleached and Deodorized Palm Oil (RBDPO) which is the product of further refining process of CPO has been established as one of the promising POs which can used as dielectric insulating oil in transformers [12]. RBDPO is environmental friendly and has high fire safety as compared to the MO [13-14]. It is widely available in Malaysia and its characteristics i.e. biodegradability and non-toxicity are similar to other types of VO [3].

Several researches have been carried out to study the suitability of RBDPO as alternative dielectric insulation oils in transformer. Most of the study cover on electrical properties, physiochemical properties and breakdown voltage performance [14-20]. There are other characteristics of RBDPO that need to be examined including the effect of particle contaminant on the AC breakdown voltage of RBDPO.

The contamination can be in types of moisture, metallic particles (copper, iron, etc) and non-metallic particles (cellulose). The presence of those contamination on insulation oil in transformers can affect the performance of dielectric strength of the insulation oil.

The presence of moisture on insulation oil could weaken the dielectric strength of the insulation oil since moisture which is water have low resistivity [21-22]. Since the nature of VO such as RBDPO is more hydrophilic than MO, the water saturation level of the VO is higher than MO [23-24]. Hence the effect of different moisture levels on dielectric strength can be further examined for RBDPO and compared with MO.

The presence of metallic particle on insulation oil is well known to weaken the dielectric strength of insulation oil since the metallic particle is conducting material which can increase the chance for the breakdown to occur in the transformers [25 -26]. While, the presence of non-metallic particles found in transformers which is cellulose also can affect the performance of dielectric strength of insulation oil. Cellulose particles mainly come from the insulation paper used in transformers. Generally, as the insulation oil is stressed under electric field, the cellulose particles are polarised and causes the formation of cellulose chain bridge which lead breakdown in transformers [27]. On the contrary, the presence of cellulose particles in insulation oil may help to absorb the moisture content on the insulation oil [28] and hence improve the performance of dielectric strength of insulation oil.

Therefore, a study is proposed to examine the effects of contaminants i.e. moisture, copper and cellulose particles on RBDPO and MO. In addition, the combined effect of the contaminants is investigated and analyzed through statistical analyses.

1.2 Problem statement

For decades, MO has been used as one of the main insulations in transformers owing to its good electrical and physiochemical properties. However, MO has several environmental, biodegradability and safety issues. The spillage of MO can contaminate the waterways and can caused harm to the ecosystem. Hence, VO has been proposed as possible alternative in order to address the stated issues.

Different types of VOs have been examined and tested at either laboratory levels or in-service for the past few years. One of the VOs that has been considered for application in transformers is PO. It is biodegradable, non-toxic and have higher flash point as compared with MO. PO has slight differences in term of AC breakdown performances as compared to MO contributed mainly due to variability of the chemical and physiochemical properties.

One the main issues in the transformers is the contaminations which could affect the AC breakdown voltage performances of dielectric insulating oils. Several works have been carried out to examine the impact of contaminants on MOs [21-22]. A few studies have also been carried out to investigate similar effect on VOs [22-28].

However, all previous studies focus mainly on the individual effects of contaminations on either PO or MO under separate experimental works. Currently, there is no study that has been carried out to examine the effect of individual contaminants on the AC breakdown voltages of PO and MO in one particular study. The knowledge and information of the effect of individual contaminants on the AC breakdown voltages of PO and MO in one particular study can help other researcher on their study to investigate the suitability of PO as one of the insulating fluids for transformer.

It is known that the contaminants i.e. moisture, copper and cellulose could co-exist together in the in-service oils. Currently, there is no study to examine the effect of combined contaminations on the AC breakdown voltage of either MO or PO in order to further improve the condition interpretation of transformers filled with these oils. The examination of the effect of combined combinations to the AC breakdown voltage of MO and PO can be beneficial to other researcher or manufacturer to understand better how the insulating oils behave under different level of contaminations.

Prediction on the AC breakdown performance is quite crucial to estimate the AC breakdown performance of the MO and PO. The in-service AC breakdown data normally does not correlate well with either the measured moisture or particles due to the co-existence of these contaminants. Hence, a prediction of the AC breakdown voltage is required to estimate and understand the condition of the dielectric insulating oils in order to improve the assessment of transformer's condition.

1.3 Research aim and objectives

The aim of this research is to investigate the performance of AC breakdown voltage of RBDPO and MO under the influence of combined contaminants which are moisture, copper and cellulose. In order to achieve the aim of this research, several objectives have been identified as follows:

1. To investigate the effect of moisture, copper and cellulose particles separately on the AC breakdown voltages of RBDPO and MO.
2. To examine the AC breakdown voltage of RBDPO and MO under different levels of combinations of contaminations.
3. To evaluate and predict the AC breakdown strength performances of RBDPO and MO under the influence of contaminations based on statistical approaches.

1.4 Scope of work

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

1. This research considers 3 types of well-known contaminants in transformers known as moisture, copper and cellulose.
2. This research focuses on the AC breakdown voltage under quasi-uniform field based on 1 mm electrode gaps of VDE electrodes as per ASTM D1816.
3. This research only uses commercial Refined, Bleached and Deodorized (RBDPO) Olein and Mineral Oil.

1.5 Contributions of the research

1. The knowledge of the AC breakdown strength of RBDPO and MO under the influence of combination of moisture, copper and cellulose can be useful for interpretation of condition assessment based on AC breakdown voltage of in-service MO filled transformers as failure preventive approach.
2. The statistical prediction of AC breakdown voltages for RBDPO and MO under the influence of moisture, copper and cellulose particles combinations can be useful for manufacturers to consider during the design and manufacturing processes of transformers as well as for estimation of condition of transformer's condition.

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 describes the background of this research, problem statement, research aim and objectives, scope of work and contributions of the research.

Chapter 2 discusses the background of insulation oil of transformers. Next, this chapter also discussed the AC breakdown theories on insulation oils and the influence of contamination on the performance of AC breakdown voltage of insulation oils.

Chapter 3 presents the procedure of pre-processing of RBDPO and MO. This chapter also describes the pre-processing of particles used on this study which are copper and cellulose powders. The measurement procedures of AC breakdown voltage, moisture, particle, FTIR and statistical analysis are also discussed in this chapter.
Chapter 4 discusses the final results and analysis of the research. In this chapter, in-depth analyses based on AC breakdown voltage data, FTIR and statistical calculation are presented. Prediction of the AC breakdown voltage under different scenarios are developed based on the statistical analyses.

Chapter 5 summarizes and concludes this research. At the end of this chapter, recommendations for future work on the RBDPO and MO under the influence of moisture, copper and cellulose are described.

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