‘’I hereby declare that I have read through this report entitled “Influence of Aluminium and Copper on Thermal Ageing of Synthetic Ester Oil (Midel 7131)” and found that it has complied the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

Signature :………………………………...

Supervisor’s Name :………………………………..

Date :………………………………..

INFLUENCE OF ALUMINIUM AND COPPER ON THERMAL AGEING OF SYNTHETIC ESTER OIL (MIDEL 7131)

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A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

I declare that this report entitled "Influence of Aluminium and Copper on Thermal Ageing of Synthetic Ester Oil (Midel 7131)" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in the candidate of any other degree.

Signature :…………………………………

Name :…………………………………

Date :…………………………………

DEDICATION

To my late beloved father ABDUL RAZAK BIN MOHAMED (1959-2015)
May Allah place you amongst the righteous men

To my lovely mother A'ABDAH BTE JAAFAR
May Allah grant you patience and serenity

Relatives and Siblings

Classmates and Friends

ACKNOWLEDGEMENT

In the name of Allah S.W.T, the most gracious and merciful, praise to Allah the lord of universe and may blessing and peace of Allah be upon his messenger Muhammad S.A.W. First of all, I would like to thank Allah for granting me the courage and health for the completion of this project report.

I would like to thank my supervisor Dr Hidayat Bin Zainuddin who taught me how to become a researcher. His professional behaviour and excellent guidance in this project makes all the difficulties an easy one

I have spent 3 months of my final year project in high voltage lab in the Faculty of Electrical Engineering (FKE) at Technical University of Malaysia Melaka (UTeM). I would also like to thank Mr Wahyudi for giving me the permission to use the high voltage lab.

During these 23 years of being a student, I have had many teachers who worked hard to educate me. I am aware of the great influence they have had on my life. I say thanks to all my teachers.

Being far from my family for nearly 6 years, I can understand better how precious they are. I believed my parents did a magnificent job on educating their kids even though they had very little resources available. Thanks to my late father and my mother for their parental advice.

ABSTRACT

Insulating oil in power transformer is subjected to the degradation because of the ageing, high temperature and chemical reactions such as oxidation. Thermal ageing of transformer oil is due to the degradation of insulating paper which contributes the moisture content in the oil thus lowering the dielectric strength of the insulating oil. While, copper is widely used in transformer winding due to its better conductivity compared to aluminium, comparisons between both conductors in thermal ageing is still fairly unclear. Hence, the aim of this project is to investigate the level of breakdown voltage and compare the level of moisture content between transformer oil that is thermally aged with copper and aluminium. In this project, the influence of aluminium and copper in transformer oil is investigated under accelerated thermal stress. The methods in this project are based on past researches on how to aged transformer oil. The approach is by conducting thermal ageing under different temperature. The data obtained is analysed and compared which consists of the average breakdown voltage and moisture content of each sample. The results reduction in breakdown voltage and moisture content are proportional to the temperature. It appears that samples with aluminium powder has a slightly lower breakdown voltage and a higher moisture content rather than the samples with copper powder. For future work, it is better to acquire an alloyed alumnium 6101 which is better than pure aluminium.

ABSTRAK

Minyak penebat dalam transformer tertakluk kepada kemerosotan minyak kerana penuaan, suhu yang tinggi dan tindak balas kimia seperti pengoksidaan. Penuaan haba minyak transformer adalah disebabkan oleh kemerosotan kertas penebat yang menyumbang kepada kandungan kelembapan dalam minyak seterusnya mengurangkan kekuatan dielektrik minyak penebat. Walaupun tembaga digunakan secara meluas dalam lilitan transformer kerana pengaliran yang lebih baik berbanding aluminium, perbandingan antara kedua-dua konduktor dalam penuaan haba masih agak tidak jelas. Oleh itu, tujuan projek ini adalah untuk mengkaji tahap voltan kerosakan dan membandingkan tahap kandungan kelembapan antara minyak transformer yang dituakan dengan haba dengan kehadiran tembaga dan aluminium. Dalam projek ini, pengaruh aluminium dan tembaga dalam minyak transformer dikaji di bawah tekanan haba yang dipercepatkan. Kaedah-kaedah dalam projek ini adalah berdasarkan kajian lepas tentang bagaimana untuk menuakan minyak transformer. Pendekatan ini adalah dengan melakukan penuaan haba pada suhu yang berbeza. Data yang diperolehi dianalisa dan dibandingkan antara purata voltan kerosakan dan kelembapan kandungan bagi setiap sampel. Pengurangan nilai dalam voltan kerosakan dan kandungan lembapan adalah berkadar terus dengan suhu. Ternyata bahawa sampel dengan serbuk aluminium mempunyai kerosakan voltan yang rendah dan kandungan lembapan yang lebih tinggi berbanding sampel dengan serbuk tembaga. Untuk kerja-kerja masa depan, ia adalah lebih baik untuk memperoleh aluminium aloi 6101 yang lebih baik daripada aluminium tulen yang telah digunakan dalam kajian ini.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

Ppm	-	Parts Per Million
°C	-	Degree Celsius
IACS	-	International Annealed Copper Standard
DGA	-	Dissolved Gas Analysis
PCB	-	Polychlorinated Biphenyl
NN	-	Neutralization Number
IFT	-	Interfacial Tension
OQIN	-	Oil Quality Index
IEC	-	International Electrotechnical Commission
PSM	-	Projek Sarjana Muda

CHAPTER 1

INTRODUCTION

1.1 Oil-Filled Transformer

Transformer oil or insulating oil is steady at high temperatures and has phenomenal electrical properties. It is utilized as a part of oil-filled transformers. Its capacities are to protect, suppress corona and arcing, and to serve as coolant. To enhance cooling of substantial power transformers, the oil-filled tank might have external radiators through which the oil circulates by regular convection. Transformer oils are liable to electrical and mechanical stress while a transformer is in operation. In addition, there are contaminations caused by chemical interactions with the windings and other insulation, catalysed by high operating temperature. The synthetic properties of transformer oil changes gradually over a period of time, rendering it ineffectively for its purpose. The oil in large transformers is tested for its electrical and chemical properties periodically to ensure whether it is suitable to be used. In some condition the oil can be improved by filtration and treatment.

The tests for insulating oil include dissolved gas analysis (DGA), Furan analysis, and Polychlorinated Biphenyl analysis (PCB). There are also general electrical and physical tests such as colour and appearance, breakdown voltage, water content, acidity or neutralisation number (NN), dissipation factor, resistivity, sediments and sludge, flash point, pour point, and interfacial tension (IFT). Some transformer oil tests can be carried out in the field, using portable test apparatus. Other test, such as dissolved gas, normally requires a sample to be sent to a laboratory. In addition, there are ways to determine the condition of the oil just by observation. Therefore, quality index system is one of the ways to observe the oil characteristics and is the division of interfacial tension (IFT) by neutralisation number (NN) that provides a value that is useful to evaluate the oil condition. To calculate the Oil Quality Index (OQIN):

$$\text{OQIN} = \frac{IFT}{NN} \quad (1.1)$$

$$1500 \quad = \frac{45.0\ (typical\ new\ oil)}{0.03\ (typical\ new\ oil)} \quad (1.2)$$

Cooling, insulation, protection against chemical attacks, and preventing sludge build up are all functions of insulating oil. From Table1.1 it shows the first category which is good and perfect for transformer operation. The second category Proposition A provides the function, however a drop in IFT may signal the formation of sludge in solution. The third category, Marginal Oils is not providing proper cooling and winding protection. Organic acids are beginning to coat winding insulation; sludge in insulation voids is highly probable. The categories 4 to 6 Bad Oils, sludge has already been deposited in and on transformer parts in almost 100% of these units which leads to insulation damage, reduced cooling efficiency and high operating temperatures. The last category which is Disastrous Condition, the concern should be how much life remains in the transformer. Once the colour changes from yellow to amber's brown, the oil has degraded to the point where the insulation system has been affected.

Table 1.1: Transformer Oil Classification [1]

No	Oil Condition	Neutralisation Number (NN)	Interfacial Tension (IFT)	Colour	Oil Quality Index (OQIN)
1	Good Oil	0.00–0.10	30.0–45.0	Pale Yellow	300-1500
2	Proposition A Oils	0.05-0.10	27.1-29.9	Yellow	271-600
3	Marginal Oils	0.11-0.15	24.0-27.0	Bright Yellow	160-318
4	Bad Oils	0.16-0.40	18.0-23.9	Amber	45-159
5	Very Bad Oils	0.41-0.65	14.0-17.9	Brown	22-44
6	Extremely Bad Oils	0.66-1.50	9.0-13.9	Dark Brown	6-21
7	Oils in Disastrous Condition	1.51 or more	-	Black	-

1.2 Problem Statement

Power transformer utilizes oil as a heat transfer medium and a dielectric material, together with cellulose. Breakdown voltage (dielectric strength) is one of the most important parameters of transformer oil. It is measured when the transformer is taken into use and typically monitored by sampling during its operational lifetime. It has been reported that breakdown voltage is affected by several factors such as moisture, particles, acidity, and pressure.

Presence of moisture content in insulating oil is a critical condition for transformer lifecycle. Because the lifecycle of a transformer is highly dependent on its insulation condition. Other than that, factors such as high temperature and oxidation also contribute to the deterioration of transformer insulation.

When a high voltage transformer is reaching its service lifecycle the transformer oil will age faster compared to a new transformer. Degradation of oil and paper in a transformer mainly because of thermal ageing and moisture content [2]. This is due to the oxidation of the copper winding inside the transformer causing the insulation paper to degrade. The degradation of the paper will cause enhancement in moisture in the transformer oil. Furthermore, it will lower the dielectric strength of the transformer oil [3]. It is important to note that water and oxygen are the two major factors that contribute to the speed up of transformer oil ageing and degradation [4].

Power transformers have long been a noteworthy guaranteeing concern. Malfunctioning of a solitary unit can bring about boundless loss of administration with notable lost income and also substitution and other security cost. The ascent in the costs of crude material copper and stainless steel, the fundamental materials utilized as a part of transformer manufacture, has been quickened by elevated amounts of military utilization and developing worldwide interest. All copper item cost records expanded in abundance of 25% in 2007 [5]. Metal costs, rising quickly for as far back as couple of years are the reason this research has to be carried out.

1.3 Objectives

The objectives of this project are:

1. To investigate the level of breakdown voltage for Ester oil that is thermally aged with copper or aluminium under different temperatures.
2. To investigate the presence of moisture in Ester oil that is thermally aged with copper or aluminium under different temperatures.
3. To compare the levels of breakdown voltage and moisture content between Ester oils that is thermally aged with copper and aluminium.

1.4 Scope

This project focuses on the comparison study between copper and aluminium alloy as catalyst to oxidation of Ester oil. The Ester oil that is used in this project is Midel EN 7131. The measurement of moisture content is carried out using the Karl-Fischer method, according to IEC 814 while the breakdown test is conducted using Megger Breakdown Voltage Kit, according to ASTM D1816-84A.

1.5 Report Outline

This report consists of five chapters. Chapter 1 explains the overview and the problem statement of the project. The objective and scope have been outlined.

Chapter 2 describes the details of each section regarding this project based on past researches and projects. Reviews from past researches and projects are important to compare and find the similarity of this project. This chapter reviewed mostly on the thermal ageing and the effect of copper as catalyst towards insulating oil.

In Chapter 3, experimental setups and experimental procedures for this project are described. From ageing of mineral oil to identifying the breakdown voltage and moisture content are carefully explained steps by step.

Chapter 4 shows the results obtained from the experiment that have been conducted. This chapter begins with the results and analysis taken from the experiment. From the results, it can be used to determine the outcome of the project.

Chapter 5 is the conclusion of the whole research which includes recommendation for future work if there is any part that can be improved.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the theory and basic principles associating with this project. The following sub-sections overview the principles of a transformer, the insulation of a transformer and its importance, ageing of a transformer and how does an ageing affect the lifespan of a transformer, conductors in a transformer, effect of the conductor towards insulating agent and the parameters lead to ageing of insulation of a transformer

2.2 Transformer Design

Generally, a transformer comprises basically of the magnetic core built-up of insulated silicon steel lamination which are wound two different sets of coils termed as primary and secondary windings. The plan and structure of high voltage transformers differ from supplier to supplier. The active part of a transformer consists of core and windings. The core is made up from laminated cold rolled grain oriented silicon steel while a paper insulated copper conductor is used for windings. There are three main parameters in choosing a transformer which is it has enough capacity to handle the substantial loads, possible increasing capacity to handle potential load growth, and its life expectancy. Hence, the capacity is based on the unit application, type of insulation, type of winding material. It is noted that the normal temperature is between 65°C to 100°C. During these temperatures insulation materials experience slow ageing facing mechanical and electrical properties loss [2]. Figure 2.1 shows the design of a basic oil-filled transformer.

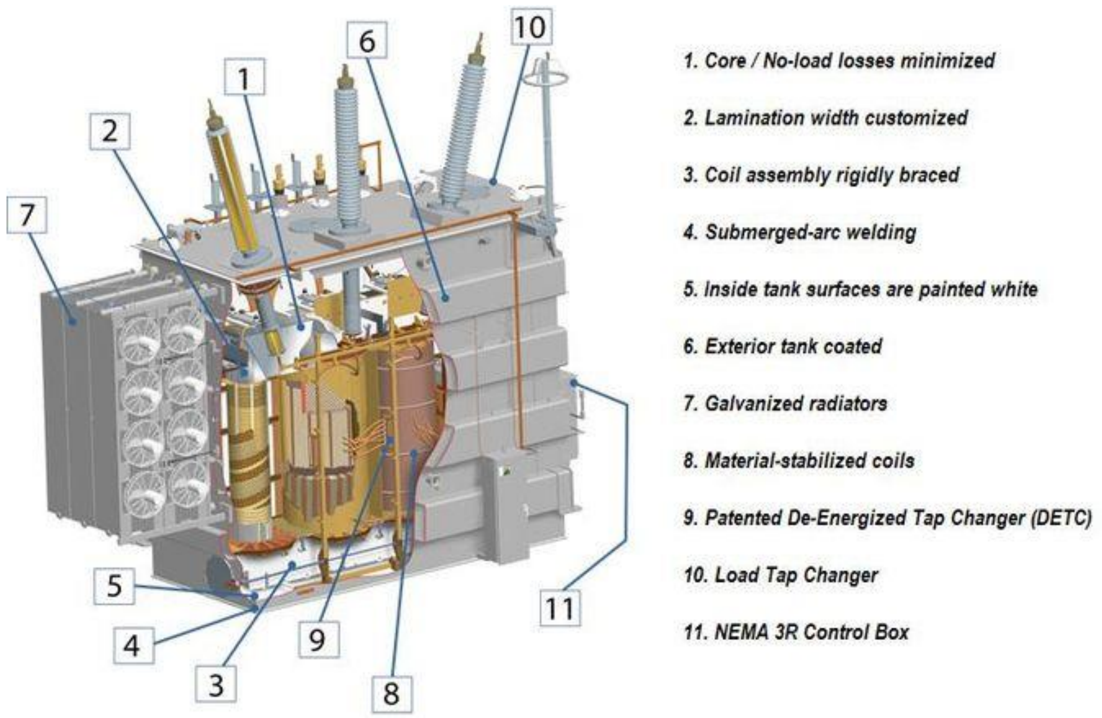

Figure 2.1: Oil-filled transformer design [1]

2.3 Composite Insulation in Transformer

Insulation is one of the most important constituent of a transformer. The durability and stability of the transformer depends upon the proper utilization of insulating materials in it. Hence in a transformer mainly three insulating materials are used which are the transformer oil, insulating paper and pressboard. Moreover, transformer oil is the most vital part in power transformers [6, 7]. Nowadays there are many types of transformer oil being used ranging from mineral oil, vegetable oil and ester based oil. However, for this research, mineral oil is used because mineral insulating oils are the largely engaged liquid in power transformers [8]. It is one of the important factors because transformer oil determines the life and operation of the transformer. Transformer oil provides insulation in combination with the insulating materials used in the core and windings which are immersed in the oil filled tank. Another insulation structure in a transformer is the cellulosic material which is the insulating paper and pressboard. In addition, insulating paper and pressboard is made from vegetable fibres and contain cellulose. Figure 2.2 and 2.3 shows the insulating paper and pressboard materials. Although these materials have been proven to have great chemical and physical properties as an electrical insulator; these materials age in time [2]. Hence, which decreases the dielectric properties when impregnated in oil under thermal stresses. Transformer oil is one of the primary factors influencing the well-being of a network system [9].

Figure 2.2: Insulating paper

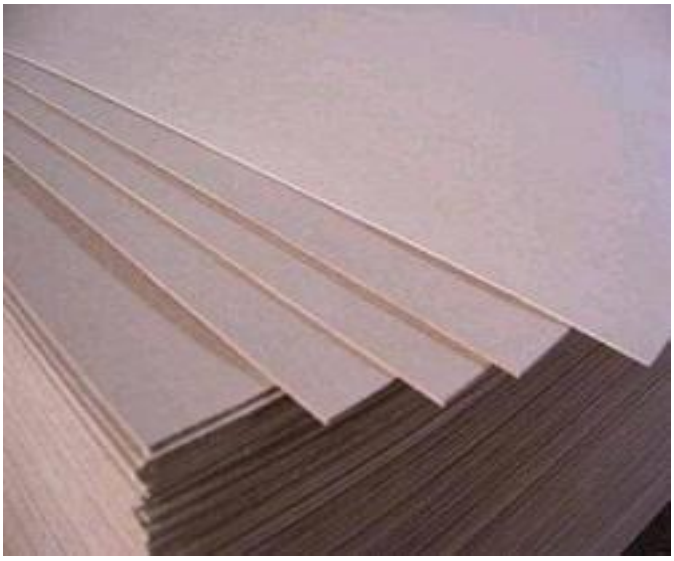

Figure 2.3: Pressboard

2.4 Accelerated Ageing Methods

Accelerated ageing is defined as a testing that uses irritated conditions of heat, oxygen, sunlight, vibration, etc. to hasten the standard aging processes of items. This method is generally used in laboratory by inhibited standard test methods. It is useful to help determine the extended term effects of expected levels of stress within a short time. Thus, it assists researchers to approximate the lifetime of a product when the actual lifespan data is not available. The parameters and factors influencing transformer oil ageing has been considered as well as its performance under electrical and thermal stress [10, 11]. Table 2.1 shows the long term ageing that has been conducted at temperatures in the range of 90°C to 145°C for time up to 100 weeks based on previous researchers. While short term ageing also has been done led at high temperatures in the range of 130°C to 190°C and for a period of 20 days as depicted in Table 2.2.

Table 2.1: Long term ageing

Temperature	Period	References
90°C to 110°C	70 weeks	Montsinger [12]
100°C to 135°C	100 weeks	Dakin [13]
110°C to 140°C	180 days	Shroff et al. [14]
90°C to 135°C	400 days	Moser et al. [15]

Table 2.2: Short term ageing

Temperature	Period	References
120°C to 180°C	7 days	Oomen [16]
145°C to 190°C	20 days	Moser et al. [15]

2.5 Comparison between Copper and Aluminium

Arguments over the good and the bad of aluminium versus copper conductor have been analysed for many decades. Copper and aluminium are the two most frequently used equipment for conductors and bus bars in electrical installation. Pryor et al [17] published a paper on aluminium versus copper and includes the comparison of mechanical and electrical properties and their significance as applied to electrical supply products. Table 2.3 shows the physical properties of copper and aluminium.