''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)

MUHAMMAD RIDHWAN BIN ABDUL RAZAK

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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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):

$$\text{OQIN} = \frac{IFT}{NN} \tag{1.1}$$

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

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.

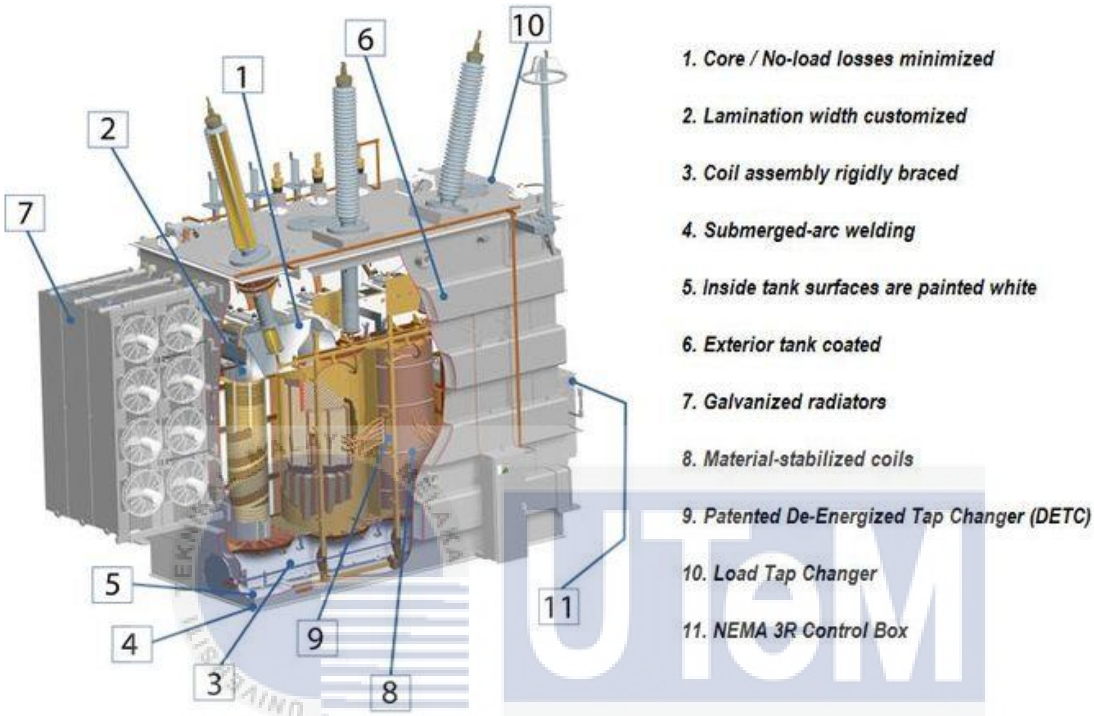


Figure 2.1: Oil-filled transformer design [1]

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

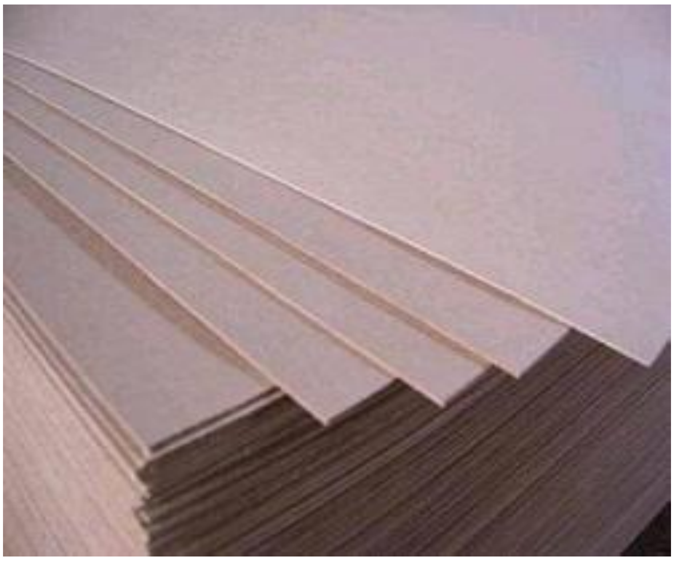


Figure 2.3: Pressboard

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.

Table 2.3: Physical Properties of Copper and Aluminium [17].

Characteristics	**Copper**	**Aluminium**
Tensile Strength (lb/in2)	50000	32000
Tensile Strength for same conductivity (lb)	50000	50000
Weight for same conductivity (lb)	100	54
Cross section for same conductivity	100	156
Specific resistance (ohms-cir/mil ft) (20°C ref)	10.6	18.52
Coefficient of expansion (per deg. C x $10^{\wedge -6}$)	16.6	23

2.5.1 Current Carrying Capacity of Copper and Aluminium

Pryor et al [17] expressed that the electrical and mechanical properties of a material are reliant on its alloy. The copper utilized as a part of electrical system is apparently 98% conductivity financially hard in view of the International Annealed Copper Standards (IACS). Pure aluminium is not utilized as an electrical transmitter as a part of hardware since it is too delicate for mechanical gatherings and is in this way aluminium is alloyed with different materials. The aluminium (Al) alloy 1350 utilized in 1975 was assigned as Electrical Conductor (EC) grade aluminium with 99.50% aluminium content. Despite the fact that it has 61% the conductivity of Cu, it is needed in mechanical properties. This makes the Al alloy 6101 the transcendent aluminium transport bar material being used more than 1350 Al in light of the fact that it has been solidified by heat treatment, yet it just has 56% the conductivity of copper. The decreased conductivity of Al 6101 does not imply this kind of Al conductor will run hotter than the copper (Cu) conductor; however, this implies the Al conductor for the same ampere rating must have a bigger cross sectional range. Current conveying limit depend on two configuration criteria which is the temperature ascent of the conductor and the present thickness in amperes per square inch of the cross sectional zone.

2.5.2 Cost comparison between copper and aluminium

As materials become more expensive to purchase and the conventional materials in electrical installation is ageing in time, the necessity of looking for alternative materials becomes increasingly critical to cost conscious industry. One of these alternative materials is the aluminium conductor, has been the focus attention lately. Hence, because copper prices continue to increase while the aluminium market remains steady. The rate difference among copper and aluminium vary with the erratic costs of the base metals on the products market. Nowadays, aluminium conductors are already being used efficiently and their use is widespread within the electrical installation industry. Using aluminium conductor can save up to 70% in return-on-investment (ROI) if it is utilized in every possible way [18].

2.6 Effect of copper ion on ageing rate of transformer oil

Many experiments involving the ageing of mineral oil however, there are few works that have been done on the impact of copper particle on ageing rate of oil-paper protection framework. Taking into account R. L. C. Tang et al [19] copper goes about as an impetus in quickening the oxidative debasement of oil-paper protection. Moreover, in light of their outcomes show that copper particle impacts protection paper and oil amid the maturing procedure. It is demonstrated that copper advances the oxidation of the oil and quickens the maturing rate. Furthermore, P.R. Krishnamoorthy et al [20] have stated that copper acts as catalyst in accelerating oxidative degradation of oil. In addition, they deduce that copper has negligible effect on the rate of oxidation at 70°C. However, from 85°C onwards the rate of oxidation is affected by effect of copper catalyst, which means to obtain the result of ageing the temperature must be higher than 85°C. Another research has been done by R. Maina et al [21] stating that the mineral insulating oils may react with the copper conductors' surface, forming copper compounds that can be detected in the oil itself. This phenomenon is commonly observed in transformers impregnated with mineral oil, and it may result in an enhancement of the oils' dielectric losses. Thus, ionic (soluble) forms of copper should be accounted for having a higher mobility within the oil, and contributing to oil's losses.

2.7 Effect of Thermal Ageing on Transformer properties

Degradation is a response and all things considered ought to comply with the Arrhenius hypothesis of response energy, which relates the log of the response steady to the corresponding of the total temperature [22]. Hence, S. Abdi et al [23] conducted the effect of thermal ageing on transformer properties. They performed tests on (BORAK22) mineral oil. To keep up the virtue of the test oil, little glass compartments were cleaned, dried and after that were set in a vacuum oven at 110°C for one hour which wipes out all indications of mugginess. They distributed predictably of 5000 hours for dielectric loss component, relative permittivity, resistivity and diverse tests, for instance, breakdown voltage, causticity degree, water substance, shading and thickness. Two developing tests were finished at predictable temperature of 80°C and 120°C. They found that the breakdown voltage encounters slight diminishment. This decline is more basic for oil developed at the highest temperature. This reduction is thought to be a result of outside conditions engaged reactions of oxidation and to the region of water in the wake of overheating in the midst of developing. They expected that the region of dirtying impacts may achieve proliferation and brief breakdown. From the outcome of Table 2.4 the oil test developed to 120°C has a lower breakdown voltage. It should be noted that for a transformer to have an extraordinary lifespan it needs to have a high breakdown voltage. Similarly, to S. Abdi et al [23], L.M Dumitran et al [24] performed three cases with regular ester and mineral oil in the drying oven at three temperatures (135°C, 155°C, and 175°C) for a total of 1250 hour. However, they chose to test for relative permittivity, setback variable, resistivity and water content

Table 2.4: Variation of Breakdown Voltage with respect to different thermal ageing temperature [23].

Oil sample	Breakdown Voltage (kV)
New before ageing	63
Aged to 80°C	62
Aged to 120°C	58

2.8 Water Content in Thermally Aged Oil

The anticipated water level in a transformer toward the end of life at 80°C in the oil is around 0.1% and 5% in the insulation paper [24]. In this manner moisture collection significantly affects insulation life. S. Abdi et al [23] have found that thermal ageing of the oil test causes an increment of substance in water that changed from 38 ppm for the new oil to 41 ppm for the oil test ageing at 80°C, and to 46 ppm for oil matured at 120°C. The presence of distinctive amounts of water for every ageing temperature, is the outcomes of the oil contact with air (500 hours of maturing). From the Table 2.5 they infer that a decent thermal ageing is at a temperature of 80°C and its properties essentially stay steady, while for temperature of 120°C, disintegration should be within a short period.

.

Table 2.5: Content of Water in Oil Before and After Ageing [23].

Oil Sample	**Content in water (p.p.m)**
New Before Ageing	38
Aged to 80°C	41
Aged to 120°C	46

2.9 Summary

From previous researches, it is proven that oxygen and temperature are the main reason of transformer oil ageing. The oxidation of copper conductor has led to the release of copper ion in the transformer oil therefore reacts with the insulation paper thus degrading the cellulose paper. This phenomenon causes the increased level of moisture in the transformer oil and lowers the dielectric strength. Therefore, leading towards the shorten lifecycle of a power transformer.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the experimental setup and the procedure to investigate the influence of aluminium and copper on thermal ageing of transformer oil under different temperatures. This experiment comprises two important parts which are:

a) Sample preparation through thermal ageing of Ester oil in the oven
b) Measuring the water content and breakdown voltage of the aged oil sample

3.2 Flowchart of project

This project started with the study of past researches regarding the ageing of transformer oil and the effect of copper catalyst on the rate of ageing of transformer oil. It is important to gain knowledge from previous research as it will guide this project in the correct path. Hence, samples will be prepared based on the proposed technique that is permitted. The results obtained will be tabulated and compared. Figure 3.1 shows the flowchart of this chapter.

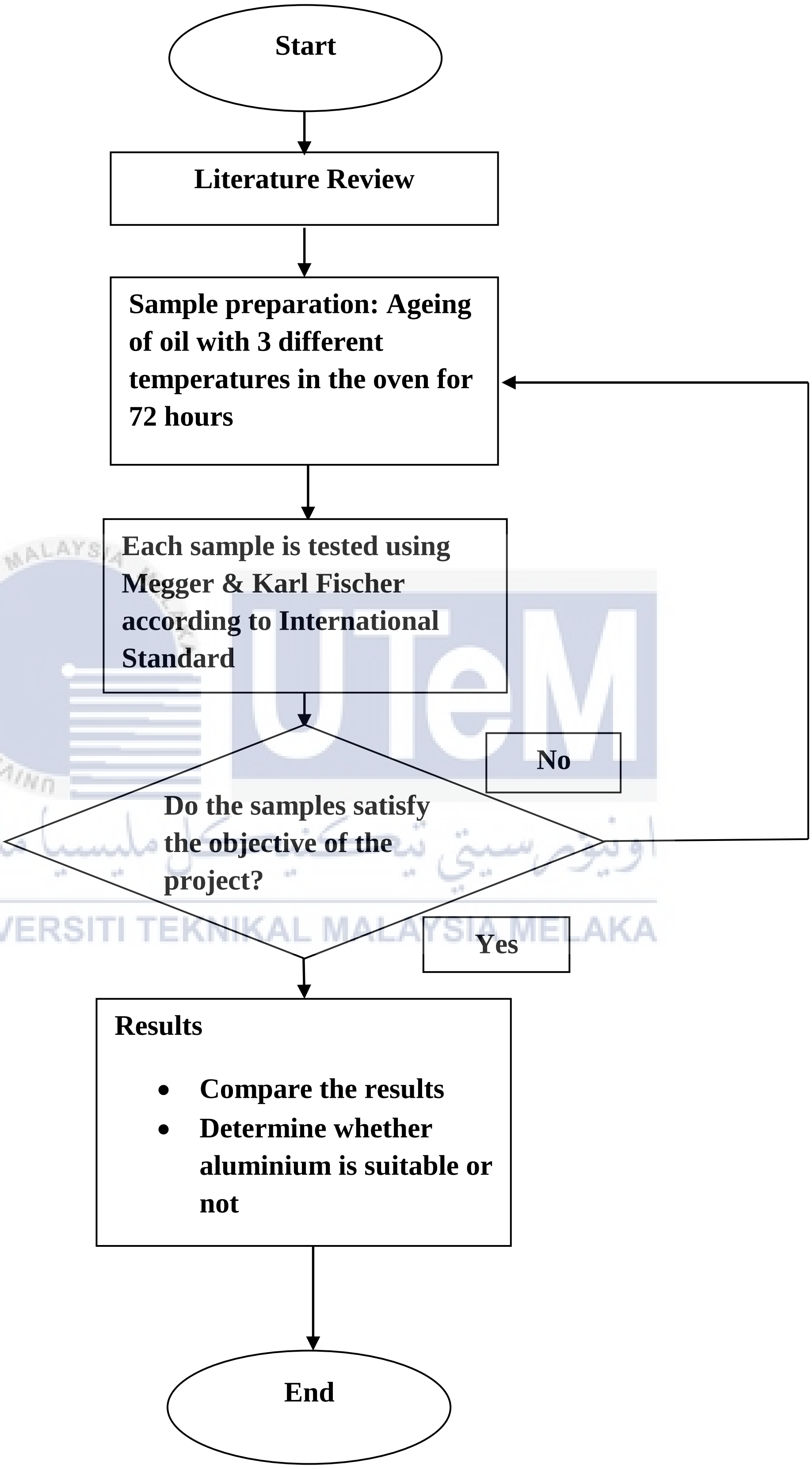


Figure 3.2: Flowchart of project

3.3 Sample Preparation

To prepare for one oil sample:

1. Firstly, a beaker of 1000ml is filled with 800ml of oil.
2. Secondly, copper or aluminium is measured according to their weight with the same conductivity.
3. From the Table 2.3, 100lb of copper has the same conductivity with 54lb of aluminium. Therefore, the weight is converted into 453.59g of copper and 244.94g of aluminium.
4. The amount is reduced by ratio to 45.36g of copper and 24.5g of aluminium to match the ratio of the oil in the 1000ml beaker.
5. For each temperature, two oil samples are prepared.
6. Both samples are thermally aged in a ventilated oven.
7. Steps 1 to 6 are repeated with different temperature.

3.4 Thermal Ageing of Mineral Oil

In this experiment, samples of mineral transformer oil Midel EN 7131 are aged. In order to avoid contagion of the test container, two piece of 1000 ml beaker are cleaned, dried out and then are placed in an oven at 110°C for one hour which eliminates all traces of moisture. The cleaned beakers are then filled with new oil for tests and the beakers are added with copper powder while the others are added with aluminium powder. For this experiment, pure aluminium powder is used and not a treated aluminium.

To start the test, the first sample of Midel EN 7131 is tested with Megger Oil Test Sample to determine the initial breakdown voltage before ageing. In addition, the oil is also tested with Karl Fischer Coulometer to determine the initial water content. These tests are conducted as a controlled parameter of the oil. There will be several samples that needs to be tested, firstly three oil samples will be aged under three different temperatures, secondly three oil samples with copper powder will be aged under three different temperatures. The second step is repeated replacing copper powder with aluminium powder. The temperatures will be fixed to 80°C, 120°C and 180°C. All the samples will be tested with Megger Oil Test Sample and Karl Fischer Coulometer after the thermal ageing of 72 hours and the ageing will be carried out separately for each samples. After the ageing has completed, it is compulsory to filter out the sample so that only the oil is obtained.

3.5 Breakdown voltage tests with Megger Breakdown Test Kit

Each sample will be tested with the Megger Breakdown Test Kit to determine the dielectric strength or the breakdown voltage. Determining the breakdown voltage is very important as it shows the capacity of the oil whether it is suitable to be used as an insulating and cooling agent in a power transformer. To start the breakdown test, samples will be filled inside the vessel of the device. Next, the electrode spacing is adjusted according to standards, in this case ASTM D1816-84A will be chosen and the electrode spacing will be 2.5mm. The tests will start when the test voltage is applied and is increased up to the breakdown constant. At a certain level of breakdown, arcing will occur and the voltage will collapse. The tests will be completed after 5 consecutive repetitions to obtain the average value. The results will determine whether the sample is suitable or not, the lower the value of the breakdown voltage, the poorer the quality of the transformer oil.

Figure 3.1: Megger Breakdown Test Kit

3.6 Identifying moisture content with Karl Fischer Coulometer

Each of the samples must be tested with the Karl Fischer Coulometer to identify the presence of the water content in the mineral oil after the thermal ageing. Below are the steps in using the Karl-Fischer Coulometer based on the IEC 814 standard [1]:

1 The first step is to obtain the aged sample from the oven and extract approximately 1 milliliter of the sample into a syringe.
2 Next, to operate the Karl Fischer Coulometer, the device is turned on and Karl Fischer Coulometric method is chosen.
3 The stirrer will spin and the screen will show drift with a value of micrometer per gram. However, the drift needs to be stabilized by the stirrer until the value is below 20 micrometer per gram and a sound is heard.
4 The syringe containing 1 ml of the sample is weighed on an electronic balance.
5 Next, the sample is injected into the reagent and the weight of the sample is entered to the device. The device will process the result and the screen will show how many parts per million of the moisture content of the sample.
6 The test is repeated using different samples.

3.7 Conclusion

Each of the sample is aged for 72 hours separately under different temperature. The samples are then tested with Megger Breakdown Voltage Kit and Karl Fischer Coulometer. All of the experiment has been done in high voltage laboratory condition with referring to the national standard test, which is ASTM D1816-84A for AC Breakdown test and IEC 814 for moisture content test. While the method used for thermal ageing is based on IEEE past researches on Thermal Ageing of Insulating Oil.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the results of this project of different temperatures affecting the breakdown voltage and the moisture content of Ester oil with the presence of copper and aluminium powder. Each sample shows five readings of breakdown voltage with an average of each reading. According to the ASTM D1816-84A which is the standard specification for ester oil used in electrical apparatus state that the acceptable limit breakdown voltage of ester oil using the test method of ASTM D1816-84A are 20 kV. Thus, in the result show that the oil without the presence of copper and aluminium are still acceptable because the value for the breakdown voltage are above 20 kV. It indicates that the oils are still in good condition although the oil shows a decrease in breakdown voltage with the time for 72 hours' period. The oil with the presence of copper and aluminium shows that the breakdown voltage is very low. It indicates that the oil is in a very bad condition and the oil can no longer be used as the insulation for the power transformer.

4.2 Breakdown Voltage Analysis

The data was obtained from oil ageing using ventilated oven for three days for each sample with the temperature ranging from 80°C to 180°C. R. Maina et al has conducted the effect of temperature on the tendency of unused oils to dissolve and deposit copper in a range 80°C to 140 °C. Tests were performed at 80°C, 100°C, 120°C and 140 °C. These temperature levels also include conditions beyond the maximum allowed operating temperature (according to IEC Loading Guide, 105 °C) [21]. The purpose of the temperature above 105°C is to speed up the process of ageing. It is postulated that the presence of impurities may cause a propagation of streamers and, consequently, lead to breakdown, as suggested in [23]. The reading shows uniform results based on the past research. The data contains the breakdown voltage level of different temperature and the moisture content of each sample.

4.2.1 Comparison Between Breakdown Voltage of Three Different Temperature

Each sample was tested five times with each test consists of five readings for statistical analysis. As discussed in previous section 3.4, precautious measures are taken to avoid error when obtaining the accurate result. Figure 4.1 shows the distribution of Ester oil breakdown voltage for the virgin Midel 7131. This data is used as a benchmark for the rest of the sample.

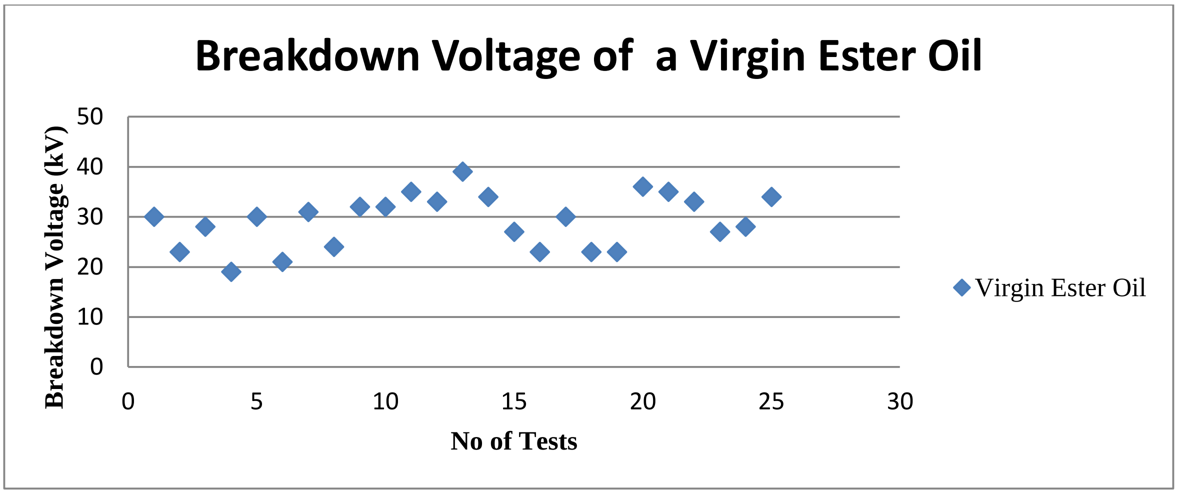


Figure 4.1: Graph of Breakdown Voltage of a Virgin Ester Oil at Room Temperature

Figure 4.2 shows the graph of close comparison between the breakdown voltage of virgin, copper and aluminium at 80°C. The graph shows clear differentiation where the oil sample with copper powder added has a higher breakdown voltage. The average reading is lower than that of the initial reading due to addition of copper powder and being aged thermally. This shows that aluminium has a greater impact towards the oil. The percentage of ionised aluminium powder is higher than copper powder, therefore the oil sample with aluminium powder has a lower breakdown voltage. The temperature 80°C is also the starting temperature which the oil samples start to degrade

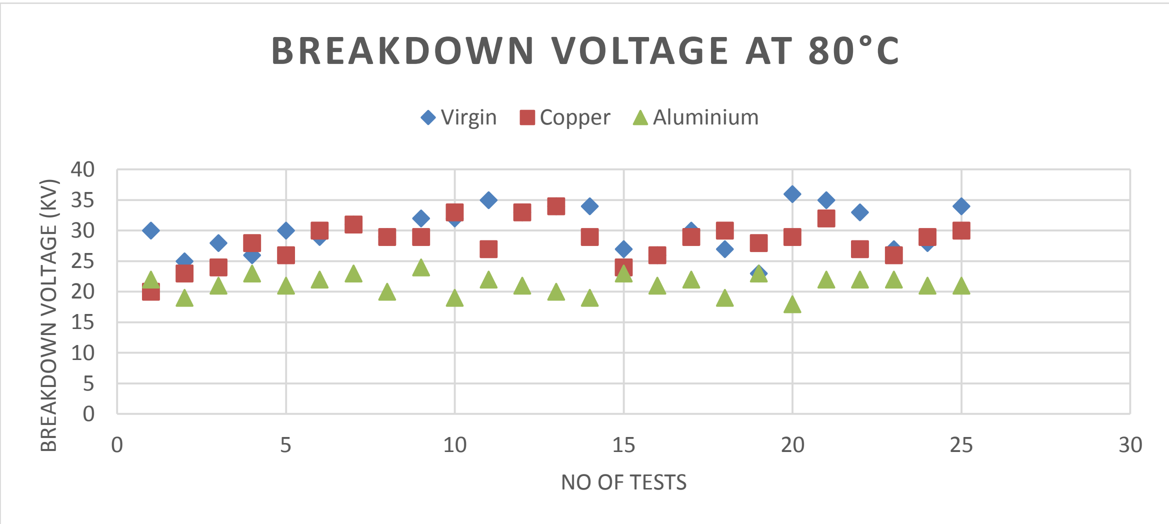


Figure 4.2: Graph of Breakdown Voltage between Virgin, Copper and Aluminium at 80°C

Figure 4.3 shows the graph of breakdown voltage between oil samples with virgin, copper powder and aluminium powder. The value may vary but the graph shows that the oil sample with copper powder has a higher breakdown voltage. The breakdown voltage has decreased few margins from the initial reading. This is due to the temperature increase and the addition of metal powder added. Similarly, for the temperature at 80°C, the sample which contains aluminium has a slight decrease in breakdown voltage compared to the sample which contains copper powder and the virgin oil. The value of the breakdown voltage decreases proportionally when the temperature is raised. From these results, a pattern of readings can be seen. These pattern of readings are crucial in determining the outcome of the experiment.

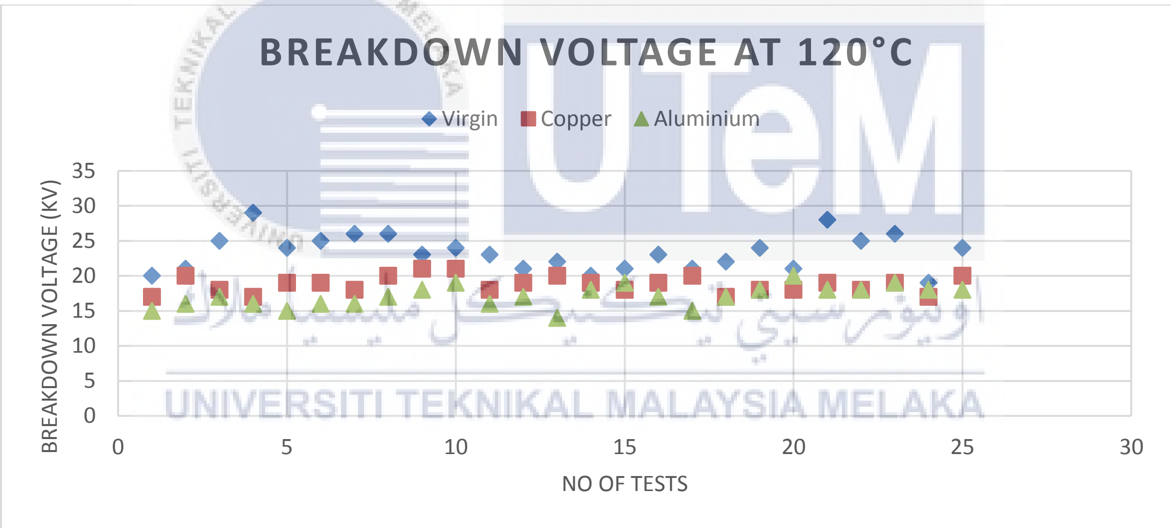


Figure 4.3: Graph of Breakdown Voltage between Virgin, Copper and Aluminium at 120°C

Figure 4.6 shows clearly the difference in breakdown voltage between virgin, copper and aluminium at 180°C. The breakdown voltage between copper and aluminium has a substantial difference than that of the virgin oil sample. The oil sample with aluminium still shows a breakdown voltage lower than the oil sample with copper. This is a clear proof that aluminium is not a suitable conductor to replace copper in high voltage transformer. All of the oil samples in the graph has a very low breakdown voltage which is categorized as bad oil The results were consistent where the sample which contains aluminium has a slightly lower breakdown voltage. The value of the breakdown voltage acquired is very low that the oil cannot be used again. This phenomenon is due to the collapse of the insulating properties in the oil which is affected by thermal ageing. The oil experiences permanent molecular or physical changes thus creating a weakened path for the sudden current.

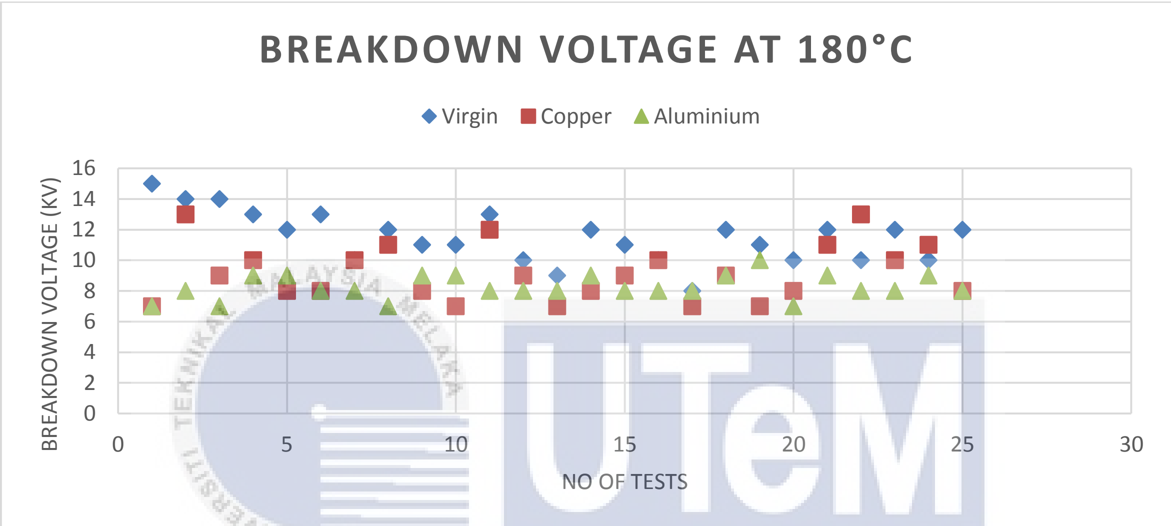


Figure 4.4: Graph of Breakdown Voltage between Virgin, Copper and Aluminium at 180°C

4.2.2 Average Breakdown Voltage in Ester Oil Midel 7131

Table 4.1 represents the whole data of the analysis. The average reading was taken and compared between them. The decrease in value of the breakdown voltage for the oil without copper and aluminium indicates that the oil will fully degrade with the time when the oil is under high operating temperature which is 120 ˚C. Thus, the effect of the thermal stress shows the quality of the oil will degrade causes the breakdown strength of the oil to decrease. Another reason for the decreasing of breakdown voltage is because the copper influence plays an important role in aging process. The copper can trigger the oil to undergo oxidation which can accelerate the aging process. Thus, the presence of copper and aluminium in the oil will make the breakdown voltage lower compared to the oil without the copper and aluminum (virgin oil sample).

Table 4.1: Average Voltage Breakdown

Average Breakdown Voltage	Virgin	Copper	Aluminium
80°C	30	28	21
120°C	23	19	17
180°C	11	9	8

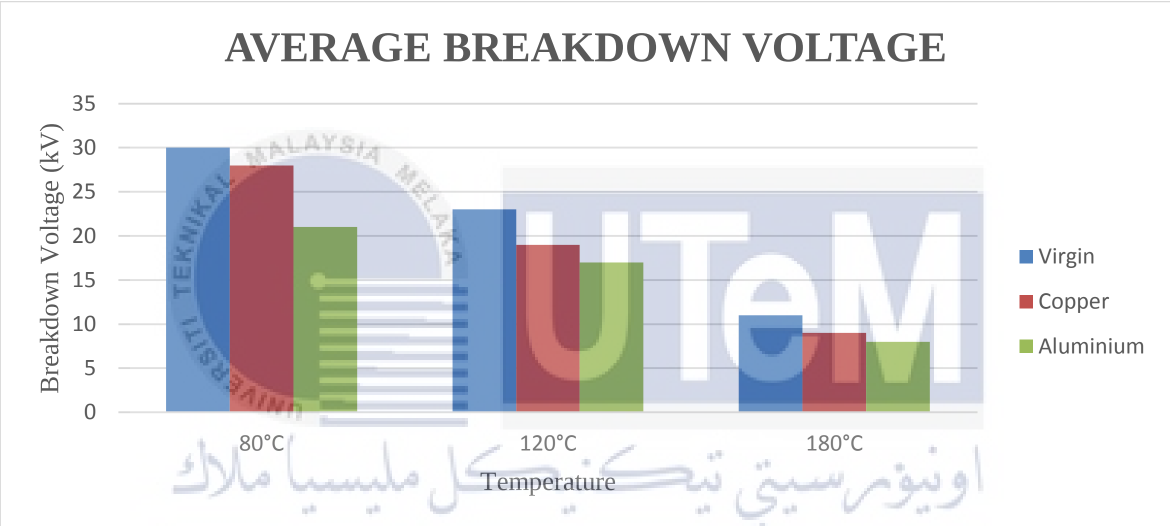


Figure 4.5: Graph of Average Breakdown Voltage

4.3 Moisture Content in Oil Samples

The following results are the moisture content present after thermal ageing for 72 hours in a ventilated oven. Figure 4.6 shows the moisture content in parts per million where the oil sample with aluminium has a higher content in water than oil sample with copper. It also shows the moisture content at 120°C where it can be seen oil with copper has lower water content. In addition, the graph shows that there is a huge increase in water content from a high temperature of 180°C. The sample with virgin oil maintains a low water content. However, the result still has the consistency where the oil with aluminium has higher water content. The higher the water content, the lower the breakdown voltage. This is proven when the results show that the oil sample with aluminium has a lower breakdown voltage than the oil sample with copper. From three temperatures 80°C, 120°C, and 180°C, the oil sample with aluminium shows a higher moisture content than the oil sample with copper. The results are consistent and related to the value of the breakdown voltage. To deduce this analysis, aluminium have a very low affinity to water. It has been verified that the natural ester can accommodate more water than mineral transformer oil [24]. Therefore, explains the moisture content having a high value after thermal ageing.

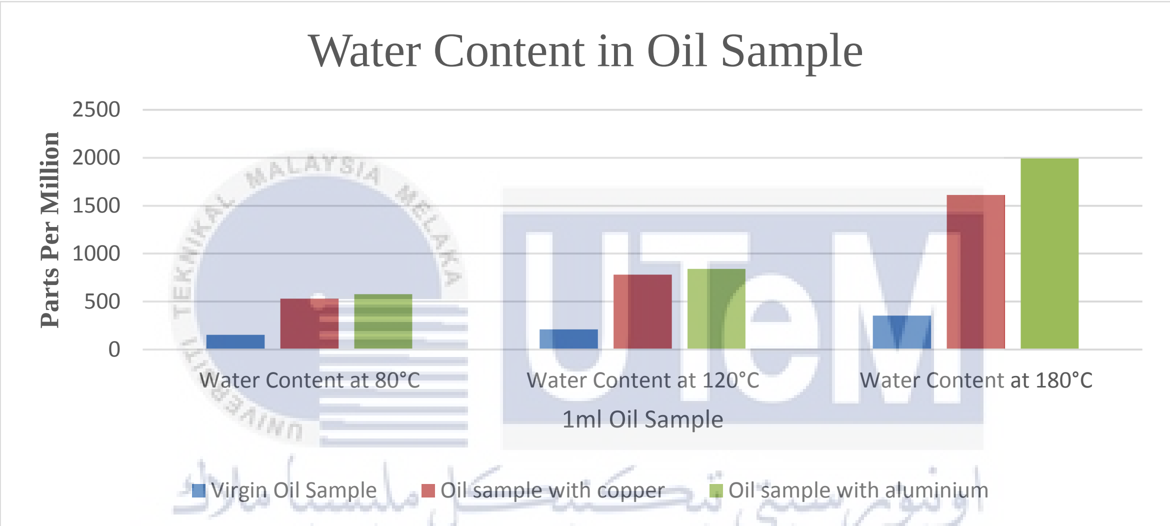


Figure 4.6: Graph of moisture content with 1ml oil sample at 80°C,120°C & 180°C

4.4 Color Difference of Oil Sample between Ageing of Different Temperature

As can be observed from Table 1.1: Transformer Oil Classification [1], Figure 4.7 shows the original color of the oil sample which has a pale yellow color. The progressive change of the color factor for virgin oil sample in Figure 4.8 a) is from yellow at 80°C to bright yellow for oil aged at 120°C, and to amber at 180°C. For Figure 4.8 b) which contains aluminium powder, the color changes from bright yellow at 80°C to amber at 120°C and to brown at 180°C. Lastly for Figure 4.8 c) which contains copper powder, the color changes from amber at 80°C to brown at 120°C and dark brown at 180°C. This color change is essentially due to the oxidization of oil in service which, consequently, leads to the formation of the acidic products.

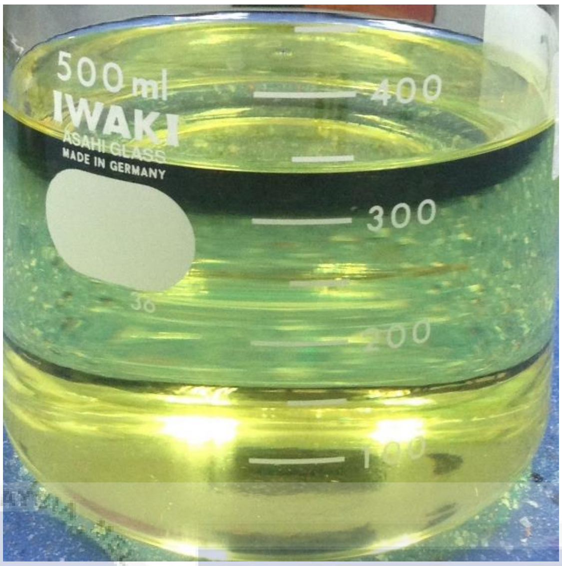
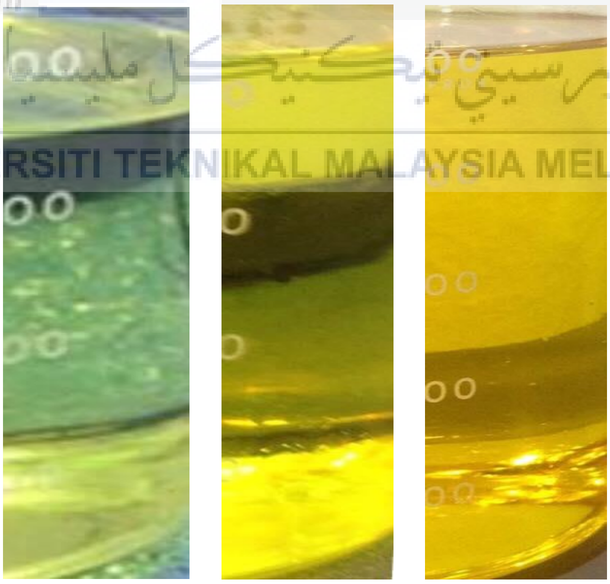
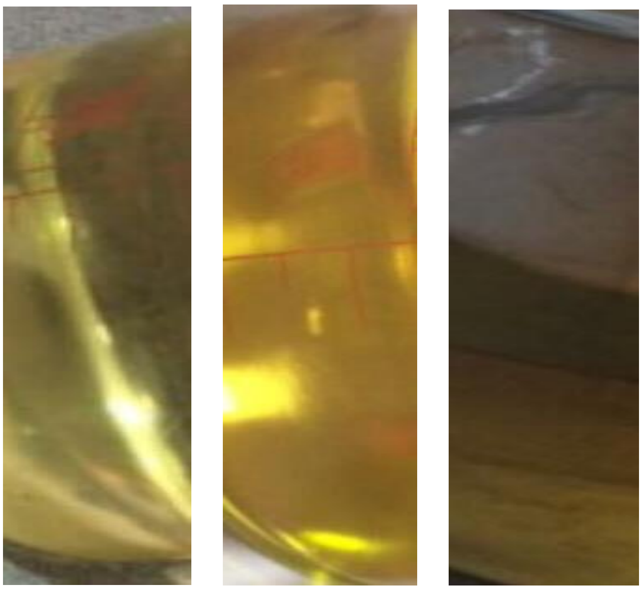


Figure 4.7: Synthetic Ester Oil (Midel EN 7131) at Room Temperature



80°C 120°C 180°C

Figure 4.8 a): Virgin Oil Sample



80°C 120°C 180°C

Figure 4.8 b): Aluminium Oil Sample

80°C 120°C 180°C

Figure 4.8 c): Copper Oil Sample

4.5 Summary

From the first reading, it can be concluded that the higher the temperature, the lower the breakdown voltage. There is a difference in breakdown voltage reading where the oil sample with copper powder has a slightly higher reading than the oil sample with aluminium powder. This is due to the ionisation of the metal powders. The temperature acts as a catalyst for the metals to ionise in the oil. The result shows aluminium has a higher rate of ionisation in the oil than copper. The result clearly shows that oil samples with aluminium have a weaker statistics compared to an oil sample with copper. This shows from the result of the breakdown voltage and the moisture content. Oil sample with aluminium has a lower breakdown voltage and a high moisture content overall. The results are consistent in each temperature. Therefore, aluminium is not suitable as a conductor in a high power transformer.

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusion

In conclusion, the influence of aluminium and copper has been investigated. The experiment consists of comparing the breakdown voltage and moisture content between a thermally aged synthetic ester oil Midel 7131 with the presence of aluminium and copper powder. The results showed that both oil sample in three different temperatures with aluminum and copper has a lower breakdown voltage than the virgin oil sample. However, between the copper oil sample and aluminium oil sample, it is clear that aluminium has a lower breakdown voltage. The results in moisture content is proportional to the results in breakdown voltage. The oil sample which contains aluminium powder has a very high water content which leads to the low breakdown voltage. This is caused by the bridging of ion between the electrode gap. When bridging occurs, the oil is not able to become a good insulator because the free ions in the oil becomes the conductor which allows current through the electrode. Based on the results obtained, it is known that the higher the moisture content the lower the breakdown voltage. Pure aluminium does not have the capacity to replace copper winding in high power transformer due to its low standards of conductivity and poor result in the experiment.

5.2 Recommendation

There are several things that needs to be improved for future work. Firstly, pure aluminium cannot be used to compare with copper as it does not recognized as a proper conductor that is typically used due to its mechanical properties and electrical properties. However, another grade of aluminium can be tested to verify whether all aluminium has the same properties or will the alloy fusion changes the result of the experiment.

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APPENDICES

Table 4.1: Initial reading with room temperature (28°C)

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	30	21	35	23	35
T2	23	31	33	30	33
T3	28	24	39	23	27
T4	19	32	34	23	28
T5	30	32	27	36	34
Average	**26**	**28**	**34**	**27**	**31**

Table 4.2: Virgin Oil Sample at 80°C

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	30	29	35	26	35
T2	25	31	33	30	33
T3	28	29	34	27	27
T4	26	32	34	23	28
T5	30	32	27	36	34
Average	**24**	**30**	**29**	**28**	**29**

Table 4.3: Oil sample with copper powder and temperature at 80°C

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	20	30	27	26	32
T2	23	31	33	29	27
T3	24	29	34	30	26
T4	28	29	29	28	29
T5	26	33	24	29	30
Average	**24**	**30**	**29**	**28**	**29**

Table 4.4: Oil sample with aluminium powder and temperature at 80°C

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	22	22	22	21	22
T2	19	23	21	22	22
T3	21	20	20	19	22
T4	23	24	19	23	21
T5	21	19	23	18	21
Average	**21**	**22**	**21**	**21**	**22**

Table 4.5: Virgin Oil Sample at 120°C

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	20	25	23	23	28
T2	21	26	21	21	25
T3	25	26	22	22	26
T4	29	23	20	24	19
T5	24	24	21	21	24
Average	**18**	**20**	**19**	**18**	**19**

Table 4.6: Oil sample with copper powder temperature at 120°C

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	17	19	18	19	19
T2	20	18	19	20	18
T3	18	20	20	17	19
T4	17	21	19	18	17
T5	19	21	18	18	20
Average	**18**	**20**	**19**	**18**	**19**

Table 4.7: Oil sample with aluminium powder temperature at 120°C

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	15	16	16	17	18
T2	16	16	17	15	18
T3	17	17	14	17	19
T4	16	18	18	18	18
T5	15	19	19	20	18
Average	**16**	**17**	**17**	**`17**	**18**

Table 4.8: Virgin Oil sample at 180°C

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	15	13	13	10	12
T2	14	10	10	8	10
T3	14	12	9	12	12
T4	13	11	12	11	10
T5	12	11	11	10	12
Average	**9**	**9**	**9**	**8**	**11**

Table 4.9: Oil sample with copper powder temperature at 180°C

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	7	8	12	10	11
T2	13	10	9	7	13
T3	9	11	7	9	10
T4	10	8	8	7	11
T5	8	7	9	8	8
Average	**9**	**9**	**9**	**8**	**11**

Table 4.10: Oil sample with aluminium powder temperature at 180°C

Breakdown Voltage (kV)					
Test	**1**	**2**	**3**	**4**	**5**
T1	7	8	8	8	9
T2	8	8	8	8	8
T3	7	7	8	9	8
T4	9	9	9	10	9
T5	9	9	8	7	8
Average	**8**	**8**	**8**	**8**	**8**

Table 4.11: Moisture content in the samples at 80°C

Oil Sample	**Content in water (p.p.m)**
Virgin Oil Sample	154.7
Oil sample with copper	530.7
Oil sample with aluminium	578.9

Table 4.12: Moisture content in the samples at 120°C

Oil Sample	**Content in water (p.p.m)**
Virgin Oil Sample	209.6
Oil sample with copper	780.3
Oil sample with aluminium	842.5

Table 4.13: Moisture content in the samples at 180°C

Oil Sample	**Content in water (p.p.m)**
Virgin Oil Sample	354.7
Oil sample with copper	1611.5
Oil sample with aluminium	1993.4

Table 4.14: Average Breakdown Voltage

Average Breakdown Voltage	Virgin	Copper	Aluminium
80°C	30	28	21
120°C	23	19	17
180°C	11	9	8