UNIVERSITI TEKNIKAL MALAYSIA MELAKA

FACULTY OF ELECTRICAL ENGINEERING

BEKU 4894

FINAL YEAR PROJECT REPORT II

STUDY ON THE DIELECTRIC STRENGTH OF RECLAIMED WASTE COOKING PALM OIL FOR POWER TRANSFORMER APPLICATIONS

Name :Nor Hafiz Bin Nor Rahman

Matric No. :

Supervisor :Puan Nor Hidayah Bt Rahim

Course :Bachelor of Electrical Engineering (Power Industry)

" I hereby declare that I have read through this report entitle "Study On The Dielectric Strength Of Reclaimed Waste Cooking Palm Oil For Power Transformer Applications" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature : …….

Supervisor's Name : Puan Nor Hidayah Bt. Rahim.…….

Date : 1st June 2016…….

STUDY ON THE DIELECTRIC STRENGTH OF RECLAIMED WASTE COOKING PALM OIL FOR POWER TRANSFORMER APPLICATIONS

NOR HAFIZ BIN NOR RAHMAN

A report submitted in partial fulfillment of the requirement for the degree of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2016

I declare that this report entitle "*Study on the Dielectric Strength of Reclaimed Waste Cooking Palm Oil for Power Transformer Applications*" 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 candidature of any other degree.

Signature : …….

Name : Nor Hafiz Bin Nor Rahman…….

Date : 1st June 2016…….

DEDICATION

Alhamdulillah Hirrabbil'alamin, I am full of gratitude to Illahi with His grace, I have completed this Final Year Project II with great success for 14 weeks. During this period, it would not have been possible without the help from other people surrounding me.

Thank you for those who helped me a lot especially my supervisor and project teammate for giving me a guidance during this 14 weeks. A special thanks to my supervisor, Puan Nor Hidayah Bt Rahim for her guidance and monitoring. I would like to extend my sincere thanks to the most important person, Mr Sharin B Ab Ghani, head of project who always guide me to complete this project. All of them really inspired and motivate me to finish the project.

Plus, I would like to express my special gratitude and thanks to my parents and friends whose always give moral support and pray for me in order to finish this final year project. From this project, I grabbed new knowledge and gain more experience that I never get before. I've been exposed to such great working surrounding and also feel it by my own.

ACKNOWLEDGEMENT

In preparing this report, I was in contact with many people, researchers, academicians and practitioners. They have contributed towards my understanding and thought. In particular, I wish to express my sincere appreciation to my project supervisor, Puan Nor Hidayah Bt Rahim for encouragement, guidance critics and friendship. I am also very thankful to my co-supervisors Mr. Sharin B Ab Ghani for his guidance, advices and motivation. Without them continued support and interest, this project would not have been same as presented here. I am also indebted to Mr. Wahyudi as an Assistant Engineer in High Voltage Engineering Research Laboratory for his permission and guide to use the laboratory's equipment. Not forget to Universiti Teknikal Malaysia Melaka (UTeM) for supplying the relevant literatures. My fellow postgraduate students should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

ABSTRACT

Liquid insulation is a vital medium in power system especially transformers which acts as insulation as well as coolant. As the year passed, the liquid insulation in transformer will degrade and start to lose its function as an insulation medium and this will affect the life and efficiency of transformer. The problem arises when the waste mineral oil is change to new mineral oil. Mineral oil in transformer can be potentially hazardous to the environment when occur accident during its working time. In order to prevent that from happen, vegetable oil is used as an alternative insulation liquid for transformer oil because it is more environmental friendly. In this work, waste cooking palm oil is reclaimed to replace mineral oil. Reclamation of oil is the process of removing contaminant using adsorbent and produce new oil that have almost same characteristic as new oil. This process is carried out by mixing and heating 1000 ml of waste cooking palm oil with 100 g of Fuller's earth as an adsorbent for 4 hours before filtration to remove the used adsorbent. In this work, investigation of various parameters such as breakdown voltage, total acid number (TAN) and moisture content of different samples of cooking oil like waste cooking palm oil, new cooking palm oil, reclaimed cooking oil and antioxidant-reclaimed cooking oil using the standard of ASTM. From this experiment, it prove that the reclamation of waste cooking oil helps to improve the performance of this liquid insulation as its breakdown voltage, moisture content , and total acid number is reduced.

ABSTRAK

Penebat cecair adalah medium penting dalam sistem kuasa yang bertindak sebagai penebat dan juga penyejuk. Semakin masa berlalu, cecair penebat dalam pengubah akan merosot dan mula kehilangan fungsinya sebagai medium penebat dan ini akan memberi kesan kepada kehidupan dan kecekapan pengubah. Masalahnya timbul apabila minyak yang digunakan ditukar kepada minyak baru. Minyak mineral sangat bahaya kepada alam sekitar sekiranya berlaku kemalangan semasa waktu kerja. Dalam usaha untuk mengelakkan kejadian sebegini daripada berlaku, minyak sayuran digunakan sebagai cecair penebat alternatif kerana ia lebih mesra alam. Dalam kajian ini, sisa minyak sawit digunakan untuk menggantikan minyak mineral. Penambakan minyak adalah proses mengeluarkan bahan cemar menggunakan penjerap dan menghasilkan minyak baru yang mempunyai ciri-ciri hampir sama dengan minyak baru. Proses ini dilakukan dengan mencampurkan 1000 ml minyak yang dipanaskan dan dicampurkan digunakan dengan 100 g tanah Fuller selama 4 jam sebelum penapisan untuk membuang bahan penjerap digunakan. Dalam kajian ini, siasatan pelbagai parameter dilakukan seperti voltan pecahan, jumlah asid dan kandungan lembapan sampel dengan menggunakan standard ASTM. Dari kajian ini, penambakan sisa minyak masak membantu meningkatkan voltan kerosakan, kandungan kelembapan dan juga jumlah asid.

TABLE OF CONTENT

LIST OF FIGURE

LIST OF TABLE

LIST OF ABBREVIATIONS

BdV	-	Breakdown Voltage
TAN	-	Total Acid Number
DP	-	Degree of Polymerization
PFAE	-	Palm Fatty Acid Ester
TNB	-	Tenaga Nasional Berhad
DDP	-	Dissolve Decay Product
ASTM	-	American Society for Testing and Materials
IEC	-	International Electrotechnical Commission

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Power transformers are essential in the transmission of alternating current and are the most costly equipment in the substation. The transformer lives mostly rely on the insulating oil used which the function is for heat transfer medium. Basically, transformer oil work for two purposes which are for liquid insulation in power transformer and for dissipates heat of the transformer which is act as a coolant. Solid (kraft paper and press board) and liquid (mineral oil) are typically two dielectric mediums that are used in transformer [1]. Between these medium, liquid medium dominate in transformer because of its multifunction. However, the performance of transformer insulating oil starts to decrease with respect to time because of the chemical reaction. The change in insulation characteristics is most probably due to the effects of chemical, thermal, electrical and mechanical stresses, such as hot zones, voltage spikes and vibrations [2]. The interaction between solid and liquid create byproduct which then will deteriorate the oil and causing the insulating oil to lose its functionality as transformer insulation. In essence, the moisture content in transformer like in the cellulose-

based paper used as an insulation in the windings can result in electrical breakdown which resulting the increasing of dielectric dissipation. Other than that, aging of solid insulation is always in combination with aging of transformer oil. Oxidation is the predominant mechanism leading to formation of carboxylic acids in oil [3]. The increase of acid number happened due to the oxidation process that cause of excessive temperature and oxygen which can damage the insulation paper. An action need to be taken to protect the state of insulation system as the contaminants from the byproduct can harm the insulation system.

1.2 Problem statement

Production of mineral oil came through the oil refinery which crude oil is process and refined into some useful product. This process produced gaseous which come from the combustion of the crude oil and will affect the environmental and give bad consequent to the community. Since the oil used at transformer will degrade after a long time, the oil need to change to a new oil for a better insulation. This will lead to more oil incineration in order to produce new oil. More oil incineration means more oil pollution will happen. In addition, mineral oil may harm the environment if any accident occurs during working time.

In order to prevent pollution and costing problem from happen, other step should be taken which is to reuse waste cooking palm oil by reclamation process. To restore the characteristics of used oil such as dielectric strength and dissipation factor, reclaim the used oil [2]. Oil reclamation helps to improve the performance of the oil by reducing the level of contamination found in the age transformer such as sludge, acids, ketones and also moisture produced from a degradation process [3]. There are a few adsorbents that can help used oil to

retain its features and could be used back as a new oil. The adsorbents mostly produce from clay material which also used in industries as a fertilizers, cleaning agent and pesticides.

1.3 Motivation

Therefore, it is motivate to do the project on the reclamation of waste cooking palm oil by improving the performance of the oil using reagent also known as adsorbent. The process of reclamation would help to reduce the production of new oil and also oil disposal since it reuse back the waste cooking oil. This process also can be applied to different usage of oil such as motor oil lubricants. With this step, energy provider could save more money rather than buying new oil which is costly. Figure 1.1 shows graphically the percentage of oil disposal at United States of America (USA) in 1991. From that figure, it shows that 67.2 percent of used oil was burned as fuel and this will increase air pollution and harm the environment.

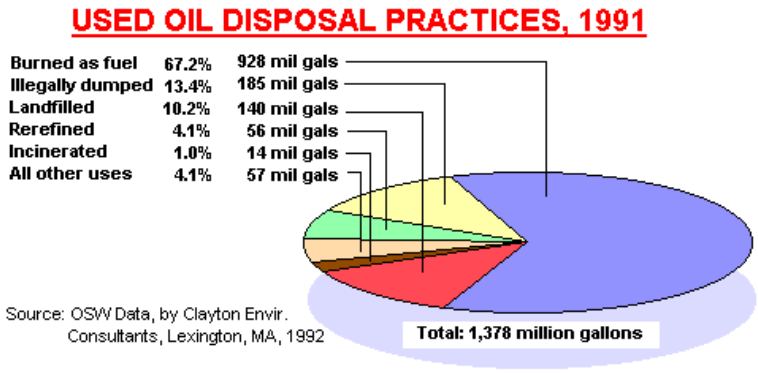

Figure 1.1: Used oil disposal practices in 1991 [1]

1.4 Objective

The objectives of this project are:

1. To reclaim waste cooking palm oil using Fuller's earth as an adsorbent.
2. To determine the breakdown voltage (BdV), total acid number (TAN) and moisture content on a reclaimed cooking palm oil.
3. To analyze the performance of reclaimed cooking palm oil in term of breakdown voltage, total acid number and moisture content.

1.5 Scope

This project focus on the

1. Study the breakdown voltage, total acid number and moisture content on the reclaimed cooking palm oil.
2. Waste cooking oil that has been used for frying process only.
3. Reclamation of waste cooking oil using Fuller's earth as an adsorbents.
4. Standard test used ASTM D1816-12, Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes, ASTM D974, Standard Test Method for Acid and Base Number by Color-indicator Titration, and ASTM D1533, Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration.

1.6 Project outline

This report consist five chapters. This report starts with the introduction of the project and the following five chapters of this report are arranged as follows:

Chapter 1: Covers the short explanation of the background project, problem statement, objectives and scope of the project.

Chapter 2: Covers the theoretical background of this project including the detail about basic type of transformer oil, the general adsorbents used and the technique of oil reclamation.

Chapter 3: Covers about the project methodology. This chapter consists of the flowchart of the project, milestone, Gantt chart, simulation model, hardware design and the switching method used in this project.

Chapter 4: Gathered all the result of experimental setup.

Chapter 5: Summary of this project and the recommendation for the further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Transformer oil is an oil that has great electrical insulating characteristics and very stable at high temperature. The function of the oil is to cool the transformer and also as insulator. During the early stage as an insulator, the oil is as clear as water since it has no particle or chemical reaction occur. During the operation in the transformer, the oil is facing several process which comes from heat, oxygen and electrical discharge that lead to its deterioration especially through oxidation process. Most of this time, the acidity of the oil is increase due to the result of by-product, and this will affect the cellulose insulating material since it may attack them. After a few years, this transformer oil will start to lose its primary functions of insulation and heat transfer as aging products will reduce the electrical characteristic and cooling efficiency.

Transformer oils perform at least four basic functions in an oil-immersed transformer. Oil provides insulation, cooling (heat distribution), and helps extinguish arcs (voltaic

discharge). Oil also dissolves gases generated by oil degradation, deterioration, and gases and moisture from whatever atmosphere the oil is exposed to [6].

2.2 Transformer Oil

Oil that is used in industry such as hydraulic, transformer and engine oil are come from special grade petroleum oils, which had different level of specific gravity and viscosity [7]. Generally oil is spoiled by carbon, which can be extracted by filtration and by fractional distillation technique. The oil that is use in transformer has their specific boiling range and degree of refining process to get the characteristic of resulting oil. The different level of boiling range is used to make other products such as kerosene, gasoline and other chemical products.

2.2.1 Mineral Oil

Alkanes in the range of C15 to C40 are mineral oil that contains various colorless and odorless taken from mineral source especially a distillate petroleum [8]. This mineral oil comes from the by-product of the distillation of petroleum in order to generate gasoline and other petroleum-based products from crude oil. Crude oil is produce from the extraction source called as crude petroleum comes beneath the Earth's surface. It is essentially a mixture of hydrocarbon and non-hydrocarbon features and mainly present as elements of complex molecules.

The majority of power transformers used in the world make use of mineral oil and cellulose insulation system to handle the dielectric stresses. The mineral oil production processes are generate from the distillation technique and the end product consists of a few bases known as paraffinic, naphthenic and aromatic which come from the long chain of hydrocarbon contain in crude oil. Conventional engine lubricating used paraffinic based oil because it have good oxidation stability, approximately contain higher wax, high pour point and also have great viscosity index [11]. It usually referred to as alkanes and the simplest paraffin molecule is methane, CH_4. Naphthenes or naphthenic base oil also referred as cycloalkanes are saturated hydrocarbon compounds. Main application of naphthenic based oils is in electrical industry as a transformer oil, lubricant industry, chemical and tire industry. It has low viscosity at high temperature and excellent solvency at low temperature. Aromatic is very different from paraffinic and naphthenic oil because it contain benzene ring which is unsaturated but very stable and commonly act as saturated compound. Because of its reactive nature, aromatic base oils are very useful as petrochemical building blocks and also capable to generate synthetic fluids and other petrochemical compound [11].

2.2.2 Natural Ester

Natural esters are produce from vegetable oil which is manufactured from plant crops. It has good biodegradability but most of natural esters have problem in oxidation stability as other types of insulating liquids. Generally, natural esters for electrical utilization are most commonly come from soya, rapeseed and sunflower oil. The reason is because of its availability, cost and performance distinctive. In addition, they are biodegradable and have

greater flashpoint. Transformer with vegetable oil can be operated in large population areas. The characteristic of natural esters are not only give advantages to the surroundings, but also let the customer to think the cost advantage over other type of insulating liquids.

2.2.3 Palm Fatty Acid Ester

In 2005, 36 million tons of palm oil and palm kernel oil had been produced and since then it has become the most abundant and consistently produced vegetable oil around the world including soybean and rapeseed oils [12]. Palm fatty acid ester (PFAE) has oxidative stability, biodegradability and intense toxicity to fish and have been concluded that this oil is better than mineral oil because it has 0.6 times lower in viscosity and 1.3 times more dielectric constant. This factor cause a transformer oil that contain PFAE as an insulation liquids has better cooling efficiency and better insulation performance, thus the size of conventional transformers immersed in mineral oil could be reduced. In addition to its biodegradability, the PFAE is said to be environmental-friendly insulating oil than mineral oil if it were spill onto soil or water. Table 2.1 shows the comparison properties of PFAE, vegetable oil and mineral oil.

Table 2.1: Comparison properties of PFAE, vegetable oil and mineral oil [12].

Properties	PFAE	Vegetable Oil	Mineral Oil
Density (40°C) g/cm³	0.86	0.93	0.88
Pour point °C	-32.5	-20	-45
Flash Point (COC) °C	186	330	152
Kinetic Viscosity (40°C) mm²/s	5.06	32.9	8.13
Total acid value mgKOH/g	0.005	0.0035	<0.01
Moisture content ppm	15	43	<10
Breakdown voltage kV/2.5mm	81	77	70-75
Relative permittivity (80°C)	2.95	2.91	2.2
Tanδ(80°C) %	0.8	0.7	0.001
Volume resistivity (80°C) Ωcm	$1.9x10^{13}$	$3.7x10^{12}$	$7.6x10^{15}$

2.3 General Adsorbents for Oil Reclamation

In oil reclamation process, a few operations need to be taken which is to restore the properties and performance of the insulating liquids so that it can be reused again. It will perform various combinations of process from removing solid suspensions until purifying the oil. The purifying process to take away the by-product of chemical reaction that occurred inside a transformer during their operation need to use adsorbent which will blend together with the oil to capture and remove extremely fine impurities. A few adsorbents that typically used are Fuller's Earth, bentonite and activated carbon.

2.3.1 Fuller's Earth

Fuller's earth is specify as a natural adsorbent clays which consists of varying structure of hydrous aluminum silicates (clay minerals) [12]. It has the substantial ability to decolorize oil or other liquids and adsorb impurities without dealing with any chemical process. Figure 2.1 shows Fuller's earth substances that can be used as an adsorbent. Its name comes from textile workers (called fullers) whose cleaned woolen cloth by blending it in a mixture of water and fine earth to adsorb oil and other greasy impurities from the cloth as a finishing process.

Figure 2.1: Fuller's Earth

2.3.2 Bentonite

Bentonite, also known as Montmorillonite consists of 2:1 clay mineral consists of an octahedral sheet between two tetrahedral sheets [2]. It also an adsorbent that available with low cost and widely used for removing toxic (contaminant) metal ions from waste water. Many numbers of chemical elements has been removed when applying bentonite [13]. Figure

2.2 shows the sample of substances of bentonite. It is applied in the elimination of impurities in oils where the adsorption properties are vital in regenerate used oil. Activation treatment can be done on bentonite to improve its bleaching capacity such as acid activated.

Figure 2.2: Bentonite

2.3.3 Activated Carbon

Activated carbon also referred as activated charcoal is one of main carbon adsorbents that contain high porous construction and have tremendous specific area. It is extensively used in industrial application, medical uses, environmental application, transportation and other fields that require the adsorption characteristics and regeneration process. Activated carbon is tiny particles that have been processed to increase its surface area so that the adsorption of contaminants or impurities from fluids, vapors or gas is increase by which the impurities will adhere to the wall of the activated carbon. The sample of activated carbon is shown in Figure 2.3.

Figure 2.3: Activated Carbon

2.4 Oil reclamation technique

There are several reclamation techniques have been used to the transformer oil in order to be reused back. The techniques involve the process of changing the oil composition by removing the contaminants in the oil. A few techniques had been done by some researchers and some oil regeneration company. It consists of reclamation through adsorption and filtration type. The explanation below show four techniques usually applied for reclamation process.

2.4.1 Mechanical agitation

This method use different type of adsorbents and an insulating oil. Two liter Erlenmeyer flask is used to put one liter of insulating oil and 100g of adsorbent. This mixture is then stirred for 4 hours at 25°C using magnetic stirrer. After that, to remove the adsorbents, the mixture is vacuum filtered through 3-µm paper and the reclaimed oil can be tested [3].

2.4.2 Percolation

There are two techniques for percolation; by gravity and pressure. Percolation by gravity use gravity as the hydrostatic head of a column of oil to force the oil through column of adsorbent such as clay [14]. Basic percolation by gravity system consists of three tanks on different level. The first level is for the dirty oil reservoir which the oil that wanted to be reclaimed. Then the tank that contains adsorbent for filtering purpose and the lowest level is the tank for reclaimed oil. There will be equipped a float valve at the middle tank so that the oil will continue to flow from the dirty oil reservoir. This process takes a long time since the flow rate is slow but the process is efficient because the oil keep contact with adsorbent during percolation.

Percolation by pressure occurs with the additional of pump to force the oil through the adsorbent. A special chamber is used to hold a container that contain adsorbent and it is designed to ensure that oil is enter and pass through the adsorbent before leaving the chamber. The full view of this setup is shown in Figure 2.4. This system take a shorter time than by gravity and suitable for large volumes of oil. Therefore, the adsorbents need to change frequently to maintain the efficiency.

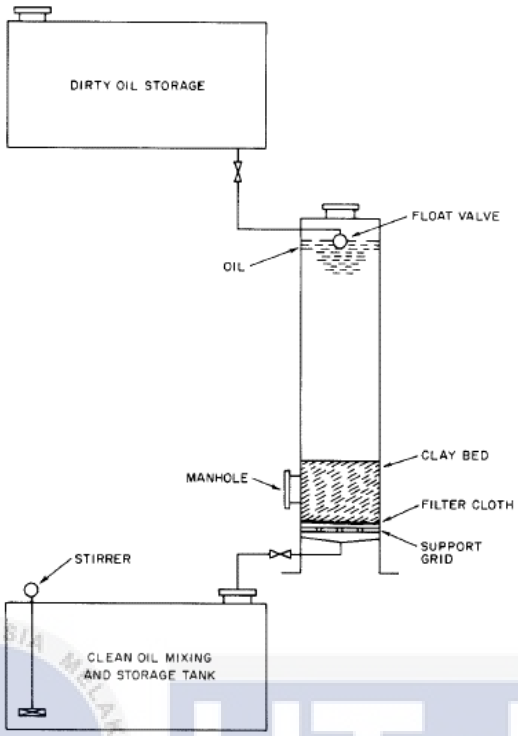

Figure 2.4: Schematic diagram of percolation by gravity [14].

2.4.3 Adsorption of soluble contaminant

Reclamation process using adsorption techniques use a ratio of 1 gram of adsorbent to 100 ml of insulating oil. Typically the process is carried by taking 5 gram of adsorbent and 500 ml of used transformer oil. These adsorbent and oil is mixed using magnetic stirrer under 750 rotations per minute (rpm) for one hour. For fine mixing, the oil is heated up to 80°C first before adding adsorbent. After that, to completely remove the adsorbent, the mixture is filtered using Whatman filter paper no. 42 [2]. Multiple reactivations also can be done using this method. The reclaimed oil from the first cycle is mixed with new adsorbents and the process is repeated as before for second cycle. Usually, the use transformer oil starts to decolorize at eighth cycle. To regenerate the used oil same as the new oil, the cycle is repeated

until the oil start to change to transparent. This cycle is repeated to ensure that the dissolved decay is completely removed.

2.4.4 Reclamation by Trisodium Phosphate

The trisodium phosphate method is a method of heating a mixture of oil and trisodium phosphate while agitating them for one hour before let the mixture to separate [14]. The used phosphate solution is drained from the tank whereas the rest is spray with water to wash from the oil. Then the oil is drafted away through a centrifuge and a heater into another tank which the clay is added into the tank before the mixture is agitated for 15 minutes and let the clay spend overnight. Thereafter, the oil is washed again with hot water and drafted through a centrifuge for further dehydrated and lastly through vacuum dehydrator or filter. This technique is economical and able to produce uniform result depending the amount of reactivation agents used as being determined by the analysis of degradation of oil.

2.5 Breakdown voltage

One of the characteristic of the transformer oil that need to take into account as an insulation is the breakdown voltage, BdV. Breakdown voltage is a properties of insulation liquid to withstand the maximum voltage before the insulator become electrically conductive. The higher the BdV, the better the insulation of the liquid. Usually, factors that affect Bdv are water content, particles and viscosity.

Water content will decline the level of breakdown voltage because of the bubbles formed in the oil as the boiling point of water is lower than mineral oil. This water content will form at lower voltage in the mineral oil thus the breakdown occurs at lower voltage due to the existing of dissolved water. In transformer, the by-product of oxidation and chemical process that occurred inside transformer will form solid impurities such as copper, iron, carbon and cellulose. These impurities may bridge the gap inside transformer and will cause declination in BdV. Besides that, BdV also related to viscosity. The decrease in viscosity will lead to decrease in breakdown voltage of mineral oil since it increases the mobility of charge carriers. In addition, the possibility to get partial discharges also high.

2.6 Acid number

Oxidation usually occurs in transformer oil which then will degrade and reduce the quality of oil, thus will affect the insulation and cooling properties. The process of oxidation will form acid, called carboxylic acid when the oil make contact with oxygen. A series of free radical reactions with the involved of peroxides will produce carboxylic acids [15]. The acid will degrade the cellulose paper in the transformer, later will form sludge and varnish deposits. This will immediately reduce the dielectric strength of the oil as well as reduce heat transfer if it is deposited inside the radiator pipes. The acid content in the transformer oil is measured by chemical titration which involving the mass of potassium hydroxide required to neutralize the acids in the oil sample (mgKOH/g) also known as neutralization number [3]. Cellulose paper and water have a relation with carboxylic acids due to the ability to bond with hydroxyl group (-OH).

2.7 Statistical Analysis Technique – Weibull Probability Plot

Applying Weibull distribution involve in characterizing the distribution of life lengths or failure times of certain devices. This is mainly due to its weakest link properties, but other reasons are its increasing failure rate with device age and the variety of distribution shapes that the Weibull density offers. The increasing failure rate accounts to some extent for fatigue failures.

A probability plot allows the user to plot time to failure data on a specially constructed plotting paper, which differs from distribution to distribution. Based on the linearity of the data points on the plot, the user can determine whether he or she has chosen a distribution that is appropriate to the data. The user can also make estimates of the distribution's parameters from scales on the plot. A distribution's probability plotting paper is constructed by linearizing the cumulative density function (cdf) or unreliability function of the distribution. Once this has occurred, the scales for the x and y axis of the distribution's plotting paper can be constructed and the plotting can commence.

2.7.1 Failure Points Plot

For the sake of simplicity, a simple set of failure times from a test group of six units that failed at 10, 20, 30, 40, 50, and 80 hours and assume that these failure times follow a two parameters Weibull distribution. Unreliability estimates for each of our failure times are needed in order to plot the data on a two-dimensional plot graph. These unreliability estimates are accomplished with median ranks (MR) [16]. The MR represents the estimate for the true

unreliability for a failure, based on the total number of failures and the order number of the failure in question. There is also an approximation that can be used to estimate MR, called Benard's approximation which as follow:

$$MR = \frac{j-0.3}{N+0.4} \tag{2.1}$$

where N is the total number of failures and j is the failure order number. Based on Benard's approximation, unreliability estimates for each of failure times are shown in the Table 2.2.

Table 2.2: Unrealibility estimation on each failure time.

Failure Time (hours)	Unreliability Estimate
10	10.9%
20	26.6%
30	42.2%
40	57.8%
50	73.4%
80	89.1%

The y-coordinate of the graph represent the unreliability estimate which from 1% to 99% while the x-coordinate represent failure times from 1 hour to 100 hours as shown in Table 2.2. With these data, a Weibull probability is plotted as shown in Figure 2.5

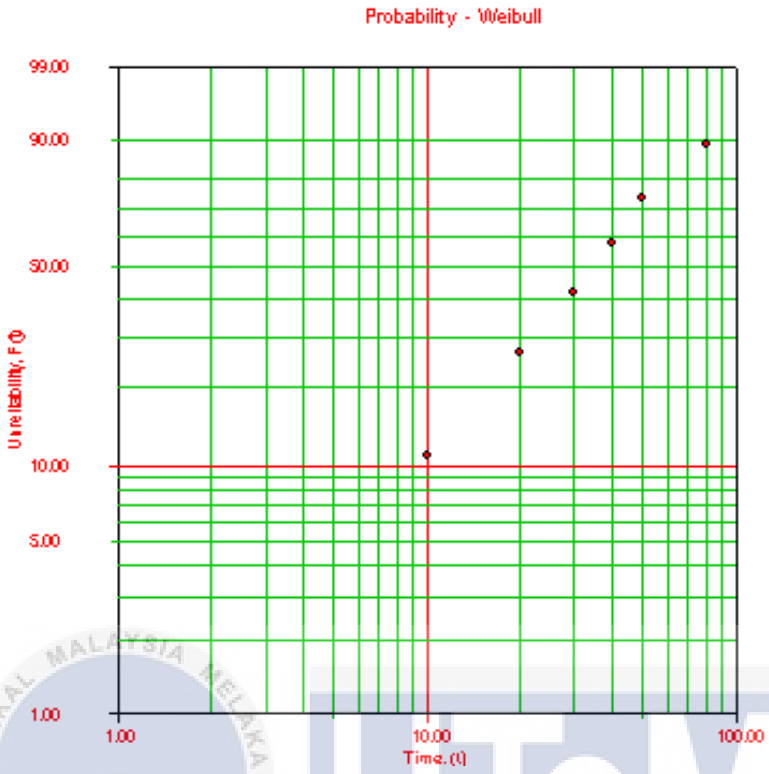

Figure 2.5: Weibull Probability Plot

The failure times plotted on Weibull probability plot paper in Figure 2.5 fall in a fairly linear fashion, indicating that our choice of the two parameter Weibull distribution was valid. Then draw a best fit line through the points.

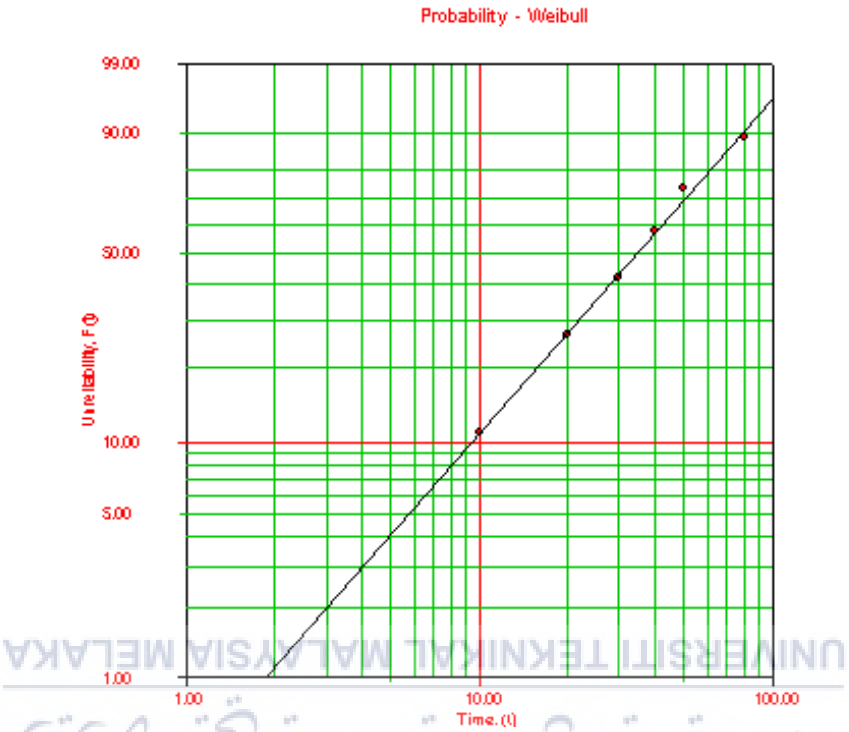

Figure 2.6: Best-fit line of Weibull probability plot.

2.7.2 Determining Parameters Estimate

Useful information need to be obtained from the probability plot which is the estimation of Weibull distribution parameters, slope parameters (β), scale parameter (η) [16]. Weibull slope, β is relatively easy. In other words, the slope of the linearized line on the Weibull probability plot is equal to the Weibull slope (or shape parameter). For instance, by drawing a line parallel to best-fit line in the Weibull probability plot able to estimate the value of β as shown in Figure 2.7 which the data set is approximately 1.4.

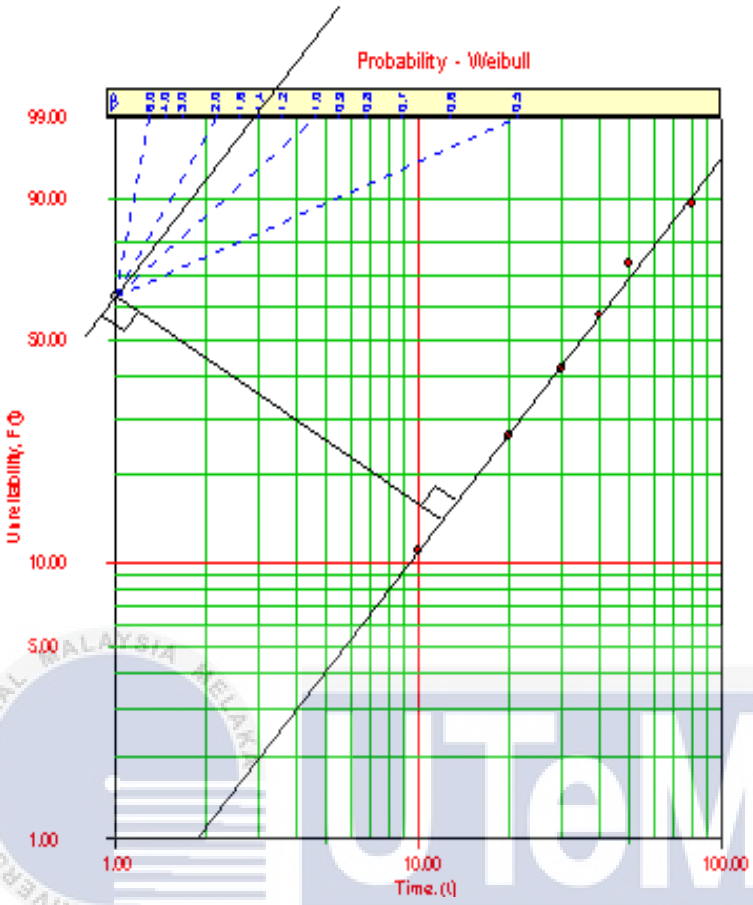

Figure 2.7: β estimation using Weibull probability plot

Mathematical manipulation of unreliability equation will be required to determine the estimate of η, the Weibull scale parameter. The two-parameter Weibull unreliability function is given by:

$$Q(T) = 1 - e^{-(\frac{T}{\eta})^{\beta}} \tag{2.2}$$

Substituting $T = \eta$ into equation 2.2;

$$Q(T) = 1 - e^{-(\frac{T}{\eta})^{\beta}}$$

$$= 1 - e^{-1}$$

$$= 0.632$$

$$= 63.2\%$$

Hence, η is where the best-fit unreliability model line intersects with a horizontal line extended from the 63.2% level of the unreliability, or y-axis scale as graphically shown in Figure 2.8.

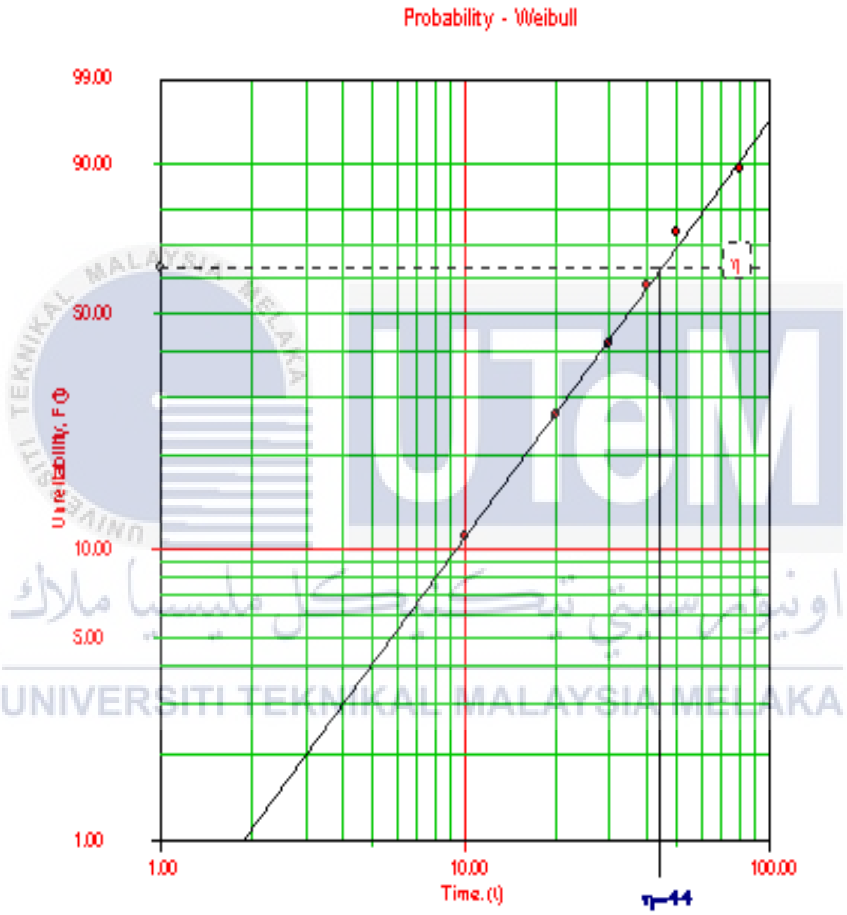

Figure 2.8: η estimation using Weibull probability plot

From Weibull probability plot in Figure 2.8, the best-fit line model intersects the 63.2% unreliability line at approximately 44 hours. Thus, the estimate η for the sample data is 44 hours [16].

2.8 Related Previous Research

In recent years, an expanding number of highly aged transformers have been conducted past the manufacturer's design life. Since no demonstrated record has been set up to date for transformers having been operated for many years, various studies have been conducted on the age related degradation state of insulating liquid. For insulating oil specifically, a decrease in characteristics can be seen under long term operating conditions and studies on the preservation and management. Researchers from [3] said that billions of liters of oil are being utilized as a part of electrical equipment all through the world. This is because of technical efficiency, accessibility, low cost compared to other dielectric means and capability to be reactivated.

Transformer oil is made by refining a small amount of the hydrocarbons gathered during the refining of a petroleum rough stock. The boiling range fraction is collected and the degree of filtering process is selected so that the oil produced has the features that fall within the limit prescribed for use in transformers. Lower and higher boiling fractions are utilized to produce different products. The raw petroleum stocks and the refining processes used to make these oils are usual technique to produce many petroleum lubricating oils.

Throughout the operation of power transformers, many corrosion activity happen, bringing degradation of insulating system. Research done by [17], he said that the impacts of thermal, electrical, mechanical and chemical stresses like hot zones, voltage spike and vibrations are liable for changes in insulation characteristics. These difference ought to be checked to ensure great performance of electrical device and also to prevent breakdown which will reduce the cost of maintenance. Since the oil in the transformer is aging, the oxidation

process occurred and the characteristics of the oil begin to degrade [19]. The by-products from oxidation activity will strike the chemical bonds in the insulating material. One of the by-product is acid and it is predicted that the acidity plays a vital role in rate of paper deterioration with the water content. The results that have been published by [20] on the effect of acidity on paper degradation, it showed that the presence of low molecular weight of acids could increase the rate of paper degradation. The decomposition of paper is measured on the number of polymerized glucose rings or called degree of polymerization (DP) as stated in IEC 60450. During paper degradation, the DP value is reduce thus the tensile strength is decrease due to the process of hydrolysis, pyrolysis and oxidation. Figure 2.5 shows the results from [20] on the DP value with different temperature using formic acid. Number of chain scission states the rate of aging of the kraft paper. Transformer oil acidity is not good for the performance of the transformer, if the insulating oil gets acidified then the moisture content will get high at the saturated level, this will affect the paper insulation winding. Obviously, contain of acid in transformer oil could harm the insulation paper thus will affect the insulation system of the transformer.

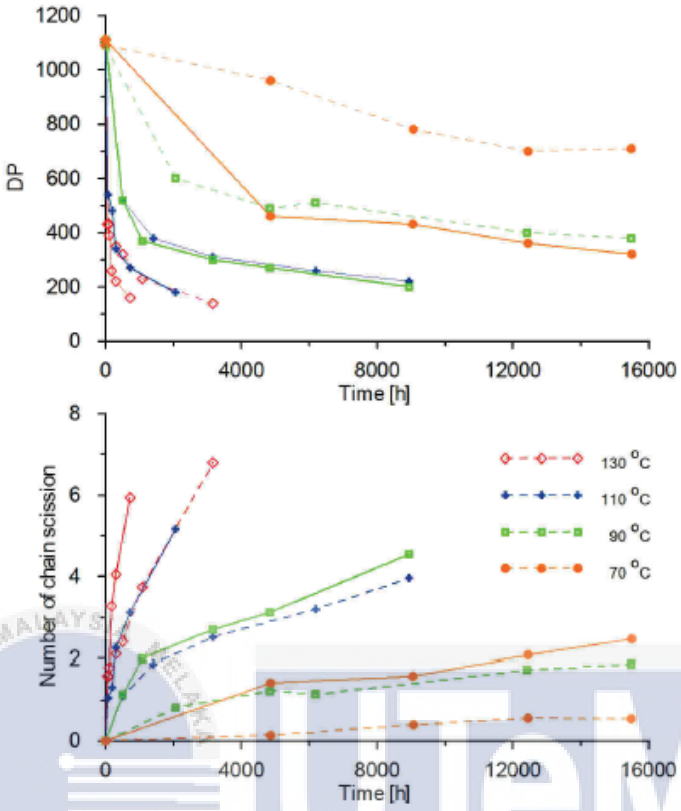

Figure 2.9: Aging of dry and wet kraft paper with formic acid [19].

Cellulose paper plays vital role as an insulation of transformer and generally the mechanical strength represent the transformer life. As the paper ages, the performance of a transformer may decline. For instance, a decrease of mechanical strength could make the paper unable to withstand the external stresses during short circuit or enormous vibration created from transformer. Oil performance also could reduce with the presence of moisture or water vapor at the cellulose paper. As reported by [21], the presence of water in transformer generally come by atmosphere and paper insulation, and increase in water content may decrease the dielectric strength and insulating characteristics of the oil. Besides that, the research done by [22] said that water content could deteriorate copper and other metals that

accommodate inside the transformer. If this thing continues to happen, transformer failure may occur.

Changing aged transformer oil with the new mineral oil is very costly. In addition, the aged oil when dispose could harm the environment and also human life. Therefore, oil reclamation or regeneration is introduced. Oil reclamation is a process removing acid component, water vapor and oxidation products by using an adsorbent during adsorption process. This process give many benefits to the utility company as well as to the community as it will help to reduce oil incineration, generated during combustion of petroleum subordinate. Experiment conducted by [13] of oil reclamation using Fuller's Earth. They executed the experiment using a laboratory made-plant which the oil is heated to 60°C. By using multiple reclamation, they observed that to decolorize the used oil, it need 15 cycles of reclamation. This also will affect dissolve decay products (DDP) removal rate which will decrease gradually as the cycle increase.

Authors [23] examined that the use of Fuller's earth helps to improve in kinematic viscosity. The viscosity is decrease from 34.55 cSt to 34.49 cSt and this is due to the removal of insoluble contaminant. They also conducted the experiment using different temperature which is 40°C and 100°C. Both result showed the improvement in kinematic viscosity. Besides viscosity, breakdown voltage also is important for insulating oil as it will determine the withstand capacity of an insulating oil. Used transformer oil typically has low breakdown voltage due to the by-product and chemical activity happened inside the transformer. Studies from [24] and [25] showed that after a few reclamation, the breakdown voltage is increase from 9 kV to 16 kV and this is due to the removal of DDP or contaminants in the reclaimed

oil. Thus, the reclamation process using Fuller's earth able to improve the performance of insulating oil.

Mineral oil always undergoes oxidation process in the presence of oxygen that will produce number of oxidation products. Usually, the final products of oxidation process are acidic which can affect the properties of insulating liquid as well as the components inside the transformer. To prevent these types of reaction, oxidation inhibitor is used that will interrupt and terminate the free radical process of oxidation. This also will improve breakdown voltage because antioxidant may help to delay the process of oxidation in oil and protect the oil as long as there is inhibitor present. Study from [26], they blended antioxidant with different kind of vegetable oil to observe the performance of breakdown voltage, viscosity, water content, interfacial tension, acidity, flash point and fire point. The antioxidant used is Gallic acid with different weight which was 1 gram and 5 gram. From that experiment, the breakdown voltage increase as the weight of antioxidant used is increase and the antioxidant improve the properties of insulating oil. Apart from that, the additions of antioxidant also reduce the acidity content in the oil and satisfy the standards.

2.9 Summary of previous research

Process improving the characteristics of used transformer oil to get the characteristics same as or almost same as new transformer oil is important especially, the selection of adsorbents and also the filtration technique. Based on previous research, Fuller's earth is a great adsorbent to be used in reclamation process as the dissolve decay product removal rate is decrease gradually. To identify the performance of the reclaimed oil, BdV test was conducted because it is one of the characteristic that should be considered for the liquid insulation. Antioxidant is add to improve the properties of insulating oil because it inhibits the oxidation process in oil. It is proposed to do reclamation process using waste cooking oil by adding Fuller's earth with mechanical agitation method and record the total acid number and moisture content before test it in BdV to determine the properties of reclaimed oil. Then add antioxidant to improve the characteristics of insulating oil.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss about the methodology of this project and also the flowchart of project will be used as a guideline to conduct the experiment and step to analyze the result. This part also will discuss about the method that suitable to be used in the process of oil reclamation with the adsorbent used in detail explanation to get the new reclaimed oil. Therefore, the result and data obtained will be analyzed and the performance of the reclaimed oil will be tested to compare with new transformer oil.

3.2 Flow of the study

The steps of the process to complete this project must be followed by sequence to make sure this project done within planned time. There are flowcharts, milestones and Gantt chart and all the steps timeline will be followed entirely in this FYP for completing this project.

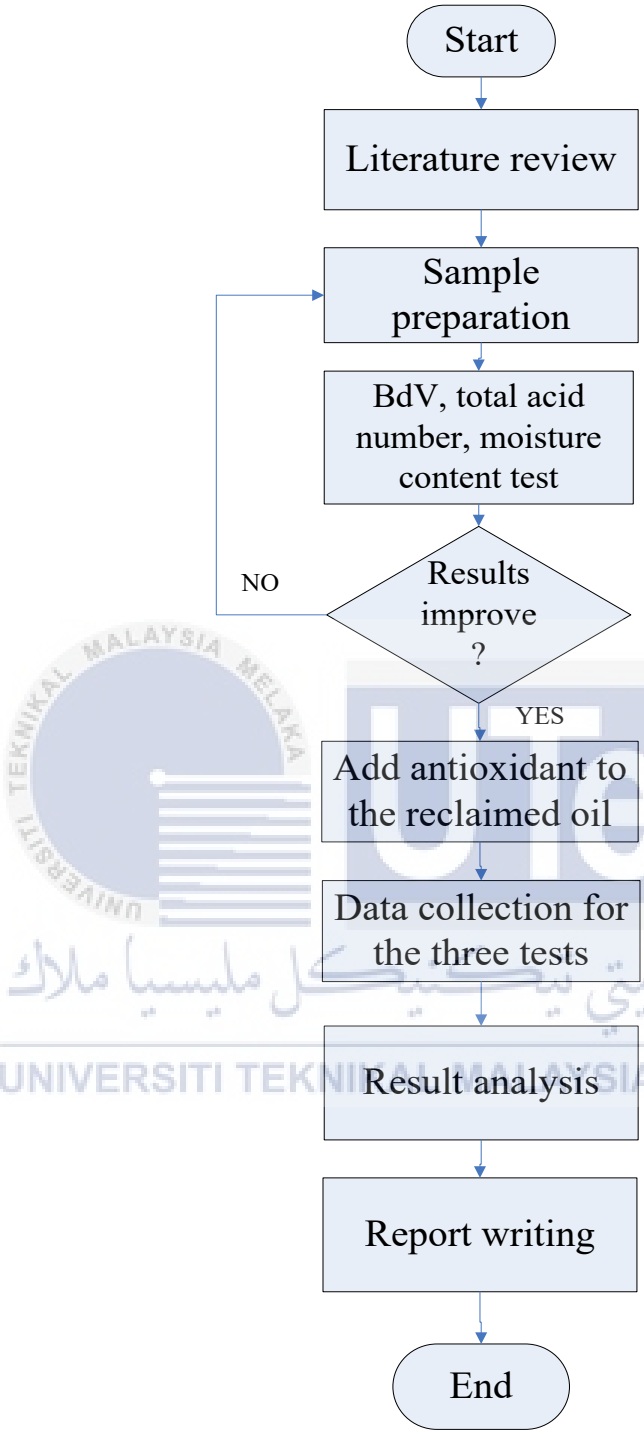

Figure 3.1: Flowchart of the project methodology.

3.2.1 Literature review

This purpose of this step is to prepare a sample of reclaimed oil to be used for breakdown voltage test, total acid number test and moisture effect test. Oil reclamation is a process where all the contaminants in used transformer oil are removed by using an agent also refer as adsorbent. Adsorbent will be mixed in with oil so that contact process occurs between those mixtures and helps to eliminate the by-products of the waste oil. The reclaimed oil will be tested on its level of breakdown voltage, acidity number and also moisture content. The details theoretical and information for this part already mentioned in Chapter 2.

3.2.2 Experimental planning (Sample preparation)

For this project, the sample used is waste cooking palm oil taken from UTeM's café. The cooking oil had been used for frying process. This sample will be used for the whole experiment in Final Year Project (FYP). For adsorbents, Fuller's earth is selected for oil reclamation process. The first step of sample preparation is by taking 1 liter of cooking oil and 500 gram of Fuller's earth and put in a beaker which is then heat to 60°C while stirring using magnetic stirrer at 750 revolution per minute (rpm) for 4 hours [3]. Figure 3.2 shows the sample is heated first before adding adsorbent.

Figure 3.2: Cooking oil is heated to 60°C with 750 rpm.

Then, to separate the mixture, glass microfiber filter paper is used for filtration by applying filtration technique by pressure. A pump will be used to force the mixture pass through the filter paper and the filtered oil is then collect into the Erlenmeyer flask as shown in Figure 3.3. After finish filtering the mixture, the reclaimed oil is put in the amber glass bottle with label and sealed it until used. The glass bottle needs to fill with nitrogen gas and seal tightly to prevent any oxygen trap inside the bottle.

In this experiment, there will be four samples of palm oil which are waste cooking palm oil, new palm oil, reclaimed palm oil and reclaimed with the addition of Propyl Gallate (PG) as an antioxidant. PG is measured for 0.3% of the mass of the oil sample and heat with reclaimed vegetable oil at 149°C (melting point of PG) for 7 minutes. Then the mixture is allowed to cool in the vacuum oven for a day before keep it in the amber glass bottle.

Figure 3.3: Experimental setup for sample preparation.

3.2.3 Testing procedure

In this section, there are three test will be conducted. The first test is breakdown voltage which is to determine the voltage that the palm oil can withstand, the second test is total acid number test which is to determine the number of acid in the oil and the last test is to discover the moisture in the oil. All this test will be conducted to know the validation and justify the performance of reclamation oil produced.

3.2.3.1 BdV Test

BdV measurement is set up according to standard ASTM D1816 standard [27]. Using Megger OTS60PB portable oil test to measure AC breakdown voltage of reclaim oil. The minimum value of oil for testing is 350ml. This equipment consists of two electrodes which the voltage breakdown will occur. The electrode needs to be cleaned first before testing process begins. The gap of electrode is set up to 1 mm and the rate of voltage is 2.0kV/s. The sample will be divided into two sample; sample A and sample B which each sample of oil will be tested up to 25 breakdown voltage test. The total of 50 test taken from two sample will be recorded and the mean of breakdown voltage test is obtain from probability plot (Weibull).

Figure 3.4: The example of BdV test

3.2.3.2 Total acid number

Total acidity or called total acid number (TAN) is the measurement of acidity that is needed by the amount of potassium hydroxide (in milligrams) which is required to neutralize the hydrogen ions (H^+) in one gram of oil.

3.2.3.2.1 Procedure to conduct TAN test

1) Set Up
   i. Set up apparatus (electrode, tubing, and stirrer).
   ii. Rinse and fill the burette with KOH in IPA (0.1 mol/L).
   iii. Standardize the KOH in IPA 0.1 mol/L.

2) Calibration
   i. Calibrate the electrode with buffer solution.
   ii. Slope 97% - 103%.

Figure 3.5: Calibration process.

3) Standardization

i. Weight around 0.1g of KHP into beaker, add approximately 8omL of DI water, titrate with KOH in IPA 0.1 mol/L.

ii. Result/ titer value will save automatically into system. (Use for sample calculation).

Figure 3.6: Standardization process

4) Blank Titration

i. Perform blank titration dairy. Measure 20mL of solvent (IPA) into titration vessel and titrate with KOH in IPA 0.1 mol/L.

ii. Duplicate the blank titration.

iii. Blank value will be auto save at Common Variable.

5) Sample Titration

i. Weigqht around 5g of sample into titration vessel.

ii. Add 20mL IPA solvent.

iii. Titrate with KOH in lPA until pH 11.5

iv. TAN result show at screen.

Figure 3.7: Sample titration process

6) Rinsing Electrode
   i. Rinse electrode with titration solvent IPA then follow by DI water. Keep the electrode moist with the electrolyte.

3.2.3.3 Moisture content

Moisture of oil is determine using Karl Fischer titration. Unlike other techniques, Karl Fischer method can trace low levels of free, emulsified and dissolved water accurately. It is a chemical analysis procedure which is based on the oxidation of sulfur dioxide by iodine in a methanolic hydroxide solution. This titration can be done volumetrically or coulometrically.

3.2.3.3.1 Procedure to conduct moisture content

1) Prepare the Karl Fischer Coulometer. The equipment is ready to use if the screen show a value which is less than 30.
2) By using syringe, measure 5g of samples.
3) On the screen, click 'add sample' and put the sample in the tube of coulometer.
4) Measure the empty syringe and put the measured value in the 'add sample' space.
5) Click 'Ok' and the equipment will run itself.
6) Record the value of water content in ppm

3.2.4 Analysis technique – Weibull Probability Plot

1) Open Minitab software
2) Fill in the data recorded in the worksheet as shown in Figure 3.8.

C3
Waste cooking oil [BdV (kV)]
6
7
6
6
6
7
6
6
6

Figure 3.8: Minitab Worksheet

3) Go to 'Graph' and choose 'Probability Plot'.
4) Select 'Single' and click 'Ok' as shown in Figure below.

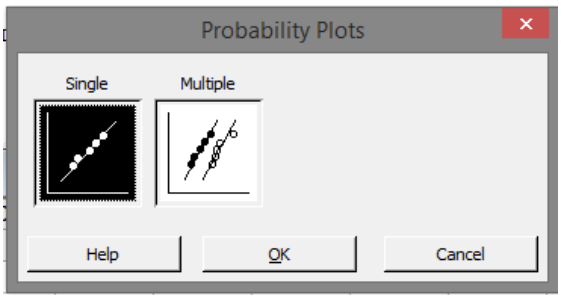

Figure 3.9: Probability plot options.

5) On the left pane, click the data that has been filled in and it will automatically show in Graph Variables box. Click ‘Ok’.

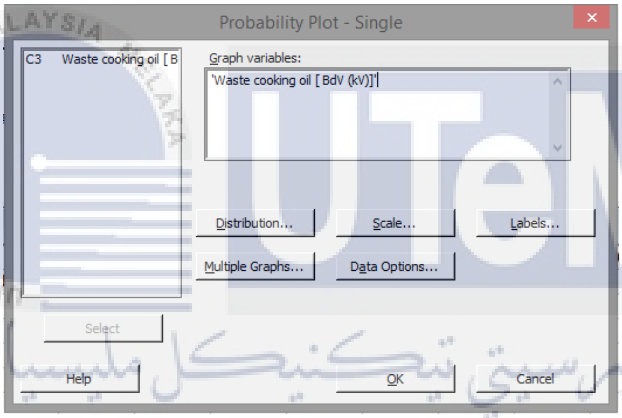

Figure 3.10: Probability plot setting

6) Pop up window will show the probability plot. The scale value is the estimate value for 63.2%. To mark the value on the plot, right click on the plot and choose ‘Add’, then select ‘Percentile Lines’. Add 63.2 value in the first box. Click ‘Ok’.

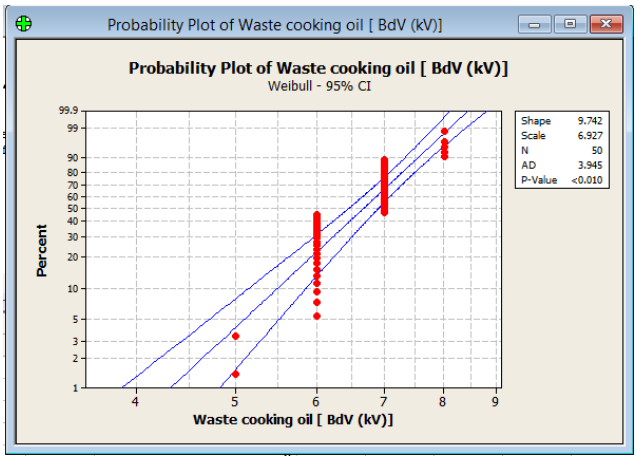

Figure 3.11: Weibull Probability plot window

3.2.5 Result analyzing

Result from BdV test are record and is analyze based on the correlation of transformer oil effect before and after reclamation process as well as after adding antioxidant. The acidity and moisture content in the oil will be analyzed to observe the effect of reclamation process and the relation with the breakdown voltage. All the data collection will be shown graphically and it will be discussed on the next chapter.

3.3 Project Milestone

There are 6 milestones set for this project to ensure this project run systematically. These milestones are referred from project Gantt Chart in Appendix A.

Milestone 1: Literature review

The first milestone is to study the concept and topology of oil reclamation and study the characteristic of new and used transformer oil and also the adsorbents used.

Milestone 2: Study the suitable method to reclaim the transformer oil and sample preparation.

The second milestone is to study the method that is suitable and efficient to reclaim or filter used transformer oil using various method.

Milestone 3: Conduct breakdown voltage and thermal conductivity test.

Start conducting breakdown voltage test and thermal conductivity test on reclaimed oil.

Milestone 4: Observe and record the data obtained

Observe the changing of physical characteristic of reclaimed oil and record the data to analyse.

Milestone 5: Analyse the result

Data obtained from the test is analyse.

Milestone 6: Report writing.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This part will discuss detail on this results of this experiment based on the testing that has been done. The discussion will focus on the breakdown voltage, total acid number and also moisture content in four conditions of palm oil which are used oil, new oil, reclaimed oil and reclaimed oil with antioxidant.

4.2 Physical change of oil samples

The reclamation process using and adsorbents changed the color of sample of waste cooking oil to light brown from dark brown. The changing of color from dark to light indicates that some of the contaminant in the oil is successfully remove. Figure 4.1 shows the result obtained from the reclamation process using Fuller's earth. The dark color signifies that the oil is contaminated with acid and other chemical composition. It will keep darken as the

deterioration process occurred [13]. For this project, the Fuller's earth will be used as an adsorbent in reclamation process.

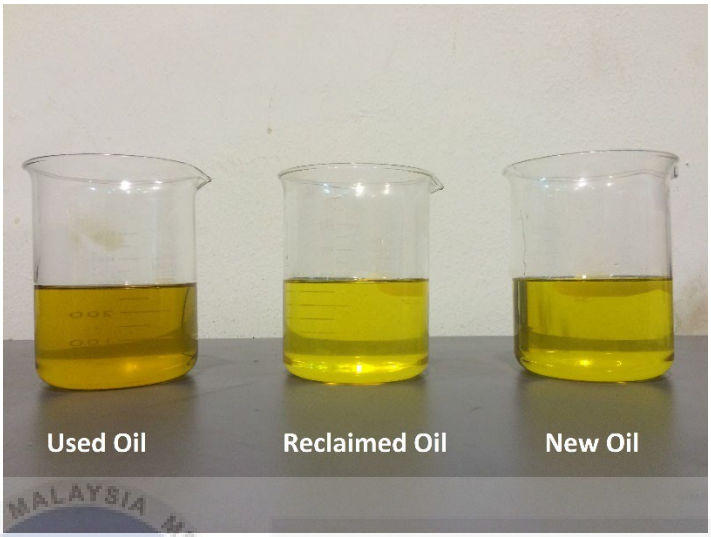

Figure 4.1: Color of cooking oil for three stages.

Based on Figure 4.1, the reclamation process of waste cooking oil produced new oil which has almost similarity in color with the new cooking oil. From this process, it can be concluded that most of the contamination contained in the waste cooking oil has been absorbed by Fuller's Earth during contact process for four hours. The process of mechanical agitation helps to improve the content in the oil hence it has high possibility to be used as an insulation liquid inside a transformer.

4.3 Breakdown voltage test

In assessing the condition of oil's insulating properties; the breakdown voltage measurement plays an important role. The important factors that determine the breakdown voltage of the oil are moisture, air bubbles, suspended solid matters and acidity of fluid. BdV

test in this research is conducted with four sample of oil which is for waste cooking oil, new cooking oil, reclaimed cooking oil and reclaimed cooking oil with the addition of antioxidant. Each oil is divided into two samples which then each sample has been conducted with 25 BdV test. So the total BdV test that has been done for each oil is 50 test based on the standard ASTM D1816 with 1 mm electrode gap. Weibull probability plot is used to measure the best value of the data as it has been widely used for voltage endurance test data to insulation specimens and also measured the breakdown voltage in experiments. The probability value of the data falls at 63.2% where it is the point corresponds to the time of failure of the specimen under test [230].

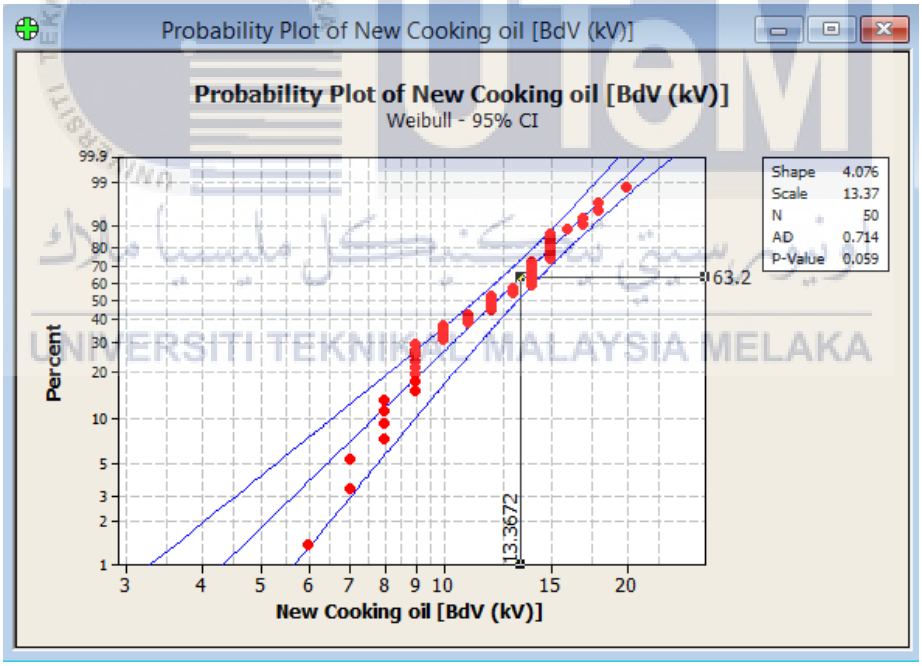

Figure 4.2: Weibull probability plot of new cooking oil.

Based on Appendix B in Table B.1, the breakdown voltage for new cooking oil shows scattered value for two sample. Sample A shows 6kV of minimum BdV test and 14kV for

maximum BdV test while sample B shows 9kV of minimum and 20kV of maximum BdV test. Between these samples, sample B has high average value of BdV test. By applying Weibull probability plot, the best-fit model line intersects the 63.2% unreliability line at approximately 13.3672 kV as shown in Figure 4.2.

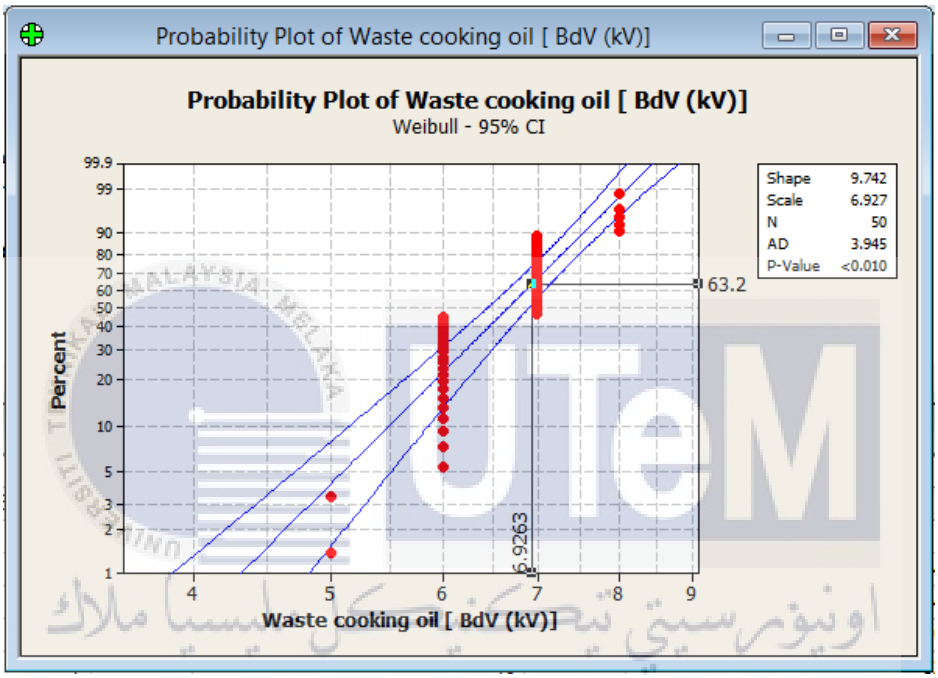

Figure 4.3: Weibull probability plot of waste cooking oil

Breakdown voltage for waste cooking oil shows uniform value from both tests as shown in Appendix B in Table B.2. Based on Figure 4.3 of Weibull probability plot, the approximate value of BdV that intersects the 63.2% unreliability line is 6.9263 kV. It can be observed from Table B.2 that the value of waste cooking oil is low. This is due to the contamination contained in the oil that will affect the breakdown voltage.

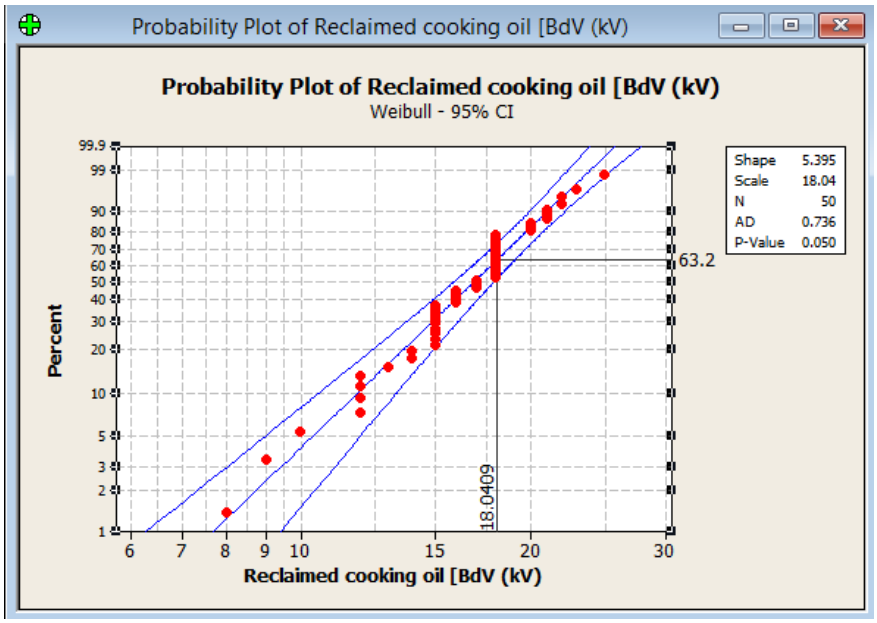

Figure 4.4: Weibull probability plot of reclaimed cooking oil.

After reclamation process, there is some improvement in breakdown voltage of the oil as shown in Appendix B in Table B.3. Based on Figure 4.4 of Weibull proability plot, the approximate value of BdV that intersects the 63.2% unreliability line is 18.0409 kV. From the calculation, the percentage of enhancement is 160.47% from the BdV value of waste cooking oil. The increasing of BdV is depending on several factors such as the removal of the relative content of DDP, moisture and solid particles during the reclamation process [24]. The number of water that presence in the oil could affect the properties and performance of liquid insulation [21]. Thus, the absorption of contaminant by adsorbent helps to gain the breakdown voltage.

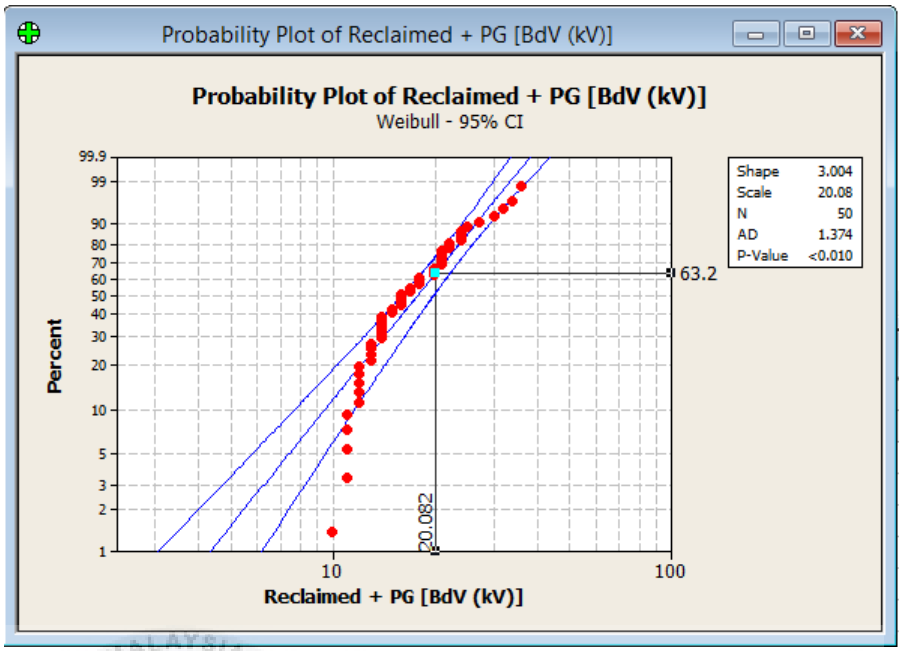

Figure 4.5: Weibull probability plot of reclaimed cooking oil with antioxidant.

In the last sample, the reclaimed cooking oil was add with antioxidant which is Propyl Gallate (PG). The value of breakdown voltage has been recorded in Appendix B in Table B.4. From the calculation, there is improvement about 189.94% when compared to BdV value of waste cooking oil and 11.31% when compared to BdV value of reclaimed cooking oil which from the Weibull probability plot, the approximate value of BdV that intersects the 63.2% unreliability line is 20.082 kV as shown in Figure 4.5. The additional of PG as an antioxidant helps to improve breakdown voltage of reclaimed cooking oil as it prevent the oil from oxidize thus slowing the degradation of cooking oil as insulation liquid [26]. Besides that, one of the properties of antioxidant is to inhibit the process of oxidation in the oil. Therefore, by adding antioxidant in the liquid insulation, it will improve the performance of the liquid insulation.

4.4 Total acid number

The acidity of transformer oil does not give any benefit to the performance of the transformer and its function. At any moment, if the oil is acidified, this will later affect the paper insulation of the winding thus increase the oxidation process in the transformer oil. Different types of oil contain different compound and structure. Due to hydrolysis reaction that occurred only in vegetable oil and also different chemical structure than other oil, vegetable oil is said to have high acidity than mineral oil. High molecular acids (HMA) such as oleic and stearic acids usually contain in vegetable oil while low molecular acids (LMA) such as formic, acetic and levulinic acids contain in mineral oils [30]. All the total acid number test (TAN) is recorded from test 1 until test 3 based on the ASTM D974. The average value of TAN is calculated from the three test. The main point of this test is to study the effect of TAN in vegetable oil with different sample of oils.

Table 4.1: Result of TAN test with different oil sample.

Oil samples	Acid Number (mgKOH/g)			
	Test 1	Test 2	Test 3	Average
New Oil	0.1886	0.1857	0.1912	0.1885
Waste Oil	1.0734	1.0686	1.0721	1.0714
Reclaimed oil	0.7777	0.7807	0.7856	0.7813
Reclaimed oil + Antioxidant	3.1314	3.1105	3.1463	3.1294

Result in Table 4.1 shows the value of acid number for three tests and it average with four different kind of oil sample. The new oil shows the value of TAN is 0.1885 mgKOH/g while used vegetable oil shows higher value of average of acid number which is 1.0714 mhKOH/g. The high value of acid number happened due to the contamination in the oil. The oil will be more acidic if it is being exposed to oxygen and easy to oxidize hence reduce it functionality as an insulation [24]. In this case, the waste oil formerly was a cooking oil. The oil had been used many times for frying process, thus the contaminant is high and very acidic. After reclamation process, the acid number is decrease to 0.7813 mgKOH/g but higher than the value of new oil. From the calculation, the enhancement is 27.08% from waste cooking oil. The reduction of acid number is due to the removal of carboxylic acid compound by the adsorbent such as free fatty acids which was formed during the aging of insulation liquid [33]. The adding of antioxidant increase the acid number gradually to 3.1294 mgKOH/g due to the contents in Propyl Gallate itself which was formed by the condensation of gallic acid and propanol.

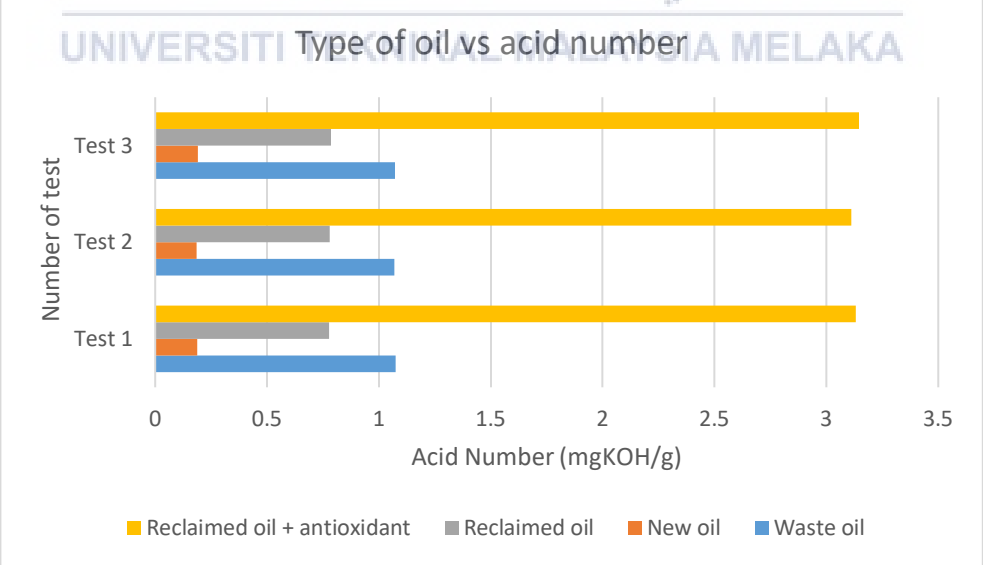

Figure 4.6: Type of oil vs acid number

Figure 4.6 shows the graphical view for type of oil versus acid number for each test on the samples. New oil has lowest value of acid number because it has never been exposed to air, waste cooking oil ranks third lowest due to the oxidation happened to the oil and the oil has become acidic. After reclamation process, some of the contamination has been removed by the adsorbents, thus the value of acid number is decrease. The addition of antioxidant increase the value of acid number because the presence of gallic acid in that antioxidant.

4.5 Moisture content

One of the most destructive factors that affect the life of paper insulation in power transformers is water. Water also will reduce the performance of transformer oil as an insulation liquid. There are a few ways water enter into power transformer for example the residual water during the manufacturing process, water vapor absorbed from the environment during installation process and also water produced from the deterioration of cellulose paper [34]. The increase of water vapor in insulation liquid may not only reduce its dielectric strength but also changes the partial electrical field distribution which then will cause in discharge or breakdown of insulation.

Table 4.2: The result of moisture content for different oil samples.

Oil sample	Moisture content (ppm)			
	Test 1	Test 2	Test 3	Average
New Oil	833.1	835.9	842.5	837.2
Waste Oil	1218.8	1201.6	1211.4	1210.6
Reclaimed oil	694.5	688.7	690.1	691.1
Reclaimed oil + Antioxidant	173.5	183.2	185.0	180.6

This experiment was conducted using Karl Fischer method to verify the effect of reclamation process on the moisture content inside reclaimed oil. Four sample were prepared to conduct the test which are for new oil, used oil, reclaimed oil and reclaimed oil with antioxidant. Three tests were conducted for each sample and the average values of moisture content were calculated. From Table 4.6, used oil contains high part per million (ppm) which is 1210.6 ppm in average while new oil has 837.2 ppm. This high ppm most probably due to the long exposed to the surrounding before the oil was taken for this experiment. The exposed oil will damaged the oil itself because of the presence of water vapor and might affect the withstand capability of oil as an insulation [33]. After reclamation process, the moisture content in the oil is slightly decrease to an average value of 691.1 ppm with improvement of 42.91% from waste cooking oil. Thus, the used of Fuller's earth as an adsorbent give significant reduction in moisture content [35]. The addition of antioxidant gradually reduces the moisture content as the result recorded value as low as 180.6 ppm with 85.08% enhancement from waste cooking oil and 73.87% from reclaimed cooking oil.

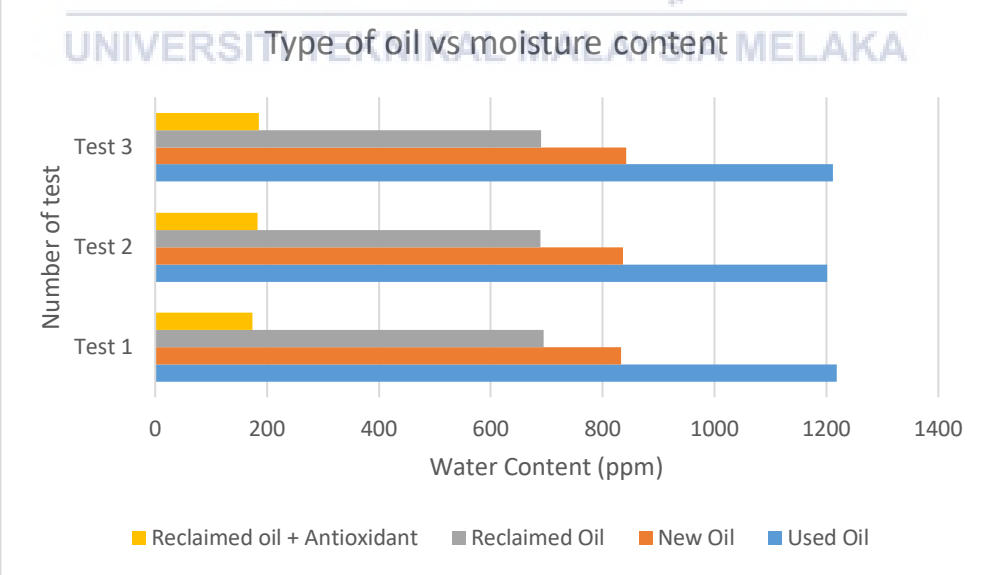

Figure 4.7: Type of oil vs moisture content

4.6 Summary of result

Table 4.3: Results for all tests.

Tests / Oil samples	Breakdown Voltage (kV)	Total Acid Number (mgKOH/g)	Moisture Content (ppm)
New Cooking Oil	13.3672	0.1885	837.2
Waste Cooking Oil	6.9263	1.0714	1210.6
Reclaimed Cooking oil	18.0409	0.7813	691.1
Reclaimed Cooking Oil + Antioxidant	20.082	3.1294	180.6
Percentage Enhancement	189.94%	27.08%	85.08%

Table 4.3 shows the summary of all the results that have been done. Based on the average data collected, reclamation of waste cooking palm oil helps to improve the performance of oil. This is proof from the value of breakdown voltage recorded which has reached up to 20.082 kV after adding antioxidant with 189.94% improvement of which compared from waste cooking oil. The addition of antioxidant also improves the moisture in the oil which the recorded value is 180.6 ppm with 85.08% improvement when compared to waste cooking oil. The reclamation of waste cooking oil reduced the total acid number to 0.7813 mgKOH/g with 27.08% improvement when compared to waste cooking oil.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the previous work, oil reclamation is the process of removing all contaminants and solid impurities as the by-products of oxidation and chemical reaction that occurred inside a transformer. This method helps to decolorize waste cooking oil into light color which indicates some of the contaminant had been removed by using an adsorbent called Fuller's earth. Fuller's earth was mixed with waste cooking oil before filtration processes to remove the used adsorbents and obtain only reclaim cooking oil. The addition of Propyl Gallate as an antioxidant prevent oil from oxidize thus improve the performance of oil as an insulation liquid. The study of dielectric strength of reclaimed waste cooking oil shows that the improvement in breakdown voltage by 189.94% due to the removal of contamination during reclamation process and the additional of antioxidant inhibit the process of oxidation, the oil will be protected as long as there is inhibitor present. Reclamation process improves the performance of waste cooking oil as the total acid number and moisture content can be reduced by 27.08% and 85.08% respectively. Thus, it can be concluded that the reclamation of waste cooking oil has great potential to be used as liquid insulation in power transformer because it is more environmental friendly compared to mineral oil.

5.2 Recommendation

Heat, moisture, oxidation and others are the characteristics that can reduce the properties of insulation oil during their operation. Since the temperature of insulation oil in the transformer is different based on their operation, it is suggested to further study on the effect of variation of heat on the value of breakdown voltage, acid number and also moisture. The range of temperature could be set from 30°C to 100°C with different of 10°C.

Besides that, to enhance those parameters, it is recommended to use two or more antioxidants to see the efficiency of mix of antioxidants and analyze their oxidation stability to observe the effectiveness of the antioxidant.

REFERENCES

[1] Recycling Resources. Retrieved from http://www.ehso.com/recyclingfacts2.php. Accessed on 8th December 2015.

[2] Raymon and R. Karthik: Reclaiming Aged Transformer Oil with Activated Bentonite and Enhancing Reclaimed IEEE Transactions on Dielectrics and Electrical Insulation Vol. 22, No. 1; February 2015.

[3] H. M. Wilhelm et al.: Reclaiming of In-service Natural Ester-based Insulating Fluids IEEE Transactions on Dielectrics and Electrical Insulation Vol. 20, No. 1; February 2013

[4] C. Homagk, K. Mossner, T. Leibfried: Investigation on degradation of power transformer solid insulation material. Institute of Electric Energy Systems and High Voltage Technology. University of Karlsruhe, Germany.

[5] Transformer Oil Analysis. Retrieved from http://www.machinerylubrication.com/Read/282/transformer-oil-analysis. Accessed on 12 October 2015.

[6] D. N. Tanteh, S. Y. Al-Liddawi, D. Ssekasiko. Properties of transformer oil that affect efficiency. Department of Electrical Engineering, Blekinge Institute of Technology, January 2014.

[7] Re-refining of Engine Oil, Transformer Oil & Hydraulic Oil. Retrieved from http://npcs.in/profiles/profile/1713/re-refining-engine-oil-transformer-oil-hydraulic-oil.html. Accessed on 7 Nov 2015.

[8] Knowledge Base: Transformer Oil/ Insulating Oil. Retrieved from http://powerlinkoil.com/knowledge-base-transformer-oil-insulating-oil/. Accessed on 7 Nov 2015

[9] Babuparamashiva, U.; Chaudhari, S.; Bhatia, A.K., "Experimental investigation of iso-paraffinic oil for application in high voltage power transformers," in *Properties and Applications of Dielectric Materials (ICPADM), 2012 IEEE 10th International Conference on the*, vol., no., pp.1-4, 24-28 July 2012.

[10] Langhame, Y.; Castonguay, J.; Bedard, N.; St-Onge, H., "Low Temperature Performance of Naphthenic and Paraffinic Oils in Transformers and Automatic Circuit Reclosers," in *Power Apparatus and Systems, IEEE Transactions on* , vol.PAS-104, no.4, pp.910-917, July 1985.

[11] Petroleum and Mineral Oil Products Information. Retrieved from http://www.globalspec.com/learnmore/materials_chemicals_adhesives/industrial_oils_fluids/petroleum_mineral_oil_products. Accessed on 8 Nov 2015.

[12] Kano, T.; Suzuki, T.; Oba, R.; Kanetani, A.; Koide, H., "Study on the oxidative stability of palm fatty acid ester (PFAE) as an insulating oil for transformers," in *Electrical Insulation (ISEI), Conference Record of the 2012 IEEE International Symposium on* , vol., no., pp.22-25, 10-13 June 2012

[13] N'Cho, J.S.; Fofana, I.; Beroual, A.; Aka-Ngnui, T.; Sabau, J., "Aged oils reclamation: Facts and arguments based on laboratory studies," in *Dielectrics and Electrical Insulation, IEEE Transactions on* , vol.19, no.5, pp.1583-1592, October 2012.

[14] C. Breen, "Thermogravimetric study of the desorption of ciclohexylamine and pyridine from and acid-treated Wyoming bentonite, Clay minerals, Vol. 26, pp. 473–486, 1991.

[15] R. A. Lipshteĭn and M. I. Shakhnovich, *Transformer Oil*, 2nd ed., rev. and English translated from Russian by IPST staff. Jerusalem, Israel: Israel Program for Scientific Translations, 1970.

[16] Probability Plotting, The Issue's Reliability Basics. Retrieved from http://weibull.com/hotwire/issue8/relbasics8.htm. Accessed on 15th May 2016.

[17] M. R. Meshkatoddini, "Aging Study and Lifetime Estimation of Transformer Mineral Oil", Am. J. Eng. Appl. Sci., Vol. 1, No. 4, pp.384-388, 2008

[18] IEEE Guide For the Reclamation of Insulating Oil and Criteria for Its Use," in *ANSI/IEEE Std 637-1985*, vol., no., pp.0_1-, 1985.

[19] Hariharasudhan, T.; Sankara Kumar, S., "Ageing analysis of insulating oil under various atmospheric conditions," in *Circuit, Power and Computing Technologies (ICCPCT), 2014 International Conference on* , vol., no., pp.1018-1021, 20-21 March 2014.

[20] L. E. Lundgaard et al.: Ageing of Mineral Oil impregnated Cellulose by Acid Catalysis IEEE Transactions on Dielectrics and Electrical Insulation Vol. 15, No. 2; April 2008.

[21] Jung-Il Jeong, Jung-Sik Anand and Chang-Su Huh "Accelerated Aging Effects of Mineral and Vegetable Transformer Oils on Medium Voltage Power Transformers"

IEEE Transactions on Dielectrics Electrical Insulation, vol. 19, no. 1, pp. 156-161, 2012.

[22] Kohtoh, M.; Kaneko, S.; Okabe, S.; Amimoto, T., "Aging effect on electrical characteristics of insulating oil in field transformer," in *Dielectrics and Electrical Insulation, IEEE Transactions on* , vol.16, no.6, pp.1698-1706, December 2009.

[23] M.A. Usman , O.G. Kayode-Sote, Reclamation Of Used Lubricating Oils, Department of Chemical Engineering, University of Lagos, Nigeria.

[24] S. Ab Ghani, N. Asiah, H. Zainuddin., "Performance of Palm Shell Activated Carbon as an Alternative Adsorbent for Reclamation of Used Transformer Oil', Institute of High Voltage and High Current, Malaysia, 2015.

[25] Huifei Jin. "Dielectric Strength And Thermal Conductivity Of Mineral Oil Based Nanofluids" Delft University of Technology, Netherlands, April 2015.

[26] M. Karthik, M. W. Iruthayarajan and M. Bakrutheen, "Investigation of vegetable oil blended with antioxidant," *Electrical, Computer and Communication Technologies (ICECCT), 2015 IEEE International Conference on*, Coimbatore, 2015, pp. 1-7.

[27] Malaysian Standard, "MS IEC 60156:2012 Insulating liquids — Determination of the breakdown voltage at power frequency — Test method." 2012.

[28] S. Krawiec, S. Leath,"Improved Heat Transfer Capability Using Iso-Paraffins Versus Naphthenics In Transformers", International Doble Conference LUB-2403E, August 2011.

[29] R. Karthik, T.S.R. Raja and S. Madavan, "Enhancement of Critical Characteristics of Transformer Oil Using Nano Materials", Arabian J. Sci. Eng., Springer Publications, Vol. 3, No. 20, pp. 369-374, 2012.

[30] G. C. Stone, E. A. Boulter et al, “Electrical Insulation for Rotating Machines: Design, Evaluation, Aging, Testing and Repair”, IEEE Pres Series on Power Engineering,2004.

[31] N. Lelekakis, J. Wijaya, D. Martin, “The effect of acid accumulation in power transformer oil on the aging rate of paper insulation” IEEE Electrical Insulation Magazine, vol. 30, no. 3, May 2014.

[32] A. Ciuriuc, P. V. Notingher, M. Jovalekic and S. Tenbohlen, "Experimental study on vegetable and mineral transformer oils properties," *Optimization of Electrical and Electronic Equipment (OPTIM), 2014 International Conference on*, Bran, 2014, pp. 169-174.

[33] H. M. Wilhelm, L. Tulio, R. Jasinski and G. Almeida, "Aging markers for in-service natural ester-based insulating fluids," in *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 18, no. 3, pp. 714-719, June 2011.

[34] Junru Xiang, Jian Li and Zhaotao Zhang, "Influence of water content on the aging performance of natural ester-paper insulation," *High Voltage Engineering and Application (ICHVE), 2012 International Conference on*, Shanghai, 2012, pp. 663-666.

[35] P. M. Mitchinson, P. L. Lewin, I. L. Hosier, G. Chen and P. Jarman, "Oil reclamation - just a question of moisture?," *2006 IEEE Conference on Electrical Insulation and Dielectric Phenomena*, Kansas City, MO, 2006, pp. 73-76.

APPENDIX A

Project Gantt Chart

Milestone	Year	2015				2016				
	Month / Task	9	10	11	12	1	2	3	4	5
1	Literature review									
2	Sample preparation									
3	BdV and thermal conductivity testing									
4	Record and data collection									
5	Result analysis									
6	Report writing									

APPENDIX B

Table B.1: Breakdown voltage of new cooking oil

Sample / Test	A	B	Value of 63.2% using Weibull probability plot (kV)
	BdV (kV)	BdV (kV)	
1	8	17	
2	9	15	
3	7	15	
4	13	10	
5	9	13	
6	8	12	
7	8	15	
8	10	15	
9	7	11	
10	8	15	
11	11	16	
12	9	14	
13	14	9	13.3672
14	12	18	
15	12	14	
16	9	17	
17	12	14	
18	6	14	
19	10	15	
20	14	14	
21	9	14	
22	9	18	
23	11	20	
24	10	9	
25	12	15	

Table B.2: Breakdown voltage result for waste cooking oil

Sample / Test	A	B	Value of 63.2% using Weibull probability plot (kV)
	BdV (kV)	BdV (kV)	
1	6	6	6.9263
2	6	6	
3	7	7	
4	6	7	
5	7	7	
6	6	8	
7	6	7	
8	6	6	
9	7	7	
10	6	8	
11	6	7	
12	6	7	
13	7	7	
14	7	6	
15	6	6	
16	7	6	
17	6	6	
18	7	8	
19	5	6	
20	7	8	
21	7	7	
22	5	7	
23	7	8	
24	6	7	
25	7	6	

Table B.3: Breakdown voltage result for reclaimed cooking oil.

Sample / Test	A	B	Value of 63.2% using Weibull probability plot (kV)
	BdV (kV)	BdV (kV)	
1	13	15	18.0409
2	12	21	
3	15	12	
4	14	22	
5	18	15	
6	18	21	
7	10	22	
8	16	20	
9	17	8	
10	18	18	
11	15	18	
12	16	25	
13	16	18	
14	18	12	
15	9	18	
16	18	18	
17	20	18	
18	15	17	
19	12	23	
20	15	20	
21	15	17	
22	15	18	
23	16	18	
24	14	18	
25	15	21	

Table B.4: Breakdown voltage result for reclaimed cooking oil with antioxidant.

Sample / Test	A	B	Value of 63.2% using Weibull probability plot (kV)
	BdV (kV)	BdV (kV)	
1	15	27	20.0820
2	13	20	
3	12	12	
4	11	16	
5	11	14	
6	14	16	
7	14	21	
8	12	17	
9	11	20	
10	16	20	
11	12	22	
12	18	24	
13	22	34	
14	14	25	
15	21	36	
16	13	15	
17	10	18	
18	14	18	
19	13	17	
20	14	21	
21	21	24	
22	16	24	
23	12	30	
24	13	32	
25	11	21	