DIELECTRIC PROPERTIES OF VIRGIN COCONUT OIL

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UNIVERSITI SAINS MALAYSIA

2018

DIELECTRIC PROPERTIES OF VIRGIN COCONUT OIL

by

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Thesis submitted in partial to fulfillment of the requirements for the degree of Bachelor of Engineering (Electrical Engineering)

JUNE 2018

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere gratitude to my supervisor, Ir. Dr. Norasiah Binti Muhamad for the continuous support of my final year project, for her patience, motivation, and immense knowledge. Without her assistance and dedicated involvement in every step throughout the process, this paper would have never been accomplished. I would like to thank you very much for her support and understanding over these two semesters.

I would also like to thank Asscociate Professor Dr. Ir Syafrudin Bin Masri of the Electric and Electronic School of Universiti Sains Malaysia as the second reader of this thesis, and I am gratefully indebted to him for his very valuable comments on this thesis.

In addition, I would also like to thank the technician of Discharge and Insulation Laboratory, En Jamaludin and En Shauki for their guidance and help during the experiment. Not forgotten, my special thanks to all my friends for their encouragement and understanding over these past four years.

I would also like to acknowledge School Of Electrical and Electronic Engineering of Universiti Sains Malaysia for giving me an opportunity to finish my final project. Also, thanks to TJH2b Analytical Services Sdn. Bhd. for their cooperation and patience in testing the sample.

Last but not least, I would like to express my very profound gratitude to my family, my parents, brother and sister for supporting me spiritually throughout writing this thesis and my life in general. This accomplishment would not have been possible without them. Thank you.

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LIST OF ABBREVIATIONS

VCO	Virgin Coconut Oil
kV	Kilo Voltage
ASTM	American Society for Testing and Materials
IEC	International Electro Technical Comission
BDV	Breakdown Voltage
cSt	Centistoke
ppm	Parts per million
max	Maximum
min	Minimum

SIFAT DIELEKTRIK MINYAK KELAPA DARA

ABSTRAK

Pengubah voltan telah menjadi salah satu peralatan terpenting dalam sistem kuasa elektrik terutamanya dalam sistem pengagihan kuasa. Oleh itu penggunaan cecair penebat seperti minyak mineral (yang paling biasa digunakan) adalah sangat penting untuk mengurangkan kadar kegagalan, kesan penuaan, meningkatkan jangka hayat dan bertindak sebagai medium penyejuk (agen pemindahan haba). Minyak mineral mempunyai kekuatan dielektrik dan prestasi penyejukan yang baik, tetapi ia mempunyai kesan negative yang serius terhadap alam sekitar seperti sumber yang tidak boleh biodegradasi, tidak boleh diperbaharui dan sukar dilupuskan setelah minyak mineral rosak sepenuhnya. Oleh itu, tiga ujian iaitu voltan pecah tebat, kandungan air dan kelikatan dilakukan untuk menyiasat sifat-sifat dielektrik minyak kelapa dara kerana ia mengalami proses penguraian sepenuhnya tanpa toksik dan mudah diperoleh di negara tropika. Walau bagaimanapun, kemasukan kelembapan ke dalam minyak penebat boleh mengubah ikatan hidrokarbon asid lemak dan menurunkan voltan pecah tebat. Oleh itu, kertas ini akan membentangkan kajian tentang kesan tahap kelembapan pada voltan pecah tebat dan kelikatan kinematic minyak kelapa dara. Voltan pecah tebat dijalankan mengikut piawaian IEC601566 manakala kandungan air dan kelikatan kinematic dijalankan mengikut piawaian ASTM D1533 dan ASTM D445. Hasil yang diperolehi untuk voltan pecah tebat, kandungan air dan kelikatan minyak kelapa dara masing-masing adalah 22.9kV, 1235ppm dan 22.9cSt. Walau bagaimanapun, minyak kelapa yang dipanaskan pada suhu 70°C mempunyai voltan pecah tebat yang lebih tinggi iaitu 99.8kV. Juga, penurunan voltan pecahan adalah berkadar dengan peningkatan kelembapan tetapi kelikatan kinematik sedikit berubah. Selain itu, kadar penurunan voltan pecah tebat dengan peningkatan kelembapan untuk VCO adalah lebih rendah berbanding minyak mineral. Oleh itu, minyak kelapa dara mempunyai voltan pecah tebat yang baik dengan keupayaan untuk menyerap lebih banyak kelembapan dari kertas Kraft supaya kertas tersebut kering. Walau bagaimanapun, kelikatan kinematik yang tinggi menyebakannya tidak sesuai dijadikan sebagai penebat.

DIELECTRIC PROPERTIES OF VIRGIN COCONUT OIL

ABSTRACT

The transformer has become one of the most important equipment in electrical power system, especially in power distribution system. Therefore, the application of liquid insulator such as mineral oil (most commonly used) is very important to reduce the failure, ageing effect, increase the life span and act as a cooling medium (heat transfer agent). Mineral oil has a good dielectric strength and cooling performance, but it has serious negative environmental impact such as non-biodegradable, non-renewable resource and difficult to dispose when the mineral oil deteriorates completely. As a result, three tests, breakdown voltage, water content and viscosity are carried out to investigate the dielectric properties of virgin coconut oil since it biodegrades completely without toxic and easy to obtain in the tropical country. However, the moisture ingress into the insulation oil can alter the hydrocarbon bond of the fatty acid and lowering the breakdown voltage. Therefore, this paper presents a study about the effect of the moisture level of VCO on breakdown voltage and kinematic viscosity. The breakdown voltage (BDV) is conducted according to IEC 601566 standard, while water content and kinematic viscosity follow ASTM D1533 and ASTM D445 respectively. The result obtained for BDV, water content and viscosity of VCO are 22.9kV 1235ppm and 22.9cSt respectively. However, dry VCO has higher BDV which is 99.8 kV. Also, the decrease of breakdown voltage was proportional to the increase of moisture, but the kinematic viscosity was slightly changed. The kinematic viscosity of mineral oil varied ±1.282% in descending order while VCO varied (-0.873 to 1.31) % in ascending order. These happened due to the high intermolecular forces in VCO. Then, the rate of breakdown voltage decrease with the increasing of moisture for VCO is lower than mineral oil. Therefore, the VCO has good breakdown voltage with the ability to absorb a lot of moisture keeping the Kraft paper dry. However, high kinematic viscosity making it not favorable to be used as insulation in transformer.

CHAPTER 1

INTRODUCTION

1.1 Research Background

In electrical equipment, there is an electrical insulator that prevents the flow of current to earth from its supporting points or in other words, that material does not conduct the electricity [1]. It plays a vital role in the electrical system. Practically, to prevent the current flow, the resistive path through the electrical insulator must be very high. There are three principal media used for insulation. Those are gases, vacuum, solid and liquid, or a combination of these media. The simplest and the most commonly found dielectrics are gases. Most of the electrical device uses air as the insulating medium. Liquid dielectrics also have the properties that make them appear as though they would be more useful as insulating materials than either solid or gases. Liquid dielectrics normally are mixtures of hydrocarbons and are weakly polarized. To be able to use for electrical insulation purpose they should be free from moisture, products of oxidation and other contaminants[2].

Power transformer is an equipment that use oil (liquid dielectrics) to serve the dual purposes, insulation and cooling medium. It is used to filled the gaps between coil conductors and the spacing between windings and tank, and thus increases the dielectric strength of the insulation system[3]. Therefore, the quality of the oil in a transformer plays an important role in maintaining performance of power transmission and distribution. Its characteristics have been examined and reported on for decades[4]. The mineral oil is the most commonly used as dielectric insulator because of the price is the cheapest among all others liquid with excellent dielectric properties. It is obtained by fractional distillation of crude petroleum and have almost colorless liquid consisting of a mixture of hydrocarbons which includes paraffin, iso-paraffins, naphthalenes and aromatic[2]. To qualifying oil as the transformer oil, there are several important properties such as dielectric strength, flash point, viscosity, specific gravity and pour point. All of them have to be considered when qualifying new oil as transformer oil [5].

The mineral oil has a good dielectric properties yet it gives a terrible effect on the environment and it is non-biodegradable[6]. The serious case is when spills of mineral oil happen because it can cause contamination to the waterways and soil. Leakage from transformer also might cause explosion that affect the nature[6]. Hence, due to the environmental issue, a renewable friendly oil such as vegetable oil is investigated to substitute the mineral oil. There is also much research done to propose new oil with good dielectric properties as the alternative insulating oil such as sunflower oil and coconut oil. With the development of technology, the scientist does the oil treatment and purification to increase the lifespan of oil in the transformer and reduce the maintenance cost. Study on coconut oil has been done by research. This type of oil have an advantage where the rate of moisture absorption of coconut oil is very low compared to mineral oil under similar conditions of exposure to the atmosphere while the disadvantage is it has high pour point which is approximately 23°C[3]. At this temperature it will be completely solidified and loses its flow characteristic. Thus, this study tries to look on the possibility of using virgin coconut oil(VCO).

Virgin coconut oil is a colorless to pale white liquid. At a specific temperature, it appears as greasy, somewhat crystalline, white to yellowish solid fat. It is extensively used for edible and industrial purposes[3]. Until now, Malaysia has very precious resources such as virgin coconut oil. This will give the advantages if the transformer in this country can use virgin coconut oil as the medium insulator.

Moisture in oil is one of a factor that can decrease the life-span of high power transformer and the water content in the oil need to be tested periodically. This is because the presence of large water content can causes many problems for a power transformer including electrical breakdown between either its windings or one winding with neutral, increase in the amount of partial discharge and sundry minor problems[7]. However, the coconut oil able to absorbs much moisture compared to the mineral oil due to the content of fatty acid in it and able to keep cellulose paper in the transformer dry and slowing down the degradation process. Therefore, in this study, the water absorption characteristic in VCO also will be study to see its changes toward the added moisture in oil.

This research was conducted with aims to test and investigate the break down voltage, moisture content and viscosity of new oil which is virgin coconut oil. This study is important before this oil can be proposed as an alternative insulating liquid in the transformer. The experiment will be carried out on two sample oil, virgin coconut oil (VCO) and mineral oil under different condition of moisture, thus able to compare the rate of moisture and breakdown voltage between VCO and mineral oil. Mineral oil is use as reference oil in this research. Afterward, performance of VCO was compared with this reference oil in each test.

1.2 Problem Statement

Mineral oil has been used for over a period as liquid insulator in the power transformer and other high voltage apparatus due to its excellent insulating properties. It can provide excellent dielectric and thermal conductivity compared to another oil plus it can be obtained at a reasonable price. Substitution of chlorine atoms for hydrogen atoms in hydrocarbon molecules (mineral oil) makes synthetic oils[3]. However, these types of oils are said to be non-biodegradable, give severe impact on the environment and resources of non-renewable energy. Thus, it is required to substitute these oils with another alternative insulating liquid that has a better quality of dielectric properties, environmental friendly and inherently safe. Environmentally benign alternative oils such as vegetable, soya bean, sunflower, etc. have been tested by researchers to be used as an alternative for liquid insulation. Unfortunately, the price of most of these oils are very high when compared to mineral oil at final stage product. Apart from vegetable oil and sunflower oil, some investigations have been carried out on coconut oil, which is non-toxic free and has preferable environmental properties. This source is cheaper compared to soya bean and sunflower oil.

Next, disposal is often a problem and the mineral oil may end up in water bodies or in the soil, killing plants and animals and poisoning large amounts of water. Besides, used oil is very hazardous to human health. In some cases, used oil has been named as the cause of cancer in humans[8]. The problem is getting worse if the oil spill and contaminate the daily water source. Considering this problem, new suitable biodegradable oil must be identified to substitute mineral oil so that, human health can be protected and minimized the expenses needed to manage the used oil.

Then, transformer internal condition degrades as the population of the transformer is growing older and at the same time increase the risk of failure. The aging and deterioration process of the transformer is dependent on the type of oil insulation used and the moisture equilibrium it can maintain. Since the transformer devices are expensive, some research is carried out to improve the reliability of power transformer and minimize the need for investments of liquid dielectric and costly maintenance. These two problems are the main challenges that the electrical utility industries are facing nowadays. Therefore, special focus has been given on insulating materials, especially insulating oils. Malaysia is well-endowed with natural resources such as palm oil and coconut oil, thus there is research conducted on dielectric properties of coconut oil for power transformer. However, the dielectric strength of coconut oil is less than 20kV for a 2.5 mm sphere gap and the pour point which is approximately 23˚C does not satisfy the requirement of standard IEC 60296[3, 9]. Hence, this research tries to look on other product of coconut oil which is VCO.

When consider the local circumstance, the virgin coconut oil should be employ and undergo the process of treatment to make it as an alternative to transformer oil. Malaysia is one the tropical paradise country in Asia situated on the line of equator which has sunny days and rainy days throughout the year. Thus, a lot of mature coconut fruits are found throughout the Malaysia and become the authentic resources known as the "tree of one thousand uses". Hence, this experiment is to investigate whether the virgin coconut oil possesses the good breakdown voltage or not. There is no many research conducted on virgin coconut oil but since the coconut is an indigenous resources of tropical country, it will be very useful if this type of oil undergoes the treatment to comply the standard. Thus, this investigation is an initial step for proceeding further research and discussion concerning requirement in the standard to be good insulating oil.

Then, the moisture ingress into the insulation oil can alter the hydrocarbon bond of the fatty acid. This will cause the breakdown voltage to decrease and lead to the failure of the transformer. Therefore, it is also important to study how the moisture in virgin coconut oil affect the other dielectric properties such as breakdown voltage and viscosity.

There is a difference between antioxidants content in regular coconut oil and virgin coconut oil(VCO). Research that has been conducted show VCO has the highest breakdown voltage, lowest moisture and viscosity compared to palm oil and coconut oil[6]. Thus, a proper test is suggested to determine the dielectric properties of the virgin coconut oil and make a comparison between virgin coconut oil and mineral oil. The effect of moisture increase on other physical properties of the oils like viscosity also should be studied to gain a more comprehensive understanding of the oil behaviour as moisture changes[10].

1.3 Objective of Research

The objectives of the project are as follows:

- To determine the breakdown voltage, water content, and viscosity of virgin coconut oil.
- To find moisture absorption characteristic of the virgin coconut oil properties.
- To identify the effect of moisture level of VCO on breakdown voltage and kinematic viscosity.

1.4 Scope of Research

This study will focus on the laboratory experiment to identify the potential of virgin coconut oil as biodegradable dielectric liquid in the transformer. The tests conducted in this experiment included breakdown voltage for electrical properties and kinematic viscosity, water content for chemical properties. The research is limited to two type of oil, virgin coconut oil (VCO) and mineral oil. Then, the result obtained from these two oil samples is analyzed and compared between each other to see the performance of breakdown voltage of each oil. Afterward, each type of oil sample is prepared with different moisture to study the effect of moisture on the breakdown voltage. In addition, the kinematic viscosity for each different moisture is tested to develop the relationship between them.

1.5 Thesis Outline

This report consists of five chapters which will cover the procedure of experiment at work and discussion of each type of test in the investigation of dielectric properties of virgin coconut oil as the alternative biodegradable transformer oil. Here is an overview of the content of each presented chapter:

Chapter One: This chapter is about the introduction of insulating liquid to gives an overview about the study on dielectric properties and the main factor for choosing the virgin coconut oil. This chapter also discusses the scope of the study, the significance of the study and its objectives.

Chapter Two: This chapter summarizes the literature review on dielectric properties which is the previous related works that been done before. Moreover, this chapter represents relevant information to understand more the relationship between each of dielectric properties.

Chapter Three: This chapter present the details of the selected methodology for the test of breakdown voltage, moisture and viscosity.

Chapter Four: This chapter is to analyze the result obtained in the experiment that has been carried out by referring to IEC 60296 and compare the result with mineral oil.

Chapter Five: This chapter is to conclude the performance of virgin coconut oil after compare it to mineral oil and state the recommendations for improvement on this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The transformer is a very essential apparatus in an electrical power system and its reliability is of utmost importance as a transformer failure results in a very costly and difficult to predict interruption of energy delivery[11]. It is used as the link in the transmission and distribution of electrical power system. One main element of transformer component is insulating fluid and this fluid performs two major functions in a power transformer. First, it acts as an electrical insulation to withstand the high voltages carried by the transformer. Second, it functions as a heat transfer medium to remove the heat generated within the transformer windings by convection. Therefore, the electrical properties of the oil must be maintained in a good condition while resisting thermal degradation and oxidation. The properties and characteristic of insulating liquids are often categorized as chemical, physical and electrical. Electrical parameters include dielectric strength, specific resistance, dielectric dissipation factor while chemical parameter include water content, acidity, sludge content and physical parameters include inter facial tension, viscosity, flash point, pour point[12].

Mineral oil is the most commonly used as dielectric liquid in power apparatus. It is an almost colorless liquid. In practice, the choice of a liquid dielectric for a transformer application is made mainly on the basis of its chemical stability. Other factors such as saving of space, cost, previous usage, and susceptibility to the environmental are also considered[2]. Thus, there are many researches on new biodegradable oil and coconut oil gain attention at tropical country due to dry and wet climate with average temperature between 21 to 30 ˚C. Complete specification for the transformer can be referring to the Table 2.1 obtained from IEC 60296 standard[9].

Table 2.1 General specification for transformer oil in IEC 60296[9].

Property	Test method	Limit
Viscosity at 40°C	ISO 3104	Max. 12 mm^2/s
Pour point	ISO 3016	Max. -40°C
Water content	IEC 60814	Max. 30 mg/kg
Breakdown Voltage	IE 60156	Min. 30 kV
Density at 20°C	ISO 3675 or ISO12185	Max. 0.895 g/ml
Acidity	IEC 62021	Max. 0.01 mg KOH/g
Flash point	ISO 2719	Min. 135°C

Liquid insulator should have the following characteristic:

1. High electric strength to withstand the electric stress.
2. Low viscosity to circulate and transfer heat efficiently.
3. Proper oxidation
4. Good resistance to emulsion to prevent holding water in suspension in it.
5. Free from inorganic acid and alkali.
6. High flash or fire point.
7. Low pour point.
8. Low water content.

2.2 Transformer

Transformer is a device to increase or decrease the power from one circuit to another without changing frequency and its efficiency must be always more than 95%[13]. Since there is no rotating part in the transformer, it is called the static device. After that, electrical power transformer was introduced in the high voltage electrical power system and plays a vital role in power transmission. It is expected to function reliably and efficiently for many years. In the transformer has a medium oil. The transformer has two winding, primary winding, and secondary winding. During the transformer operation, there is electromagnetic induction process that create the loss such as core loss, copper loss and stray losses in the winding. Then the insulating oil will allow the heat pass through it and flows to the radiators by natural convection circulates. Convection process is when the fluid is heated and then travels away from the source, it carries the thermal energy along. This process is very important to dissipate the heat and slowly cooling down which automatically cools the transformer winding as well[14]. Insulation oil also can prevent the electrical discharges between the transformer coil such as corona and arc. Typical transformer failure can be internal or external. Internal failure are insulation deterioration, loss of winding clamping, overheating, oxygen, moisture, and contamination while the external failure such as lightning strikes, system switching operation, system overload and system fault.

2.3 Mineral Oil

The mineral oil used in transformer is extracted from the petroleum. It is made by refining a fraction of the hydrocarbons collected during the distillation of a petroleum crude stock. The boiling range of the collected fraction and the kind of degree of the refining process are selected so that the resulting oil has characteristics that fall within limits specified for use in transformers. The crude oil stocks and the refining processes used in producing these oils are typical of those used in producing many common petroleum lubricating oils. Because of the wide availability and the cost benefit that results from this kinship, petroleum-based transformer oils are probably the most widely used as electrical insulating liquids in the world today and have been for the past century[4].

It has several advantages over the other types of oils such as higher resistance to the aging method and excellence dielectric properties. Other characteristics like the low relative permittivity give an advantage regarding their behaviour for insulation in transformer operation[15]. Mineral oil is produced by several countries and is relatively inexpensive. But, the main drawback occurs when there is a transformer leakage and the mineral oil will contribute to environmental hazards because of its poor biodegradability[15].

Mineral oil consists essentially of a complex mixture of organic compounds known as hydrocarbons, of which there are four main types—paraffinic, naphthenic, olefinic and aromatic. Paraffin hydrocarbons consist of straight or open chain and branched chain compounds, the structure of which is usually represented in a manner similar to that given below for hexane as shown in Figure 2.1, one of the lower members of the paraffin series of hydrocarbons[4].

$$CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_3 \quad \textbf{(Hexane)}$$

Figure 2.1 Structure of hexane[4]

The naphthenic hydrocarbons have a closed chain structure and are known alternatively as cyclo-paraffins[13]. Cyclo-octane may be represented by Figure 2.2:

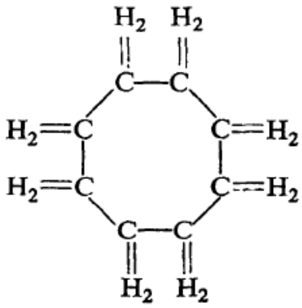

Figure 2.2 Structure of cyclo-octane[4]

The aromatic hydrocarbons are those with a closed, condensed ring structure, such as benzene, naphthalene and anthracene as shown in Figure 2.3:

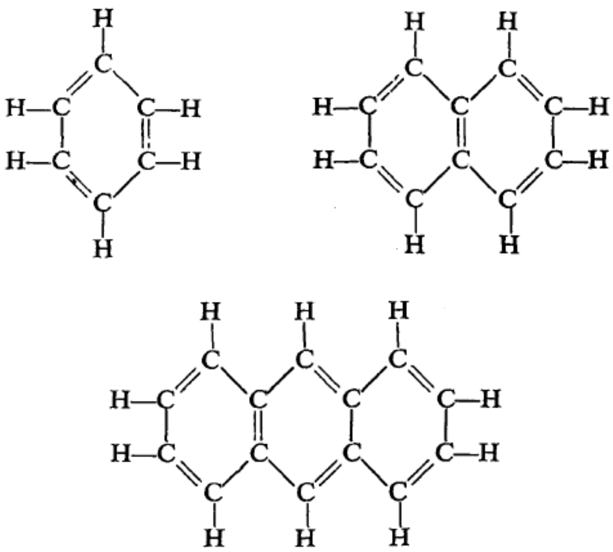

Figure 2.3 Structure of aromatic hydrocarbon[4].

Mineral has several advantages over the other types of oils such as higher resistance to the aging method and excellence dielectric properties. Other characteristics like the low relative permittivity give an advantage regarding their behaviour for insulation in transformer operation. It is produced by several countries and is relatively inexpensive. But, the main disadvantage is it will contribute to environmental hazards because of its poor biodegradability.

Table 2.2 The dielectric properties of mineral oil[14].

Property	**Test method**	**Mineral oil**
Density at 20°C, kg/dm^3	ISO 3675	0.88
Viscosity at 40°C cSt	ASTM D445	8.9
Viscosity at -30°C cSt	ASTM D445	1.080
Pour point, °C	ISO 3016	-63
Flashpoint, °C	ISO 2719	146
Water content, Ppm	IEC 60814	<20
Ac breakdown volt, kV	IEC 60156	>70
tan^{δ} at 90°C (50Hz)	IEC 60247	0.001

Other than mineral oil, synthetic ester and silicon oil are used in transformer. Substitution of chlorine atoms for hydrogen atom in hydrocarbon molecules (mineral oil) produce synthetic oil[3]. Polychlorinated Biphenyl (PCB) which originated from synthetic oil is used as insulating oil because of their low flammability and good dielectric properties. However, their used is now banned in many countries due to their negative environmental impact[3]. Moisture absorption also is one of mineral oil inherent properties[4].

2.4 Virgin Coconut Oil

Coconut oil is commercially derived from copra, which is the dried kernel or ‘meat’ of coconut. It is colorless to pale brownish yellow. Coconut oil contains a high level of low molecular weight saturated fatty acids, the distinctive characteristic of lauric acid[16]. In contrast, virgin coconut oil (VCO), which is extracted by a wet process directly from coconut milk under controlled temperature, may have more beneficial effects than copra oil since it retains most of its beneficial components[16]. VCO is one of a renewable resource that biodegrades quickly and completely without toxic, has preferable environmental properties in addition to its availability in tropical country. Table 2.3 show the composition of coconut fruit in percentage and Table 2.4 show the percentage of fat acid in VCO.

Table 2.3 Composition of coconut fruit [16]

Coconut fruit	**Weight (%)**
Coconut fiber	35
Coconut shell	12
Kernel	28
Coconut water	25

Table 2.4 The main component of VCO is saturated fat acid about 90% and unsaturated fat acid just 10% [16].

Fat acid		**Chemical formula**	**Quantity (%)**	**Boiling point (°C)**	**Melting point (°C)**
Saturated fat acid	Caporat acid	$C_5H_{11}COOH$	0,4 - 0,6	60	-4
	Caprilate acid	$C_7H_{17}COOH$	5,4 - 10,0	80	16
	Caprate acid	$C_9H_{19}COOH$	4,5 – 8,0	135	31
	Laurat acid	$C_{11}H_{23}COOH$	43,0 - 53,0	225	44
	Miristat acid	$C_{13}H_{27}COOH$	16,0 - 21,0	-	54
	Palmitat acid	$C_{15}H_{35}COOH$	7,5 – 10,0	390	63
	Stearate acid	$C_{17}H_{35}COOH$	2,0 – 4,0	361	72
Unsaturated fat acid	Oleat acid	$C_{17}H_{33}COOH$	5,0 – 10,0	229	16
	Linoleat acid	$C_{17}H_{31}COOH$	1,0 – 2,5	237	-5

The Table 2.5 below is a list of the content of fat for 14g VCO obtained from the label attached to the bottle of VCO. The brand of VCO is from Absolute Coco.

Table 2.5 Content of fat in sample VCO

Fat	**1tbsp (14g)**
Saturated	13.2g
Monosaturated	0.7g
Polyunsaturated	0.1g

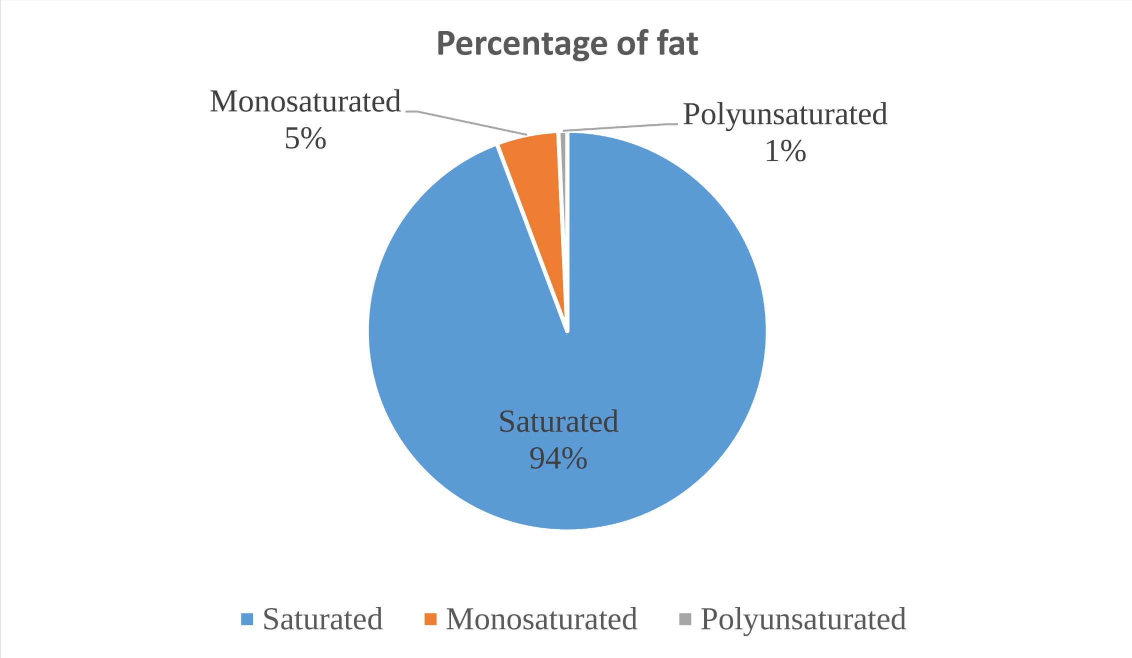

Figure 2.4 The percentage of fat in VCO

The pie chart in Figure 2.4 show the percentage of saturated fat in VCO is 94% which is very high. When the saturated fat is very high, the kinematic viscosity also could be very high. Also, saturated fatty acids has high melting point.

Then, increase of temperature would decrease the fat content in VCO[17]. VCO is produced very simple by mechanical treatment and just need minimum heat, without any chemical additives. Therefore, VCO is pure and colorless, not easy to get rancid, and can endure for two years[17]. When exposed to heavy magnetic fields, oil with a higher unsaturated degree of fats may break but coconut oil having a very low degree of unsaturated fats, ensures consistent properties at heavy magnetic fields essential for insulating oils[3].

2.5 Dielectric Properties

Insulating oil acting as a liquid insulation in an electrical power transformer and secondly dissipating heat of the transformer (coolant). Also, it helps preserve the core and windings of the transformer for they are dipped in it. Due to oxidation susceptibility of the cellulose (paper insulation) made for the windings, the transformer oil prevents direct contact of atmospheric oxygen[15]. There are several tests to determine dielectric properties such as breakdown voltage, viscosity, and water content.

2.5.1 Breakdown Voltage

Breakdown voltage is one of the important properties to define the efficiency of oil as an insulator. The ability of the oil (acting as a dielectric) to oppose the flow of a current is determined by breakdown voltage test which shows its dielectric strength. The breakdown voltage of a material is not a definite value. It is referred to as withstand voltage where the probability of failure at a given voltage is so low that it is considered at the moment of designing insulation, with the assurance that the material will not fail at this voltage[15]. The presence of water in the oil can cause a rapid drop in the dielectric strength. There exist two ways for measurement of the breakdown voltage of a material which includes the impulse breakdown and the AC breakdown voltages. AC voltages are the line frequencies of the mains, while with the impulse breakdown voltages (BDV), they are simulating lightning strikes[15]. The method used to test the breakdown voltage is measured by observing at what voltage, spark strands between two electrodes immersed in the oil, separated by a specific gap by referring the international standard IEC 60156[18]. Breakdown in liquids can be explained by several theories. Those are suspended particle mechanism, cultivation and bubble mechanism, and stressed oil volume mechanism[2].

2.5.2 Viscosity

The viscosity is divided into two. Those are dynamic viscosity and kinematic viscosity. Dynamic viscosity is the ration between applied shear stress and rate of shear of oil. The unit is Poised. Kinematic viscosity is resistance of flow of oil under gravity and it is measured in Centistokes(cSt). It is sensitive to the temperature. Therefore, it is kept in special oil bath to maintained the temperature. In general, viscosity of a fluid refers to a measure of its resistance with reference to its gradual deformation by shear stress or tensile stress[19]. With the emphasis on viscosity of transformer oil, viscosity refers to opposition to flow at all factors constant (normal condition) or resistance to flow simply describes opposition to convection circulation of oil in the transformer[15]. The oil used in transformers with low viscosity is essential and simultaneously important. Transformer oil viscosity should not change much if the temperature is decreased[15]. It should be noted that all liquids get more viscous with a decrease in temperature. Low viscosity is more better in order to provide the better environment for low resistance to a conventional flow of oil, hence proper transformer cooling[15].

The ratio of kinematic viscosity (v) defined as equation (1),

$$v = \frac{\eta}{p} \tag{1}$$

Where η is the dynamic viscosity and ρ is the mass density of the fluid.

The viscosity of Coconut oil is much lower compared to palm oil[20]. Oil with high content of fatty acids has excellent viscosity performance. The percentage of high unsaturated fatty acid contents could affect the oxidation performance of oil. So, it is necessary to equalize the fatty acids to optimize its application in transformers[20].

2.5.3 Water Content

Water is a very undesirable pollutant to transformer oil and other insulators in a transformer. It influences the life of a transformer in many ways. The presence of water causes the process of hydrolysis occurs and the aging of insulator accelerated[21]. In other words, the presence of moisture in transformer can deteriorates transformer by decreasing both the electrical and mechanical strength[22].

The water in transformers mainly originates from three sources: residual water, ingressing from atmosphere and aging products[23]. Usually, residual water content is from less dried paper insulation which will gradually migrate into the transformer oil during service[24]. Then, moisture from atmosphere ingress into transformer due to poorly maintained seals. Water produced by thermal aging of cellulose materials also will further accelerate the cellulose aging and produce more water[24].

Water in transformer liquid may exist in three states: associated water, dissociated water and water drops[24]. Associated water indicates number of dissolved water molecules tightly linked to the polar/charged groups of the liquid molecules by hydrogen bond while the dissociated water refers to most of the dissolved water molecules either as 'monomer' or 'clusters'[25]. When moisture in oil exceeds the saturation value, the water drop will appear. This can happen when a transformer with moist solid insulation cools down and may affect the behaviour of the transformer[21]. Moisture makes the oil less thick with a lower boiling point than oil[26]. The Water content of oil sample is measured as per IEC 60 814 using Karl Fischer titration method. In Karl Fisher Titration, water (H_2O) chemically reacts with iodine (I_2), sulphur dioxide (SO_2), an organic base (C_5H_5C) and alcohol (CH_3OH) in an organic solvent[27]. Iodine that is generated is proportional to the quantity of electricity according to Faraday's Law.

2.6 Effect of Moisture on Breakdown Voltage

The breakdown voltage of oil heavily depends on the water saturation. When the water present in the oil increase, the breakdown voltage will be decreased. High moisture content coupled with dissolved gases that have pressures higher than the ambient pressure also leads to bubbling effect in transformers[28]. Therefore, it is important to monitor the moisture in oil regularly. The presence of moisture in insulation oils is one of the leading causes of electrical breakdown because it increases the ionic conductivity of the oil hence lowering the breakdown voltage[29].

After exceeds saturation level, free water drops appear in oil and it could function as the weakest-links and significantly reduce the breakdown voltage of oil[24]. The water droplets are elongated and the local breakdown would easily develop into a full liquid breakdown as shown in Figure 2.5 Breakdown of an insulating liquid due to instability of water globule[30].

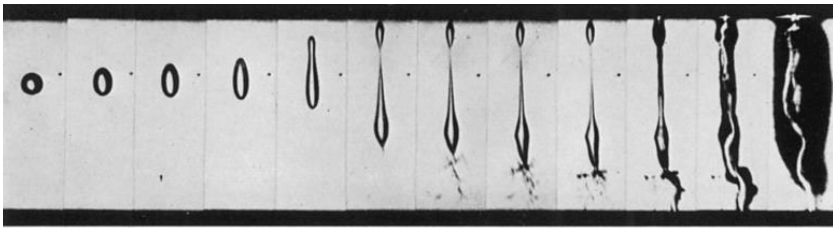

Figure 2.5 Breakdown of an insulating liquid due to instability of water globule[30].

2.7 Effect of Moisture on Viscosity

Moisture content in the oil increases with increase in pressure, this in turn causes the increase in viscosity of oils[26]. But for transformer mineral oil having lower intermolecular forces, its viscosity decreases as the moisture content increases. Whereas in case of vegetable oils being low molecular liquids have higher intermolecular forces. Hence its viscosity increases[26].

2.8 Comparison between Coconut and Other Oil Insulator

From the previous research, several important properties, specified in transformer oil standards were compared with the relative values of coconut oil is shown in Table 2.6. The dielectric strength of coconut is much higher than standard oil which is 60kV. This is because the coconut oil used is already purified. It has two good properties which is good dielectric strength and higher flash point.

Table 2.6 Comparison of Properties of Oils[3]

Property	Coconut Oil	Standard Oil (IEC296)
Dielectric Strength (kV)	60	50
Pour Point (°C)	20	-40
Flash Point (°C)	225	154
Moisture Content (mg/kg)	1.0	1.5
Viscosity (cSt) at 40°C	29	13
Density(kg/dm^3)	0.917	0.895

Then, from another research, three dielectric properties were compared between coconut and virgin coconut oil[6]. Those are breakdown voltages, moisture content and viscosity. The results are shown in Table 2.7. It can be seen that virgin coconut oil has most potential properties compared to coconut and palm oil because it has high breakdown voltage, low moisture content and low viscosity.

Table 2.7 Comparison between coconut, virgin coconut and palm oil[6]

Dielectric Property	**Coconut Oil**	**Virgin Coconut Oil**	**Palm Oil**
Breakdown Voltage (kV)	18.20	43.30	34.80
Moisture Content (%)	4.38	1.86	1.92
Viscosity (mPas)	61.75	49.50	64.8

Table 2.8 shows some important physical properties of coconut oil, commercially available vegetable oil for transformers and recommended levels for uninhibited mineral oil of class I. Even though the viscosity of coconut oil is higher than the recommended value, it is less than some of the vegetable oils currently used as alternative oil. Other laboratory experiments has proven that partial solidification of coconut oil at temperature below the melting point does not significantly affect its breakdown voltage[31].

Table 2.8 Comparison of physical properties of coconut oil and typical vegetable oil[32]

Property	**Coconut Oil [31]**	**Vegetable Oil [33]**	**Uninhibited class I mineral oil [9]**
Dielectric strength (kV)	60	74	50
Viscosity (cSt at 40°C)	29	33-45	14
Pour Point (°C)	23	-15 to -25	-40
Flash Point (°C)	170-225	310-325	154
Specific gravity at 20°C	0.917	0.91-0.95	0.895
Moisture content (mg/kg)	1	5-10	1.5

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This project is divided into two parts. The first part is doing the dielectric feasibility study on the virgin coconut oil and compared with mineral oil while the second part is to conduct the dielectric test according to the standard IEC 60296 [9] to fulfil the research objectives. Mineral oil is extracted from crude oil has poor biodegradability and future scarcity, thus virgin coconut oil is studied as an alternative transformer oil. The proposed tests to investigate dielectric properties of virgin coconut oil are the breakdown voltage test, water content (Karl Fischer test), and kinematic viscosity. Firstly, the pre-test was carried out using the mineral oil until get accurate procedure repeatability data by referring to the standard value of mineral oil dielectric properties. Then, the test procedure was continued by using virgin coconut oil and was done several times to ensure the consistency and give the relevant value. The sample of virgin coconut oil was prepared with different moisture contains 10ppm until 160ppm to investigate how the level moisture will affects the breakdown voltage at room temperature (27 ± 5 °C). Figure 3.1 shows the flow for this research. Each process will be future explain in this chapter.

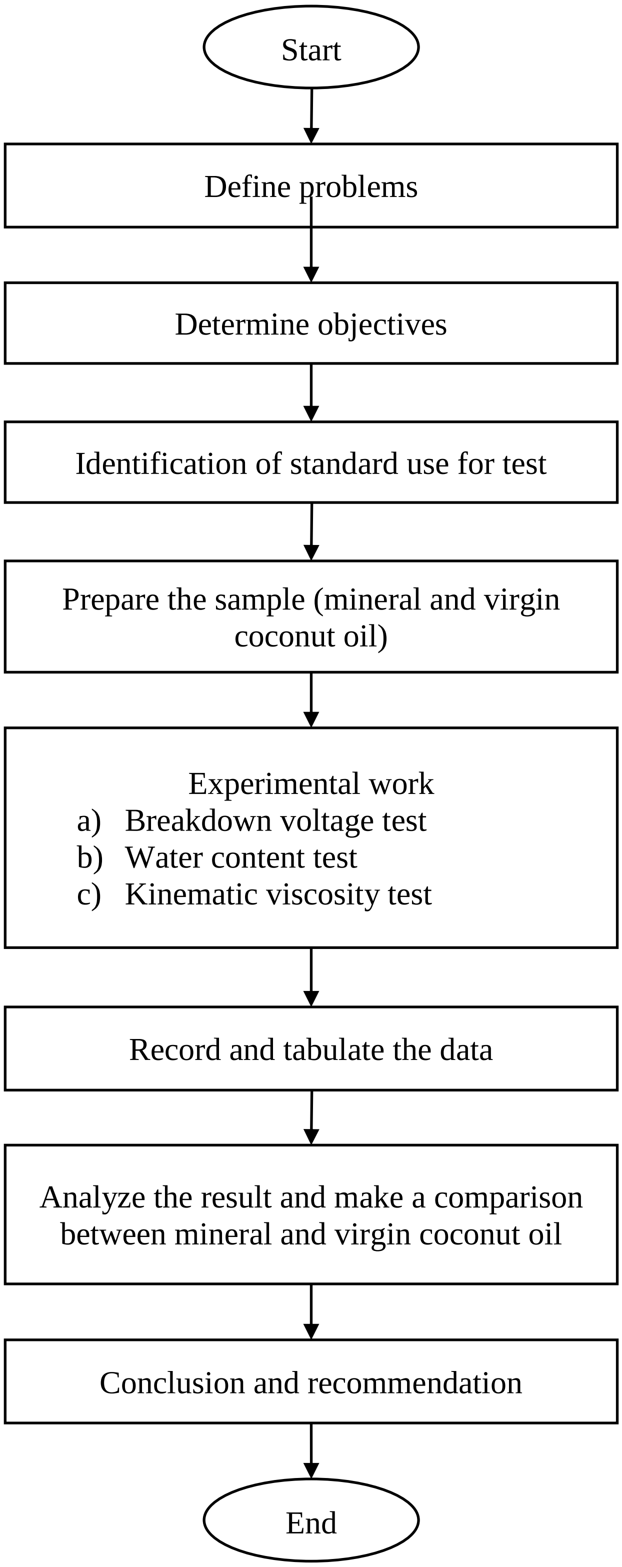

Figure 3.1: Project flow

3.2 Oil Samples Preparation

Two type of oil that will be used in this project are mineral and virgin coconut oils. Each of oil sample is divided into three moisture conditions; dry, normal and moisture. The purpose of testing in different condition of these oil is to compare and analysed the breakdown voltage and viscosity when the moisture contain level is varied.

3.2.1 Virgin Coconut Oil

The virgin coconut oil used as sample in this research is obtained from the local market without any modification. Thus, the moisture contain in it could be very high. The brand of VCO is Absolute Coco as shown in Figure 3.2.

Figure 3.2 The brand of virgin coconut oil (Absolute Coco) used for test

Next, Table 3.1 shows the list of chemical properties of virgin coconut oil that are obtained from the manufacturer (Absolute Coco). It is very important to know the chemical properties before conduct the experiment to prevent any unwanted accident. From the Table 3.1, the melting point of virgin coconut oil is 27°C. Melting point is the temperature at which the solid starts to change to liquid. The test is conducted in the room that is equipped with an air conditioner. During the rainy days, the temperature of the virgin coconut oil could go below the melting point. Thus, the oil sample must be keep in air dry cabinet at room temperature. Next, the boiling point is decomposed which mean that the VCO will never reach the boiling point, but it will decompose. Decomposition is the changes of the material into others chemical compound. However, the temperature rapidly increasing above 250°C due to the decomposition that release a large amount of heat and possibly resulting in a fire or explosion [34].

Table 3.1 The chemical properties of VCO

Melting point	27°C
Boiling point	Decomposes, rapidly increasing above 250°C
Vapour pressure	Negligible at 25°C
Moisture and volatiles	Less than 0.1% at 100°C
Flash point (open cup)	Greater than 270°C
Solubility	Insoluble in water. Soluble in hydrocarbons, chlorinated solvent and ester. Slightly soluble in alcohols, ketones. Miscible with lower fatty acids.
Appearance	White when solid, clear liquid when melted.
Relative density at 30°C	0.9198
Free Fatty Acid content as Lauric acid Max	0.05
Moisture & Other matter volatile at 105°C % by mass max	0.10
Iodine value	6.0
Saponification value min	262.1

3.2.2 Mineral Oil

The mineral oil used is SHELL Diala mineral oil. This oil is a common insulator oil used in transformer and other equipment. It is stored in the drum where its seal is always tightened when not in used. Thus, the quality of the mineral oil in that drum is still in good condition and the breakdown voltage should be more than 50 kV.

3.2.3 Samples Preparation

As preparing the oil samples as listed in Table 3.2, some of the samples will undergoes dry process for drying the oil samples, direct collect from drum for normal oil sample and adding moisture process for wet oil condition (10, 20, 30, 40, 50, 60, 80, 160 ppm). The method for drying process is a sample from each type of oil is heat in the vacuum oven at 70°C for 24 hours as shown in Figure 3.3. Then, it is left in vacuum oven to cool down until it reaches room temperature for about 7 hours. The purpose of heating process is to reduce the moisture inside the oil.

While for normal condition the oil is freshly poured-out of the-container. Then, there are eight sample of VCO and 4 samples on mineral oil with different moisture concentration. The moisture is increased by adding a desired quantity of distilled water into normal oil sample to achieve required ppm as shown in Table 3.3. Afterward, the mixture of oil and water is stirred using a magnetic stirrer as in Figure 3.4 at constant temperature of 40°C for a period of 24 hours for the coconut oil and 48 hours for the mineral oil until all water droplets became visibly absent from the sample[10].

Table 3.2 List of samples used

Type of oil	**Sample**	**Moisture Condition**
Mineral oil	MD	Dry
	MN	Normal
	M10	Normal + 10 ppm
	M20	Normal + 20 ppm
	M30	Normal + 30 ppm
	M40	Normal + 40 ppm
Virgin coconut oil	VD	Dry
	VN	Normal
	V10	Normal + 10 ppm
	V20	Normal + 20 ppm
	V30	Normal + 30 ppm
	V40	Normal + 40 ppm
	V50	Normal + 50 ppm
	V60	Normal + 60 ppm
	V80	Normal + 80 ppm
	V160	Normal + 160 ppm

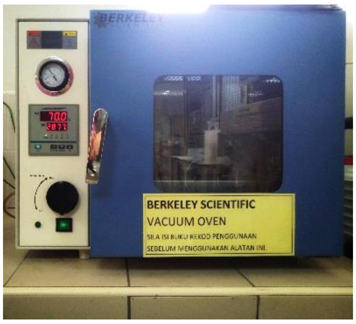

Figure 3.3 Vacuum oven used for drying process

Table 3.3 Water addition to the normal oil

Type of oil	Volume of oil (ml)	Desired water content (ppm)	Water added (ml)
Mineral oil	500	10	0.005
	500	20	0.010
	500	30	0.015
	500	40	0.020
Virgin coconut oil	500	10	0.005
	500	20	0.010
	500	30	0.015
	500	40	0.020
	500	50	0.025
	500	60	0.030
	500	80	0.040
	500	160	0.080

Below shows the equation and calculation to determine the volume of water added to achieved desired water content:

Formula: $\text{Water add, x(ml)} = \text{Desired water content} \times \text{Volume of sample(ml)}$

10 ppm, $x = 10 \times 10^{-6} \times 500 = 0.005\ \text{ml}$

20 ppm, $x = 20 \times 10^{-6} \times 500 = 0.010\ \text{ml}$

30 ppm, $x = 30 \times 10^{-6} \times 500 = 0.015\ \text{ml}$

40 ppm, $x = 40 \times 10^{-6} \times 500 = 0.020\ \text{ml}$

50 ppm, $x = 50 \times 10^{-6} \times 500 = 0.025\ \text{ml}$

60 ppm, $x = 60 \times 10^{-6} \times 500 = 0.030\ \text{ml}$

80 ppm, $x = 80 \times 10^{-6} \times 500 = 0.040\ \text{ml}$

160 ppm, $x = 160 \times 10^{-6} \times 500 = 0.080\ \text{ml}$