STUDY OF THERMAL STRESS EFFECT ON ESTER OIL USING BREAKDOWN AND FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR) TEST

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2016

"I hereby declare that I have read through this report entitle "Study of Thermal Stress Effect on Ester Oil Using Breakdown and Fourier Transform Infrared Spectroscopy (FTIR) Test" and found that it has been comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power).

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Date : 17/6/2016

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

Faculty of Electrical Engineering
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2016

I declare that this report entitle "Study of Thermal Stress Effect on Ester Oil Using Breakdown and Fourier Transform Infrared Spectroscopy (FTIR) Test" 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 : MUHAMAD IZWAN BIN MOHD YAHYA

Date : 17/6/2016

To my beloved mother and father

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In the name of Allah, the Most Beneficent and The Most Merciful. It is a deepest sense gratitude of the Almighty that give me strengh and ability to complete this Final Year Project report.

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ABSTRACT

The power transformer is one of the most important equipment, ensuring the safety of the operation for power grids and it plays a vital role across the electrical grid network. The insulation materials which are the insulation oils are decide as the operational life of the transformer. The insulation oils have been chosen as the insulating medium of a high voltage transformer, but it has effect due to thermal and electrical aging. Once the transformer is set up into operation, the insulation oils will be starting to ages over time and this will cause the dielectric properties of the insulation oils will tend to decrease. Thus, the aim of this project is want to measure a breakdown voltage (BdV) and using Fourier Transform Infrared (FTIR) to examine the condition of the oil when under thermal stress. The influence of the copper and cellulose in the oil are being observed which affect the breakdown strength of oil sample. The standard of ASTM D1816 and ASTM D2144 are use as guideline in the testing procedure and confirm the result. The result show the effect of the thermal stress with influence of copper and cellulose in the oil affect the breakdown voltage value which show 26.71% in ester oil without copper and cellulose compared to ester oil with copper and cellulose is 11.11% and show changing in absorbance spectrum of FTIR.

ABSTRAK

Transformer adalah salah satu alatan yang paling penting untuk memastikan operasi yang selamat bagi grid kuasa dan ia memainkan peranan yang penting di seluruh rangkaian grid elektrik. Bahan penebat iaitu minyak penebat ini boleh menetukan hayat operasi sesebuah transformer. Minyak penebat telah dipilih sebagai medium didalam transformer yang bervoltan tinggi, tetapi ia mempunyai kesan terhadap haba dan elektrik yang menyebabkan minyak itu telah mencapai had penggunaan. Apabila transformer berada di dalam keadaan operasi, minyak penebat akan mula menampakkan hayat penggunaanya berada didalam keadaan yang maksimum dari masa ke masa dan ini akan menyebabkan ciri-ciri ketahanan dielektrik minyak akan berkurang. Oleh itu , tujuan projek ini adalah untuk mengukur voltan pecahtebat dan menggunakan Fourier Transform Infrared (FTIR) untuk memeriksa keadaan minyak apabila di bawah tekanan haba. Pengaruh tembaga dan selulosa dalam minyak diperhatikan dimana akan memberi kesan kepada pecah tebat terhadap sampel minyak. ASTM D1816 dan ASTM D2144 digunakan sebagai garis panduan dalam prosedur ujian dan digunakan untuk mengesahkan keputusan ujian. Hasilnya menunjukkan kesan tekanan haba dengan pengaruh tembaga dan selulosa dalam minyak menjejaskan nilai voltan pecahtebat yang menunjukkan 26.71 % dalam minyak ester tanpa tembaga dan selulosa berbanding minyak ester dengan tembaga dan selulosa adalah 11.11 % dan menunjukkan perubahan dalam kuantiti spectrum FTIR.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The electrical power system in Malaysia divided into three sections which is generation, transmission and distribution. This system is known as national grid system which used to transmit the electricity to all over the country. The organization that controls the electrical power system in Malaysia is Tenaga Nasional Berhad (TNB) which is responsible to maintain the electrical generation to all over the country. Between the generation and transmission section the uses of power transformer is important as to step up the voltage becoming high voltage to go through the transmission line.

The electrical equipment such as power transformer needs protection and insulation system because it may suffer from the overload condition which might lead to the transformer failure. The insulation system plays an important role to determine the transformer life. In the insulation system of the transformer it has two type of the insulation which is solid and liquid. The solid insulation consists of the paper or pressboards are used in the winding of the transformer. For the liquid insulation the most common use is the transformer oil.

This oil insulation has two main purposes when the transformer in operating condition. First, the insulation oil is serving as an effective insulator in electrical power transformer. Second, the insulation oil is act as a cooling medium when heat dissipates from the transformer. This purpose is important toward the protection of core or winding in the power transformer. The insulation oil must good in dielectric strength to make it strong in term of breakdown of the oil. However, the dielectric strength of the oil will decrease because the oil will degrade over the time due to thermal stress or other stress that presence in the transformer.

The transformer oil known as mineral oil which from the petroleum base. Mineral oil has been used as main source of the insulation material until now. Mineral oil can be potential dangerous to the environment due to its poor biodegradable characteristic. Nowadays, many countries are trying turning toward the replacement of oil petroleum based into green material. Recent study show that the ester based oil are suitable for the replacing the mineral oil due to good biodegradable characteristic toward the environment.

Before going make the ester oil to be the filled in the power transformer several diagnosis tests must be conduct to determine dielectric strength of the oil before it can be used. This test is to measure the quality and performance of the insulation oil in the laboratory. The test such as breakdown voltage measurement, moisture and acidity are usually used in the oil laboratory. Another alternative diagnosis test has been used such as FTIR which is the tool to evaluate the condition of the insulation oil. So, this project purpose is to analyse the performance of the ester oil when the thermal stress effect happen on the oil by using breakdown voltage measurement and FTIR test.

1.2 Problem Statement

Power transformer is the most expensive equipment in electrical network system which the price reached over Millions (RM). It plays an important role in energy transmission. Transformer must operate safely and reliable at all time around the clock. For this reason transformer literally built like a tank. However, the aging process apply to transformer never relax. The transformer oil for example is indispensable for cooling, impregnation and isolation agent. However, just like every other organic compound, it ages with time when under the thermal stress. This thermal stress occurs during the operation of transformer. The winding of the transformer become hot and then the heat is transfer through the cellulose paper and insulation oil. Cellulose on oil produces various degradation products. Almost all of these products are acid, peroxide, and water. Additionally deposit and sludge form on the surface of the transformer winding. These reduce the heat transfer capability and therefore the cooling capability of the oil. The decomposition product also attack the paper insulation of the transformer winding and the paper is loses the mechanical and dielectric properties. The process finally results in defective spot in the insulation. This is making the transformer incapable of dealing with overvoltage in power network. So, in this project the uses of ester oil to replace the mineral oil as the transformer oil is want to see whether the effect of thermal stress will cause the changing in the ester oil in term of performance of the dielectric strength of the oil.

1.3 Objective

The objectives of this project are:-

1. To analyse the effect of the thermal stress on ester oils using breakdown voltage and FTIR.
2. To analyse ester oil sample with different condition with and without the copper and cellulose
3. To compare the performance of dielectric strength on the ester oil sample.

1.4 Scope

The scope for this project is carried out in the laboratory and several measuring equipment are being used. The material of the insulation oil that use will be synthetic ester oil (MIDEL7131). There are two different condition for prepare the oil sample. First condition is the ester oil without presence copper and cellulose. A 500 ml of oil needed for each sample preparation. The oil samples are heated at temperature of 120 ˚C with four difference times which is 0 hour, 6 hour, 24 hour and 48 hour. Second condition is the ester oil with the presence of copper and cellulose. The copper used are copper strip with the 15 cm length and 1 cm width. For the cellulose, 5g of the cellulose needed for each samples. Then the copper and cellulose put into the oil sample and heated same with the first condition which is 120 ˚C with four difference time 0 hour, 6 hour, 24 hour and 48 hour. The testing parameter that used for this experiments are Breakdown Voltage test an FTIR test. Megger OTS60PB Breakdown Tester is use for Breakdown Voltage test according to standard of ASTM D1816. FT/IR-6100 JASCO with IR analyse is used to do FTIR test by follow the standard of ASTM D2144

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the basic theory behind the experimental work on insulating oil in power transformer will be introduced and discussed. The factor that causes the power transformer to be failure is when the dielectric strength of the oil is decrease. It indicate that the oil undergo aging process due to thermal stress. So, researchers are doing experiment to research the performance of the insulation oil toward the thermal stress.

2.2 Insulating oil for power transformer

The insulation oils are mainly used as impregnates in high voltage cable or for the power transformer. Each of insulation oil has their own classification and categories. Since 1900s, the mineral oil was dominate for the insulation of the transformer oil due to its low cost and good properties[1].

In insulation oils, there are several requirements that insulation oil should possess in power transformer:

a. The insulation oil must excellent in heat transfer because the oil can act as cooling medium which it can absorb heat from the core and the winding inside the transformer.
b. The insulation oil also must good in dielectric properties because want to maintain the insulation become breakdown.

The mineral oils are divided into three types which are naphthenic, paraffinic and aromatic. It contains hydrocarbon compound and a small portion of sulphur and nitrogen [2]. The paraffin consists of straight or branched carbon rings saturated with hydrogen atoms and the molecular formula is C_nH_{2n+2}. The example is methane (CH_4), ethane (C_2H_6), propane (C_3H_8), normal butane (nC_4H_{10}) and isobutene (iC_4H_{10}).

For the naphthenes, it consists of carbon rings with side chains and saturated with hydrogen atoms. It also has similar properties to paraffin. The molecular formula for naphthenic is C_nH_{2n}, and the example is cyclohexane C_6H_{12}. For aromatic, it have a ring of six carbon atoms with alternating double and single bonds and have six attached hydrogen atoms. The molecular formula is C_nH_n, which is benzene C_6H_6.

The mineral oils are considered flammable because they are petroleum based and it can be potentially hazardous to the environment. If something happen due to the incident during the operational time when the explosion of the transformer can lead to leakage the oil to the environment. It will endanger the environment such as soil and water because of its poor biodegradability[3]. But recently, there are many researches studies for alternative source for insulating oil in power transformer. Therefore, the researcher found that the ester oil is the best alternative to replace mineral oil[4].

Ester oils are commonly called as vegetable oil. This oil represent as an option for insulating liquid in power transformer. Ester oil also gives a good impression due to its biodegradability characteristic compared to mineral oil. The biggest advantage of ester oil is non-toxic material characteristic in which it will not produce any toxic product during fire. It is also less flammable with minimum flash point is above 300°C compared to mineral oil that the flash point is between 160-170°C. Moreover the ester oil is also characterized by a relatively high viscosity compared to mineral oil in which it would give less efficiency of heat transfer in transformer.

There are two type of the ester oil which is Natural Ester and Synthetic Ester. The Natural Ester is a seed based esters which are consisting of liquid fats and oils. It known as triglycerides which is derived from fatty acid with 8 to 22 carbon atom[5].

For the synthetic ester is an organic synthetic chemical compound which is known as polyol(pentaerythitol). It consist of four ester group –COOR at the end of the cross structure of the compound and the organic groups R maybe same or can be different[6]. Table 2.1 show the comparison between the insulating oil that can be used in the transformer. It show the breakdown voltage that will get almost similar for mineral, silicone and synthetic ester oils compared to vegetal oil is little bit higher. Then, the flash point of the mineral oils is lower which is 100-170 °C compared to silicone, synthetic ester, vegetal oils are higher which 250°C and above.

Table 2.1: Comparison of Transformer Insulating oils[7]

	Mineral Oils	Silicone Oils	Synthetic Esters	Vegetal Oils	Test Method
Dielectric Breakdown, kV	30-85	35-60	45-70	82-97	IEC 60156
Relative permittivity at 25°C	2.1-2.5	2.6-2.9	3.0-3.5	3.1-3.3	IEC 60247
Viscosity at 0°C, $mm^2.s^{-1}$	<76	81-92	26-50	143-77	ISO 3104
Viscosity at 40°C, $mm^2.s^{-1}$	3-16	35-40	14-29	16-37	
Viscosity at 100°C, $mm^2.s^{-1}$	2-2.5	15-17	4-6	4-8	
Pour point, °C	-30- -60	-50 - -60	-40- -50	-19 - -33	ISO3016
Flash point, °C	100-170	300-310	250-270	315-328	ISO 2592(1)
Fire point, °C	110-185	340-350	300-310	350-360	
Density at 20°C, $kg.dm^3$	0.83-0.89	0.96-1.1	0.90-1.0	0.87-0.9	ISO 3675
Specific Heat,$J.g^{-1}.K^{-1}$	1.6-2.0	1.5	1.8-2.3	1.5-2.1	ASTM E1269
Thermal Conductivity, $W.m^{-1}.K^{-1}$	0.11-0.16	0.15	0.15	0.16-0.17	(DCS)
Expansion Coefficient, $10^{-4}.K^{-1}$	7-9	10	6.5-10	5.5-5.9	ASTM D1903

2.3 Thermal aging of the insulation oils

When the power transformer under service, the quality of the insulating oils gradually deteriorates under the effect of the electrical, chemical and thermal stresses [8]. It means that these effect cause the insulating oil become ageing. Electrical stress can lead the insulation oil to partial discharge, treeing and dielectric heating due to loss insulation or have highly conductive contaminant. Thermal stress can be recognised by the temperature gradient of insulation during the long term operation of the transformer and it can be the factor to the insulation oil decaying. High temperatures cause long-term effects on the internal chemicals of the insulating oil because of the interaction between the hydrocarbon and dissolved oxygen from air which cause the formation of sludge by the oxidation process. In figure 2.1 show that these stresses can cause the degradation of the insulation of oil leading the transformer become failure.

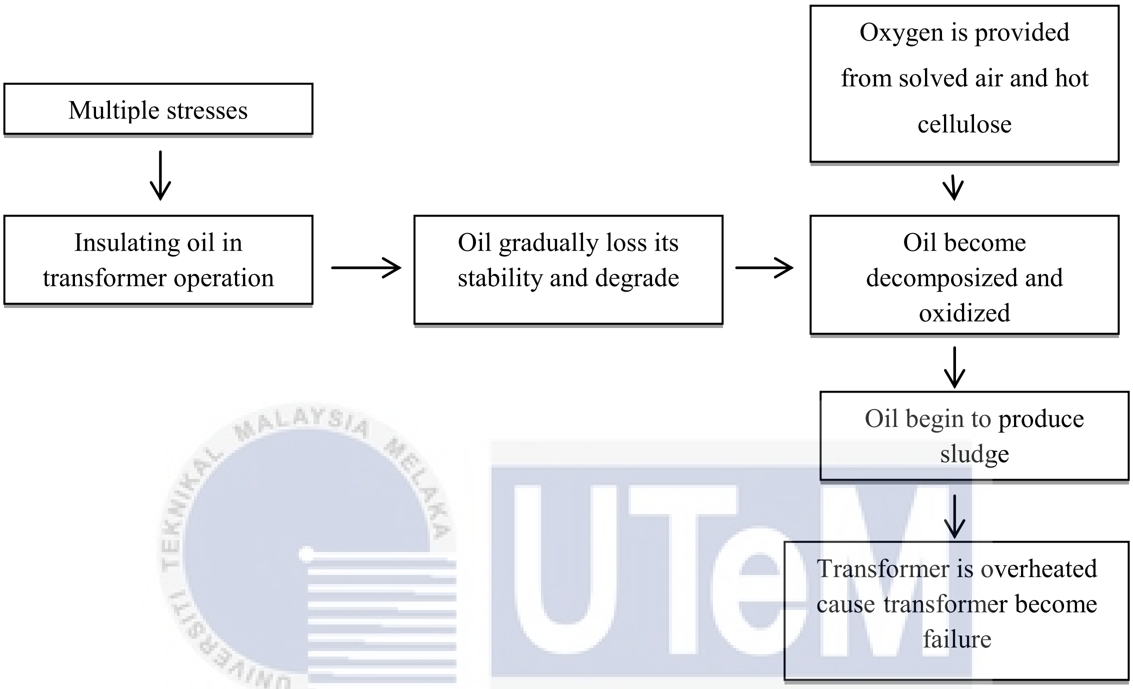


Figure 2.1: Degradation mechanism in oils

A research conducted by A. Johari and Ruijin Liao[4] [9], which the oil are being heated at certain temperature with the different time period in hour. When the oil undergoes an accelerated thermal aging, the colour of the oil change as the oil aged. This show that the change in colour which serve as indication of the degree of oil deterioration.

2.3.1 Aging of cellulose at transformer

In power transformer, the insulation system consists of the oil impregnated paper on the copper winding. The oil impregnated paper usually known as pressboard and it is a natural cellulose polymer. Cellulose is a macromolecule which having micro cell void within the structure. It is act as the insulator in the area of high electrical stress. Usually the temperatures are the important factor for aging which is the temperature can influence the aging of paper and also the aging of oil. During the aging, the formation of organic radical and oxidation are formed in the oil impregnated paper which can accelerate the aging of paper. It also produces a water and organic acid such as formic and acetic acid as the result the further in acceleration aging of the paper and oil.

The aging rate of the cellulose insulation can be significantly slow down when the paper are impregnated with the natural ester compared to mineral oil[10]. According to Steve Moore[10], the reduction and the suppression of moisture build up in cellulose are the main reason that the aging rate of the natural ester reduced. There are two reasons for the moisture reduction of the cellulose in natural ester oil which is moisture migration and hydrolysis.

i. Moisture Migration

The natural ester oil has more moisture compared to the mineral oil. The majority of the moisture is held in the cellulose not the insulation oil. It is because the moisture in the cellulose can be migrated and dissolve to natural ester. When do new natural ester retrofill to the transformer, the new ester will be increase more in water content and the cellulose will decrease in water content. The moisture migrations are not enough to remove all the moisture by itself but it will slow the aging rate of the cellulose.

ii. Hydrolysis

Hydrolysis is a chemical reaction with the water that further explains the moisture reduction in the cellulose. The moisture in the natural ester will react with the fluid to form a new compound which is the long chain fatty acid. The formation of this compound make that the moisture cannot go back into cellulose as the fluid temperature increase. The fluid become drier which allow to absorb the additional moisture in cellulose. Thus the moisture content of the cellulose reduced. So, it will slow the aging process of the cellulose.

2.3.2 Copper influence on aging rate of oil

During the normal operation of the transformer, the insulation oil and paper cannot avoid to connect with the copper winding. Thus there must have some copper ion are found in the insulation oil or paper[11]. The copper ion played a big role in the aging process of the oil-paper insulation which it triggers the oil to undergo oxidation. Thus it will accelerate the aging process of the oil-paper insulation.

Chao Tang et.al[12] conduct an experiment in accelerating thermal aging. The oil samples are prepared in two group of sample which is with and without copper. Then the samples are put in the aging chamber for 80°C and 130 °C. The researcher state that the influence of copper in paper and oil insulation will promote the oxidation and it will accelerate aging rate. The result show that the oil have higher level in acidic number, lower water content and lower the aging rate of the insulation paper.

Tronstad et.al[13] investigated effect of copper and additive in transformer oil by using isothermal micro-calorimeter to see the oxidation phenomena in the oil. The uses of the Hexadecane as model oil are found that it less prone compared to the base oil. In this experiment 0.3 to 0.4 g of copper were added the oil. It shows that, the oil that contains additive, dibenzyl disulphide is found to be good antioxidant which will reduce the oxidation effect when the copper are present in the oil.

2.4 Breakdown in oil

In high voltage, the important materials used in the system are the conductor and the insulator. The conductor means that something material can carry the current. For the insulator it prevents the flow of current to a undesired part. Usually there are many type of the insulation used in the protecting the electrical power system. The insulation that used is gasses, vacuum, liquid and solid. The developed in dielectric strength of the insulating material are important factor in the high voltage system.

The dielectric strength can be defined as the maximum dielectric stress which material can withstand [14]. It is depend on the temperature, humidity, pressure, dielectric material and surface condition of the electrode. To test the dielectric strength of the insulation, the highest voltage applied to the insulation where it cannot withstand the voltage at the moment of the breakdown is called the breakdown voltage.

2.4.1 Breakdown Phenomena

The breakdown phenomena in oil can be analysed by electro-optical means[15]. When the breakdown occurs, the electric field are release free bound electron. If there have increasing in applied electric field, the free electron will accelerates to a velocity which the electron can liberate additional electrons during collision with the neutral atom. This process is called as avalanche breakdown. The breakdown that occurs will result the formation of electrical conductive path through the material.

Breakdown in insulating oil occur when there have difference of potential are applied at the pair of the electrode which are immersed in the oil and a small conduction current is first observed. If the voltage is raised continuously, the spark of the voltage can be seen which it passed through between the electrodes which will happen at the critical point of the oil to be breakdown. These passages of spark that through the oil are explained in the below:

- The flow of the large quantity of electricity are determined by the characteristics of the circuit
- A bright luminous path between the electrode can be seen
- The evolution of the bubbles of gas and the formation of solid product of decomposition.
- The formation of the small pit on the electrode.
- An impulsive pressure through the liquid with an explosive sound can be hearing.

2.4.2 Classification of breakdown mechanism

The breakdown mechanism depends on the nature and condition of the electrodes, liquid physical properties, impurities and gasses. It explain the breakdown in insulation oil which consist of suspended particle mechanism, cavitation and the bubble theory and thermal mechanism of breakdown

i. Suspended particle mechanism

The presence of the solid impurities in the insulating oil cannot be avoided. These impurities can be present in the form of fibre or small particles. The electrostatic force will act on the particles and these particles will experience a force that drives the particle toward the maximum stress area. The particles will gather together and it will become aligned and bridging between the electrode gaps.

ii. Cavitation and the Bubble theory

The presence of the bubbles in the insulating oil can cause the breakdown process through mechanism of cavitation and bubble. These bubbles can be formed due to:

- Formation of gasses pockets at the electrode surface
- Electrostatic repulsive force between the space charges which may not be enough to overcome the surface tension.
- Gaseous product from the dissociation of liquid molecules by electron collision
- Vapourization of the liquid by corona discharge.

When the bubble was formed, it will drag out in the direction of electric field under the influence of electrostatic force. The volume of the bubbles will remain constant during the drag out. The breakdown will occur if the voltage drop across the bubble are equal to the minimum breakdown for the gas according to the Paschen's curve[16].

iii. Thermal mechanism of breakdown

This mechanism is based on the experimental observation of the extremely high current before the breakdown. The high density of current pulse gives rise to localised heating of the oil which leads to the formation of vapour bubbles. The breakdown will happen due to the formation of vapour bubbles because the elongation to critical size or when it completely bridge the gap between the electrode. Thus, the formation of spark will happen. The breakdown strength is depending on pressure and the molecular structure of the oil.

2.4.3 Influences of thermal in breakdown of oil

There are many factors that cause the insulating oil to be degraded. One of the factors is the thermal stress. This thermal stress can cause the oil easily to be breakdown as the oil aged. It show that, the low breakdown voltage indicate the lower insulation ability of the oil when the high voltage is applied on them. When the thermal stress goes on such a long period, it can lower the dielectric properties. So, it weakens the properties of the insulating oil which can cause the insulation failure.

A.Johari et al. [4] reported the breakdown voltage (BdV) test result seen the voltages become decrease as the oil sample age. The oil used was been thermally accelerated for 200 hour of aging period at elevated temperature of 150°C. When under sustain high operating temperature the quality of the insulation oils will degrade as the result of the breakdown voltage decrease. This experiment use two different ester oil which is PFAE and FR3 oils show that difference in breakdown voltage value when undergo BdV test. Figure 2.2 show breakdown voltage plotted against the ageing time which the breakdown voltages decrease along with the ageing time.

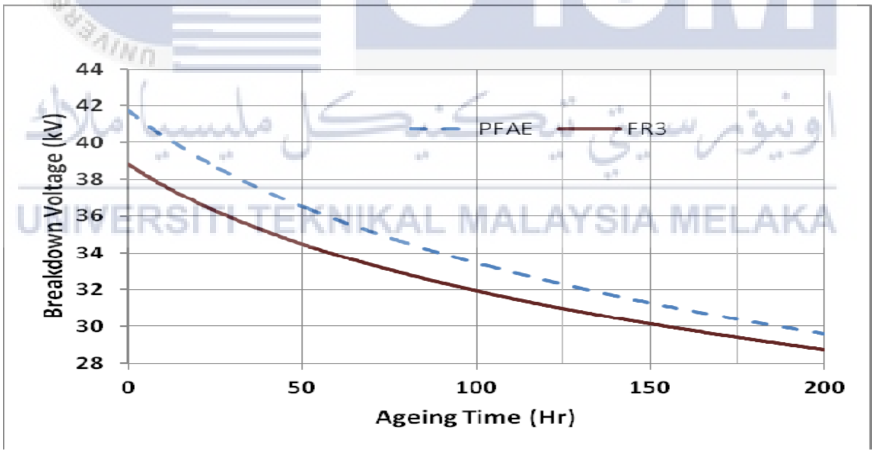


Figure 2.2: Breakdown voltage of PFAE and FR3 [4]

C. Perrier and A. Beroual [17] reported, the oil used was been thermally accelerated for 14 days of aging period at elevated temperature of 120°C. Before the ageing of the natural and ester oil, the BdV result of both oil present close to mineral oil. After the ageing, the natural ester keep a good value for a BdV result and are sometimes more better than the mineral oil.

I. Fofana et al.[18] reported, the breakdown voltage for mineral oil mixture with and without Transclene must be point out because the values are strongly temperature dependent. Lower the temperature the lower the breakdown voltage. The cause of this is because of the water saturation limit. If the water content is higher than this saturation limit the breakdown voltage will be lower.

A research by Abdul Rajab et al.[3] state that the breakdown voltage of all tested insulating oil which is mineral, palm and silicone oils show the temperature increasing significantly from 25°C up to 70°C. Meanwhile, the temperature from 70°C to 120°C shows that the breakdown voltage is slightly increased. Figure 2.3 show the graph of breakdown voltage against temperature. This research also have similar trend that was reported by Suwarno and Erawan S.D. [19] and C. Yeckel et al. [20] which is the breakdown voltage of the insulating oil was increased.

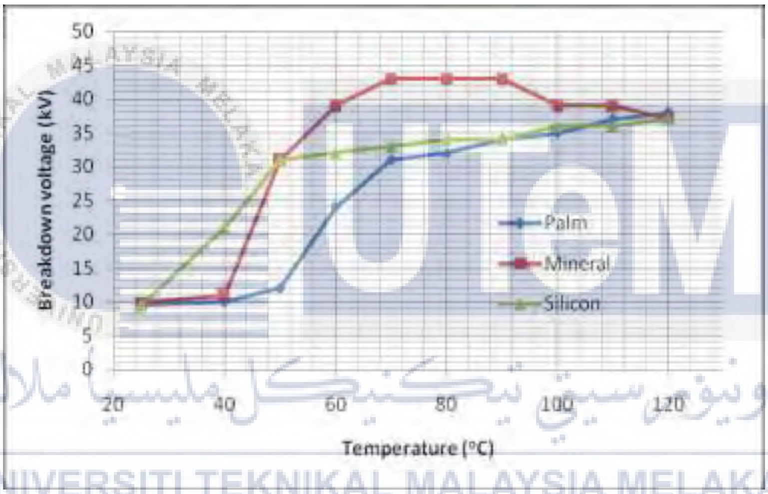


Figure 2.3: Breakdown voltage against temperature[3]

2.5 Fourier Transform InfraRed (FTIR) Spectroscopy

FTIR is one of the tools that use to analysis the oil in the laboratory. It is a tool that used to detect the contaminant, degradation byproduct and additive which is within the oils. The preferred method for FTIR is the infrared spectroscopy. It use when the infrared radiation is passed through the sample. The radiation was absorbed by the sample at very specific wavelength and some just passed through it. The resulting spectrum creates a molecular fingerprint of the sample. Like a fingerprint no two unique molecular structures produce the same pattern and wavelength. This makes FTIR are useful for several types of analysis.

This method is very quick to perform and can detecting multiple parameters such as water, oil, oxidation, soot, glycol and additives. It produces direct information which the size of the peak is a direct indication of the amount of the specific material found in the sample. The FTIR parameters are show in Table 2.2 which represents the parameter of interest and information on obtaining and using them. The spectrum plot in figure 2.4 show a used oil difference spectrum and label the peak of interest which indicate in the Table 2.2.

Table 2.2: FTIR Parameter [21]

Parameter of Interest	Spectral Location (approx. cm^{-1})	Type of Measurement	Traditional measurement
Soot	2000	Tending carbon load (diesel engines)	Total insoluble, Thermogravimetric analysis
Oxidation (carbon)	1700	Trending oil degradation	Total base number, Total acid number, Viscosity*
Nitration	1630	Trending oil degradation (engines only)	Total base number, Total acid number, Viscosity*
Sulfation	1150	Trending oil degradation (engines only)	Total base number, Total acid number, Viscosity*
Water	3400	Contaminant screening	Crackle test, Karl Fischer
Diesel fuel	800	Contaminant screening	Flash point, Viscocity, Gas chromatography
Gasoline	750	Contaminant screening	Flash point, Viscocity, Gas chromatography

Antifreeze (glycol)	880	Contaminant screening	Colorimetric assay, Gas chromatography
Antiwear additive	960	Additive depletion	Elemental zinc

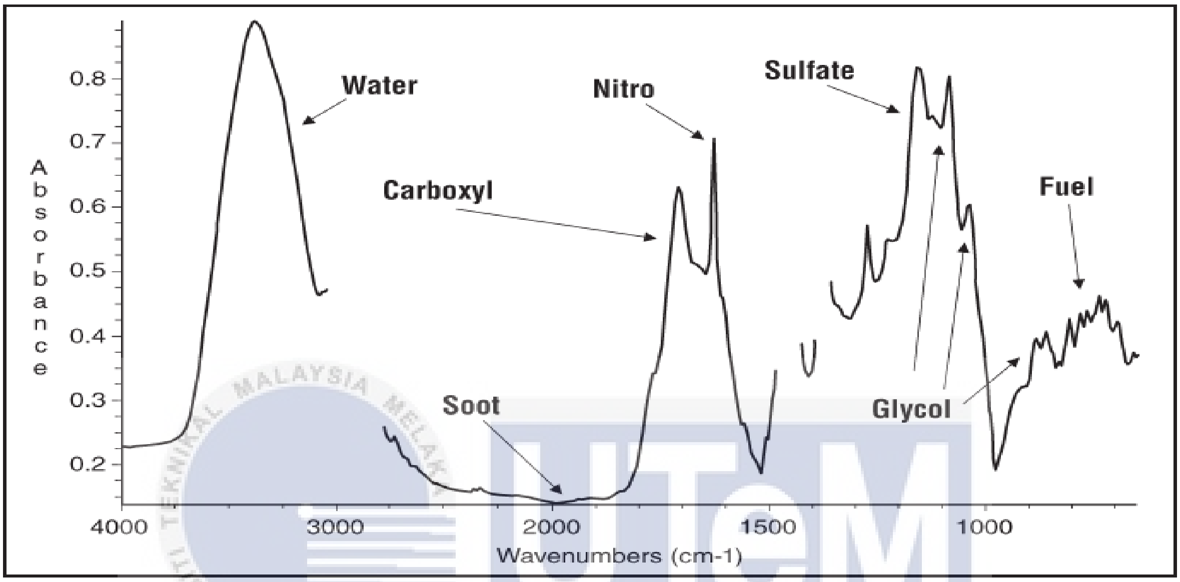


Figure 2.4: Wavenumber Spectrum[21]

2.5.1 Group Frequency

FTIR is based on the fundamental principles of molecular spectroscopy. The basic principle behind the molecular spectroscopy is when specific molecules absorb infrared light at a specific wavelength. It is known as their resonance frequencies. The FTIR can scan from 4000 to 400 cm^{-1} where at specific region of the spectrum. This parameter can be determined by using this FTIR, such as water molecule where it can resonates around the 3450 cm^{-1} of wavenumber in the infrared region of spectrum.

Somehow, there are similarities between functional groups in some molecules. The most common molecule that found in the oil samples is water, glycol and the hindered phenol antioxidant additive BHT. All these molecules are absorbed light in the range of 3600 to 3400 cm^{-1}, although the actual wavenumber will vary slightly due to the O-H functional group present in each molecule. The Figure 2.5 shows the illustrated molecules that found in the oil sample which all three molecules are having same O-H functional group.

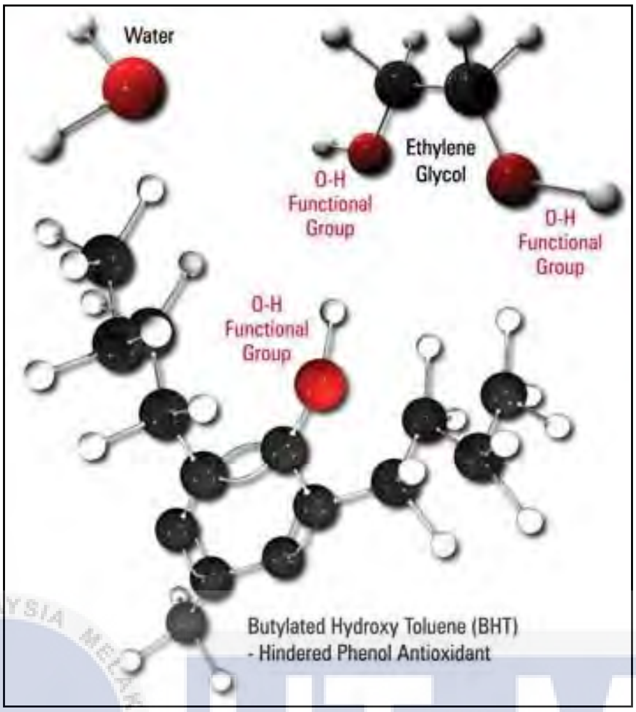


Figure 2.5: Molecules in an oil sample[22]

The similarities with the functional group can cause a problem to the FTIR. It is because the infrared absorption is recorded in the 3600-3400 cm^{-1}. It may cannot be differentiate absorption between the water, glycol, and antioxidant additive because of their absorption peak may be overlap. Fortunately, the glycol molecule also absorbs the infrared light in other different region of spectrum which is 880, 1040 and 1080 cm^{-1} which it make confirmation. However, these this illustrates molecules has weakness with FTIR for used oil analysis because of the most oil samples have a complex mixtures of a thousand of different molecules which including the base oil molecules, oil degradation by product and contaminants. The infrared spectrum of the oil sample will be very complex and difficult to interpret with any degree of certainty. However, even it have weakness, the FTIR still have result in oil analysis and it is using as screening tool by the majority of oil analysis lab.

There are some method that can minimize the effect of the base oil and additive molecular resonance which involve three stage processes. The first stage is record of FTIR spectrum of a new oil sample to get a baseline FTIR trace. Second stage is to record the FTIR spectrum of the used oil sample. The third stages are to compare between the new baseline oil with the used oil sample to get different FTIR spectrum. Figure 2.6 show the FTIR difference spectrum.

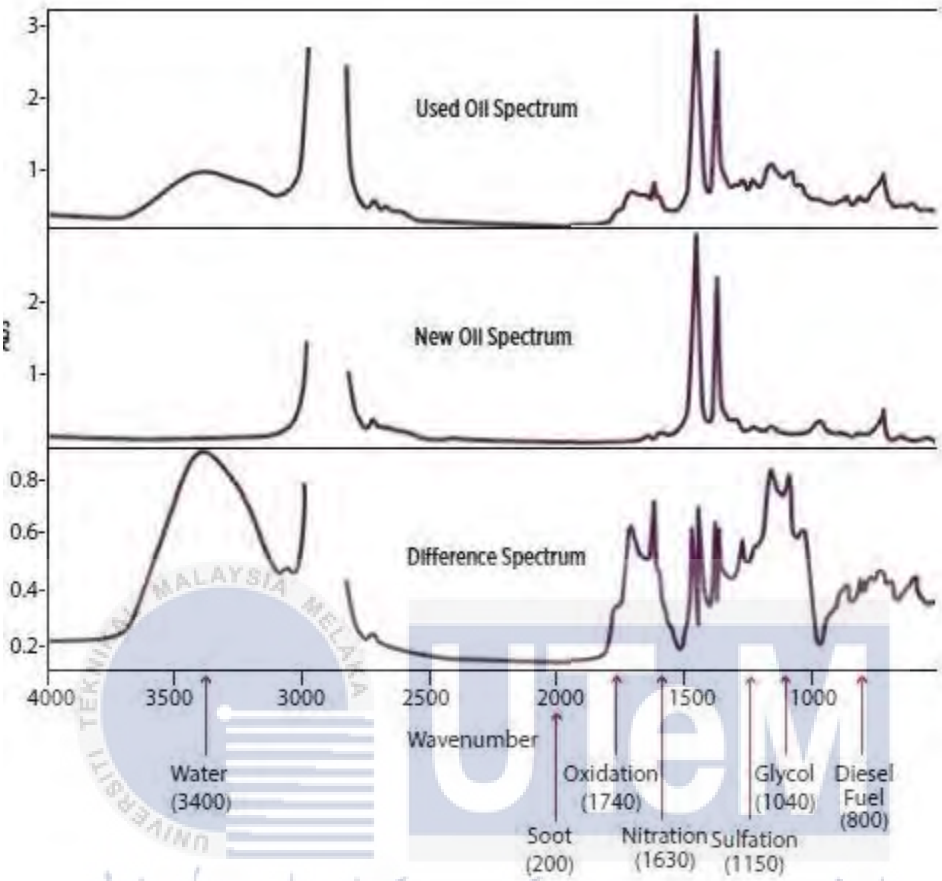


Figure 2.6: Three stage method to get different FTIR spectrum[23]

Y. Hadjadj et al.[24] has prepare an aging oil samples and monitored with the alternative technique based on the spectral analysis using FTIR. The results show that the range of the spectrum between 1620 to 1820 cm^{-1}. The intensity increase at 1710 cm^{-1} of the absorbance band show that the locations of the spectral are in oxidation parameter. Same as A.Johari et al.[4] which the intensity increase at 1762 to 1730 cm^{-1} which indicate the oil become aging because it undergo oxidative degradation. Figure 2.7 and 2.8 show the aging oil with the FTIR spectrum.

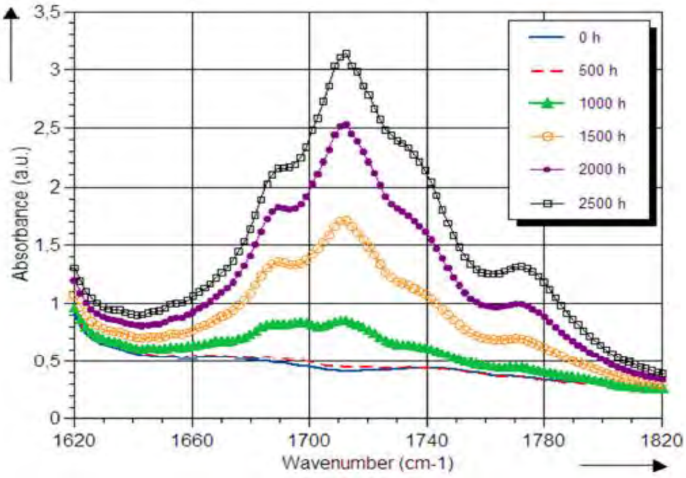


Figure 2.7: Aging effect on FTIR[24]

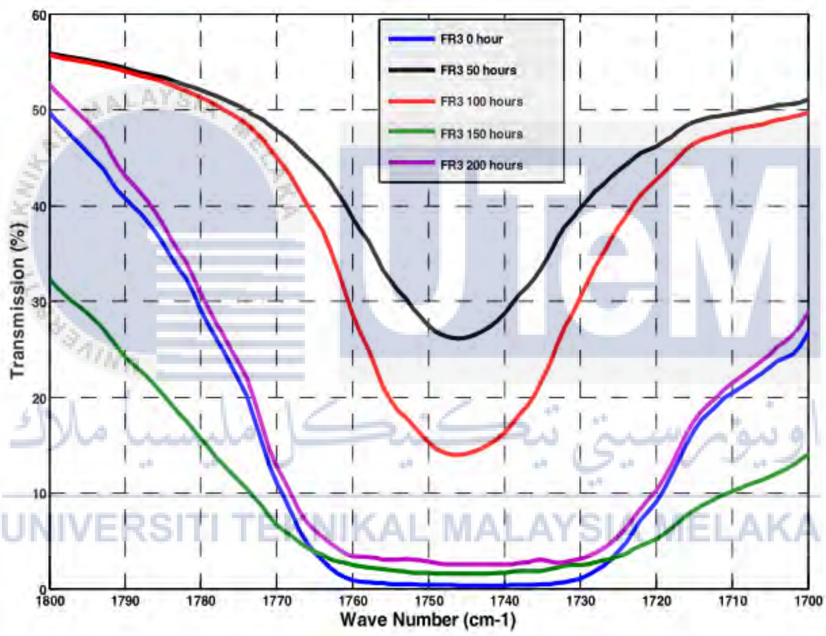


Figure 2.8: Aging FR3 oil on FTIR[4]

2.5.2 The Fourier Transform InfraRed (FTIR) Operation

The FTIR process is follow as in the Figure 2.9:

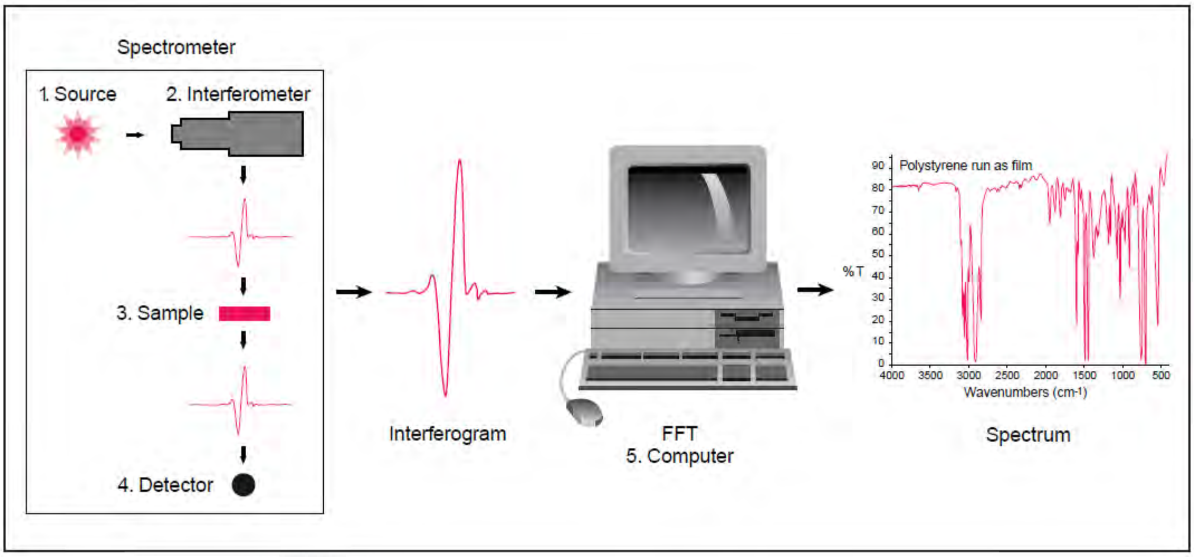


Figure 2.9: FTIR process[25]

FTIR process has many steps to be followed. First is the use of infrared energy as a source. The infrared energy is emitted to the sample and sends it through an aperture which control the amount energy presented to the sample. Then, the infrared energy enters the interferometer where the spectral encoding uses a series of stationary and movable mirror. The spectral encoding produces a signal that consists of all the important infrared frequency simultaneously. Then the infrared enter the sample compartment where it is transmitted through or reflected of the surface of the sample. This is where the specific frequencies of the sample characteristic are being absorbed. The infrared energy then escapes the sample and it sent to the detector for the final measurement. The detector is used to measure the special interferogram signal. Then the measured signal is sent to the computer where the Fourier transformation takes place. The final infrared spectrum is presented to the user for the interpretation.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss the experimental procedures that used in this project including the preparation of ester oils sample, the measurement of breakdown voltage test and the FTIR test.

3.2 Flow chart

This flow of this project start with the selection of the final year project topic and the literature review done in order to understand more detail about the overall key point of this project according the topic which related to the effect of the thermal stress on insulation oil that use in the power transformer. This project is focused on the breakdown voltage test and Fourier Transform Infrared analysis when the oil samples are prepare and this project is refer to the latest research that have been done. Figure 3.1 show the flow chart of the project.

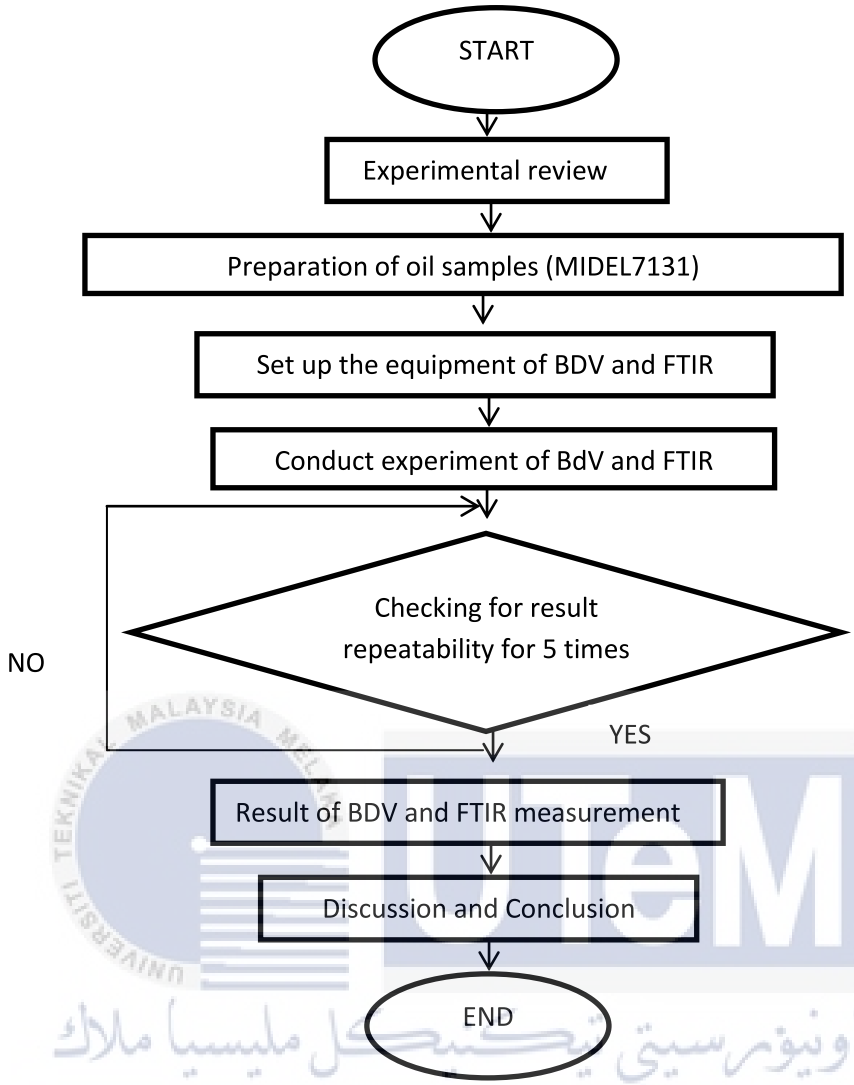


Figure 3.1: Flow chart

3.3 Preparation of oil sample

In this experiment the preparation of oil sample are important to conduct a BdV and FTIR analysis. Before start the accelerated thermal ageing process the oil samples (MIDEL 7131) are being pre-conditioned first. Firstly, make sure to clean the beaker before filled it with the oils. The oils samples are taken from the oil container. Then, all the oils samples are vacuumed in the vacuum oven as shown in Figure 3.2. These procedures are intended to reduce the moisture that may increase during the storage of the oil in the container. Moreover, others reason is the uses of the pump to suck the oil from container may introduce the moisture to the oil. The moisture content of the oil can affect the dielectric properties of the oil which can lower the breakdown withstand strength of oil[26]. The oils samples are vacuumed at the lower temperature setting which is 70°C instead of 100°C. It because the temperature is more dependable to remove moisture which can reduce problem of degradation of the oil when use high temperature. The oil samples are stored in the vacuum oven for one day for cooling the oil to decrease the temperature at room temperature.

Figure 3.2: Vacuum oven for oils pre-conditioning

The copper strip and the cellulose material are being prepared. The copper strip is being cut with the dimension of 15cm (length) x 1cm (width). Then, the copper are put into the ventilated oven to get rid of water on the copper after wash it. For the cellulose preparation, the pressboards are blend until it becomes a small particle or dust. Then, the celluloses are being filter to get more smooth particles. The cellulose needs for each sample are 5 gram. The Figure 3.3 show the copper strip and cellulose need for adding to the oil samples later.

Figure 3.3: Cellulose and copper strip for oil samples

3.4 Accelerated aging

After vacuum process of the oils is done, the oil samples are ready to put inside the ventilated oven for the accelerated aging process. The oil samples are divided into two group of sample which is the ester oil with and without the presences of copper and cellulose. These experiments are arranged for 48 hour which is in 2 day at the aging temperature of 120 °C. The oil samples are directly being exposed to the air inside the ventilated oven to represent the free breathing transformers which allow the oxidation process to happen. Table 3.1 show ageing period of oil samples and Figure 3.4 show the oil samples being aging in the oven

Table 3.1: Ageing period

Ester oil (MIDEL 7131)	Time (Hour)			
Without copper and cellulose	0(New)	6	24	48
With copper and cellulose	0(New)	6	24	48

Figure 3.4: Accelerated thermal aging of the oil

3.5 Breakdown voltage test

This breakdown voltage test is according to standard ASTM D1816 – dielectric breakdown voltage of insulating liquid using VDE electrodes[27]. There are several procedure should be followed.

3.5.1 Breakdown sample preparation

Before doing the breakdown voltage test, there are some procedure needs to be done to start the test. The procedures are state as follow.

i. The Megger OTS60PB Breakdown test set up for the oil samples is shown in Figure 3.5.

Figure 3.5: Breakdown test set up

ii. The electrode shall be polished brass spherically-capped electrode of the VDE. The electrode having the dimension shown in Figure 3.6.

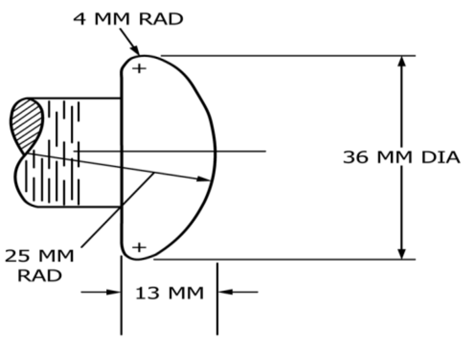


Figure 3.6: VDE electrode[27]

iii. According to ASTM D1816, for electrode spacing check the electrode with a standard round gage for 2$\pm$0.33-mm (0.079-in.) spacing. If the dieletric breakdown does not occur during any of the consecutive breakdown test should use 1$\pm$0.03-mm(0.039-in). In this experiment the spacing used is1$\pm$0.33-mm(0.039-in).

iv. Filling the oil sample into the container about 500ml and check the temperature of the oil sample which it should be equal to the ambient temperature. Put the oil into BdV test set. The electrode and the other component part should be drained with the oil samples.

3.5.2 Measurement procedure

i. First voltage application is started approximately 3 min after completion of the filling oil in the container and there should be no air bubbles which are visible in the electrode gap.

ii. Apply the voltage increasing from zero at the rate of 0.5 kV/s $\pm$ 5 % until breakdown occurs.

iii. Then fours additional breakdown waiting for 60s before application of voltage for another successive breakdown.

iv. The BdV tests are repeated for 5 times to determine the average value for dielectric strength of the oil is above or below a specified level.

v. The final result was calculated from the mean value of the 5 breakdown in kV.

3.6 FTIR test

The FTIR analysis is according to standard ASTM D2144 − Examination of Electrical Insulating Oils by Infrared Absorption[28].There are several procedure should be followed.

3.6.1 Sample preparation

i. The Jasco FT/IR-6100 is being used in the FTIR analysis as shown in Figure 3.7.

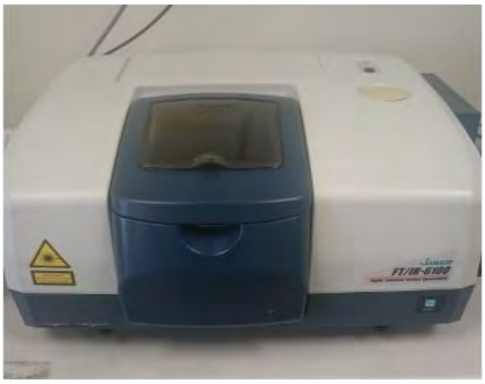


Figure 3.7: Jasco FT/IR-6100 equipment

ii. The FTIR is operating within the 4000 to 400 cm^{-1} which is the region of the spectral wavenumber.

iii. One drop of the oil sample oil sample is placing at the glass disk holder as shown in Figure 3.8. Before that make sure the glass are clean and dry from any oil or water.

Figure 3.8: One drop of oil sample

iv. Then, cover up with one more glass disk holder to spread the oil and get one layer of oil at the glass holder. After that, put glass disk holder into the FTIR equipment to run the scanning. The infrared radiation will transmit to the glass disk that contains a layer of the oil sample and the radiation was absorbed by the sample at very specific wavelength and the infrared radiation will passed through the glass holder direct to detector to doing analysis. Figure 3.9 show the FTIR process.

Figure 3.9: FTIR process

v. The oil sample is scanned for 25 times within 20-25 seconds to get the spectral wavenumber between the 4000 to 400 cm^{-1}. Make analysis from the spectral wavenumber to determine the changes in oil sample as show in Figure 3.10.

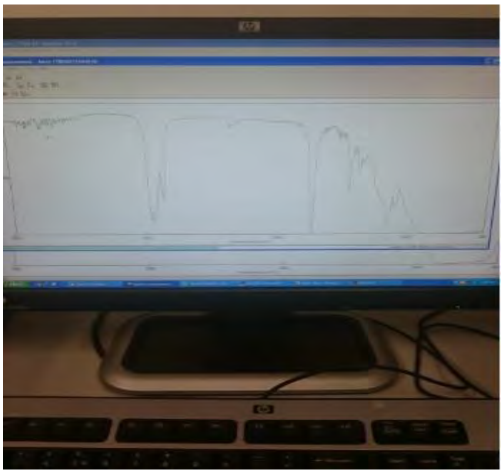


Figure 3.10: Spectral wavenumber

3.6.2 FTIR analysis

The FTIR analyses are refer to the absorption band according to standard ASTM D 2144. The absorption bands used to determine the significance of the specific absorption band and their changes in absorption of oil. It commonly used to observe in the electrical insulating oil spectra.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Some experiment had been conducted for this project which is on breakdown voltage test and FTIR test. The data collection is done for each experiment. Data is presented in a graph plot to be used for comparing the breakdown strength between the ester oil (MIDEL 7131) without adding copper and cellulose and with adding copper and cellulose.

4.2 Breakdown Voltage

The result for the breakdown voltage for ester oil without and with presence copper and cellulose are listed in Table 4.1 and 4.2. The breakdown test was performed with a 500 ml oil were used for each aging stage and five breakdown test were conducted on each sample. Each breakdown test has five breakdown voltage, so there were 25 breakdown voltage obtained for each ageing stage. The results of each ageing time listed in Table 4.1 and 4.2 are the mean values for each breakdown test.

Table 4.1: BdV without copper and cellulose

Thermal aging (hour)	Breakdown voltage ,BDV (kV)					
	Average					Mean
0	26	28	34	27	31	29.2
6	31	29	29	25	30	28.8
24	23	29	30	22	27	26.2
48	22	20	21	23	21	21.4

Table 4.2: BdV with copper and cellulose

Thermal aging (hour)	Breakdown voltage ,BDV (kV)					
	Average					Mean
0	7	6	8	7	8	7.2
6	7	7	7	7	7	7.0
24	7	6	7	7	7	6.8
48	7	7	6	6	6	6.4

A graph are plotted from the data in Table 4.1 and 4.2 to show the breakdown voltage comparison between ester oil (MIDEL 7131) with and without copper and cellulose along with time is described in Figure 4.1. It shows the ester without presence copper and cellulose has higher value breakdown voltage compared with the ester having copper and cellulose. For the 0 hour which the oil are not being heated, it indicates that the breakdown voltage is 29.2kV for without copper and cellulose compared to the ester with copper and cellulose which is 7.2 kV shows the lower in values in the breakdown voltage. After the oil samples are being heated, the breakdown voltage slightly decreased between 0 to 6 hour which is 28.8 kV and then continuously dropped for 24 to 48 hour which is 26.2 kV and 21.4 kV. For the ester with copper and cellulose, the breakdown voltage slightly decreased from 6 to 48 hour which is 7 kV to 6.4kV. From the breakdown voltage of oil without copper and cellulose show 26.71% higher in breakdown voltage value compared to the breakdown voltage of oil with the copper and cellulose only 11.11%.

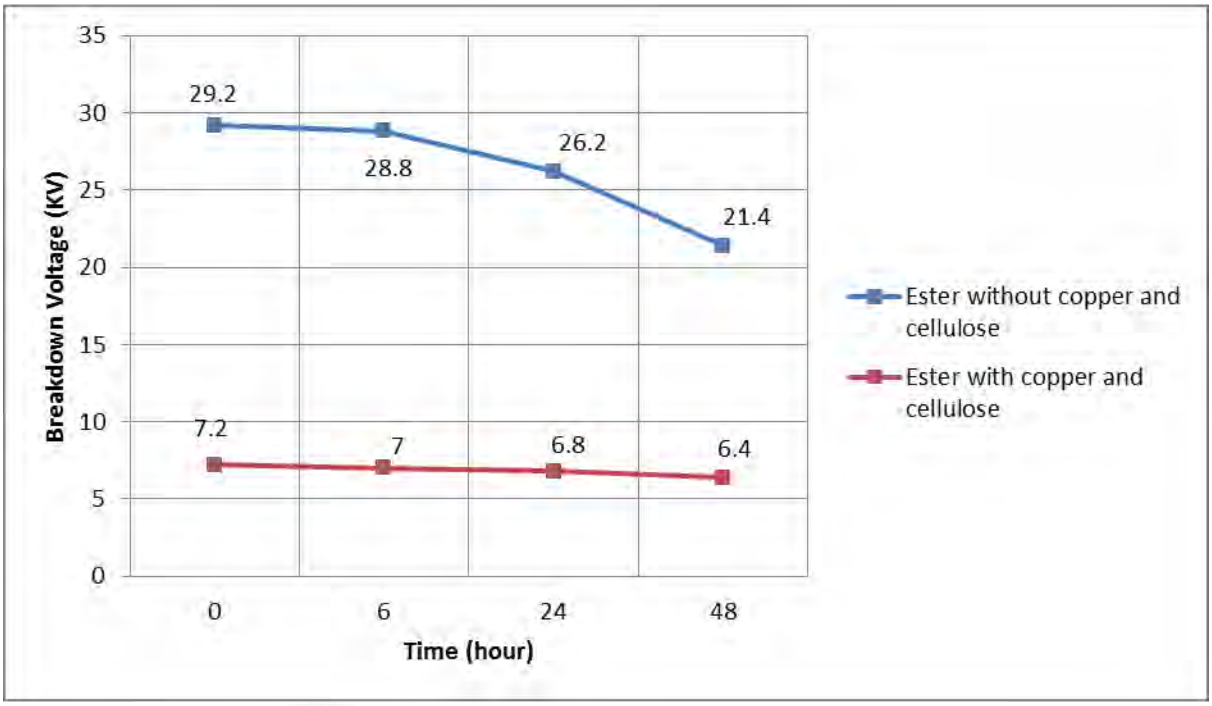


Figure 4.1: BdV vs Time

The decrease in value of the breakdown voltage for the oil without copper and cellulose indicate that the oil will degrade with the time when the oil is under high operating temperature which is 120 ˚C. Thus, the effect of the thermal stress show the quality of the oil will degrade cause the breakdown strength of the oil decrease. A similar result by A. Johari et. al [4] show the breakdown voltage for the PFAE and FR3 decrease with ageing time. So, the result agrees that the thermal stress can cause the decrease of the breakdown voltage of the insulating oil in the transformer.

The oil sample with the presence of copper and cellulose also show the decrease in breakdown voltage but the value are to lower compared with the oil that not contain the copper and cellulose. This is because the cellulose itself causes the dielectric strength of oil decrease. This cellulose is act as the suspended particles in the oil which the particles are forming a bridging in between the electrode gap. When the bridging is happen, the oil cannot be the insulator anymore because the particles become the conductor which can connect to each other when there have a current through the electrode. The spark of the voltage can be seen which it passed through between the electrodes showing that the oil become breakdown.

Another reason the breakdown voltage decreases because the copper influence in the oil play a big role in aging process. The copper can trigger the oil to undergo oxidation which can accelerate the aging process. These results are similar with the result found by the Chao Tang et.al. [12]. They observed that the copper will promote oil to oxidation which accelerates the aging rate of the oil. Thus, the presence of copper and cellulose in the oil will make the breakdown voltage lower compared to the oil without the copper and cellulose.

According to the ASTM D6871[29] which is the standard specification for ester oil used in electrical apparatus state that the acceptable limit breakdown voltage of ester oil using the test method of ASTM D1816 are 20 kV. Thus, in the result show that the oil without the presence of copper and cellulose are still acceptable because the value for the breakdown voltage are above 20 kV. It indicate that the oil still in good condition although the oil show decrease in breakdown voltage with the time for 48 hour period. The oil with the presence of copper and cellulose show that the breakdown voltage very low. At around 7kV, the breakdown happens on the oil. It indicate that the oil are very bad condition and the oil are no longer can be used as the insulation for the power transformer.

Another test which is FTIR is being conducted to relate the decrease in the breakdown voltage of the oil. This test is wanted to see if there anything changes within the oil which is to detect the contaminant, degradation by-product and additive when under the effect of thermal stress.

4.3 FTIR

FTIR analysis is used to identify the unknown material and the quality or consistency of a sample. So, the FTIR of the oil samples in this project show a molecular structure change as the oil is age. The thermal stress will cause the oil to thermo-oxidative degradation[4] which affect the molecular structure within the oil as shown in Figure 4.2 and Figure 4.3.

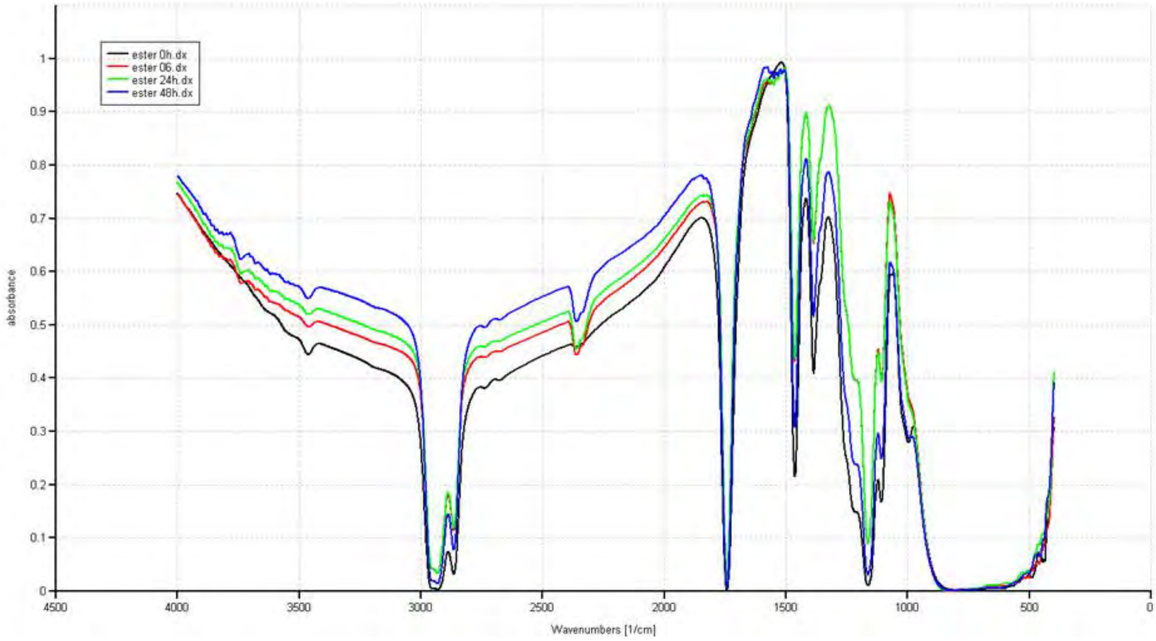


Figure 4.2: FTIR spectrum on ester oil without copper and cellulose

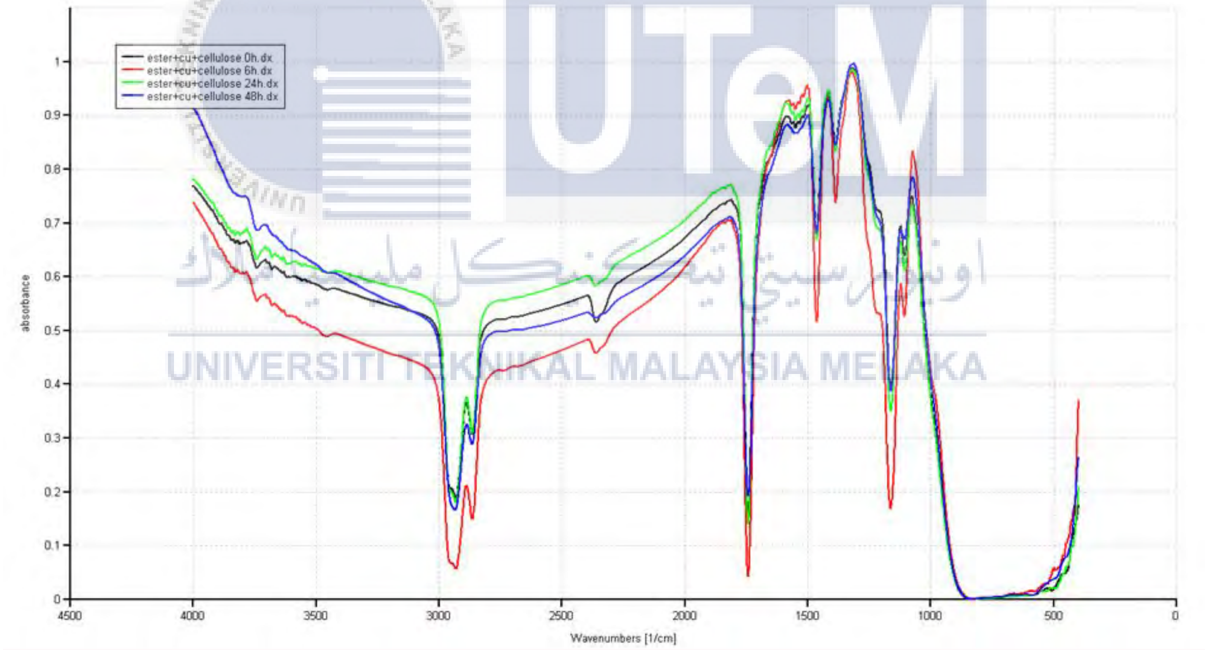


Figure 4.3: FTIR spectrum on ester oil with copper and cellulose

From the Figure 4.2 above, it show a wavenumber spectrum of the oil sample without the presence of the copper and cellulose. According to the ASTM D2144, the range of the wavenumber between 3700-3570 cm^{-1} is the region is assigned to O-H and N-H stretching vibration. It is useful for determine an absorption wavelength for moisture content. Figure 4.4 indicate the region of O-H and N-H stretching for the ester oil without the presence of copper and cellulose. Based on the region of 3700 to 3570 cm^{-1} the region that selected is 3680 cm^{-1} because this peak indicated the changing at spectrum. The ester oil with the spectrum in black colour (0 hour) indicated 0.55% of absorbance. The red colour (6 hour) showed 0.57% of absorbance which is slightly increase from the ester oil of 0 hour. The green colour (24 hour) showed a 0.59% of absorbance while the blue colour (48 hour) showed higher absorbance level which is 0.62% of absorbance. Hence, as the oil aged with the time, the absorbance levels of the ester oil are increase. As it can be seen, the spectrum is shift upwards and the shape spectrum of the red, green and blue are different with the spectrum in black colour which indicate that there are molecular structure change within the oil. The change in the oil spectrum show, with the increasing level of absorbance in the oil sample indicates the moisture content in the oil increase.

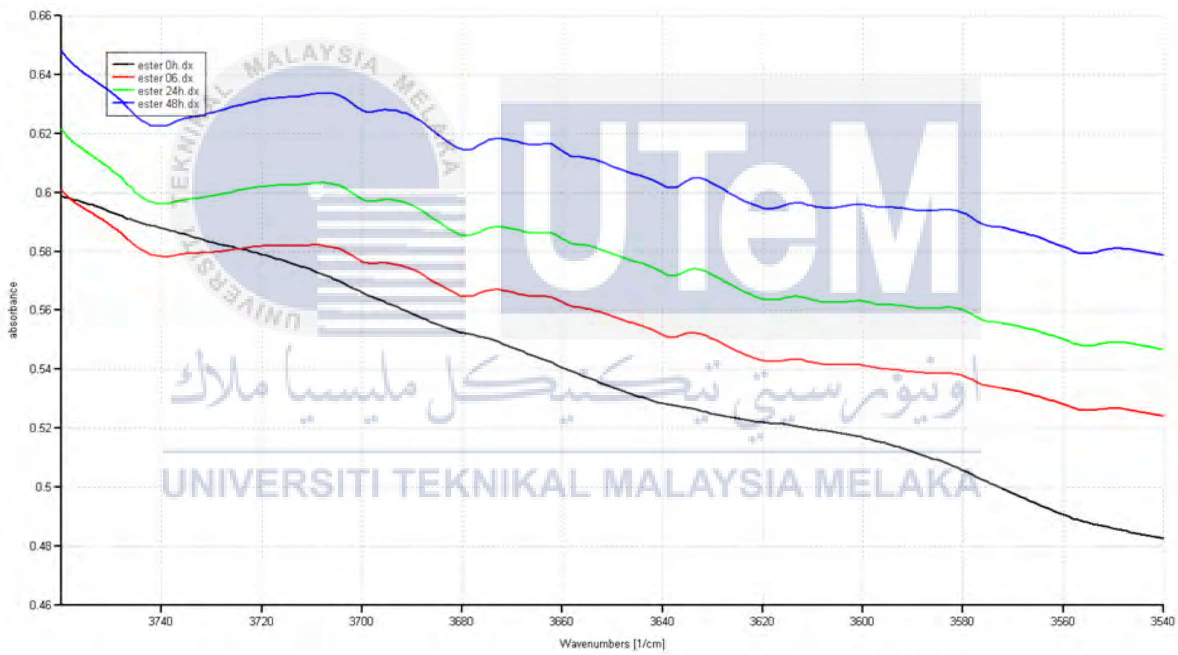
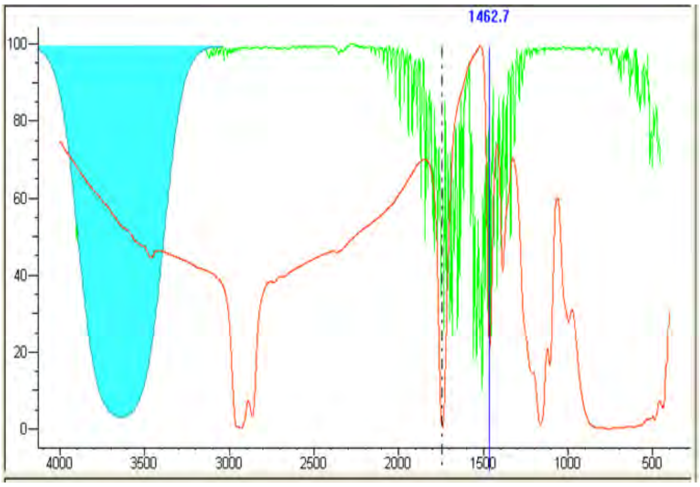
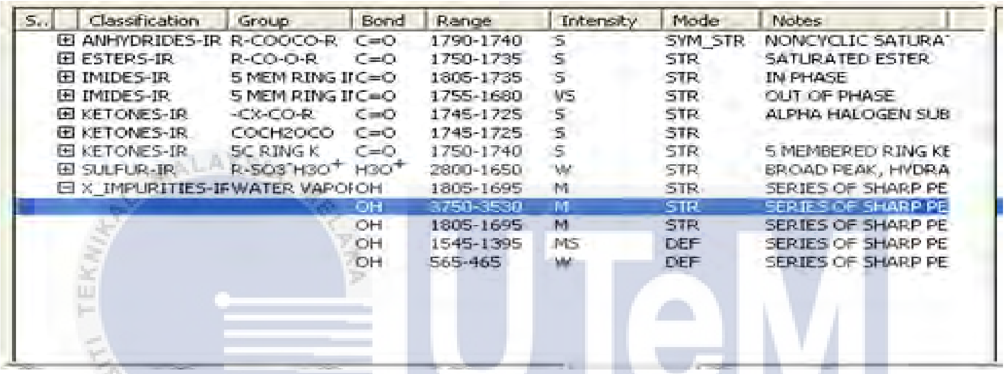


Figure 4.4: The O-H and N-H stretching vibration in oil sample at 3680 cm^{-1}

Figure 4.5 show the chemical structure appear in the ester oil with 48 hour of heating that is analysed by IR analyser. The spectrum of the oil is being compared with the selected region from the library which is included in the IR analyser shown in Figure 4.5 (a). Figure 4.5 (b) shows the selected fragment structure and the Figure 4.5 (c) show list of the structure exist in the spectrum.



(a) (b)



S..		Classification	Group	Bond	Range	Intensity	Mode	Notes
	⊞	ANHYDRIDES-IR	R-COOCO-R	C=O	1790-1740	S	SYM_STR	NONCYCLIC SATURA
	⊞	ESTERS-IR	R-CO-O-R	C=O	1750-1735	S	STR	SATURATED ESTER
	⊞	IMIDES-IR	5 MEM RING II	C=O	1805-1735	S	STR	IN PHASE
	⊞	IMIDES-IR	5 MEM RING II	C=O	1755-1680	VS	STR	OUT OF PHASE
	⊞	KETONES-IR	-CX-CO-R	C=O	1745-1725	S	STR	ALPHA HALOGEN SUB
	⊞	KETONES-IR	COCH2OCO	C=O	1745-1725	S	STR	
	⊞	KETONES-IR	5C RING K	C=O	1750-1740	S	STR	5 MEMBERED RING KE
	⊞	SULFUR-IR	R-SO3⁻H3O⁺	H3O⁺	2800-1650	W	STR	BROAD PEAK, HYDRA
	⊟	X_IMPURITIES-IF	WATER VAPO	OH	1805-1695	M	STR	SERIES OF SHARP PE
				OH	3750-3530	M	STR	SERIES OF SHARP PE
				OH	1805-1695	M	STR	SERIES OF SHARP PE
				OH	1545-1395	MS	DEF	SERIES OF SHARP PE
				OH	565-465	W	DEF	SERIES OF SHARP PE

(c)

Figure 4.5: Chemical structure appear in the ester oil with 48 hour of heating without presence of copper and cellulose (a) Spectral analysis (b) Selected fragment structure (c) List of chemical structure

As it known that the power transformer is exposed to the humidity surrounding. Thus, in this experiment the sample are directly exposed to the air inside the ventilated oven in order to represent the free breathing transformer which is allow the oil undergo oxidation process when the thermal stress are applied toward the oil sample. The Figure 4.5 proves that the chemical structure of water, H_2O exist at 3680 cm^{-1}. It prove the difference of spectrum at the absorbance value of 48 hour oil sample are higher than the absorbance value for 0 hour oil sample which the moisture content of the oil are increase. So, when the moisture content in the oil increase indicates that the breakdown voltages for the oil sample are decrease.

From the Figure 4.3, it shows a wavenumber spectrum of the oil sample with the presence of the copper and cellulose. The range of the wavenumber 1754 to 1667 cm^{-1} is the region of carbonyl (C = O) stretching vibration. This region is specific location for the absorptions to the type of compound present which is ester, acid, anhydride, and ketone. These absorption regions are to indicate the oxidation products or contaminants. Figure 4.6 indicate the region of carbonyl (C = O) stretching vibration for the ester oil with the presence of copper and cellulose. Based on the region of 1754 to 1667 cm^{-1}, the region that really can be observable is selected at 1734 cm^{-1} because this peak indicated the changing at spectrum. The ester oil with the black colour (0 hour) spectrum at 1741 cm^{-1} indicate that the absorbance is 0.16%, the red colour (6 hour) is 0.04%, the green colour (24 hour) is 0.14% and blue colour (48 hour) is 0.19%. Suddenly, at 1734 cm^{-1} the spectrums of black, blue and green colour are crossing to each other before it goes upper level of absorbance. The suddenly changing spectrum indicated the oil having oxidation product or contaminant.

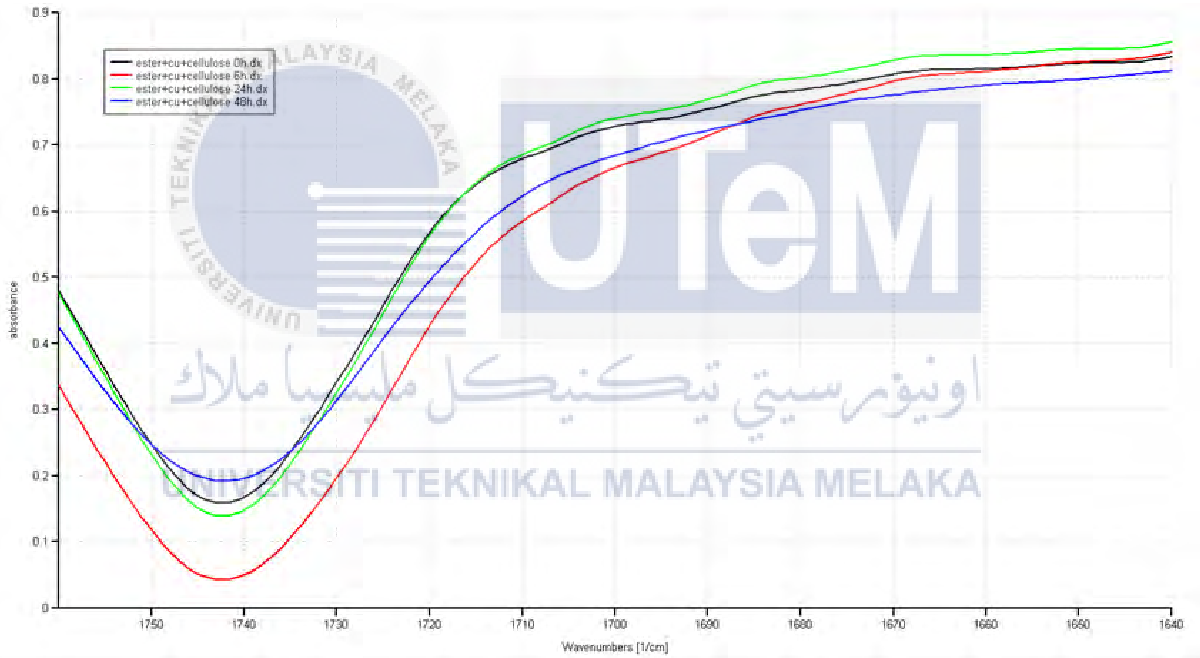
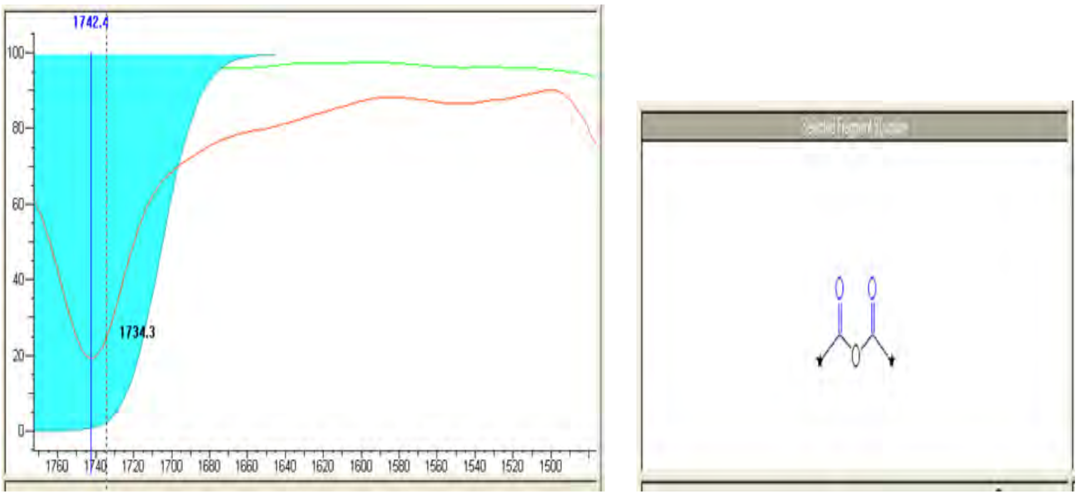


Figure 4.6: The carbonyl (C = O) stretching vibration in oil sample at 1754 to 1667 cm^{-1}

Figure 4.7 show the chemical structure appear in the ester oil with 48 hour of heating that is analysed by IR analyser. The spectrum of the oil is being compared with the selected region from the library which is included in the IR analyser shown in Figure 4.7 (a). Figure 4.7 (b) shows the selected fragment structure and the Figure 4.5 (c) show list of the structure exist in the spectrum.



(a) (b)

S..	Classification	Group	Bond	Range	Intensity	Mode	Notes
	ANHYDRIDES-IR	R-COOCO-R	C=O	1790-1740	S	SYM_STR	NONCYCLIC SATURA'
	ESTERS-IR	R-CO-O-R	C=O	1750-1735	S	STR	SATURATED ESTER
	IMIDES-IR	5 MEM RING I	C=O	1806-1735	S	STR	IN PHASE
	IMIDES-IR	5 MEM RING I	C=O	1755-1680	VS	STR	OUT OF PHASE
	KETONES-IR	-CX-CO-R	C=O	1745-1725	S	STR	ALPHA HALOGEN SUB
	KETONES-IR	COCH2OCO	C=O	1745-1725	S	STR	
	KETONES-IR	5C RING K	C=O	1750-1740	S	STR	5 MEMBERED RING KE
	SULFUR-IR	R-SO3⁻H3O⁺	H3O⁺	2800-1650	W	STR	BROAD PEAK, HYDRA
	X_IMPURITIES-IF	WATER VAPO	OH	1805-1695	M	STR	SERIES OF SHARP PE

(c)

Figure 4.7: Chemical structure appear in the ester oil with 48 hour of heating with presence of copper and cellulose (a) Spectral analysis (b) Selected fragment structure (c) List of chemical structure

The Figure 4.7 prove that the region of 1754 to 1667 cm^{-1} are the region of carbonyl (C = O) because most of the chemical structure at peak 1734 cm^{-1} are formed C = O bond. The oil sample which presence of copper and cellulose show very lower in the breakdown voltage. It because the copper trigger the oxidation process whiles the cellulose act as contaminant in the oil. It is proven by using FTIR test in the region of 1754 to 1667 cm^{-1} which states that these absorption regions are to indicate the oxidation products or contaminants.

4.4 Summary of the analysis

Once the oil is being heated in a period of time, the average of breakdown voltage is decreased for both oil samples. But with the presence of copper and cellulose in the oil, the breakdown voltages that got are lower than the breakdown voltage without presence of copper and cellulose. The chemical structures are also change respectively the spectrum shift upward at the region of 3700 to 35700 cm^{-1} and it is proven by using FTIR. For the oil with the copper and cellulose, FTIR test indicate change in spectrum in a range between the 1754 to 1667 cm^{-1} which in the region is specific location for the absorptions to the type of compound present which is ester, acid, anhydride, and ketone. These absorption regions are to indicate the oxidation products or contaminants in the oil.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this final year project report, an experimental had been conducted on insulating oil for the power transformer. The experimental is described on the breakdown of the oil and how they are affected by the thermal when undergo the accelerated thermal aging process. The insulation oil that use in this experiment is the synthetic ester oil (MIDEL 7131). The comparison of the breakdown strength between the oil sample with and without the presence of the copper and cellulose in the oil are being investigated.

The average breakdown voltage value shows a decrease after the oil is undergo accelerated aging process. The thermal stress will cause the oil to thermo-oxidative degradation. With the influence of the copper and cellulose in the oil, the breakdown voltage shows drastic decrease compared to the oil without copper and cellulose. The different condition in oil sample indicate that there have changes in term of the breakdown voltage value which show 26.71% in ester oil without copper and cellulose which is from 29.2 kV to 21.4 kV for a 48 hour time period compared to oil sample with copper and cellulose is 11.11% are from 7.2 kV to 6.4 kV. It shows that when there have contaminant in oil sample, the breakdown of the oil will be lower. Thus, it indicates the oil cannot be longer used.

In the meantime, the FTIR analysis is being used to relate the decrease in breakdown voltage of the oil sample. FTIR on oil without copper and cellulose shows that the spectrums at range 3700 to 3570 cm-1 indicate the region of O-H and N-H and it proves that the chemical structure of water, H_2O exist at 3680 cm^{-1}. So, moisture content in the oil increase indicates that the breakdown voltages for the oil sample are decrease. For the FTIR on oil with copper and cellulose are focused on the spectrum range of 1754 to 1667 cm^{-1} in the region of carbonyl (C = O) which this region indicate the oxidation products or contaminants. The changes in spectrum occur at 1734 cm^{-1} indicated the oil having oxidation product or contaminant. The result of the breakdown voltage show lower value of breakdown because copper trigger the oxidation process whiles the cellulose act as contaminant in the oil and it proven by using FTIR.

Finally, it shows that the breakdown voltage and FTIR can be used to determine the performance of the insulating oil under the effect of thermal stress. Thus, using ester oil in this experiment indicates that it can replace the mineral oil in power transformer which ester oil fulfill the limit of the breakdown voltage which is 20kV and above according to the standard of ASTM D1816. But due to thermal stress effect will cause the ester oil undergo degradation same as the mineral oil which lead to decrease in dielectric strength which it can lower the breakdown voltage below 20kV.

5.2 Recommendation for future work

Some suggestions are made to improve this experiment for future work which can resort to the new measurement methods or analysis which is to get more information about the effect of thermal stress on the oil, several chemical measurements such as oxidation stability and acidity need to perform. Other than that, test the sample on other parameter of electrical properties such as resistivity, impulse voltage and also relative permittivity. Moreover, try adding an additive in the oil to get increase the dielectric strength of the oil.

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APPENDICES

APPENDIX A

Data collection breakdown voltage test for ester oil without cellulose and copper

Date: 3/2/2016
Time: 1.00p.m

Test (0hour)	BdV(kv)	remark
1	30	s: 4.848 s/x:0.186 RH:58.9 DP:22.6 WB:25.1 AVE:26
2	23	
3	28	
4	19	
5	30	
6	21	s: 5.148 s/x:0.184 RH:58.2 DP:22.1 WB:24.7 AVE:28
7	31	
8	24	
9	32	
10	32	
11	35	s: 4.336 s/x:0.129 RH:59.9 DP:22.1 WB:24.7 AVE:34
12	33	
13	39	
14	34	
15	27	
16	23	s: 5.874 s/x:0.218 RH:62.4 DP:23.0 WB:25.1 AVE:27
17	30	
18	23	
19	23	
20	36	
21	35	s: 3.647 s/x: 0.116 RH:59.3 DP:22.0 WB:24.5 AVE:31
22	33	
23	27	
24	28	
25	34	

Date: 25/2/2016
Time: 3.10p.m

Test (6hour)	BdV(kv)	remark
1	25	s: 5.933 s/x:0.193 RH:61.7 DP:22.0 WB:24.5 AVE:31
2	39	
3	27	
4	35	
5	28	
6	27	s: 5.45 s/x:0.109 RH:57.1 DP:22.2 WB:24.7 AVE:29
7	30	
8	21	
9	30	
10	36	
11	33	s: 6.099 s/x:0.212 RH:51.8 DP:21.7 WB:24.7 AVE:29
12	37	
13	22	
14	27	
15	25	
16	22	s: 6.465 s/x:0.263 RH:46.2 DP:21.5 WB:25.3 AVE:25
17	31	
18	32	
19	18	
20	20	
21	33	s: 5.074 s/x: 0.196 RH:51.6 DP:21.3 WB24.8: AVE:30
22	35	
23	20	
24	32	
25	30	

Date: 26/2/2016
Time: 3.30p.m

Test (24hour)	BdV(kv)	remark
1	30	s: 9.925 s/x:0.432 RH:52.9 DP:21.1 WB:24.1 AVE:23
2	16	
3	31	
4	29	
5	9	
6	31	s: 2.387 s/x:0.082 RH:50.3 DP:20.8 WB:24.2 AVE:29
7	29	
8	26	
9	32	
10	28	
11	23	s: 4.336 s/x:0.146 RH:52.3 DP:21.1 WB:24.1 AVE:30
12	35	
13	29	
14	30	
15	31	
16	23	s: 6.058 s/x:0.273 RH:53.7 DP:21. WB:24.1 AVE:22
17	21	
18	22	
19	14	
20	31	
21	28	s: 2.739 s/x: 0.101 RH:52.6 DP:21.0 WB:24.2 AVE:27
22	25	
23	31	
24	27	
25	24	

Date: 17/3/2016
Time: 12.00 p.m

Test (48hour)	BdV(kv)	remark
1	11	s: 2.387 s/x:0.213 RH:64.6 DP:23.7 WB:25.7 AVE:11
2	10	
3	14	
4	13	
5	8	
6	13	s: 1.14 s/x:0.10 RH:63.8 DP:23.7 WB:25.6 AVE:11
7	10	
8	12	
9	11	
10	11	
11	10	s: 1.14 s/x:0.11 RH:62.2 DP:23.1 WB:25.2 AVE:10
12	10	
13	9	
14	12	
15	11	
16	10	s: 1.304 s/x:0.148 RH:64.1 DP:23.6 WB:25.5 AVE:9
17	8	
18	7	
19	9	
20	10	
21	12	s: 1.095 s/x: 0.213 RH:64.6 DP:23.7 WB:25.7 AVE:11
22	10	
23	12	
24	10	
25	12	

APPENDIX B

Data collection breakdown voltage test for ester oil with cellulose and copper

Date: 12/5/2016
Time: 9.00a.m

Test (0hour)	BdV(kv)	remark
1	8	s: 1.225 s/x:0.122 RH:61.8 DP:25.1 WB:26.3 AVE:7
2	9	
3	7	
4	7	
5	7	
6	8	s: 1.14 s/x:0.121 RH:63.8 DP:23.7 WB:25.6 AVE:6
7	7	
8	6	
9	7	
10	6	
11	9	s: 1.095 s/x:0.098 RH:62.2 DP:23.1 WB:25.2 AVE:8
12	10	
13	8	
14	7	
15	8	
16	8	s: 1.304 s/x:0.148 RH:64.1 DP:23.6 WB:25.5 AVE:7
17	6	
18	9	
19	7	
20	7	
21	7	s: 1.095 s/x: 0.213 RH:64.6 DP:23.7 WB:25.7 AVE:8
22	9	
23	7	
24	6	
25	7	

Date: 12/5/2016
Time: 10.00a.m

Test (6hour)	BdV(kv)	remark
1	8	s: 1.0447 s/x:0.062 RH:64.6 DP:23.7 WB:25.7 AVE:7
2	7	
3	7	
4	7	
5	7	
6	7	s: 0.447 s/x:0.066 RH:63.8 DP:23.7 WB:25.6 AVE:7
7	7	
8	7	
9	6	
10	7	
11	7	s: 0.447 s/x:0.066 RH:62.2 DP:23.1 WB:25.2 AVE:7
12	8	
13	7	
14	7	
15	7	
16	7	s: 0.447 s/x:0.062 RH:64.1 DP:23.6 WB:25.5 AVE:7
17	7	
18	7	
19	8	
20	8	
21	7	s: 0.548 s/x: 0.074 RH:64.6 DP:23.7 WB:25.7 AVE:7
22	7	
23	8	
24	8	
25	7	

Date: 12/5/2016
Time: 11.00a.m

Test (24hour)	BdV(kv)	remark
1	6	s: 0.447 s/x:0.066 RH:64.6 DP:23.7 WB:25.7 AVE:7
2	7	
3	7	
4	7	
5	7	
6	6	s: 0.548 s/x:0.086 RH:63.8 DP:23.7 WB:25.6 AVE:6
7	6	
8	7	
9	7	
10	6	
11	6	s: 0.543 s/x:0.085 RH:62.2 DP:23.1 WB:25.2 AVE:7
12	7	
13	6	
14	7	
15	7	
16	6	s: 0.447 s/x:0.066 RH:64.1 DP:23.6 WB:25.5 AVE:7
17	7	
18	7	
19	7	
20	7	
21	6	s: 0.447 s/x: 0.066 RH:64.6 DP:23.7 WB:25.7 AVE:7
22	7	
23	7	
24	7	
25	7	

Date: 12/5/2016
Time: 12.00p.m

Test (48hour)	BdV(kv)	remark
1	6	s: 0.548 s/x:0.083 RH:64.6 DP:23.7 WB:25.7 AVE:7
2	6	
3	7	
4	7	
5	7	
6	7	s: 0.447 s/x:0.066 RH:63.8 DP:23.7 WB:25.6 AVE:7
7	7	
8	7	
9	6	
10	7	
11	6	s: 1.14 s/x:0.11 RH:62.2 DP:23.1 WB:25.2 AVE:6
12	7	
13	6	
14	7	
15	6	
16	7	s: 1.304 s/x:0.148 RH:64.1 DP:23.6 WB:25.5 AVE:6
17	6	
18	6	
19	6	
20	7	
21	6	s: 1.095 s/x: 0.213 RH:64.6 DP:23.7 WB:25.7 AVE:6
22	6	
23	7	
24	6	
25	6	

APPENDIX C

Ester oil sample without and with the presence of copper and cellulose

APPENDIX D

Gantt chat

Tasks	September				October				November				December				January (2016)				February				March				April				May				June			
Weeks	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
- Supervisor meeting																																								
- literature review - Research about the previous project that be related :- journal, articles and etc.																																								
-Write report on Chap1, 2 and 3																																								
-Send draft report to SV																																								
-Preparing all oil sample, -Run the experiment -Seminar FYP 1(14-15/11)																																								
-Exam week																																								
-Run experiment on BDV vs aging time(hour) -FTIR (FKP)																																								
-Result and discussion																																								
-Conclusion -Report correction																																								
-Ready FYP II Report																																								
-Send Report FYP II																																								
-Seminar FYP II																																								
-Send Final Report -FYP Done!																																								