STUDY OF ELECTRICAL AND CHEMICAL PROPERTIES OF TRANSFORMER INSULATING OILS

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

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MAY 2014

"I hereby declare this report entitle "*Study of Electrical and Chemical Properties of Transformer Insulating Oils*" 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 : ………………………………….

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Date : 28th MAY 2014

"I hereby declare that I have read through this report entitle "*Study of Electrical And Chemical Properties of Transformer Insulating Oils*" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature : ……………………………….

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Date : 28th MAY 2014

This project and research work is dedicated to my beloved parents for their devoted caring throughout my life, also my friends for their encouragement and support.

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All admires to Almighty ALLAH, the most gracious and the most merciful, who bequeathed me with well being and abilities to complete this project successfully.

I wish to express my deep gratitude to my project supervisor, Mr. Sharin Bin Ab Ghani for his continuous heart and soul support to complete this project in the best possible way. He is always a source of inspiration and motivation for me. His encouragement and support never faltered.

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Finally, I am wildly grateful to my parents for their everlasting moral support and encouragements. I dedicated this project to them.

Ahmad Hariz Bin Tarif

FKE, May 2014

ABSTRACT

Transformer is a device in static condition. The transformer transforms electrical energy from one circuit to another and important in the power system for voltage level conversion. Transformer failure might cause by several conditions such as an overload condition and most failure were caused by an insulation problem. This research is carried out to examine the characteristic, particular substance oil and the relationship between these characteristic of transformer oil that can cause failure. This research is to study transformer insulating oil in electrical, physical and chemical properties using Meggar Oil Test Set, Fourier Transform Infrared Spectrometer (FTIR) and Viscotester. The samples only used one type of transformer insulating oils (Hyrax) but in four type conditions which are new transformer insulating oils, breakdown transformer insulating oils, different moisture content and temperature level. Moisture can cause breakdown voltage or dielectric strength value decrease, damage the winding, insulation kraf paper and proven by chemical substance analysis, the moisture break the particle chain, even moisture good in heat transfer and has a low viscosity. Temperature also can affect the viscosity and breakdown voltage value, as the temperature is increase, viscosity value is decrease and breakdown voltage is increase. Moisture and temperature categories as most influence effect to the transformer insulation problems. The result of the chemical substances, breakdown voltage and viscosity analysis shows the moisture and temperature give an impact in insulating oil particle and substances.

ABSTRAK

Alat ubah adalah alat yang berkeadaan statik , ia mengubah tenaga elektrik dari satu litar kepada yang lain dan penting dalam sistem kuasa untuk menukar tahap voltan. Kegagalan pengubah mungkin disebabkan oleh beberapa keadaan seperti beban berlebihan dan kebanyakan disebabkan oleh masalah penebat. Projek ini adalah untuk mengkaji sifat-sifat elektrik , fizikal dan kimia minyak penebat pengubah menggunakan Meggar Ujian Minyak Set, Fourier Transform Infrared Spektrometer (FTIR) dan Viscotester . Hanya satu sample jenis minyak pengubah penebat yang digunakan (Hyrax) tetapi dalam empat keadaan minyak penebat iaitu minyak penebat yang baru, minyak penebat yang lama, minyak penebat yang mengandungi kelembapan yang berbeza dan tahap suhu . Kelembapan boleh menyebabkan penurunan ketebatan minyak atau kekuatan nilai dielektrik menurun , merosakkan gelung , penebatan kertas Kraf dan dibuktikan oleh analisis bahan kimia, kelembapan memecahkan rantaian zarah , walaupun kelembapan baik dalam pemindahan haba dan mempunyai kelikatan yang rendah. Suhu juga boleh menjejaskan kelikatan, kekuatan dielektrik, peningkatan suhu dan penurunan nilai kelikatan. Kelembapan dan suhu dikategorikan sebagai kesan yang paling mempengaruhi kepada masalah-masalah penebat pengubah. Hasil daripada analisa kandungan bahan-bahan kimia , kekuatan dielektrik dan analisa kelikatan menunjukkan kelembapan dan suhu memberi kesan dalam kandungan penebatan zarah minyak.

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LIST OF ABBREVIATIONS

kV	-	kilo Volt
BS	-	British Standard
UTeM	-	Universiti Teknikal Malaysia Melaka
DC	-	Direct Current
AC	-	Alternating Current
mA	-	mili Ampere
IEEE	-	Institute of Electrical and Electronic Engineers
ml	-	mili liter
Mm	-	mili meter
Hz	-	Hertz
FTIR	-	Fourier Transform Infrared Spectrometer
ATR	-	Attenuated Total Reflectance

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The purpose of this research is to study electrical and chemical properties of power transformer insulating oil. The main point is to understand the basic of transformer function and its liquid dielectric. The transformer is a device in static condition. It transforms electrical energy from one circuit to another circuit and maintains the same frequency which is 50 Hertz (Hz) in Malaysia.

Besides that, the transformer has become important in the power system for voltage level conversion and maintaining the power flow. The transformer may step up or step down the voltage level depends on its needed. In manufacturing field, the transformer needs a lot of constructional parts. Basically, there are three main parts of transformer which is a primary winding, a secondary winding and a magnetic core. Transformer failure might cause by several conditions such as an overload condition. There is a statistic of transformer failures in the United State of America (USA) from 1997 to 2001. The most caused were by an insulation problem [1].

Insulation system is one of many reason plays in the transformer life. These three parts of the transformer are insulating and cooling by solid dielectric and liquid dielectrics. Solid dielectric, usually made of pressboard, wood and unbleached softwood pulp. The widely used know as "Kraft Paper", made of unbleached softwood pulp and flow into sulfate process. Liquid dielectric is important due to its dual purposes as heat condition and insulation to high voltage system. In this case, liquid dielectrics refer to petroleum-based mineral oils.

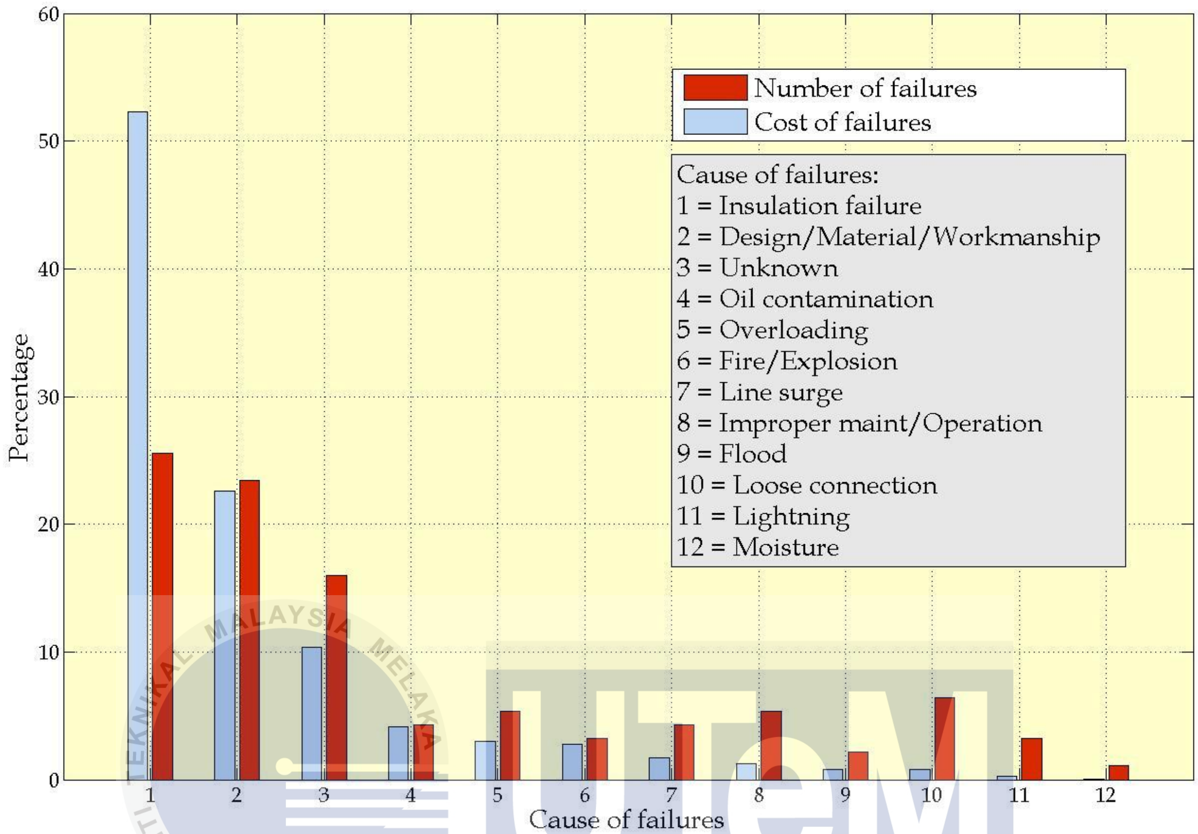

Figure 1.1: Percentage and cause of Transformer Failure in USA (1997-2001) [1]

The figure 1.1 shows the statistics of the percentage and the cause of transformer failure in the United States of America in year 1997 until year 2001. Insulation problem present the highest number of percentages and show the highest cost of transformer failure. While, moisture has the smallest number of percentages and show the less cost of transformer failure.

1.2 Problem Statement

Liquid dielectric is insulating materials that had been used widely in high voltage system include the high voltage of capacitors, cables, circuit breaker and transformers. Petroleum-based mineral oils or transformer insulating oils is one of liquid dielectric that has been analyzed in this research due to its function as heat transfer fluid and electrical insulation for the transformer. The quality of the insulating oil plays the most important role in the circulation of transformer life. Nowadays, the statistic shows that the total percentage of transformer failures increases from year 1997 until year 2001 and mostly caused by an insulation problem.

1.3 Objective

The objectives of this research are to differentiate the characteristics of the new transformer oils and effected transformer oils which are from breakdown transformer. The detail explanations will discuss in this report. Besides that, this research was conducted to analyze the power transformer insulating oil in electrical and chemical properties. This research was use the several type of tester such as Meggar Oil Test Set, FTIR and Viscotester to analysis the insulation oil in electrical and chemical properties. Lastly, this research is to determine and analyze the properties of transformer insulating oil that can cause failure in different moisture content and different temperature degree.

1.4 Project Scope

The main issue in this research is to examine the characteristics of the particular substance oil and the relationship between their characteristics of transformer oil and their causes of failure in three aspects which is in electrical, chemical and physical aspect. At the mean time, this research will limited on certain standard and guideline of each analysis to ensure the reliability of the outcome result from the experiment and has describe in detail on the next chapter.

This research deals with the high voltage generation of the electrical and the chemical properties. The experiments have been done at the high voltage laboratory Faculty of Electrical Engineering (FKE) and the physical laboratory Faculty of Information and Communication Technology (FTMK), Universiti Teknikal Malaysia Melaka (UTeM). Besides that, the transformer type use in this experiment is transformer insulating oils (Hyrax). The experiment will focus on the four aspects which in new transformer oil, breakdown transformer oil, the different moisture content and the different temperature degree have been tested.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, high voltage plays an important role in life. High DC voltages, high AC voltages and high impulse voltages are three main types of generators [2]. In generation system, transformer is one of the important and the main parts in high voltage system. The heat and the insulate problem are consuming some problem and can cause transformer failure. In order to cope with this problem, liquid dielectric as insulating material due to its function as heat transfer fluid and electrical insulation and able to adapt the problem. In order to make sure the transformer work in good condition, use the transformer insulating oil or petroleum-base mineral oil that fulfill all the requirement, specification and characteristic of good dielectric.

2.2 High Voltage Generation

Electronic valve rectifiers normally use at high DC voltages, it is able to produce up to 100 kV and as low as 100 mA output currents [2]. Basically, High DC voltage is used to transmit high power for long distances. The half wave, the voltage doubler type and the full wave have been used to convert from AC sources to produce high DC voltages act as a rectifier circuit [2]. DC voltages commonly produce using semiconductor rectifier stack that preferred silicon diodes due to the peak inverse voltage of 1kV to 2kV [2].

High AC voltages performed at the same working frequency for all equipment. Single transformer has an insulation problem due to its construction and only applicable for testing purpose. This problem is able to overcome with the use of resonant and cascade transformer. The cascade transformers consist of step-up transformer with the limited number of ground potential which is from first transformer and the insulators from second transformer [2]. The leakage reactance of the windings, the shunt capacitance and the magnetizing reactance are the construction of resonant transformer [2].

High impulse voltages can produce an ultra-short high voltage pulse by using pulse compression stages. The strength from switching surges and lightning can be tested by using high impulse voltages.

The consideration in this research is the high voltages testing such as high DC voltage testing, high impulse voltage testing and high AC voltage testing. In order to determine the flashover voltages of the insulating material, high AC voltage testing has been held [2].

2.3 Principle of Transformer

This project started with the study about high voltage generation. There are three types of generation which is the high DC voltages, higher AC voltages and the impulse voltages [3]. In this project, the transformer has been chosen as the high AC voltage. The transformer is a static electrical device that transfers energy by inductive coupling between its winding circuits [3]. The transformer has been used to increase the voltage before transmitting electrical energy over long distances through wires from one circuit to another circuit without changing frequency. The transformer can be categorized in many ways, depending on their purpose, use, construction, and others. In manufacturing field, the transformer needs a lot of constructional parts. Basically, there are three main parts of transformer which is a primary winding, a secondary winding and a magnetic core. Transformer failure might cause by several conditions such as an insulation system. [3]. In Figure 2.1 below shows a power transformer with capability of 100MVA with maximum voltage of 150kV.

Figure 2.1: Power Transformer

2.4 Transformer Insulating Oils as Insulating Material

Insulation system is one of the issue plays in the transformer life. Its function is to insulate and cooling the transformer. Same as other high voltage system, transformer also needs an insulating material to prevent heat problems. Insulating material is divided by two which is the solid and the liquid dielectric. Solid dielectric, usually made of pressboard, wood and unbleached softwood pulp, but the widely used know as "Kraft Paper" has made of unbleached softwood pulp and flow into sulfate process [4].

Liquid dielectric is a dielectric under liquid state. Liquid dielectric is to prevent electric discharge, a good liquid dielectric has high dielectric strength, able to prevent breakdown when in electrical stress, cool the windings, non flammable nature, chemical stability and good heat transfer properties [4]. The electric capacitances per unit of volume determined by dielectric constant and depend on the operating temperature of the liquid and frequency or structure of its constituent molecules. Even solid insulators are important to electrical industry, but liquid insulators are contained in many electrical parts or products. Transformer, circuit breakers, capacitors and cables are major devices that utilize liquid dielectric. The liquid dielectric has properties that need to determine whether it's a good liquid dielectric or not.

Liquid dielectric is important because of its dual purposes as heat condition and insulation to high voltage system. In this research, liquid dielectrics refer to petroleum-based mineral oils. Several properties need to count on consideration to analyze a good liquid dielectric. The properties are electrical properties, chemical properties and physical properties. The electrical properties are focused on breakdown voltage, dielectric dissipation factor and specific resistance [4]. The chemical properties of good liquid dielectric are focused on its acidity, sludge content and water content. Meanwhile, liquid dielectrics for physical properties are focused on pour point, viscosity, conductivity and flash point.

The distillations of a petroleum crude stock produce a fraction of the hydrocarbons and will produce transformer oil by refining. The collected fraction boiling range and refining degree of process was set up early. The characteristic of resulting oils has fallen within limits and suitable to use in transformers. Many international refining companies made the transformer insulating oils by using particular crude oils. The physical, chemical and electrical properties produced to some degree to assure the properties follow the standard and acceptable for use in specific apparatus. The result that has been measured for each characteristic are compared with specific standard that have been agreed by manufacturer and refiners of oils [5]. In a transformer, the amount of oils contained with several of load that the transformer carrying capability and its physical size. For example, the distribution transformer rated 25kVA and contains around 20 gallons of insulating oils. The physical characteristic of transformer insulating oil standard method of measurement and its limit that have been imposed on them are listed in Table 2.1. This table shows the various characteristics with the limitation and their standard ASTM test method.

The viscosity of oil is very important for heat transfer by natural convection and as principal parameter in design calculations. While the transformer is in operation, the transformer oils are in electrical and mechanical stresses. Interactions of chemical and winding can cause contamination and speeds up a chemical reaction by high operating temperature and make the changes of original chemical properties [5]. Its electrical and chemical properties periodically tested, to know whether it is suitable to use or not. In this research, breakdown voltage or flashover point will be determined as electrical properties. While the contaminant, molecular and substance group will be examined as chemical properties.

Table 2.1: Physical Characteristic Specification Limits of New Oils

Physical Characteristic		
Characteristic	Limits D3487	Standard ASTM Test Method
Kinematic Viscosity,cSt		D445
@100C	< 3.0	
@40C	< 12.0	
@0C	< 76	
Pour Point, C	< -40	D97
Flash Point, C	> 145	D92

2.5 Experimental Setup

In this research, firstly need to determine three properties which are electrical, chemical and physical properties. For each property will have one experimental setup using instruments that can fulfill the analysis specifications. Three experimental setups need to be done in order to analyze, breakdown voltages, viscosity and chemical substances of transformer insulating oils. These three analyses need to consider two parameters which are moisture and temperature of the characteristic of new and breakdown transformer insulating oils.

2.5.1 High Voltage AC Breakdown Voltage Test

Dielectric strength or breakdown voltage is a minimum voltage that caused a portion in insulator and it becomes conductor [6]. It happened when the insulating oil reached the time of spark between electrodes. Condition of molecular properties and atomic insulating oils may cause the breakdown voltage, but in high voltage breakdown test, material of the electrodes, moisture, temperature and gas content might cause the breakdown voltage reading increase or decrease [6]. 30kV is a standard minimum breakdown voltage of transformer insulating oils [6].

Besides that, test cells normally used to examine high voltage AC breakdown voltage test. However, the test relevant to technical problem when the assessment of electric strength is applicable for use oils, treated oils and new oils [6]. The test must have a standard specification to determine the breakdown voltage to avoid unwanted effect. The testing method based on IEEE Standard Technique which is BS 5874: 1980 standard has been used to determine the breakdown voltage in this research

Megger Oil Test Set is the equipment that will be used to determine breakdown voltage. This equipment is fully automatic to implement the standard and reading the data. Figure 2.2 shows the Megger Oil Test Set.

Figure 2.2: Megger Oil Test Set (OTS 60PB)

2.5.2 Viscosity Test

The viscosity of oils is very important for heat transfer by natural convection and as principal parameter in design calculations. In nature, viscous liquids are semi fluid and free flowing cause offered some barrier. In order to transfer heat for proper cooling, transformer oils must be freely circulated and as the result, the low viscosity of oils is produced. It can easily flow and make the heat absorption process much faster than high viscosity.

In order to determine the viscosity value, Viscotester will be used. This Viscotester are rotated and the operating principle of the Viscotester is as follows. In the beginning, the rotor rotating at a constant speed immerses into the liquid to be tested, the rotational resistance is a measure of the viscosity of the liquid. The viscosity is displayed directly. It has three measuring ranges, each depending on the rotor used. The value given in mPas or dPas is only valid when the corresponding measuring cup is used with rotor. This is based on comparative calibration measurements with Newtonian liquids. The advantage of this measuring is precise with reproducible measuring conditions. Refer to the Table 2.2: Viscosity Values of Selected Substances Conditions, to observe the viscosity values of selected substances conditions. While, the Table 2.3: Measuring Range for Selected Rotor shows the selecting the measuring cup and rotor.

Table 2.2: Viscosity Values of Selected Substances Conditions

Substance	Viscosity (mPas) bei 20c
Water	1*
Saccharose solution	6 (40g in 100ml water)
Coffee cream	10
Light crude oil	10
Glycol	20
Olive oil	100
Lubricant oil	50 bis 1000
Gear lubricant oil	300 bis 800
Rhizinus oil	1500
Honey	10000
Bitumen	1000000000*

*Beyond the measuring range

Table 2.3: Measuring Range for Selected Rotor

Viscotester 2 plus		
Display	Measuring range	Rotor
R3	0.3 until 13 dPas	3
R1	3 until 150 dPas	1
R2	100 until 4000 dPas	2

2.5.3 Chemical Substances Analysis

The chemical substances of transformer insulating oil are also the important part. The insulating oils consist of mixtures of many hydrocarbon compounds, the different hydrocarbons which come from different sources. However, characteristic of chemical substances reflects the behavior of hydrocarbon broad classes. The hydrocarbon compounds of insulating oils are categorized in three classes which are naphthenes, aromatic hydrocarbons and alkanes. The chemical formula of transformer insulating oils is $C_{12}H_{10-x}CI_x$, where $_x$ = 1-10 (poly chlorinated bi phenyl) [7]. In this research, the molecules and behavior of acidity, moisture content and against temperature has been analyzed.

Fourier Transform Infrared Spectrometer (FTIR) has been used to analyze the chemical substance of transformer insulating oils. FTIR is one of the most widely used analytical techniques. It also can be used for both qualitative and quantitative analyses of any phase. The program structure must be easy to understand for the sample measurement. The validation process is divided into two parts. One part involves setting the measurement conditions, evaluation wavenumbers, acceptable ranges, and standard data. The other part is conducting the inspection. The main screen appears at program startup. Inspection data can be printed and save. The inspection result data can also be saved. Note that, the parameter setting dialog for setting the necessary measurement parameters, evaluation wavenumbers, acceptable ranges and standard data can only be set by users who are having an authority higher than 'analysis'. The figure 2.3 shows the FTIR instrument.

Figure 2.3: Fourier Transform Infrared Spectrometer

2.6 Effect of Temperature

The increasing of transformer insulating oil's temperature will give an effect to breakdown voltage, viscosity and chemical substances. The value of breakdown voltage of the insulating oil will increase, viscosity value will decrease and the aliphatic (C-H) of chemical substance will reduce when the temperature is increased and analyze at 3000-2850 [1/cm] FTIR wavenumbers region, it is a strong band due to C-H stretch [8]. In this research, temperature will set as parameter.

2.7 Effect of Moisture

Moisture in transformer insulating oils will give a big impact to its function to insulate. The best transformer insulating oils should free from moisture. In terms of electrical properties, moisture can cause the value of breakdown voltage decrease. The moisture will break the molecular chain of oils [8]. In terms of chemical properties, the moisture will present as H_2O at 3600-3400 [1/cm] wavenumbers region of FTIR analysis and make its chain as conductor [8]. In viscosity, it is good to see its viscosity value decrease but in function, it means nothing else except failure.

2.8 Summary

In general, this chapter discussed about related information regarding to this research, analysis, behavior and method using in this research. This research is about to study the electrical and chemical properties of transformer insulating oils. The study of electrical properties will use Megger oil test set to determine the breakdown voltage with standard guideline. FTIR will used to determine chemical substances as chemical property analysis. For physical properties, Viscotester has been used to analysis the viscosity of transformer insulating oils. These three analyses have been separated in eleven samples, one sample of new transformer insulating oils, one sample of breakdown transformer insulating oils, five samples of new transformer insulating oil against temperature and four samples of new transformer insulating oils against moisture. In the new transformer insulating oil against temperature and new transformer insulating oils against moisture, the moisture and temperature will set as parameter.

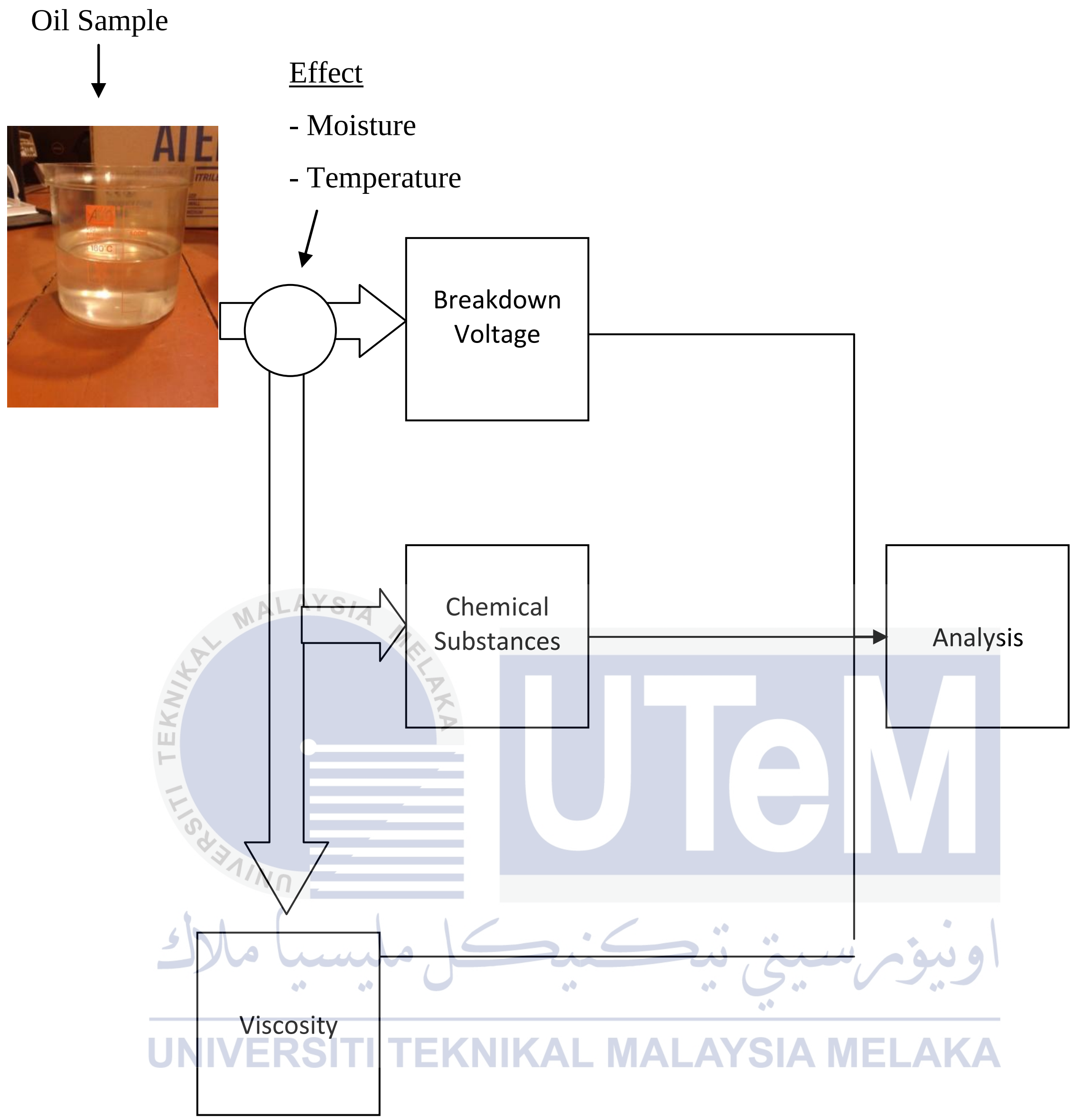

Figure 2.4: Description of Overall

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter is discussing about the research methodology or techniques and operation of related instruments. A methodology is a guideline system that will guide to solving a problem of the research. A methodology includes with specific components such as method, phases, technique, tools and tasks. Every stage of this activity can be descriptive to ensure research is run smoothly and completed accordingly as planned.

Firstly, before start the research, the basic things that important to know is safety procedure. "Safety First" is the golden key to bear in mind before start any experiment. The researcher has too familiar with the safety stop when faced with an accident while in laboratory areas. Next is planning. The researcher has to understand each of the procedures for experimental setup according to the manual hardware operation and standard of testing to conduct the experiment in a proper way. In this research, all the procedure for using the Fourier Transform Infrared Spectrometer (FTIR) instrument, Viscotester, Megger Oil Test Set (OTS 60PB) and apparatus are well described in manual books.

Besides that, in order to conduct an experiment for this research, researcher has to clearly understand and knowledgeable about the experiment procedure regarding to each part of the experiment. The most important point is, one has to clear about their expected result. This is very important to handle the experiment easier in analyze and to get precise results. In this experiment, the expected result focus on viscosity, chemical substances and breakdown voltage of the transformer insulating oils.

3.2 Methodology

The project methodology and project planning show in Figure 3.1: Flow Chart of Project Methodology below in order to review the details about the process of this research. As the function of methodology, the flow chart describes the project at all stages and also are the guidelines about the project planning.

Start

↓

Experimental Review

- Read and understand about High Voltage Generation & Measurement
- Study past journal and research related to viscosity, chemical substances and breakdown voltage of the transformer insulating oils.
- Know and study the properties and characteristic of insulating oils and liquid dielectric

↓

Identify the samples

- Transformer insulating oils (New)
- Transformer insulating oils (Breakdown)
- 5 samples Transformer oils (New 150ml+Temperature 40c,60c,80c,100c,120c)
- 4 samples Transformer oils (New 150ml+Moisture 1ml,2ml,3ml,4ml)

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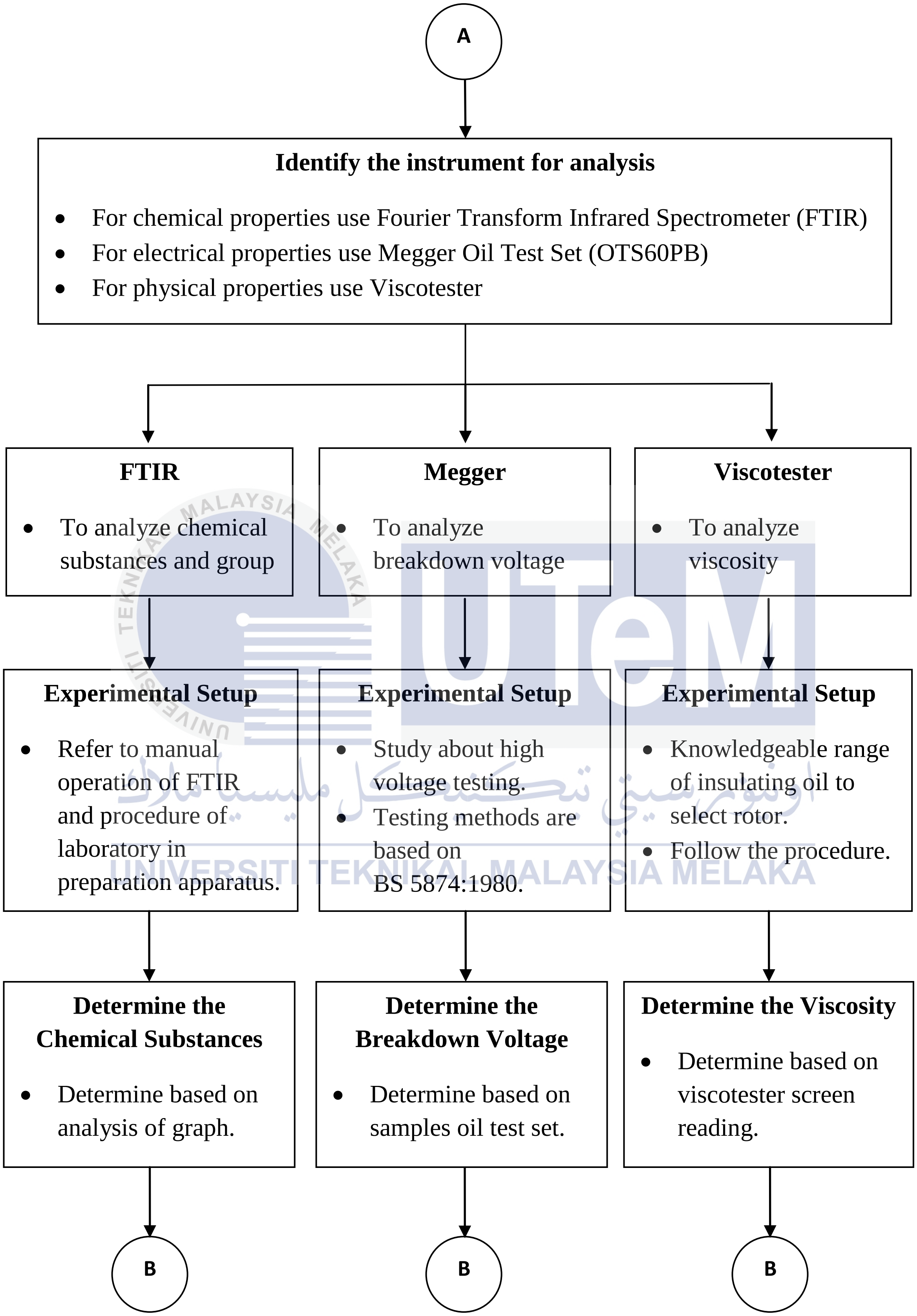
A
Identify the instrument for analysis
For chemical properties use Fourier Transform Infrared Spectrometer (FTIR)
For electrical properties use Megger Oil Test Set (OTS60PB)
For physical properties use Viscotester
FTIR
To analyze chemical substances and group
Megger
To analyze breakdown voltage
Viscotester
To analyze viscosity
Experimental Setup
Refer to manual operation of FTIR and procedure of laboratory in preparation apparatus.
Experimental Setup
Study about high voltage testing.
Testing methods are based on BS 5874:1980.
Experimental Setup
Knowledgeable range of insulating oil to select rotor.
Follow the procedure.
Determine the Chemical Substances
Determine based on analysis of graph.
Determine the Breakdown Voltage
Determine based on samples oil test set.
Determine the Viscosity
Determine based on viscotester screen reading.
B
B
B

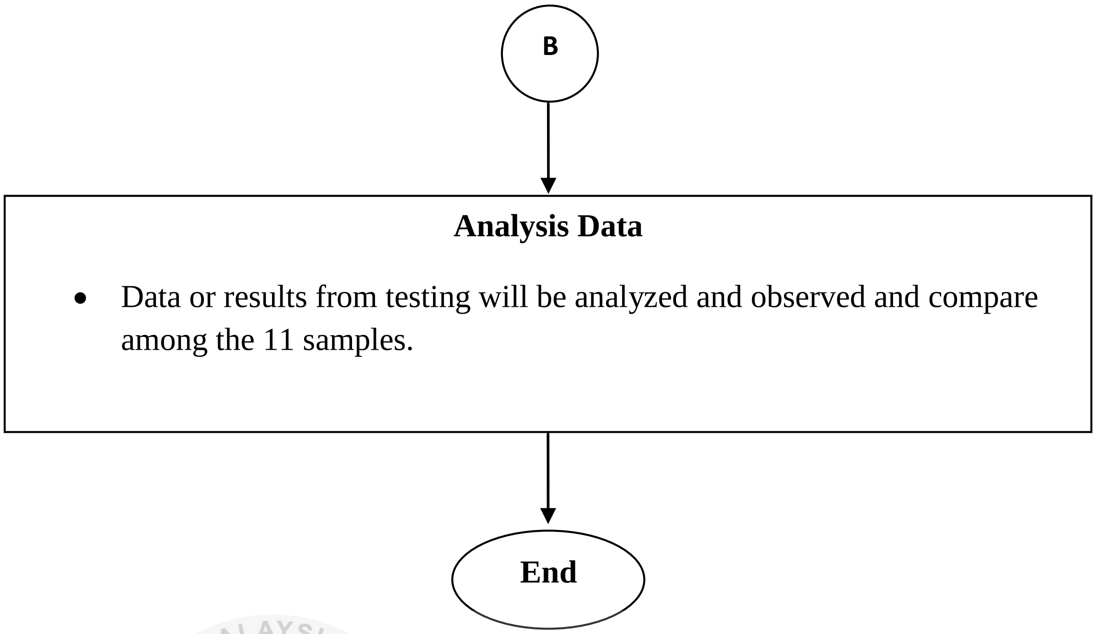

Figure 3.1: Flow Chart of Project Methodology

3.2.1 Experimental Review

This experiment started with the high voltage generation which is power transformers. There are three types of generation which are impulse voltages, high AC voltages and high DC voltages. Power transformer which is high AC voltage is important due to its function and power transformer insulate by solid dielectric and liquid dielectric. This project focuses on liquid dielectric or insulating oil. Insulating oils have some characteristic that help transformer to keep alive and insulate [9].

The three properties have been determined to analyze and study the characteristic which are the electrical, physical and chemical properties of insulating oil. Each property has the criteria that fulfill a good insulating liquid characteristic [10]. Electrical properties has been analyzing the breakdown voltage of the liquid when reached the spark between electrodes. The physical property has analyzed the viscosity of liquid. Lastly, the chemical property has analyzed the substance.

a) Identify the Samples

Classification of insulating oils is necessary to compare properties among the sample. Preparations to identify the samples are based on true facts caused of transformer failure. New transformer insulating oils (unused) will be a guideline in addition to other transformer insulating oil conditions, the eleven samples have been identified.

These are new transformer insulating oils, breakdown transformer insulating oil, new transformer oil heat up fewer than five stages temperature level and new transformer insulating oils mix up with four stages water level. The samples will produce different result and suitable to do some analysis according to standard insulating oil characteristic.

b) Identify the Instrument for Analysis

In order to get the precise result to fulfill the objectives of this research, selection of instrument must be correct with the instrument's ability. Then, to analyze the breakdown voltage of electrical properties, Megger Oil Test set is the most suitable instrument because of its principle and automatically testing based on British Standard (BS 5874: 1980).

For chemical properties, FTIR was chosen because it can show chemical substance and

conditions in the oils and group results in detail, the final results shown in graph display through software. The viscosity of the physical properties samples will test using Viscotester due to its advantage in measuring, which are precise and reproducible measuring conditions. On the other hand, it has a small sample volume and most accurate reading.

c) Experiment Setup

The three instruments have a different experiment setup. However, the basic principles of handling experiment procedure were same, such as safety precaution and do and don’t rule. Remember to plan, well prepared of the step and the apparatus of the experiment to make sure the experiment going smooth and get the expected result. For breakdown voltage testing using a Megger Oil Test set must follow the testing method based on IEEE Standard Technique which is BS 5874: 1980 standard. While the FTIR and Viscotester testing didn't have any related IEEE Standard Technique but need to follow the guideline of manual operation books [9].

d) Determine the Chemical Substance, Breakdown Voltage and Viscosity

Chemical substance, breakdown voltage and viscosity are determined based on same eleven samples, in different characteristics. Chemical substance and viscosity tests have been done at physical laboratory and breakdown voltage test will be done at a high voltage laboratory. Each sample has tested for three times with six readings for the breakdown voltage test to get accurate results. All data and result have been determined, compared and recorded.

e) Analysis Data

After all experiment has been done, the result of all the samples for each property and instrument has been analyzed. The data and result has been recorded in table and graph and is shown in the next chapter. Each property has described the best characteristic and good dielectric of insulating oil. The combination of the best characteristic and good dielectric for these three properties has been referring to good dielectric characteristic of insulating oils.

3.3 Safety Precautions

It nature every time enter the laboratory, rules and regulation of safety need to give attention. The basic safety, such as wearing the fully covered shoes and wearing the proper clothing can reduce the risk to be harmed. In order to handle or to do experiment by using instrument has the additional safety precautions depends on the instrument.

In this research, the two experiments have to be aware about the safety serious. That experiment is the FTIR, which is exposed to infrared laser that can cause harmful to the body and the Megger Oil Test set that involve in high voltage system can cause death through electrical shocks or explosion. As an extra precaution to handle this instrument, technicians must monitor the experiment.

a) Megger Oil Test Set (OTS 60PB) Safety

The precautions stated below need to consider while handling the instrument to prevent any hazard or accident. First, minimum two people are suggested to complete one experiment, one working on the test side and the other one working on the instrument. Next is, do not ever open the cover until the instrument is off. Then, make sure all areas near the instrument and the electrode are clean and in the comfort condition. Besides that, test vessel must be present while operating the instrument and used only the correct instrument vessel. Lastly, all the instrument has to be turned off before setting the electrode.

b) Fourier Transform Infrared Spectrometer (FTIR) Safety

Before starting to use the instrument, is important to ensure operational safety. Check the following installation requirements conditions before start the experiment:

I. Ensure the power voltage and frequency fluctuations are held to a minimum. Fluctuations of more than 100+-10V could lead to breakdowns.
II. Frequency or spike noise in the power supply should be minimal.
III. Use three-point power plugs.
IV. Hold temperature variables to a minimum. The operating temperature range is 17c to 27c. Temperature fluctuation during measurement should preferably be within +- 1c.
V. The operating atmospheric pressure range is 950 to 1060kPa (730-780 Torr).

VI. Avoid strong magnetic field and sources of high frequency. The instrument may not function properly when near a strong magnetic field or high frequency source.

VII. Use location where vibrations can be held to a minimum. Avoid vibration from vacuum pumps, electric motors, processing equipment and machine tools.

VIII. Avoid gas and corrosive gas. Do not install the instrument in a location where it may be exposed to dust, especially in locations exposed to outside air or ventilation outlets that discharge dust particles.

IX. No display of gas absorption should be detected within the measured wave number range (environmental conditions for satisfying the specifications).

X. Do not install the instrument in a location where it may be exposed to direct sunlight.

XI. Avoid tilting the instrument. A tilted instrument can result in unstable operations. In addition, check the stability of the installed base.

XII. Ensure that no air conditioner blows air directly onto the instrument. Direct contact for blowing air could cause the instrument to change the temperature, preventing acquisition of a stable spectrum.

XIII. Install the instrument in a location that ensure adequate space around the instrument for maintenance.

After making sure all requirements well, and then proceed to operating procedure, before start to operate this instrument, there some precautions need to be observed during operation.

I. Purging the interferometer, and sample & detector compartment.

The INLET VALVE is used for purging the interferometer an sample & detector compartments. The selector knob switches between the purging locations there are two kinds of purges, the ‘sample & detector chamber’, and the ‘sample, detector chamber and interferometer’.When not performing a purge operation, always return to purge selector knob to the ‘sample & detector chamber’ side.

II. Laser beam in the sample chamber.

The laser used in this instrument is classified as a Class 2 laser according to laser equipment classification IEC825 (JIS C 6801). Do not stare directly into the laser beam as this may result in injury. However, normally injury to the operator can be prevented by such protective action as blinking.

The laser beam is used to control the moving mirror and to verify the alignment of the optical system. Be sure to switch off the power before opening the purge case to replace the light source or beam splitter. If the laser beam is on, your eyes may be exposed directly to the beam. In addition, the laser beam used to verify the alignment of the optical system passes through the sample chamber. Be careful to avoid the reflected beam when installing an accessory or other option in the sample chamber.

III. Interferometer light exit port

There is a window at the light exit port on the interferometer side of the sample compartment. The window which transmits infrared rays is composed of a special moisture-proof material. If condensation forms on this window, the transparency of the window may be adversely affected. In order to prevent the formation of condensation, moisture free gas such as N2 or dry air should be used for purging.

3.4 Testing Procedure Manual

FTIR, Viscotester and Megger instruments have their own testing procedure manual, from preparation apparatus until recorded data and results. Preparing the samples according to their parameter such as temperature and moisture will describe clearly. For testing breakdown voltage will follow method of IEEE Standard technique BS 5874: 1980 standard while for testing chemical substance and viscosity didn’t have any related IEEE standard. However, the testing will follow the manual operation as guideline.

a) Preparing the Fourier Transform Infrared Spectrometer (FTIR)

I. To turn the power on, this is power sequence. Before the ‘POWER’ switch can be switched ‘ON’, the ‘RESUME’ switch must be switched ‘ON’ first.
II. Turn computer switch ‘ON’.
III. Start up spectrum manager and spectra measurement programs.

b) Preparing the Viscotester

I. Switching the instrument on/off, continuous pressing (button near the display)
II. The display will appear of the measuring value : rotor used : viscosity value
III. Stand clamp is to fix the viscotester in the correct measurement position (watch correctly positioning in the mold).
IV. Calibrate the viscotester with unloading condition (gravity)
V. Select the rotor and measuring cup according to range of sample viscosity.

c) Preparing the Megger Oil Test Set (OTS 60PB)

I. Switch ‘ON’ the instrument by connecting the charger to rear socket.
II. The instrument will be set up according to BS 5874: 1980 standard.
III. The electrode and test vessel must be in clean condition.
IV. Set the gap between electrodes according to BS 5874 : 1980 standard
V. The electrode must be tightened up using screwdriver according to BS 5874: 1980 standards.

3.4.1 Samples Preparation

a) Preparing Samples of New Transformer Insulating Oils

- Fill about 350 milliliters insulating oil into test vessel.

b) Preparing Sample of Breakdown Transformer Insulating Oils

- Fill about 350 milliliters insulating oil into test vessel

c) Preparing Sample of New Transformer Oils (Moisture)

I. Fill about 350 milliliters insulating oil into test vessel.
II. Drop water around 1 milliliter per sample, add another 1 milliliter for the next sample to sample number 4.
III. Put test vessel on magnetic stirrer to stir at 2000 rpm for 5 minutes for each sample.

d) Preparing Sample of New Transformer Oils (Temperature)

I. Fill about 350 milliliters insulating oil into test vessel
II. Heat up the test vessel using hot plate until reach 40 Celsius, 60 Celsius, 80 Celsius, 100 Celsius and 120 Celsius.

3.4.2 Procedure of Testing

a) Breakdown Voltage Testing Using Megger Oil Test Set

I. Press 'START' button and set standard BS 5874: 1980
II. Put the test vessel into the instrument.
III. The instrument will display the specification, press 'SELECT' and then press 'START'
IV. There will be 6 tests continues directly
V. After all of these tests completed, recorded all data and result.
VI. Repeated step I until V for other samples.

b) Chemical Substance Analysis Using Fourier Transform Infrared Spectrometer (FTIR)

I. The sample chamber must be open with the procedure. The sample compartment lid consists of an outer frame and an inner frame (transparent lid).
II. Attenuated total reflectance (ATR) was chosen as sample compartment accessories and install in sample compartment.
III. Turn the Attenuated total reflectance (ATR) knob counter clockwise and drop a few samples in ATR compartment.
IV. Turn off the knob by turning clockwise and close the sample compartment lid.
V. Discharge the nitrogen gas about 1 minute.
VI. Click 'Spectra Measurement' and click icon S to analyze.
VII. 10 minutes remaining to get the output (result), the result is in waveform.
VIII. Repeat step I until VI for another sample.

c) Viscosity Testing Using Viscotester

I. Install the selected rotor (R3).
II. Fill up the measuring cup with the sample until reach the line at rotor.
III. Press the 'ON' button continues to switch 'ON' and select R3.
IV. The display will double confirm to start testing and press the button once if confirmed to start.
V. The result will appear in a minute, show the viscosity of these liquid.
VI. Record all the data and the result.
VII. Keep repeating step I until V with other samples.

3.5 Flowchart of Testing

a) Viscotester

Figure 3.2 below shows flowchart of testing procedure manual, from preparation apparatus until recorded data or results. Related diagram or figures are shown in appendix A.

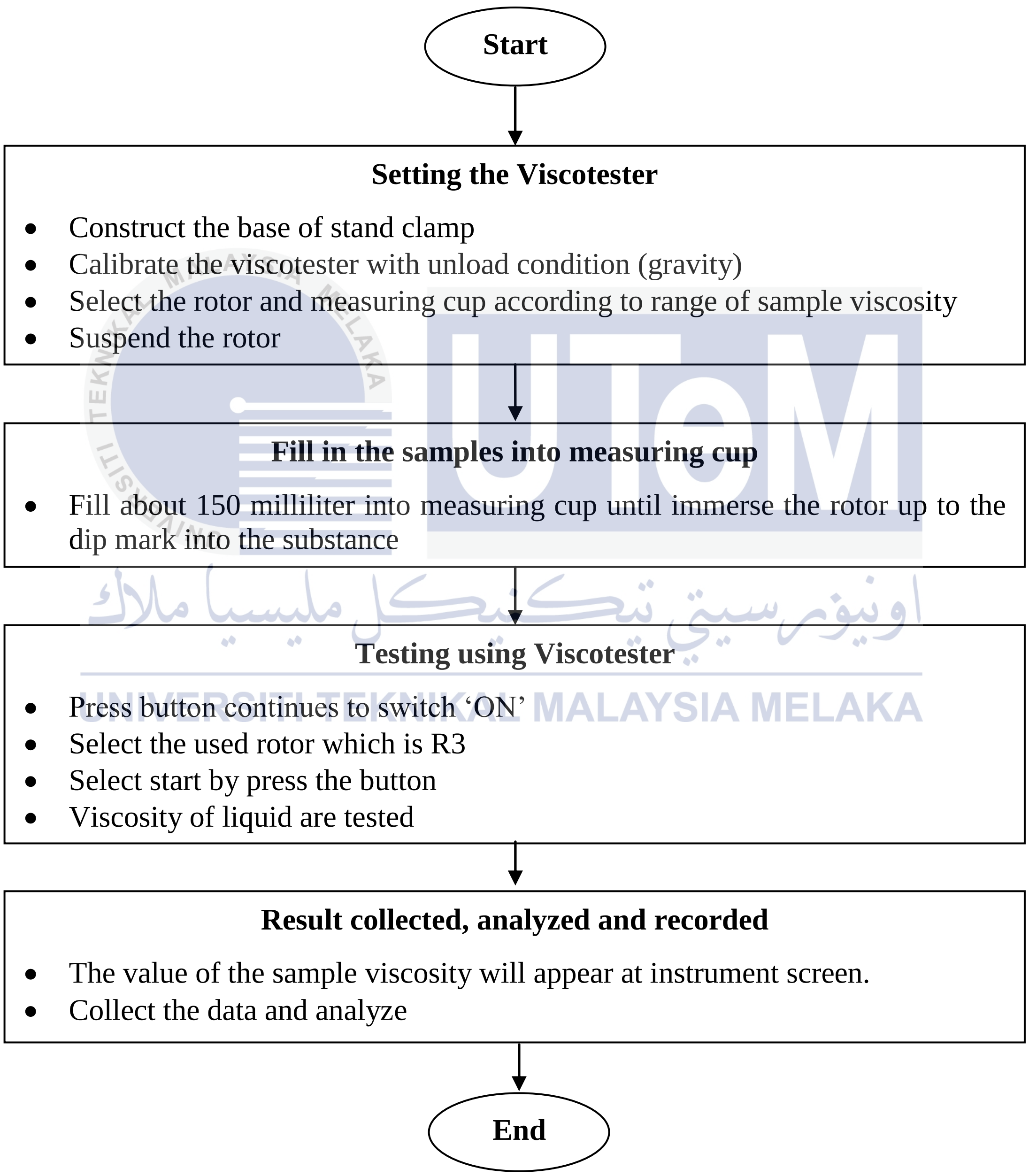

Figure 3.2: Flow Chart of Testing (Viscotester)

b) Fourier Transform Infrared Spectrometer (FTIR)

Figure 3.3 below shows flowchart of testing procedure manual, from preparation apparatus until recorded data or results. Related diagram or figures are shown in appendix A.

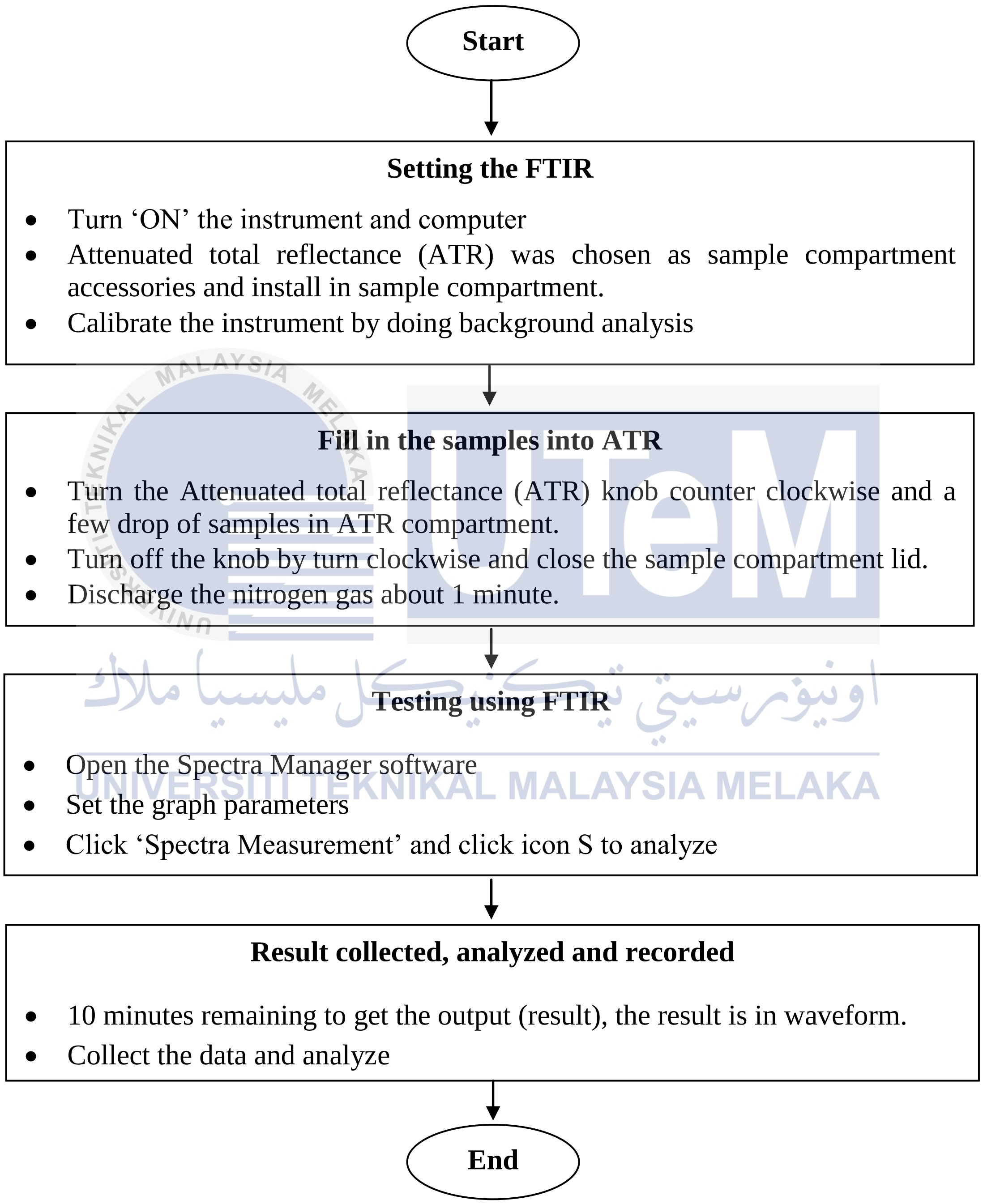

Figure 3.3: Flow Chart of Testing (FTIR)

c) Megger Oil Test Set

Figure 3.4 below shows flowchart of testing procedure manual, from preparation apparatus until recorded data or results. Related diagram or figures are shown in appendix A.

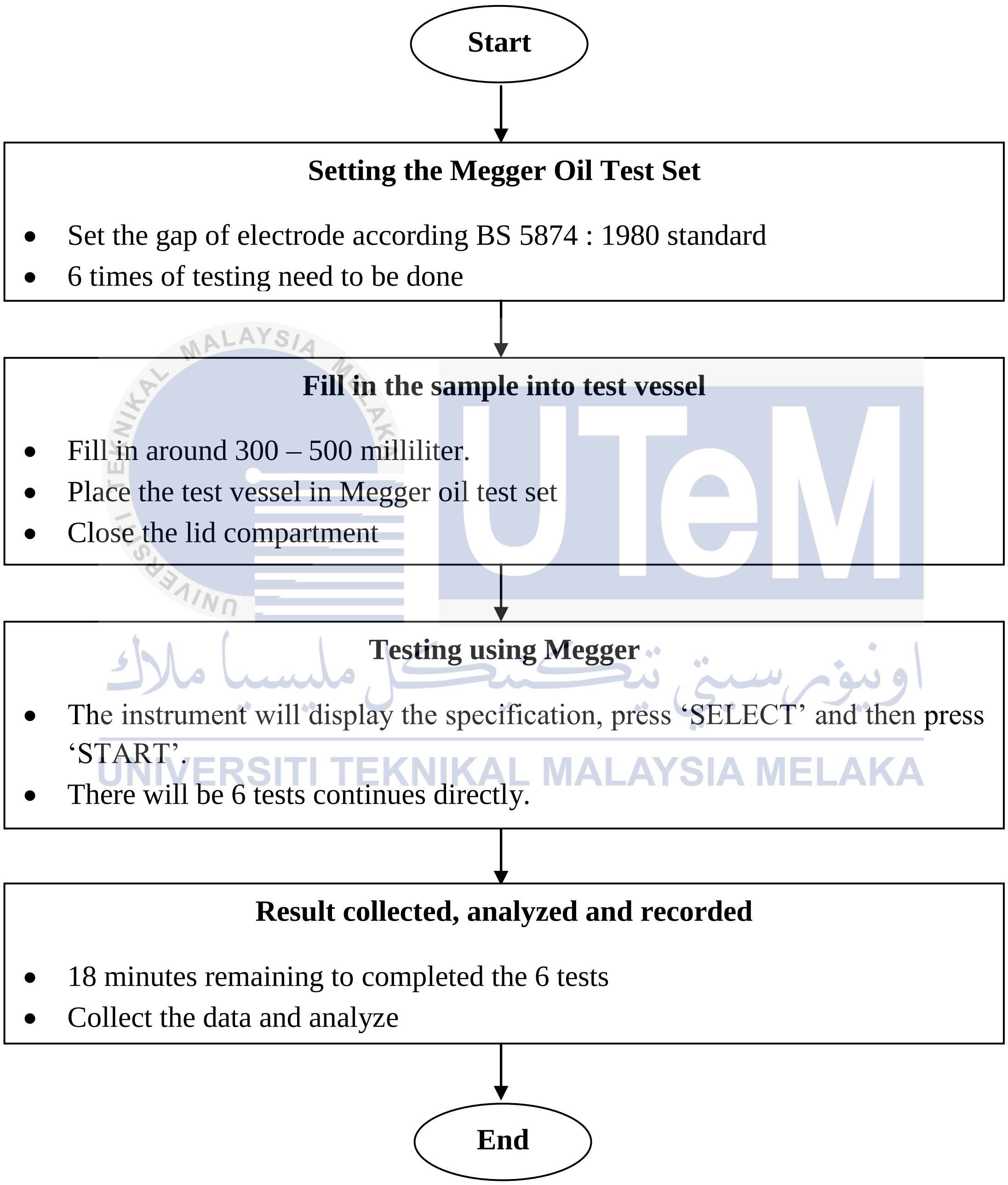

Figure 3.4: Flow Chart of Testing (Megger OTS 60PB)

CHAPTER 4

RESULTS & DISCUSSION

4.1 Introduction

This chapter describes about the result and discussion regarding to this research. The three analyses have been done to determine three properties of the Petroleum-based mineral oils which are electrical (breakdown voltage), chemical (Chemical Substances) and physical properties (Viscosity) with different moisture and temperature according to standard test method. Hyrax Hypertrans the samples of petroleum-based mineral oils used in this research. This sample type is widely used in Malaysia's transformer manufacturing. Each of the liquid dielectric properties will be tested for different moisture and temperature with different analysis, the recorded result be further discussed.

Significant of the analysis is to analyze the characteristic, particular substance oil and the relationship between this characteristic of transformer oil in three properties with the cause of the failure. This is due to transformer function as heat transfer fluid and electrical insulation for a transformer. The result was compared based on graph, bar chart and table to analyze which state of the condition that gives the best response for each property in different moisture and temperature.

4.2 Comparison on Viscosity of New and Breakdown Transformer Insulating Oils

The viscosity of new and breakdown transformer insulating oils can be seen in the Table 4.1: Viscosity of New and Breakdown Transformer Insulating Oils. The sample was set to 350 milliliter quantity of oils for each sample. All the data obtained from the experiment by using viscotester.

This experiment has taken three times of reading to get the average value. New transformer insulating oils first reading indicate 0.15 dPas, 0.15 dPas for second reading and 0.14 dPas for third reading and the average of new transformer insulating oil viscosity is 0.15 dPas. Next, for the breakdown transformer insulating oils first reading indicates 0.21 dPas, 0.19 dPas for second reading and 0.20 dPas for third reading and the average of new transformer insulating oils viscosity is 0.20 dPas. Based on this average value, the result shows that new transformer insulating oils have a lower viscosity rather than the viscosity of breakdown transformer insulating oils.

Table 4.1: Viscosity of New and Breakdown Transformer Insulating Oils

Samples	Viscosity (dPas)			
	1	2	3	Average
New transformer insulating oils	0.15	0.15	0.14	0.15
Breakdown transformer insulating oils	0.21	0.19	0.20	0.20

4.3 Viscosity Testing on New Transformer Insulating Oils (Moisture Control)

The viscosity testing of new transformer insulating oils with the changing in moisture content can be seen in Table 4.2: Viscosity of New Transformer Insulating Oils with Changing Moisture Content. The sample was set to 350 milliliter quantity of oils for each sample. All the data obtained from the experiment by using viscotester on moisture control condition.

First step is the sample has been stirred up using magnetic stirrer hot plate after adding moisture content (water). This experiment takes three times of reading to get the average value. New transformer insulating oils without adding moisture after three readings were taken, the average indicate 0.15 dPas. When 1 ml water was added, the average of three times reading recorded was 0.15 dPas of oils viscosity value and remain the same average value after 2 ml water were added. However, the readings of average value decrease to 0.14 dips after 3 ml and 4ml of water were added into the oils. In short, when the moisture is increased, the average viscosity reading is decreasing.

Table 4.2: Viscosity of New Transformer Insulating Oils with Changing Moisture Content

Moisture	Viscosity (dPas)			
	1	2	3	Average
No moisture	0.15	0.14	0.15	0.15
1 ml	0.15	0.15	0.15	0.15
2 ml	0.14	0.15	0.15	0.15
3 ml	0.14	0.13	0.15	0.14
4 ml	0.14	0.14	0.14	0.14

4.4 Viscosity Testing on New Transformer Insulating Oils (Temperature Control)

The viscosity testing of new transformer insulating oils with changing the temperature degree can be seen in Table 4.3: Viscosity of New Transformer Insulating Oils with Changing the Temperature. The sample sets to 350 milliliter quantity of oils for each sample. The samples have been heating up using hot plate to get the certain level of temperature. All the data obtained from the experiment.

This experiment will take three times of reading to get the average value. For reading new transformer insulating oils with ambient temperature, which is 22°C, the average value indicates 0.18 dPas. While, the temperature reaches 40°C, the average reading decreases to 0.14 dPas. The average reading for 60°C is 0.09 dPas, for 80°C is 0.06 dPas, for 100°C is 0.03 dPas and for the temperature 120°C indicate 0.02 dPas average of viscosity value. Viscosity of new transformer insulating oils passed the standard requirement below 0.12dPas at 40°C. As a conclusion, the higher the temperature, lowers the average viscosity (dPas) result.

Table 4.3: Viscosity of New Transformer Insulating Oils with Changing the Temperature

Temperature	Viscosity (dPas)			
	1	2	3	Average
Room temperature (22°C)	0.14	0.15	0.15	0.15
40°C	0.10	0.09	0.10	0.10
60°C	0.06	0.07	0.08	0.07
80°C	0.06	0.06	0.06	0.06
100°C	0.04	0.03	0.02	0.03
120°C	0.02	0.02	0.02	0.02

4.5 Comparison on Chemical Substances of New and Breakdown Transformer Insulating Oils

The comparison on chemical substance of new and breakdown transformer insulating oils is shown in the figure below. The Figure 4.1: Comparison of New and Breakdown Transformer Insulating Oils (Substances) shows the graph of chemical substances between new and breakdown transformer insulating oils. The parameter of the graph has been set as absorbance versus the wavenumber. The red color indicates new transformer insulating oils and black color refer to breakdown transformer insulating oils. The graph in the range 3000 to 2800 wavenumber [1/cm] have been analyzed, they show the obvious differences of carbon region. As a conclusion, the new transformer insulating oils consist of the greater observance of chemical substance compare to the breakdown transformer insulating oils.

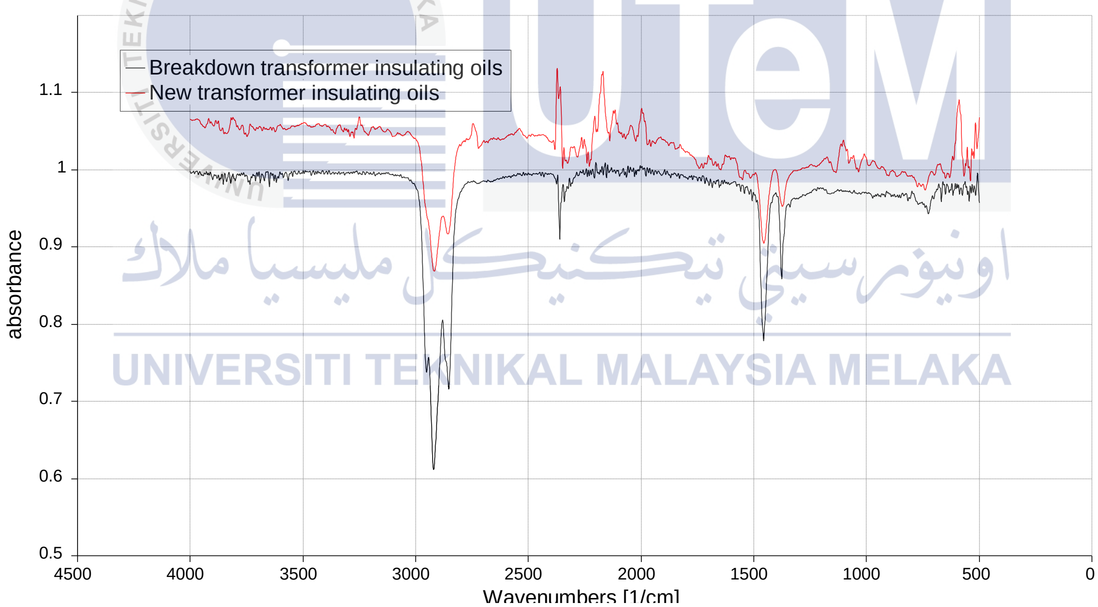

Figure 4.1: Comparison of New and Breakdown Transformer Insulating Oils (Substances)

4.6 Chemical Substances Testing on New Transformer Insulating Oils (Temperature Control)

The chemical substances have been tested on new transformer insulating oils with the temperature control shown in the figure below. Figure 4.2: Chemical Substances of New Transformer Insulating Oils with Changing the Temperature shows the graph of chemical substances for new transformer insulating oils with the temperature control.

The parameter of the graph has been set as absorbance versus the wavenumber. The black color presents the 40°C sample, red color presents the 80°C sample, green color present the 120°C, blue color presents the 160°C and light blue color present the 180°C of temperature. The graph in between 3000 to 2800 wavenumber [1/cm] have been analyzed, there have shown the clear differences of carbon region.

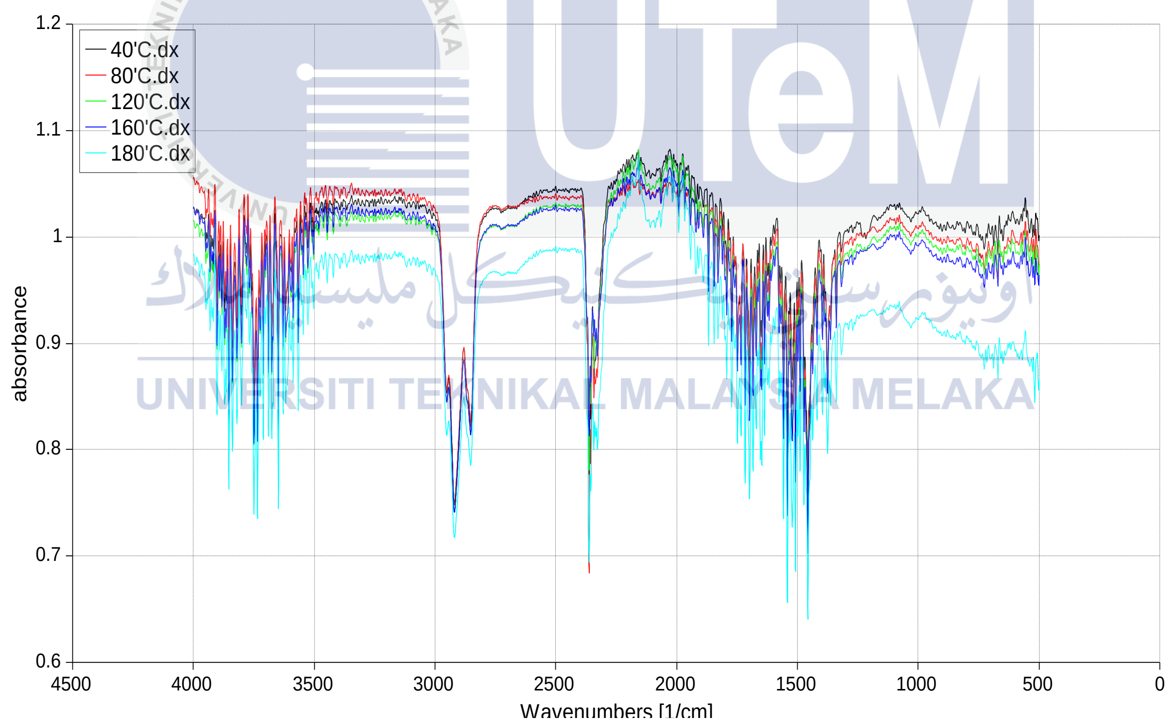

Figure 4.2: Chemical Substances of New Transformer Insulating Oils with Changing the Temperature

4.7 Chemical Substances Testing on New Transformer Insulating Oils (Moisture Control)

The chemical substances have been tested on new transformer insulating oils with the moisture control shown in the figure below. Figure 4.3: Chemical Substances of New Transformer Insulating Oils with Changing Moisture Content shows the graph of chemical substances for new transformer insulating oils with the moisture control.

The parameter of the graph has been set as absorbance versus the wavenumber. The black color presents the 1 ml of add quantity of water in 350 ml sample, red color present the 2 ml of add quantity of water in 350 ml sample, green color present the 3 ml of add quantity of water in 350 ml sample, blue color presents the 4 ml of add quantity of water in a 350 ml sample. The graph in between 3600-3400 wavenumber [1/cm] has been analyzed, due to moisture control.

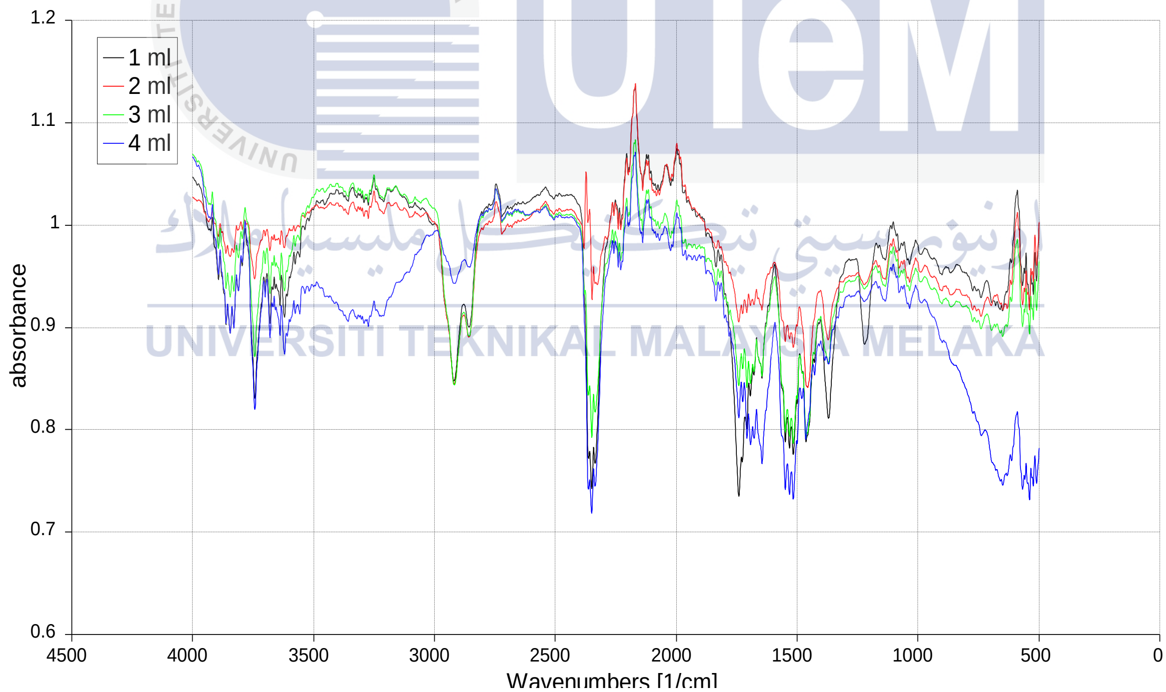

Figure 4.3: Chemical Substances of New Transformer Insulating Oils with Changing Moisture Content

4.8 Comparison of Breakdown Voltage of New and Breakdown Transformer Insulating Oils

This part was where the High Voltage AC breakdown voltage testing on new and breakdown transformer insulating oils will be performed. The breakdown voltage testing on new and breakdown transformer insulating oils can be seen in Table 4.4. The reading of this breakdown voltage was obtained using Megger Oil Test Set (OTS 60PB) through British Standard (BS 5874: 1980).

Test cell was filled up to 350 ml oils for each sample. Six readings were recorded to get the average value based on BS 5874: 1980 and each reading take about three minutes. Average of New transformer insulating oils breakdown voltage value is 60kV and Breakdown transformer insulating oils indicate 27kV of average value. The breakdown voltage of new transformer insulating oils is higher than breakdown transformer insulating oils and passes the minimum breakdown voltage value for transformer insulating oils which is 30kV.

Table 4.4: Breakdown voltage of New and Breakdown Transformer Insulating Oils

Samples	Breakdown Voltage (kV)						
	1	2	3	4	5	6	Average
New transformer insulating oils	60	60	60	60	60	60	60
Breakdown transformer insulating oils	30	25	24	31	29	25	27

4.9 Breakdown Voltage Testing on New Transformer Insulating Oils (Temperature Control)

The breakdown voltage testing of new transformer insulating oils with changing the temperature degree can be seen in Table 4.5: Breakdown Voltage Testing on New Transformer Insulating Oils (Temperature Control). The sample sets to 350 milliliter quantity of oils for each sample. The sample has been heated up by using hot plate to get the certain level of temperature and being filled up into Megger Oil Test Set (OTS 60PB) test cell.

All the data obtained from the experiment has been recorded and analyzed. This experiment will take six times of reading to get the average of values according to British Standard (BS 5874: 1980). The reading of new transformer insulating oils with ambient temperature, which is 22°C, the average value indicates 60kV. The average reading decrease to 44kV when the temperature reached 40°C and keep decrease to 41kV when the temperature degree increase to 60°C. However, Average breakdown voltage reading for 80°C increase to 55kV, at 100°C still increases up to 60kV and at the 120°C decrease to 1kV which indicates the average reading of 59kV.

Table 4.5: Breakdown Voltage Testing on New Transformer Insulating Oils (Temperature Control)

Temperature	Breakdown Voltage (kV)						
	1	2	3	4	5	6	Average
Room temperature	60	60	60	60	60	60	60
40°C	43	50	54	39	36	43	44
60°C	51	42	43	40	34	34	41
80°C	60	53	53	51	55	58	55
100°C	59	60	60	60	60	60	60
120°C	57	59	60	60	60	60	59

4.10 Breakdown Voltage Testing on New Transformer Insulating Oils (Moisture Control)

The breakdown voltage testing of new transformer insulating oils with changing the moisture content can be seen in Table 4.6: Breakdown Voltage Testing on New Transformer Insulating Oils (Moisture Control). The sample was set to 350 milliliter quantity of oils for each sample. The sample has been stirring up by using magnetic stirrer hot plate after adding moisture content (water) and filled up into Megger Oil Test Set (OTS 60PB) test cell.

All the obtained data and result from this experiment has been recorded and analyze. This experiment has taken six times of reading to get the average of values according to British Standard (BS 5874: 1980). New transformer insulating oils without adding moisture after six readings were taken, the average indicate 60kV. When 1 ml water was added, the average value recorded a decrease to 18kV which is failing the requirement of good transformer insulating oil break down voltage value and remain decrease to 14kV average value after 2 ml water was added. The readings of average value decrease to 10kV after 3 ml water was added and maintain after 4ml of water was added into the oils.

Table 4.6: Breakdown Voltage Testing on New Transformer Insulating Oils (Moisture Control)

Moisture	Breakdown Voltage (kV)						
	1	2	3	4	5	6	Average
No moisture	60	60	60	60	60	60	60
1 ml	20	10	16	13	12	34	18
2 ml	11	11	15	14	11	19	14
3 ml	10	10	10	9	10	11	10
4 ml	9	10	10	12	9	9	10

4.11 Discussion of Results

The data and results record has been studied and analyzed based on the output graph and chart result.

a) Viscosity Aspect

The viscosities of oils are important for heat transfer by natural convection and as principal parameter in design calculations. In order to transfer heat for perfect cooling, transformer oils must be freely circulated. The low viscosity of oils is a desirable parameter as it can easily flow and make the heat absorption process much faster than high viscosity. The comparative data for viscosity new and breakdown transformer insulating oils, in moisture and temperature control present in the bar chart as shown in Figure 4.4: Average Value Of New and Breakdown Transformer Oils Viscosity, Figure 4.5: Average Value Of New Transformer Oils Viscosity (Moisture Content) and Figure 4.6: Average Value Of New Transformer Oils Viscosity (Temperature Control).

A good liquid dielectric should have a low viscosity. It has a standard of viscosity value at certain temperatures that need to achieve. New transformer insulating oils (Hyrax Hypertrans) have been tested and been compare with breakdown transformer insulating oils which is taken from damages transformer.

The experiment is carried out in ambient temperature around 22°C. From the Figure 4.4, after the three readings for each sample of transformer oils has been recorded, the average value of the new transformer insulating oils indicates 0.15 dPas while the breakdown insulating oils average value is 0.20 dPas. New transformer insulating oils have a lower viscosity than breakdown transformer insulating oils. This is because the breakdown transformer insulating oils contain contaminant such as sludge and carbon. It has been made the viscosity of oils become viscous. This result is expected due to new transformer insulating oils has passed and exceed the IEC 60296: 2003 requirement of viscosity, cSt state that, at 40°C the viscosity value must below than 0.12 dPas.

For new transformer insulating oil viscosity in moisture control, four parameters which are 1 ml, 2 ml, 3ml and 4ml of water was set up. 1 ml of water was added into new transformer insulating oil sample and stir up by using magnetic stirrer hot plate at 2000 rpm for 5 minutes and tested the viscosity value using viscotester. Each sample was recorded for three times of reading to get the average value of oil viscosity. The sample was shown the same result until 4 ml of water was added into the oil sample.

Figure 4.5 shows the obtained results for viscosity average value. The viscosity of the sample at 1 ml and 2 ml are remaining the same. Even the water has very low viscosity that beyond the measuring range of the viscotester. Water or moisture may affect the viscosity of oil if the percentage of substances increase as the characteristic of oils is lead. This statement is proven due to the average value of adding 3 ml and 4 ml make the viscosity of the oils become lower.

Figure 4.6 shows the effect of temperature on viscosity of oils. The six parameters of temperature value have been chosen. Viscosity of the oils at room temperature (22°C) has discosity 0.15 dPas. It becomes decrease when the temperature increase until 120°C and indicate 0.02 dPas. As the temperature increase, interaction between neighboring molecules of the liquid decrease since the increase velocities of individual molecules. This effect an intermolecular force appears to decrease. So that, the viscosity is straightly decrease when the temperature is increase. This result achieves the requirement of insulating oils as heat transfer by natural convection.

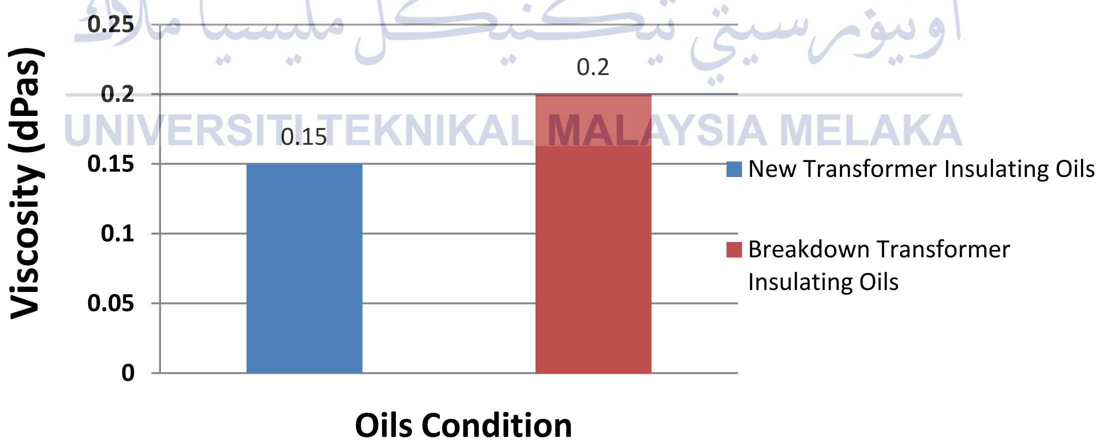

Figure 4.4: Average Value Of New and Breakdown Transformer Oils Viscosity

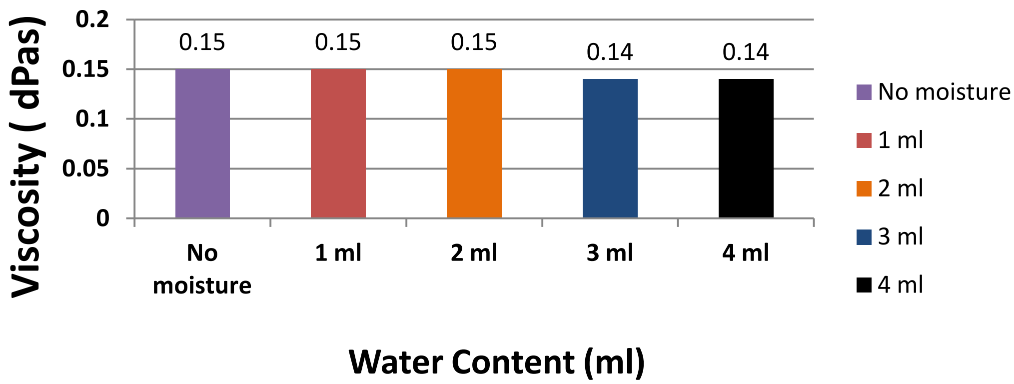

Figure 4.5: Average Value Of New Transformer Oils Viscosity (Moisture Content)

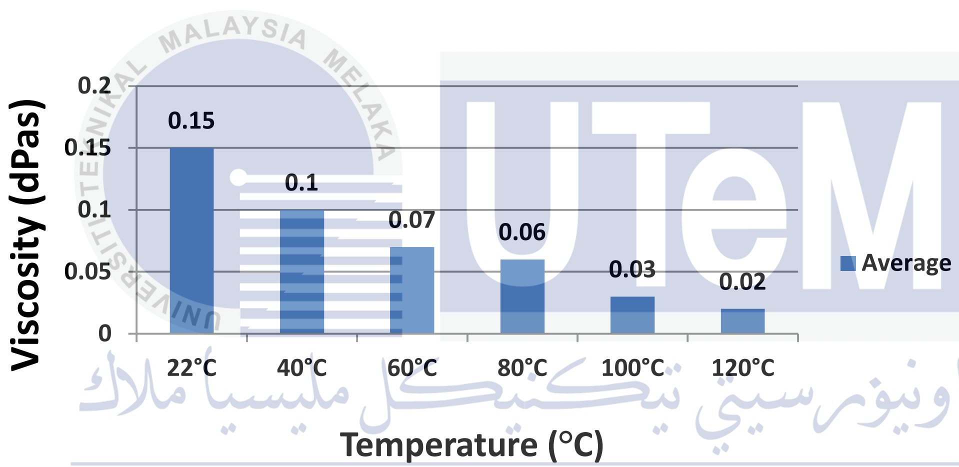

Figure 4.6: Average Value Of New Transformer Oils Viscosity (Temperature Control)

b) Chemical Substances

Characteristic of chemical substances reflect the behavior of hydrocarbon broad classes. The hydrocarbon compounds of insulating oils are in three classes which are naphthenes, aromatic hydrocarbons and alkanes. The chemical formula of transformer insulating oils is $C_{12}H_{10-x}CI_x$, where $_x$ = 1-10 (poly chlorinated bi phenyl). The molecule reaction and behavior of acidity and moisture content against the temperature present in the Figure 4.7: Comparison of New and Breakdown Transformer Insulating Oils (Substances),

Figure 4.8: Breakdown Transformer Insulating Oils (Substances), Figure 4.9: Comparison of New Transformer Insulating Oils substances (Temperature Control), Figure 4.10: New Transformer Insulating Oils At 180’C (Substances), Figure 4.11: Comparison of New Transformer Insulating Oils substances (Moisture Control), and Figure 4.12: New Transformer Insulating Oils Add 4 ml Moisture (Substances) below.

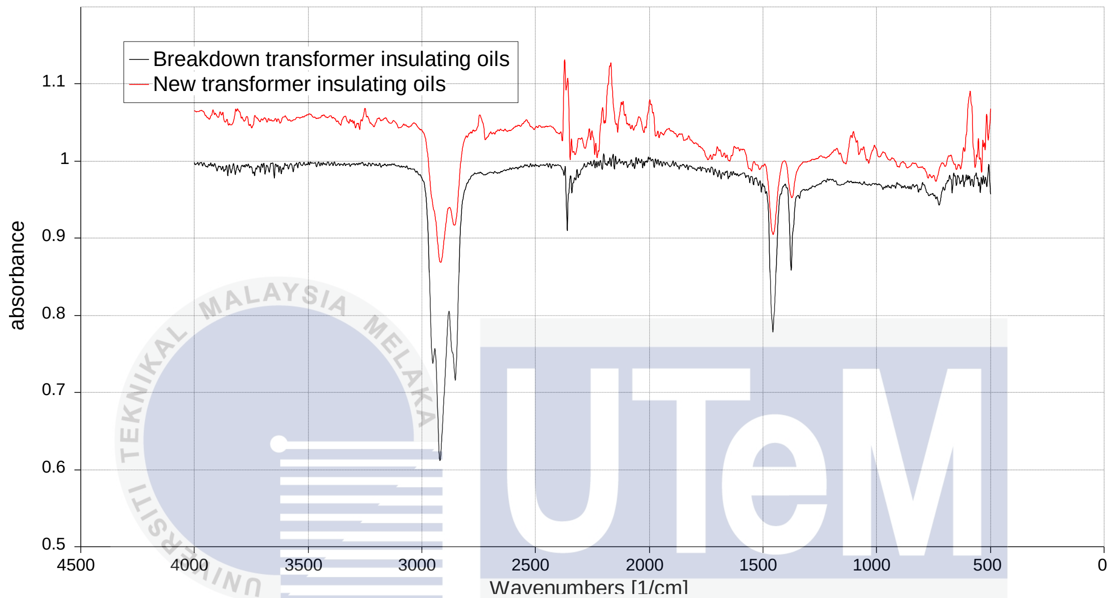

Figure 4.7: Comparison of New and Breakdown Transformer Insulating Oils (Substances)

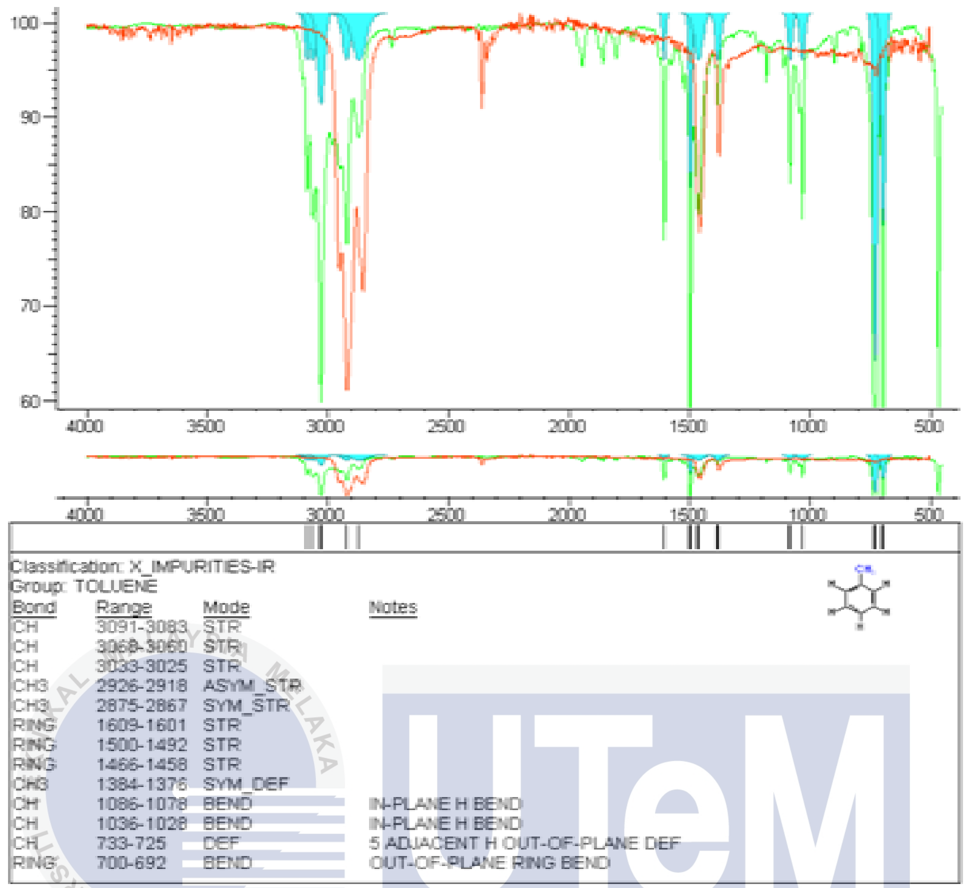

Figure 4.8: Breakdown Transformer Insulating Oils (Substances)

Figure 4.7 shows the comparison of new and breakdown transformer insulating oils IR spectrum. Typically, IR spectrum is a graph. The X-axis presents the wavenumbers [1/cm] and Y-axis present the relative amount of IR photons that are absorbed. At wavenumbers 3000-2850 [1/cm] region is strong bands due to C-H stretch and at wavenumbers 1470-1450 [1/cm] region is C-H band. Focusing on wavenumbers 3000-2850 [1/cm] region to analyze the conspicuous differences between the two samples.

The region of breakdown transformer insulating oils has a strongest transmittance. Refer to the Figure 4.8, it clearly shows the region contains CH, a carbon and a hydrogen atom, CH_3. This composed of a carbon, three hydrogen atoms and too much increment of sulfur that exist basically from metal. High transmittance of the region proves that the deficient of absorbance cause the changing of the molecule in insulating oils substances.

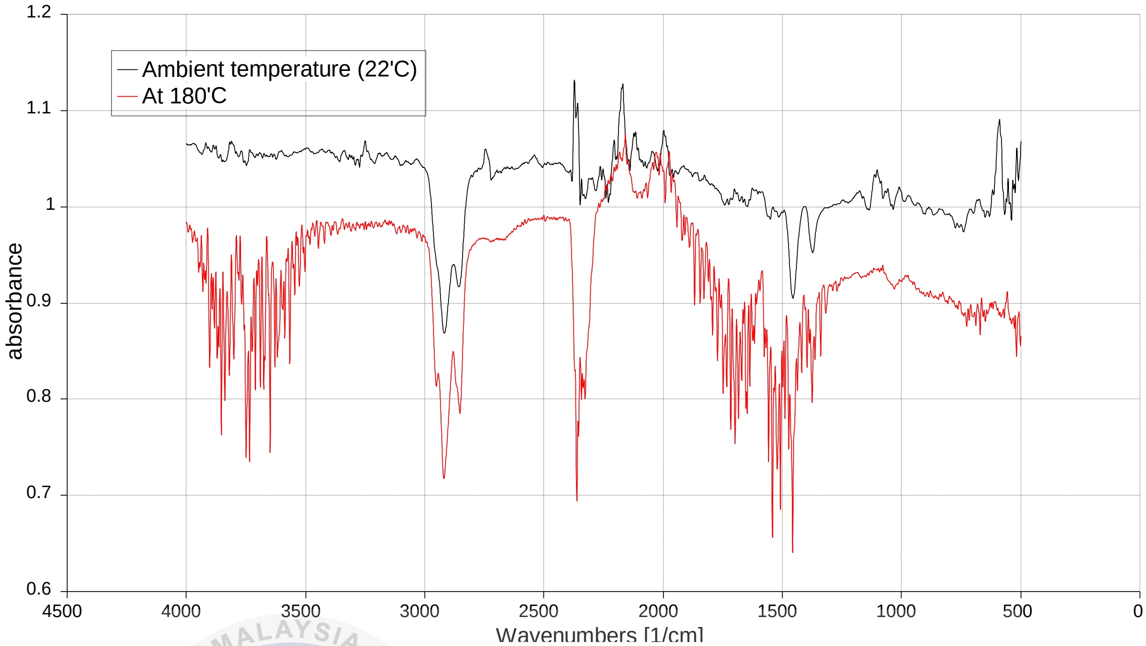

Figure 4.9: Comparison of New Transformer Insulating Oils substances (Temperature Control)

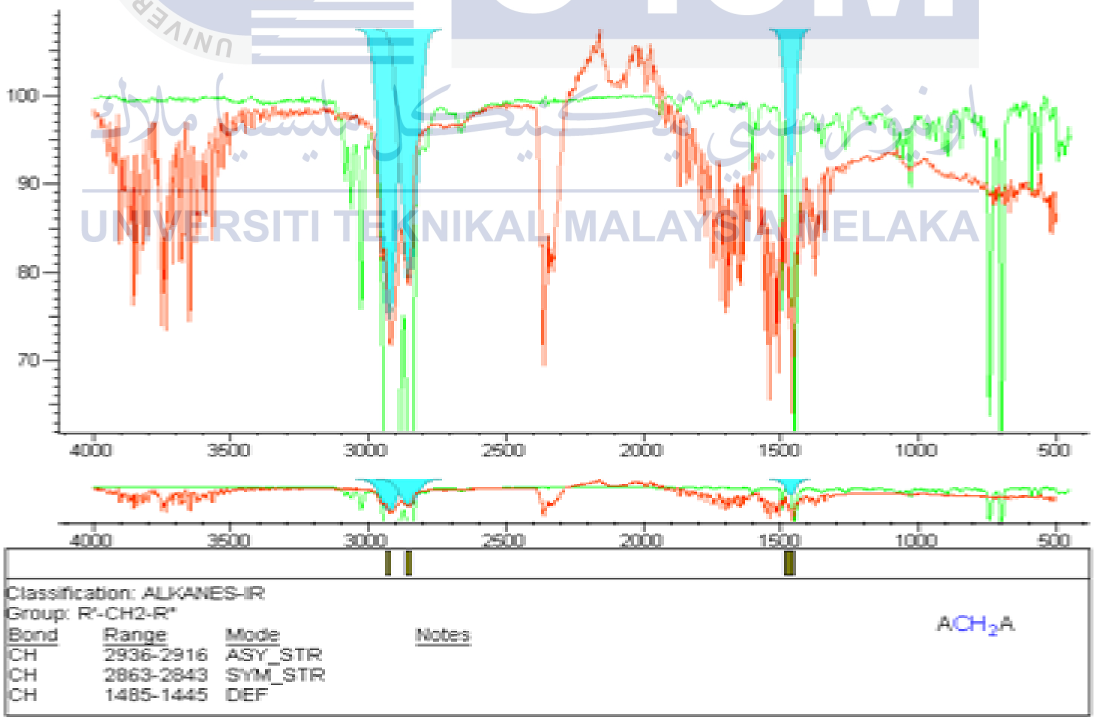

Figure 4.10: New Transformer Insulating Oils at 180’C (Substances)

The thermal or temperature plays an important role in changing transformer insulating oil molecule. Figure 4.9 recorded the comparison of the IR spectrum between new transformer insulating oils in ambient temperature conditions at 180°C. At wavenumbers 3000-2850 [1/cm] region is a strong band due to C-H stretch.

The high temperature on insulating oil can produce carbon and changing the structure of the molecule. The figure 4.10 shows the region is classification as alkanes and hydrocarbon compound which is also known as aliphatic compound. High transmittance of the region significantly reduced the CH content. The breaking of C-H bonding resulting in the appearance of combustible gases, particularly ethylene (C_2H_4) and acetylene (C_2H_2). The region, which full of carbon in substances, can cause insulation failure.

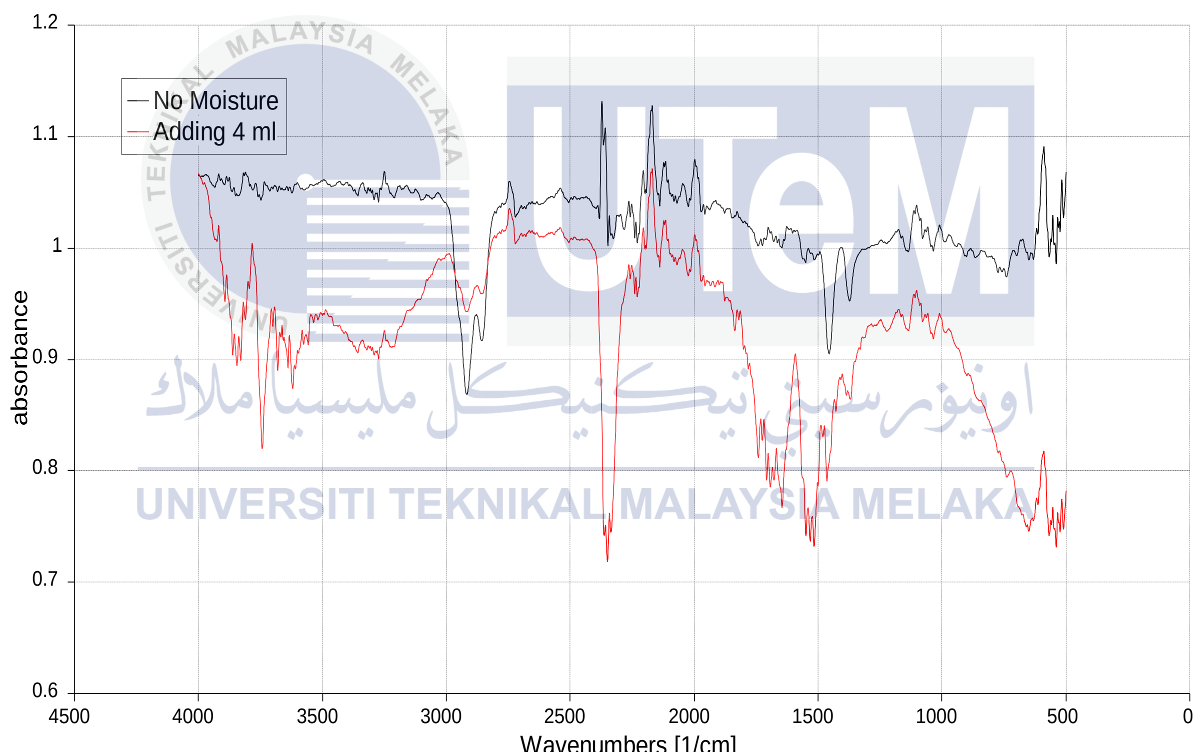

Figure 4.11: Comparison of New Transformer Insulating Oils substances (Moisture Control)

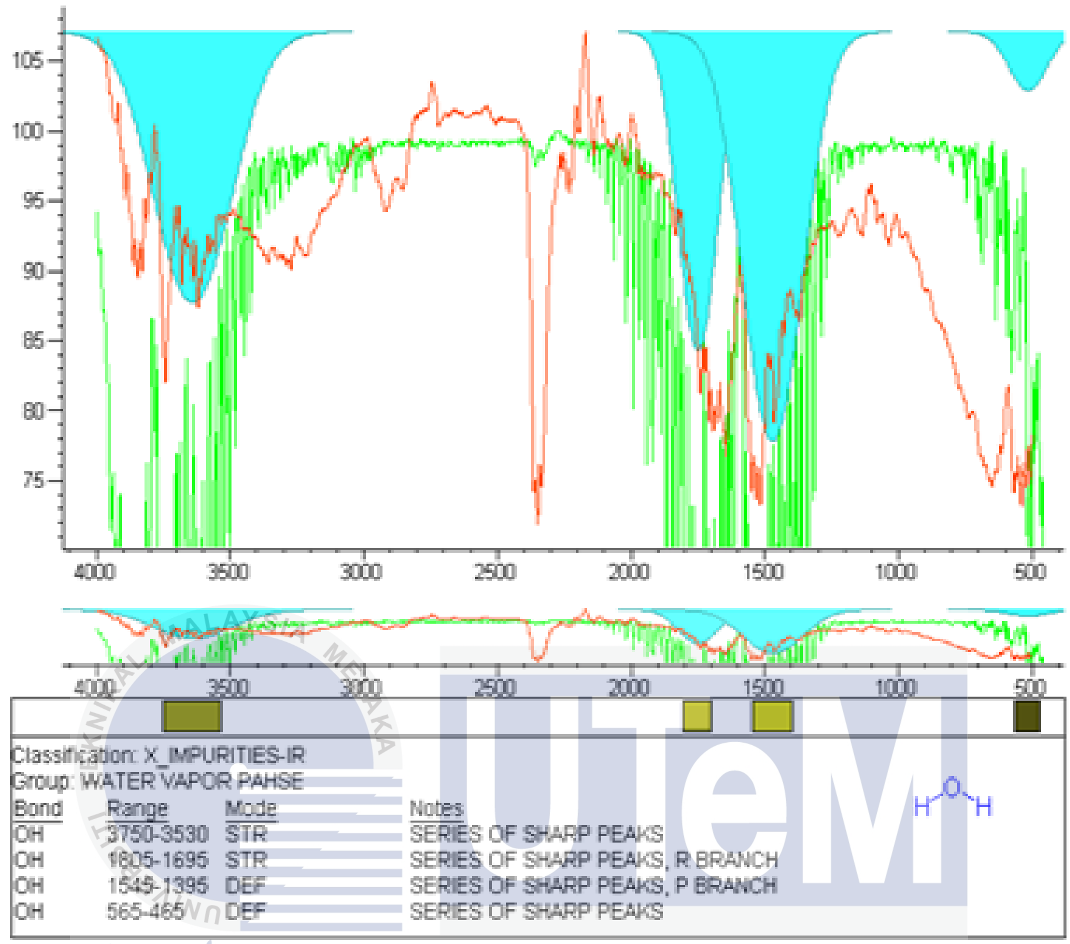

Figure 4.12: New Transformer Insulating Oils Add 4 ml Moisture (Substances)

Water or moisture is important contaminants to monitor in transformer insulating oils. Figure 4.11 shows the comparison of IR spectrum between new transformer insulating oils in non moisture conditions and the added 4 ml of water. The water band near O-H stretching (3400 [1/cm]) can directly measure the concentration of water, the area of this band is linearly correlated to the concentration of water.

Refer to the figure 4.12 at 3600-3400 [1/cm] region, these are water vapor phase which is H_2O. Moisture presents in the oils lowers the dielectric strength because of the moisture will break the molecular chain of oils and make its chain as conductor.

c) Breakdown Voltage

Breakdown voltage occurs when the insulating oil reached the time of spark between electrodes. Condition of Molecular properties and atomic insulating oils caused the breakdown voltage. Megger Oil Test Set is fully automatic whether to implement the standard or reading data. This testing will follow British Standard (BS 5874: 1980).

The comparative data for breakdown voltage new and breakdown transformer insulating oils, in moisture and temperature control present in the form of bar chart as shown in Figure 4.13: Average Value of New and Breakdown Transformer Oils Breakdown Voltage, Figure 4.14: Average Value Of New Transformer Oils Breakdown Voltage (Moisture Control) and Figure 4.15: Average Value Of New Transformer Oils Breakdown Voltage (Temperature Control).

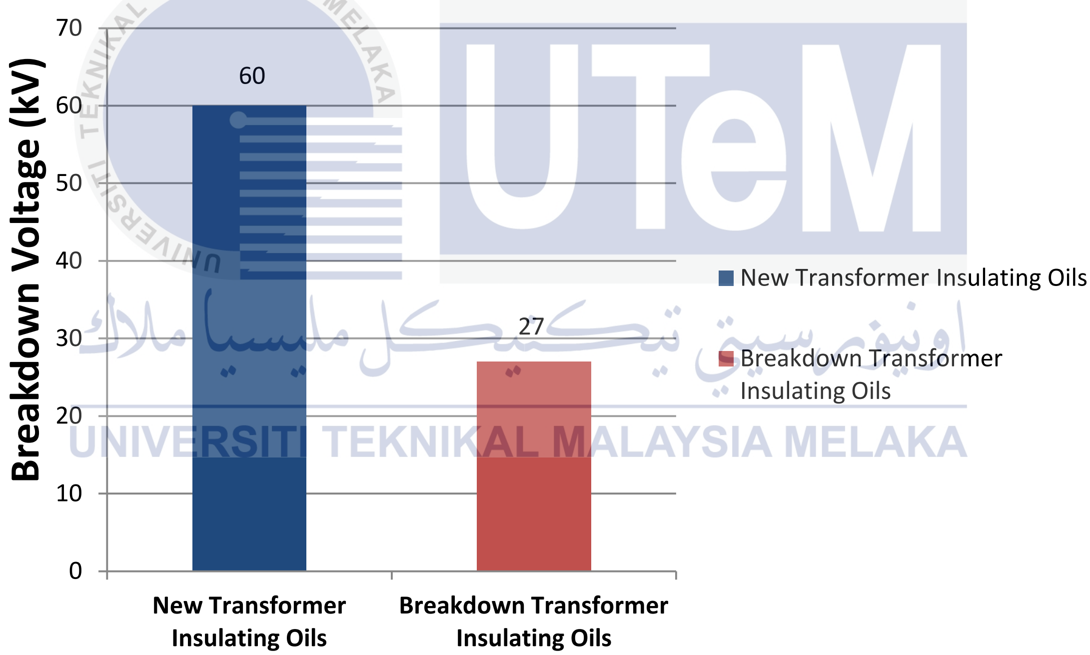

Figure 4.13: Average Value Of New and Breakdown Transformer Oils Breakdown Voltage

From the Figure 4.13 above, it is expected that new transformer insulating oils have the highest breakdown voltage value than breakdown transformer insulating oils because of the samples still unused and clean from any contaminant. While, the breakdown transformer insulating oils are taken from damages transformer and expected the substances of the oils full with contaminant to make the analysis become interesting.

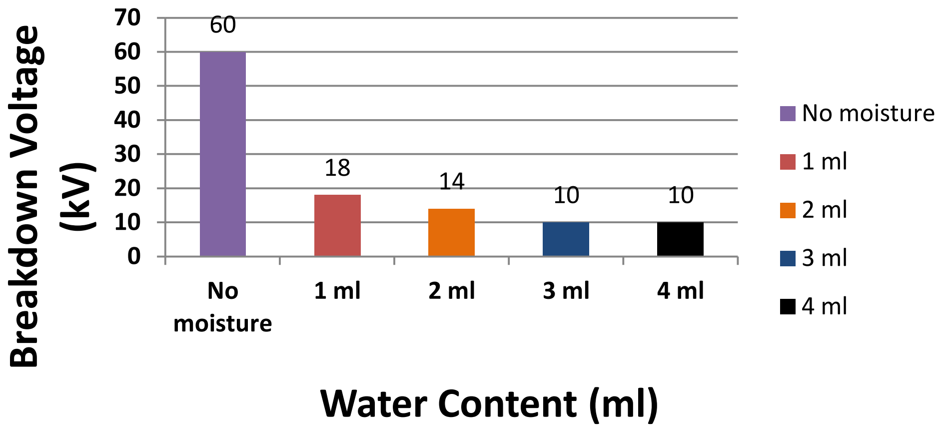

Figure 4.14: Average Value of New Transformer Oils Breakdown Voltage (Moisture Control)

Moisture content in insulating oils has to be controlled. Based on the Figure 4.14, add up of 1 ml of water equal to 2000 ppm. The breakdown voltage decreases 42kV to 18kV from 60kV in non moisture condition. The additional water just 0.285% from the insulating oils contains. This is due to the moisture delivers charge carriers and made the dielectric strength decrease. Keep continues to add the moisture into the insulating oils make the breakdown voltage slightly decrease to 14kV and maintain the breakdown voltage average value when 3 ml and 4 ml moisture was added.

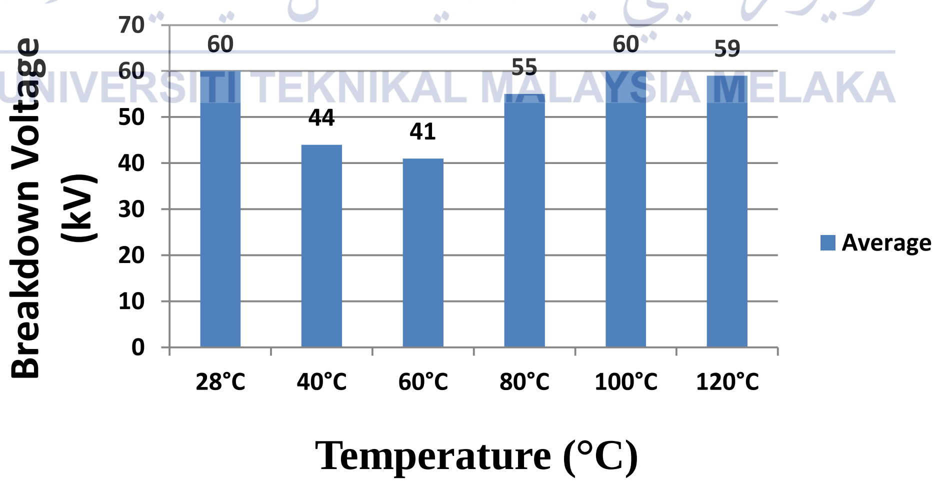

Figure 4.15: Average Value of New Transformer Oils Breakdown Voltage (Temperature Control)

While measuring the breakdown voltage, temperature is the focus of parameters. Figure 4.14 show when in ambient temperature, which is 28°C, the breakdown voltage of the transformer insulating oils is 60kV. When the temperature increase to 40’C, the average value decreases to 44kV and slightly decreases to 41kV when the temperature reached 60°C.

However, the result is still acceptable. The minimum passing point of breakdown voltage is < 30kV (BS 5874: 1980). It might because of moisture in the test cell. The transformer insulating oil has been heated up first in beaker according to a certain temperature and pour into the test cell for breakdown voltage testing. When the moisture has been heating up at 80°C and it turns into the vapors, the breakdown voltage increase to 55kV and reach 60kV at 100°C. These bar chart approve the theory of breakdown voltage, which is the breakdown voltage will increase if the temperature is increased.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This research is about several characteristic relevant to new transformer insulating oils and breakdown transformer insulating oils. The relationship between these two insulating oil conditions is to determine the properties of the oils. Three properties have been carried out to determine the characteristic of a good liquid dielectric. The properties were the electrical, chemical and physical properties. Each of these properties has been through the experiment to determine and analyze causes of transformer failure in different moisture and temperature condition.

The two parameters which are moisture and temperature are required in order to identify the effect of this parameter in insulating oils. Fourier Transform Infrared spectrometer is selected to analyze chemical substances in transformer insulating oils. While, to determine the breakdown voltage of transformer insulating oils, the Megger oil test set is being used and viscotester is used to analyze viscosity of transformer insulating oils. Testing works using FTIR, the Megger Oil Test set and viscotester are completely done and the analysis of the results and data is shown in the Chapter 4.

The result of the chemical substances, breakdown voltage and viscosity analysis shows the moisture and temperature give an impact in insulating oil particle and substances. This is due to viscosity value and breakdown voltage is decrease with addition of moisture. When temperature increase, viscosity value is decrease and breakdown voltage is increase. From the graph of chemical substances testing, its show that particles of moisture give an effect of the stability absorbance and wavenumbers. This is because of the moisture break the particle chain of oils. When the oils has been heated, molecule absorb the energy and be much active, it's present by fluctuate waveform.

5.2 Recommendations

In order to get the better understanding regarding to this analysis, the parameters that have been used in this research should be changed. Moisture and temperature should be the parameters that are determined. This is to determine both moisture and temperature parameters are able to give an impact on the insulation failure or not. Moisture is conductor and for sure it will cause a breakdown voltage or the dielectric strength value decrease, damage the winding, insulation kraft paper and proven by chemical substance analysis, the moisture breaks the particle chain.

Even the moisture good in heat transfer and have a low viscosity. My recommendation is change the moisture with nano fluids as parameter. If nano fluids apply for this project, this project will become more challenging. The new transformer insulating oils, adding up with the nano fluids with new transformer oils and determine in the three properties. Nano fluids is effective heat transfer, its nano particles have a tight chain of molecule. Its effectiveness by applying in transformer insulating oils still unknown compare to moisture that known it will cause damages.

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APPENDICES

APPENDIX A

Testing Works

a) Viscotester

Step 1: Prepared the apparatus

Figure A1: Test vessel

Figure A2: Viscotester Accessories (Rotor, Measuring Cup)

Figure A3: Digital Thermometer

Figure A4: Magnetic Stirrer Hot Plate

Step 2: Construct the base of stand clamp and install the viscotester

Figure A5: Stand Clamp

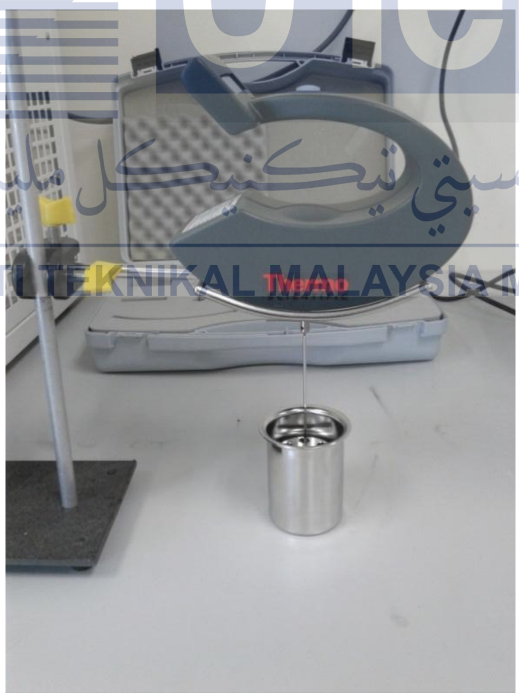

Figure A6: Viscotester Test Set

Step 3: Fill about 150 milliliter into measuring cup until immerse the rotor up to the dip mark into the substance.

Figure A7: Oil Level Reach The Rotor Dip Mark

Step 4: Testing the viscosity of the samples by press ‘START’

Figure A8: Testing in Progress

Step 5: Collected, analyzed the result

Figure A9: Display of Viscosity Result

b) Fourier Transform Infrared Spectrometer (FTIR)

Step 1: Prepare the apparatus

Figure A10: Dropper and Test Vessel

Figure A11: Attenuated Total Reflectance (ATR)

Step 2: Install the instrument accessories for liquid testing (ATR) and clean the test cell using acetone.

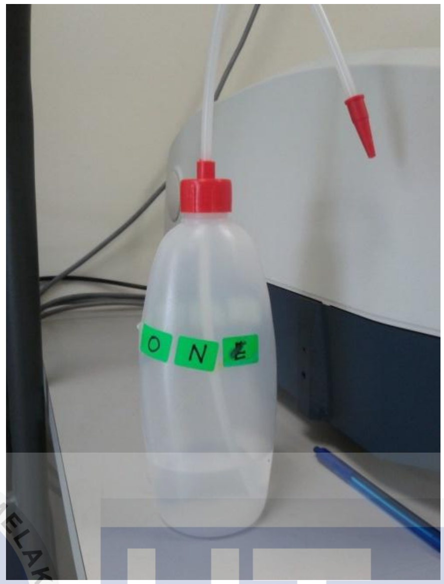

Figure A12: Acetone

Figure A13: Install ATR

Step 3: Switch 'ON' the instrument, release the nitrogen gas for awhile and calibrate the software background.

Figure A14: Nitrogen Gas Set

Step 4: Drop the sample into ATR test cell after open the ATR knob by turn counter clockwise.

Step 5: Open the Spectra Measurement software and click icon S to testing.

Step 6: Ten minutes remaining to finish testing, the result will come out in graph form.

Figure A15: FTIR Instrument Set

c) Megger Oil Test Set (OTS 60PB)

Step 1: Prepared the apparatus

Figure A16: Test cell, Beaker and Sample

Figure A17: Magnetic Stirrer Hot Plate and Megger Oil Test Set

Step 2: Pour the sample into the test cell

Figure A18: Sample In Test cell

Step 3: Put the test cell into the Megger Oils Test Set testing area

Figure A19: Electrode Immersed Into The Sample

Step 4: Run the Megger Oil Test Set and select British Standard (BS 5874: 1980)

Step 5: There will be six tests continue directly and the result whether pass or fail and average value of sample will appear at the end of testing

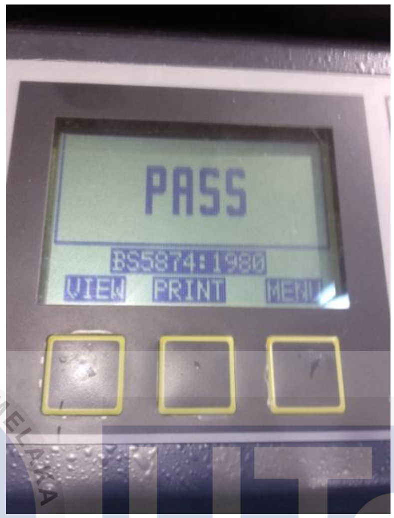

Figure A20: Result of Testing

Figure A21: Average Value of Testing

APPENDIX B

Average Viscosity of New Transformer Insulating Oils (Temperature)

Figure B1: At temperature 22°C

Figure B2: At temperature 40°C

Figure B3: At temperature 60°C

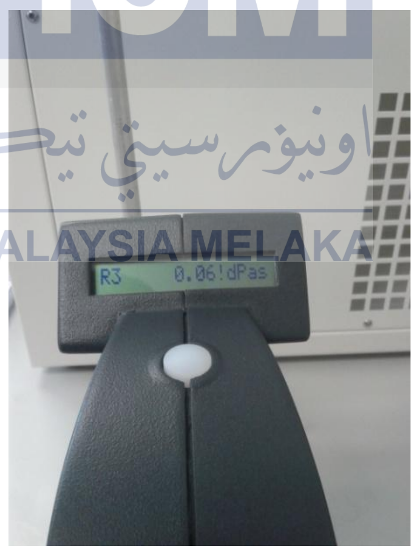

Figure B4: At temperature 80°C

Figure B5: At temperature 100°C

Figure B6: At temperature 80°C

APPENDIX C

Average Viscosity of New Transformer Insulating Oils (Moisture)

Figure C1: At drop of water 1ml and 2ml

Figure C2: At drop of water 3ml and 4ml

APPENDIX D

Average Breakdown Voltage of New Transformer Insulating Oils (Temperature)

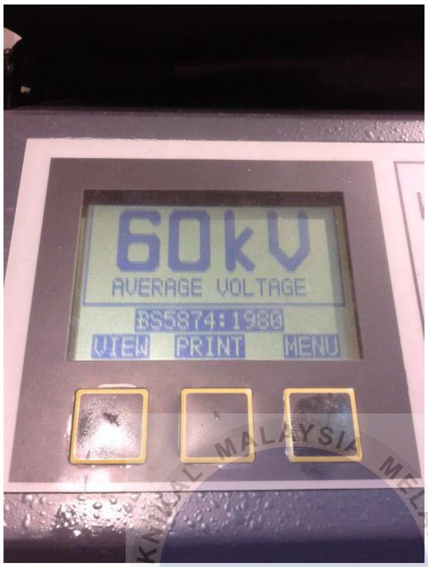

Figure D1: At temperature 28°C

Figure D2: At temperature 40°C

Figure D3: At temperature 60°C

Figure D4: At temperature 80°C

Figure D5: At temperature 100°C

Figure D6: At temperature 120°C

APPENDIX E

Average Breakdown Voltage of New Transformer Insulating Oils (Moisture)

Figure E1: At drop of water 1ml

Figure E2: At drop of water 2ml

Figure E3: At drop of water 3ml and 4ml