THE EFFECT OF MOISTURE ON AC BREAKDOWN VOLTAGE OF SYNTHETIC ESTER OIL UNDERGONE DIFFERENT MOISTURE REMOVAL METHODS

SYAHARIL BIN MAT ISA

BACHELOR OF ELECTRICAL ENGINEERING
(INDUSTRIAL POWER)
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SYAHARIL BIN MAT ISA

2016

I hereby declare that I have read through this report entitle “The effect of moisture on ac breakdown voltage of synthetic ester oil undergone different moisture removal methods “and found that is comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)

Signature : ……………………………..

Name : …………………………….

Date : ……………………………..

THE EFFECT OF MOISTURE ON AC BREAKDOWN VOLTAGE OF SYNTHETIC ESTER OIL UNDERGONE DIFFERENT MOISTURE REMOVAL METHODS

SYAHARIL BIN MAT ISA

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

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2016

I declare that the project report entitled "The effect of moisture on ac breakdown voltage of synthetic ester oil undergone different moisture removal methods" is the results from my own research except as cited in the references.

Signature : ……………………………..

Name : SYAHARIL BIN MAT ISA

Date :

To my beloved mother and father

ACKNOWLEDGEMENT

Firstly, I want to express my gratitude to Allah S.W.T for giving strength and ability in enduring this Final Year Project report. I also want to express my special thanks to my project supervisor that is Dr. Hidayat Bin Zainuddin whose give me a lot of advice and guidance in making this project and also in complete this report.

This gratitude also goes to my family and my friends whose give their support and also contribute in knowledge in this project. Besides that, I would like to give my appreciation to the staff of University Teknikal Malaysia Melaka (UTeM) whose give the instruction and give permission to me in using the equipment at the High Voltage Laboratory in conducting the experiment that necessary in this Final Year Project

ABSTRACT

Transformer is one of the valuable assets which used to deliver the electricity power to the whole nations. Inside the transformer is containing oil which its function is to cool down transformer from overheating and act as insulation for the windings. Generally, the mineral oil is used as the liquid insulator for the insulation purpose to prevent the transformer from breakdown. But unfortunately there are several weaknesses for the mineral oil. The weakness is not biodegradable, low moisture tolerance and also flammable. The ester oil has become one of the alternative ways to overcome the weakness of the mineral oil. The advantage of the ester oil is more biodegradable, excellent fire resistance and high dielectric strength. However, the occurrence of the moisture inside the transformer will affect the breakdown voltage of the insulation liquid to protect the transformer. This project will measure the effect of different moisture level on the ester oil in terms of its breakdown voltage by using breakdown tester set (OTS60PB) and also study on necessary method of the moisture removal technique in order to decrease the moisture contents inside the ester oil. The breakdown measurement comply with ASTM D1816 standard is used. For the moisture removal method, there are three techniques that been used which are by using vacuum, air ventilation and nitrogen gas treatment. Karl Fischer titration device is used to determine the water contents for those different techniques. From the analysis that been done, it is clearly shown that the breakdown strength decreases as the moisture contents increases. The breakdown voltage is the highest when nitrogen treatment is used compared to vacuum and air ventilation method. By doing this research, it is obvious that removing the moisture from the insulation oil will make the oil have great potential in overcoming electrical stress.

ABSTRAK

Transformer adalah salah satu aset dimana ia digunakan untuk menghantar tenaga elektrik kepada seluruh pengguna. Di dalam transformer mengandungi minyak dimana fungsinya adalah untuk menyejukkan transformer daripada berlaku pemanasan yang melampau serta bertindak sebagai penebatan bagi belitan transformer. Secara umumnya, minyak transformer digunakan sebagai cecair penebat bagi tujuan penebatan untuk mengelakkan transformer dari rosak. Akan tetapi terdapat beberapa kelemahan pada minyak mineral. Antara kelemahan yang terdapat pada minyak mineral ialah tidak mesra alam, toleransi terhadap kelembapan adalah rendah dan juga mudah terbakar. Minyak ester menjadi satu daripada alternatif untuk mengatasi kelemahan minyak mineral. Antara kelebihan minyak ester ialah lebih mesra alam, tidak mudah terbakar dan tahap kekuatan dielektrik yang tinggi. Akan tetapi kehadiran lembapan pada transformer boleh memberi kesan pada tahap kerosakkan dan tahap ketelusan bagi minyak mineral dan ester. projek ini akan mengukur kesan tahap kelembapan pada minyak ester dari segi tahap kerosakkan voltan dengan menggunakan set pengukur (OTS60PB) dan mengkaji teknik untuk membuang lembapan untuk mengurangkan kandungan air dalam minyak ester. Pengukuran kerosakan akan menggunakan standard ASTM D1816 dan menggunakan isipadau air yang berbeza. Bagi kaedah untuk menghilangkan lembapan, terdapat tiga cara yang digunakan iaitu dengan menggunakan vakum, pengudaraan dan gas nitrogen. Alat Karl Fischer digunakan untuk menganggar kandungan air untuk kesemua teknik yang digunakan. ia akan mengukur dalam unit parts per million (ppm). Daripada analisis yang dijalankan ia dengan jelas menunjukkan bahawa tahap pecah tebat akan berkurang apabila kandungan kelembapan bertambah. Daripada kajian ini, ia amat jelas menunjukkan dengan membuang lembapan dari minyak penebatan akan menyebabkan minyak tersebut mempunyai potensi yang lebih baik untuk menghadapi tekanan elektrik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Power transformer and distribution transformer are widely used in public and private sector which involve consumption of electricity, distribution and generation [1]. For the power utilities in Malaysia, the oil immersed type is generally used for the transmission and distribution system [2]. The oil works as electrical insulation and it also act as a medium for heat transfer to make sure that transformer is not overheated when operate in high voltage for a long time. In Malaysia mineral oil is used inside the transformer for many years. The characteristic of the mineral oil which have relatively flammable and can cause hazard for environment make the researcher studies the alternative insulation oil to replace the mineral oil. One of the alternative oil that has comparable performance characteristic such in mineral oil is ester oil.

This project investigates the effect of moisture level in ester oil by using breakdown measurement and also determines its water content by using Karl Fisher Coulometric. In this study, the synthetic ester oil is tested based on different levels of moisture contents inside the oil. That synthetic ester oil (MIDEL 7131) will undergo 3 different types of treatment in order to remove the moisture inside it before doing testing for its breakdown. The types of treatment that been used are air ventilation, vacuum and nitrogen gas treatment methods. The efficiency of each treatment method is analyzed on the basis of water content level and breakdown voltages.

1.2 Problem Statement

Transformer is very important in electrical system because it is used to transfer electrical energy from one circuit to another. Inside the transformer there is oil that is used as insulation and also to keep the transformer cool from the heat. The oil is important to preserve the core and winding and also to prevent cellulose paper from direct contact with the atmospheric oxygen. Generally, the type of oil that widely used inside the transformer is mineral oil. But the mineral oil is not biodegradable, low moisture tolerance which tends to cause sulphur corrosion and also flammable which can risk the living environment. Therefore, alternative oil is needed to overcome the weakness of the mineral oil. One of the oils that can be used to replace the function of mineral oil in the power transformer which is more biodegradable, excellent fire resistance and low dielectric losses when the frequency is more than 1 kHz is ester oil. However the occurrence of the moisture inside the transformer oil will affect the potential of the mineral oil and ester oil inside the transformer in terms of breakdown voltage. This project is conducted to study the effect of moisture level in ester oils in terms of their breakdown durability. In addition, this ester oil will be having three types of treatment method to remove the moisture inside it before undergo the testing by using vacuum, ventilated and nitrogen. This method will be compared its efficiency in removing the moisture by using Karl Fisher and also testing its breakdown for each technique that applied on that oil.

1.3 Objectives of Research

1. To compare the effectiveness of different moisture removal treatment methods on synthetic ester insulation oil by using Karl Fisher moisture measurement and breakdown voltages measurement.
2. To investigate the level of breakdown voltage for synthetic ester oil in different moisture levels.

1.4 Scope of Project

In this project, the new oil is been used for analyzing the ester oil. This ester oil is taken from the drum but in this experiment, the ester oil must undergo moisture removal treatment. This oil undergoes with three methods of treatment that is by using vacuum, air ventilation and also nitrogen gas methods. All these methods is referring the technique that been used by previous study. Karl Fisher is been used to determine the water content inside the oil to see the effect of those treatment towards the quantity of moisture inside the oil and the measurement is in unit part per million (ppm). The study will involve addition of moisture levels of 0.1 ml, 0.2 ml and 0.3 ml in the ester oil. The type of ester oil that been used is MIDEL 7131 which known as synthetic ester. The ASTM D1816 standard is been used in analyzing the effect of moisture level in ester oil for breakdown measurement.

1.5 Significance of the Study

This study is about to observe the capability of the ester oil towards the effect of moisture and also to test the method that can remove the moisture effectively from the oil. The reason of this study is because ester oil has much advantage compare to the mineral oil. The disadvantage of mineral oil compared to ester oil is flammable for certain fire point, not environment friendly and will be depleted someday because it is produce from the refinery from the crude oil. Whereas the ester oil comes from the renewable source such as plants and it is produced from the esterification process to become ester oil. It is very important for researcher to study more on the effectiveness of using the ester oil for insulation in distribution transformer. The moisture removal treatment is used because ester has more moisture contents compared with the mineral oil. This oil easily absorbs the moisture when exposed to the humidity. When higher the humidity, then the higher moisture will be absorb inside the oil molecule. The free water molecule inside the oil can cause the breakdown occur faster than the actual of that insulation oil strength. Hence, in order to get maximum capability of the ester oil, it needs to remove the moisture first before testing the breakdown. This experiment will use vacuum, air ventilation and nitrogen gas methods in removing the moisture and to see which method is more reliable to be used. This study will give impact towards the use of mineral oil as common insulation oil inside power transformer which can be replaced by ester oil that have more environment friendly characteristic and cheaper in cost compared to mineral oils.

1.6 Thesis Outline

This report consists of five chapters. This first chapter explains on the function of insulation oil in distribution transformer. This chapter also highlights the objectives, problem statement, project scope and significant of the study.

The second chapter is literature review. The literature reviews address the researches that have been carried out by other researcher that related to this project. By referring the previous research, it can be easier to find the right method and also the standard which can be used for this study to make sure that the experiment and data gathering for the analysis is correct and doing in proper way. For example, the uses of ASTM D 1816 in breakdown measurement for insulation oil is one of the standard that been review by previous research and the same method can be used in this study for analyzing the breakdown measurement.

The third chapter is methodology. This chapter explains the process of the experiment that will be conducted from the beginning until to the end of the research. The experimental setup and all the tools and device that will be used in this project are discussed.

Chapter 4 discusses the results of this project. The data from the research and experiment that been carried out is tabulated and shown clearly in the graph. The comparison on the moisture contents by using different method of oil treatment and also the effect of moisture towards the breakdown measurement on synthetic ester oil are discussed.

Lastly, chapter 5 concludes all about this project based on the observation during the experiment and the data collected in the result section. From the result that been gathered, a good conclusion can be made and also by referring from the previous researcher at the literature review section, the comparison can be made to see significant and also the contribution of this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature review focuses on the principle and also the theory of the effect moisture level in synthetic ester oil on breakdown measurement and also the different methods that been used in ester oil treatment to remove the moisture inside the oil.

2.2 Dielectric Liquid

Dielectric liquid is used to prevent electric discharge. It is used in high voltage application which it served as electrical insulator. The common application that always been used is in high voltage application such as in power transformer. For the function of dielectric transformer, it is used to cool the winding and it is also used to provide the optimal performance to make sure the transformer is in good condition. Generally, the type of dielectric liquid which commonly used for the transformer insulation is mineral oil. Although the mineral oil is widely used inside the power transformer, but nowadays researchers are trying to find the alternative oil that is comparable with mineral oil. One of the oil that has the good characteristic to become insulation oil inside the power transformer is ester oil. Below is few of the characteristic for the mineral and ester oils to be discussed.

2.2.1 Mineral Oil

Mineral oils are obtained from the crude oil which undergoes the process of fractionation and ulterior treatment. The function of this mineral oil is to preserve the core and winding where these two components are absolutely immersed inside the oil. For the structure of mineral oil, it is a mixture which is combination of three basic molecules. The molecules that consist inside the mineral oil are naphthenic, aromatic and paraffinic. The characteristic of the mineral oil is based on these three chemical compositions [3]. For the paraffinic molecule, the formula is ($C_{2n}H_{2n+2}$), naphthenic molecule is ($C_{2n}H_{2n}$) and aromatic molecule is (C_nH_n). These hydrocarbons are combination of hydrogen and carbon which linked together with mono and double bonds depending on hydrocarbon types [4]. The structures of the molecule are shown in Figure 2.1 and the characteristics of mineral oil are shown in Table 2.1.

The Paraffinic oil has a lower performance as a coolant in power transformer although the oxidation rate is lower than Naphthenic oil. For the Naphthenic oil, it has a great performance as coolant in cooling system of power transformer. This is because the sludge is insoluble compared to Paraffinic oil [1]. The Aromatic oil has higher conductivities compared to the Paraffinic and Naphthenic oils and also has very low value of dielectric loss. Even though these three have different of the characteristic, but all of them are relatively flammable and can cause hazard for environment.

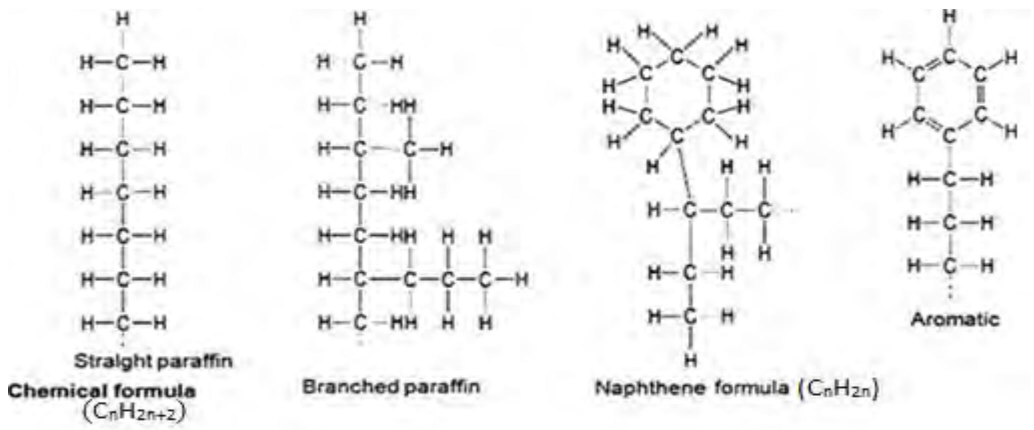

Figure 2.1: Molecular structure of mineral oil

Table 2.1: Characteristic of mineral oil [5].

Properties	Mineral oil
Density at 20°C	0.88
Kinematic viscosity at 20°C (mm^2/s)	22
Pour point (°C)	-50
Flash point to ISO 2719 (°C)	150
Fire Point to ISO 2592 (°C)	170
Permittivity at 20°C	2.2
Breakdown voltage (kV)	>70

2.2.2 Ester Oil

Ester oil is also known as vegetable oil. It is one of the new liquids which has the ability to be used as dielectric in transformer [2]. It is produced by organic compound that generated with alcohol and acid reaction. The esterification of glycerin and fatty acid produce oil and fats. Ester has triglyceride structure which came from the chemical linkage of three fatty acid and glycerol molecule. Ester is very good in biodegradability and excellent fire resistance [3]. Generally, esters have two types. They are natural ester and synthetic ester. The production of natural ester is cheaper than synthetic. However, the natural ester is more prone to oxidation process because of their difference chemical structure compared to synthetic ester [6]. Ester can be divided into five groups. They are Monoesters, Dicarboxylic esters (Diesters), Glycerinesters, Polyolesters and Complexesters. From these five groups, only Polyolester and Complexester that can be used in high voltage transformer. It is because they are adequate with high stress condition. Among of the ester oils, these groups are the strongest base stock [4]. From other previous studies, the ester-based oil has more hygroscopic than mineral oil because the ester can absorb more water and this make the paper keeps dry. However, the disadvantage of the ester oil is, it is easily oxidized and hydrolyzed. The previous research that has been done prove that ester oil is comparable with the dielectric such in mineral oil. It has similar breakdown voltage as mineral oil which can avoid the risk of failure. The increasing of water inside the oil can reduce the breakdown voltage between 5% to 10%. The research also found that ester oil has larger coefficient variation which means that it is unpredictability and have higher chance for the ester oil to breakdown at lower voltages [7]. The structures of the molecule are shown in Figure 2.2 and the characteristics of ester oil are shown in Table 2.2.

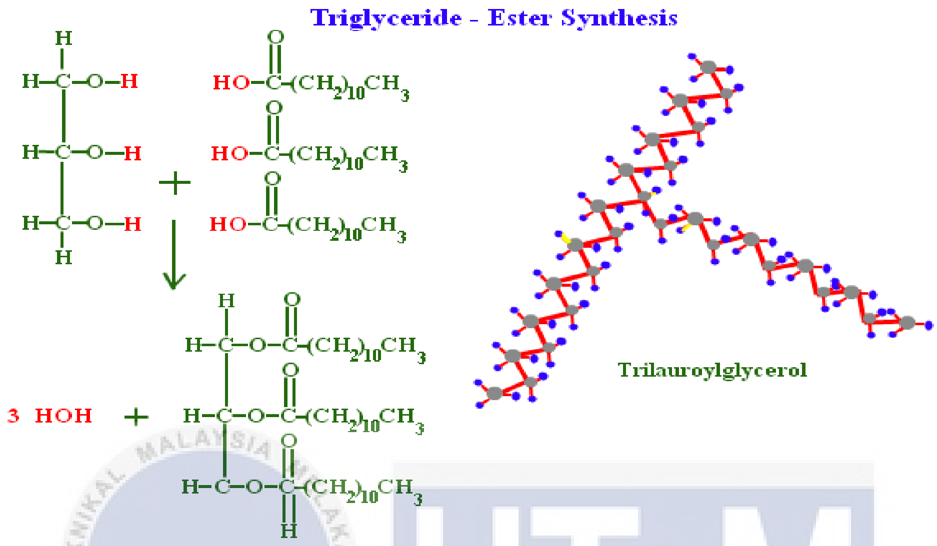

Figure 2.2: Molecular structure of ester oil

Table 2.2: Characteristic of ester oil [5].

Properties	Natural ester	Synthetic ester
Density at 20°C (kg/dm^3)	0.92	0.97
Kinematic viscosity at 20 ^{o}C (mm^2/s)	84.8	70
Pour point (^{o}C)	-31	-60
Flash point to ISO 2719 (^{o}C)	327	260
Fire Point to ISO 2592 (^{o}C)	360	316
Permittivity at 20°C	3.1	3.2
Breakdown voltage (kV)	>75	>75

2.3 Application of Oil inside Transformer

The insulation liquid inside the transformer is very important to make sure it can operate efficiently and also long lasting. The major cause of transformer failure is due to degradation of its insulation. In general, the main purposes of the transformer oil are electrical insulation and heat dissipation. In addition, it can also be used for diagnostic purpose [8]. Figure 2.4 shows the use of insulating oil in transformer.

2.3.1 Electrical Insulation

The function of liquid inside the transformer is to provide dielectric medium which acting as insulation that surrounding around the energize conductor. Besides that, this insulating liquid also gives protection by coating the metal surface to make it against chemical reaction such as oxidation process [9].

2.3.2 Heat Dissipation

The insulating liquid makes the heat that produced from the power transformer dissipated. Transformer oil removes the heat from an area and distributes the thermal energy equally from the process of convection, conduction and radiation. This can make transformer to keep cool and do not cause overheated that can short the lifespan of the power transformer [9].

2.3.3 Diagnostic Purpose

The extra function regarding the insulation liquid is that it can also be used to determine the condition of transformer operation based on its chemical and electrical effect on the liquid filled transformer. The energy will be dissipated through the liquid by chemical degradation when fault is occurs. With this chemical degradation data, the analysis can be carried out to determine the type of fault that occurs at the transformer. Example of diagnosis through insulation oil is as shown in Table 2.3

Table 2.3: Example of diagnostic purpose by using insulation oil transformer [10]

System components	Defect	Detection Through Oil	Faults	Detection Through Oil
Dielectric	Excessive water	Yes	Destructive PD	Yes
Major insulation	Oil contamination	Yes	Localized tracking	No
Minor insulation	Surface contamination	No	Creeping discharge	Yes
Leads	Abnormal aged oil	Yes	Heated cellulose	Yes
	Cellulose aging	Yes	Flashover	Yes
	Static electrification	Yes		
	PD of low energy	Yes		
Magnetic Circuit	Loosening clamping	No	Localized hot spot	Yes
Core insulation	Short/open circuit in grounding circuit	Yes	Sparking/discharges	Yes
Clamping	Circulating current	Yes	gassing	Yes
Magnetic shield	Floating potential	Yes		
Grounding circuit	Aging lamination	No		
Mechanical	Loosening clamping	No	Winding distortion	No
Windings			Radial	
Clamping			Axial	
Leads support			Twisting	
			Insulation failure	Yes
Electric circuit	Poor joint	Yes	Localized hot spot	Yes
Leads	Poor contacts	Yes	Open-circuit	No
Windings conductors	Contact deterioration	Yes	Short-circuit	Yes

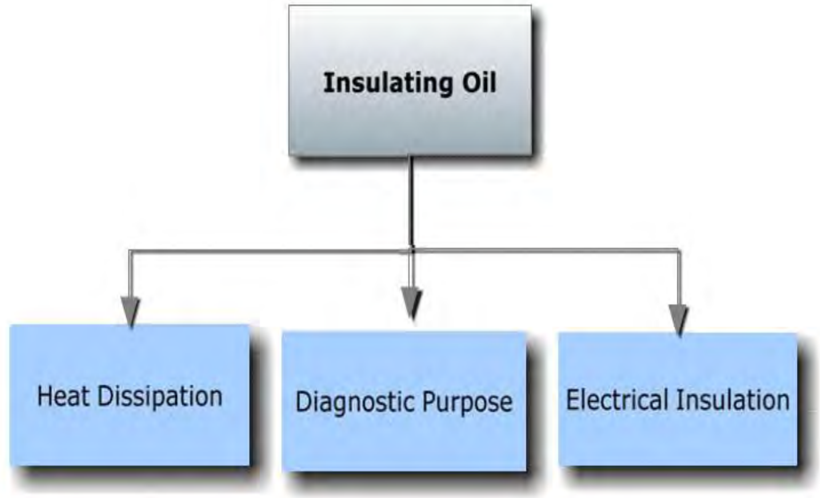

Figure 2.3: Classification of insulating oil [8]

2.4 Effect of Moisture towards the Breakdown Voltage (BdV) in Insulation Oils

Good transformer oil must have the capability to withstand the breakdown voltage. If the transformer oil has high resistance to electrical breakdown, than that oil will be considered as good insulation oil in protecting the power transformer from failure due to breakdown voltage. The effect of the moisture inside the transformer oil can decrease its resistance in order to protect from the breakdown. This project focuses on the effect of moisture inside the ester oil in order to withstand the breakdown voltage that is caused by the water inside the oil. From the previous study, the researcher found that the ester oil have more capability to endure the breakdown voltage compared to the mineral oil. This is because the ester oil has greater resistance even in high moisture conditions than mineral oil. They found that those fatty acid esters are strongly trapped by the ester group. This condition make the ester have great resistance to the breakdown voltage compare to the mineral oil. In their research, they also found that the water had triggered the breakdown of the fatty acid ester. Although the number of water molecules is extremely smaller compared to the ester molecules, but it still contribute to the breakdown voltage of fatty acid ester. The reason of small water can contribute to the breakdown in fatty acid ester is because the effect of water molecules movement surrounding fatty acid molecule [11]. For the synthetic oil such as MIDEL 7131, the saturation point limit is far higher than mineral oils which the saturation is hard to occur. It is worthwhile noting that based on ASTM D

1816 standard, the allowable moisture content in an ester is must less than 400 ppm whereas for the mineral oil, the moisture content which above than 30 ppm is out form the specification. The ability in absorbing the free water molecule that possess by synthetic ester oil more than mineral oil can affect its capability in terms of breakdown strength when enduring electric stress in different level of humidity environment [12].

It is also known that moisture can deliver the charge. This can decrease the dielectric withstand strength. The previous research has proved that when increasing the moisture saturation level from 0% to 20%, the breakdown voltage for a new mineral oil decrease from 72kV to 61 kV [13]. Figure 2.4 shows the breakdown voltage versus moisture content for different insulation oils. From the graph, we can see that the breakdown voltage for ester oil is much higher than the mineral oil although at high moisture content. In the graph also shows that the synthetic ester can withstand the higher breakdown voltage at higher moisture content compared to the natural ester oil.

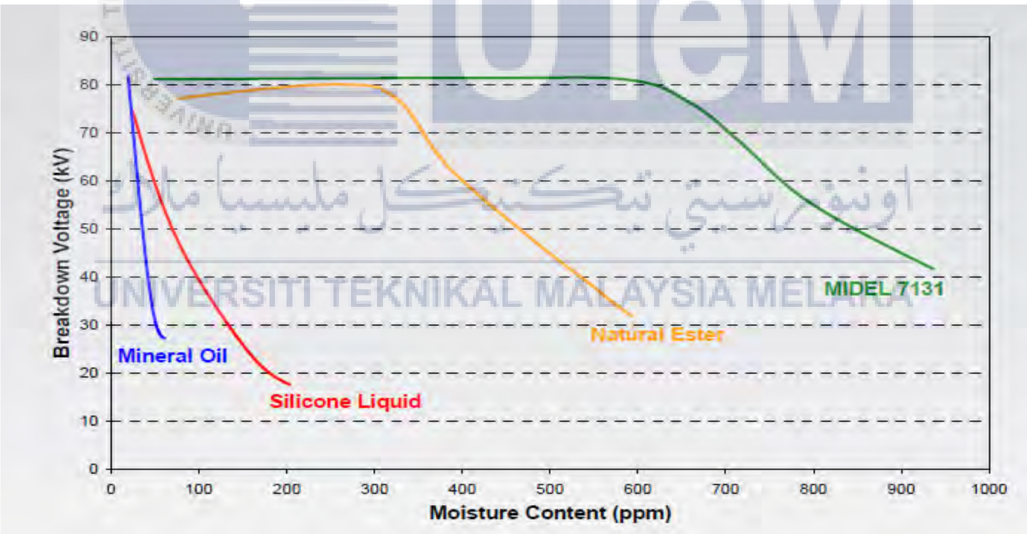

Figure 2.4: Graph for breakdown voltage versus moisture content for different insulation oils [12]

2.5 Standard for Breakdown Test

All the breakdown voltage measurement test for the insulation oil must be comply with the appropriate standard in order to ensure validity of the data that been measured. Figure 2.5 shows the standard for breakdown voltage that can be used for testing the insulation oils. For the ASTM D 877, the minimum of breakdown voltage for this standard is 30kV for new oil. In the ASTM D 877 standard the new mineral oil is 45 kV whereas for synthetic ester is 43 kV. For the ASTM D 1816, the breakdown voltage for 1 mm gap must higher than 20 kV for new oils and for the gap of 2 mm; the breakdown must exceed more than 35 kV. For the IEC 60156 standard, the breakdown voltage for new oils is 60 kV or higher to make it specified the requirement of the new oil breakdown voltage [14].

Standards		ASTM D1816	ASTM D 877		IEC 60156
			Procedure A	Procedure B	
Origin		USA	USA	USA	Europe
Electrodes	Shape				
	Gap size	2 mm or 1 mm*	2.54 mm	2.54 mm	2.5 mm
Oil sample stirring	Impeller	yes	not stirred	not stirred	optional
	Magnetic bead	no option			optional
Laboratory test temperature	Liquid	At ambient - must record	20 - 30 °C must record temperature as collected and when tested	20 - 30 °C must record temperature as collected and when tested	15 - 25 °C for referee tests
	Ambient	20 - 30 °C	Must record	Must record	Within 5 °C of oil sample
Outside test temperature	Liquid	At ambient - must record	Must record	Must record	15 - 25 °C
	Ambient	Referee tests 20 - 30 °C	Must record	Must record	Within 5 °C of oil sample
Test voltage	Rise rate	0.5 kV/s	3 kV/s	3 kV/s	2 kV/s
	Frequency	45 - 65	45 - 65	45 - 65	45 - 62
Breakdowns	Definition	<100 V	<100 V	<100 V	4 mA for 5 ms
	Number in sequence	5**	5*	1 - 5 different samples	6
	Time between breakdown	1 to 1.5 min	1 min	n/a	2 min
Test voltage switch off time following break-down	Normal (e.g. mineral oil)	Not specified	Not specified	Not specified	<10 ms
	Silicon oil	Not specified	Not specified	Not specified	<1 ms

Figure 2.5: Standard for breakdown voltage test [14]

2.6 Detecting Moisture in Oil by Using Karl Fischer Titration (KFT).

Karl Fisher is one of the tools that been used in detecting moisture inside the substance. In this project, it will be used in detecting the moisture that contain inside the mineral and ester oil. This device has highest reliability and had been used in analytic laboratories around the world. The standard that been used is BS6470 to determine the water inside the insulation oil and also for impregnated paper. Karl Fischer titration can utilize the quantitative reaction of water with iodine and sulfur dioxide in the presence of a lower alcohol such as methanol and an organic base such as pyridine [15]. The mass of water can be determined from the amount of reagent that reacts with it. There will have some factor that can make the analyses of Karl Fischer affected which is during the sampling, transportation and preparation of the sample, the moisture is always ingress inside the sample from atmosphere. This process always happens when sampling the paper from open transformer. [16]

The coulometric Karl Fischer titration is more accurate in determination for lower water level even though the volumetric KF titration also can measure it but not so accurate compared to coulometric. The coulometric technique should be considered for water content of 500 ppm or less. For the application of the Karl Fisher titration, it can be divided into two sections that are applications on organic compound and inorganic compounds. [17]. In determining the value of water content in ml for certain amount of ppm, the equation (1) can be used [15]. Figure 2.8 shows the configuration of the Karl Fisher Titration.

$$\frac{ml}{l} = \frac{(0.001\,x\,water\,(ppm)\,x\,volume\,(l)}{1l\,x\,volume\,(l)} \qquad (1)$$

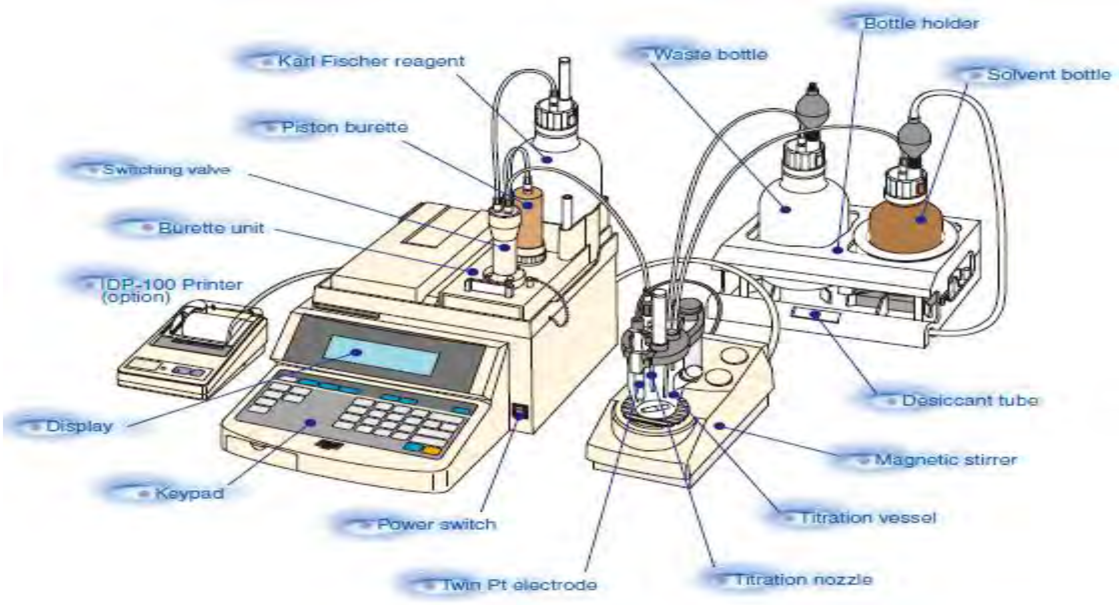

Figure 2.6: Configuration of Karl Fisher Titration

2.7 Moisture Removal Methods for Insulation Oil

Moisture is one of the degradation factors that can affect the performance of insulating oil. If the higher amount of moisture contains inside the insulation oil, then the lower the dielectric strength of the oil to resist the high voltage that applied on it. Generally, mineral oil is used inside the power transformer, but the characteristic of mineral oil which is not good when it is exposed with high humidity condition. This is because mineral oil is relatively fast in absorbing the moisture and also it is easily saturated. Meanwhile for the synthetic ester oil has great ability in absorbing more moisture and its saturated level is higher than mineral oil. That is the factor that cause the synthetic ester can endure more moisture compared to mineral oil and even the moisture contents is higher, but the breakdown voltage still comparable in dielectric strength with the mineral oil [18]. But it must be kept in mind that moisture must be reduced in order to make sure the insulating oil can perform in good manner and operate in maximum capability to protect the transformer from damage and also to provide protection to the winding and cooling the transformer from excessive heat. The study of this technique is to remove the moisture contents from the insulation oil and reduce it to the minimum value.

From the previous researcher, there are three ways to remove the moisture from insulation oil which is by using vacuum technique, air ventilation technique and also by using nitrogen gas technique.

From the previous research, oil samples that need to remove its moisture by using vacuum method is degassed and also dried individually for the pressure that been applied must be less than 1kPa. The time taken for that process is 2 days and the temperature is set at 80^0C. After the time is elapsed, it must give further day to cool down the oil in ambient temperature on vacuum condition [7]. Table 2.4 shows the water content after undergo vacuum treatment method.

For air ventilation technique, the oil samples are heated for 105^0C by using air ventilated oven. During that process, the air is circulating inside the oven during the moisture removal process. The time taken for the process is 24 hours in order to remove the moisture from the samples [19].

Another choice in order to remove the moisture is by using nitrogen gas. In this technique, the dried nitrogen gas is applied to the sample which is sealed for at least 1 hour and that dried nitrogen gas will bubble the oil sample until the time is elapsed [20].

All of these three methods are commonly used in order to reduce the moisture contents from the sample before doing the testing. It is because the moisture can degrading the samples and actual capability of the material or samples that been tested will be not accurate when testing its dielectric strength. In terms of performance, it is unclear to decide because base on the finding it is hardly to compare the performance for those method. So by doing this research will give some information in order to determine the performance of those treatment.

Table 2.4: Moisture content after vacuum treatment inside different type of oil [21]

Type of Oil	Water content (ppm)
Mineral	9
Synthetic Ester	59
Natural Ester	35

2.8 Summary of Review

This chapter is about to highlight the reviewed of the previous research and finding which can be used to guide in this study. This study is about to analyze the different methods of moisture removal treatment on ester oil and the effect of its breakdown measurement for different moisture levels. The theory from the previous research and founding that related with this study has been mention and cited in this section

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology that been used in this project. The methodology covers the preparation of sample as well as breakdown voltage measurement and also methods in removing the moisture inside the ester oil.

3.2 Preparations of Insulation Oil for Experimental Purpose

The insulation oil that has been used in this experiment is synthetic ester oil which is also known as MIDEL 7131. The oil sample is taken from the drum in the lab and been undergone different moisture removal methods. Each of the samples is prepared at 500 ml. The water is added from 0.1 ml to 0.3 ml which is having incremental of 0.1 ml for each samples. The purpose of varying the moisture content is to investigate its effect towards the breakdown voltage. The water that been used for this experiment is distill water. The use of distill water is because it has less impurities compared to the tap water which contains inorganic, mineral and metal. For the breakdown voltage of the synthetic ester oil sample, it is conducted 5 times and for each single time has 5 tests which the total amount of test is 25. The average data from the breakdown voltage is determined for each sample.

The method to insert the moisture inside the oil is by using syringe. The moisture that been inserted inside the oil is stirred for at least 1 hour depending on the volume of moisture been added inside the samples. The time taken is longer for stirring process when increasing the amount of water because to make sure the moisture can be spread inside the ester oil evenly. The Karl Fischer titration is been used in measuring the moisture content inside the oil. The moisture contents is measured in unit parts per million (ppm). This technique is implemented before adding the moisture and also after moisture is been added inside the oil samples. After all the procedure is done, the sample is ready to be used for breakdown voltage measurement.

Figure 3.1: Synthetic ester oil from drum

Figure 3.2: Process of stirring the oil sample by using magnetic stirrer

3.3 Breakdown Measurement

Synthetic ester oil samples is undergone the breakdown voltage test using portable oil test set OTS60PB (Megger). The ASTM D 1816 standard is being used for the breakdown test and each of the samples was tested five times per-set for that oil by following the standard guideline. All measurement is conducted in room temperature and the gap of electrode that been used is 1 mm^2 for all the breakdown measurement. The types of electrode for this breakdown experiment are brass mushroom capped. Before conducting the breakdown voltage measurement, it is very important to clean up all the electrode and component that will be immersed inside the tested oil. It is because any contaminant that attach at the electrode sphere gap can affected the breakdown of the insulating oil that been tested and this can make the result become lower than actual dielectric strength of the oil. The breakdown beaker also needs to be cleaned up and if that beaker is containing moisture, it must be dry it first from any moisture. When all the apparatus is completely prepared and in good condition, then the breakdown voltage of the insulation oil can be proceed. The values of the breakdown voltage is been recorded for each of breakdown measurement of the oil samples. All the data for breakdown measurement is tabulated to make sure it is clear in making the comparison for each breakdown tested for those samples and the graph of the data will show the changing of the breakdown for each sample that being tested. During the breakdown measurement, the room temperature and humidity of the surrounding is recorded because high humidity of surrounding workstation can affect the breakdown strength of insulating oil.

Figure 3.3: Megger breakdown voltage OTS 60PB

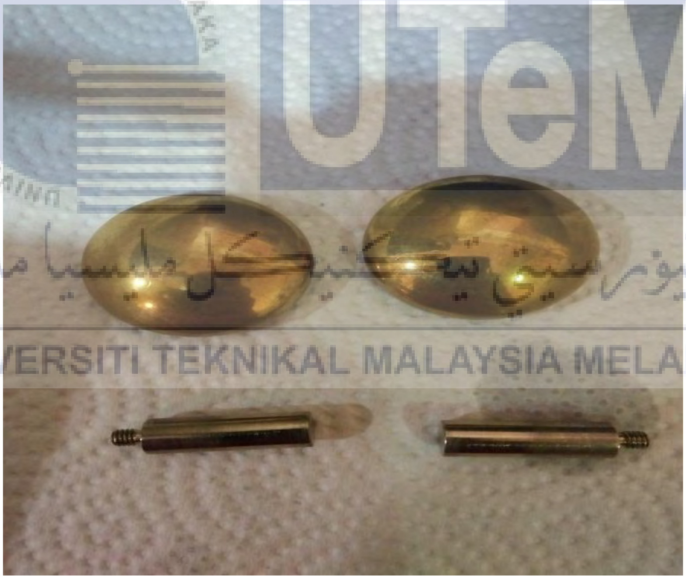

Figure 3.4: Brass mushroom capped electrode

3.4 Karl Fisher Measurement

Karl Fisher measurement is used to determine the amount of water content inside the oil samples and for this experiment this tool is used to test insulation oil that is ester synthetic oil. This method is very useful because the water contents inside the oil can influence the characteristic of the insulation oil and hence makes the breakdown become faster than the actual capability of that oil. In this experiment, Karl Fisher Coulometric is been used. The oil that been taken from the tank is tested for its water content to make sure that the range of water content is not exceed from the specification. For this experiment, ester synthetic oil is been used and the range of the moisture content that been allowed must below than 400 ppm.

In order to put the testing sample into the Karl Fisher Coulometric container which contain reagent, the small amount of synthetic ester oil which need for testing purpose need to be put inside the Karl Fisher reagent and the process of inserting the sample must follow the procedure correctly. In this case, it needs to use syringe. The use of syringe is very important because it is only the tool that safely and recommended in transferring the sample in order to measure the water content inside insulation liquid. The unit of measurement is in parts per-million (ppm) and it is appropriate to measure three times per sample to get accurate value and each oil that been injected inside the reagent is 1 ml. Before injecting the samples into the reagent, it is very important to make sure that the reagent is ready that is below than 20 µg/min. Each time before injecting the samples inside the reagent, it must to measure its oil sample weight. The weight of the oil sample is very important in order to determine the moisture content inside it. After a few minutes, Karl Fisher Coulometric device undergoes the analysis process and after completing the analyzing, it will show the amount of moisture contents in parts per-million. The higher the moisture contents, the longer it will take to appear the results.

Figure 3.5: Karl Fisher Coulometric device

3.5 Removing the Moisture for the Synthetic Ester Oil

For the ester synthetic oil that been used in this experiment is undergoing the process of removing moisture. There is certain of technique in order to make sure that moisture can be removed. This is because that synthetic ester oil that been used is having moisture that exceed the appropriate value and it is necessary to remove the moisture inside the oil to make sure that the synthetic ester oil that will be tested is in range of standard specification. The method that been used for this experiment is by using nitrogen gas, vacuum technique and also air ventilation technique. Each sample that has been prepared is in the quantity of 500ml. For each technique, it has 4 samples that are with none moisture added, 0.1 ml, 0.2 ml and 0.3 ml moisture added inside the synthetic ester oil. The reason for vary the moisture added is because to measure the effect of the different moisture level towards its breakdown measurement and also to determine which moisture removal technique have most higher breakdown voltage.

3.5.1 Nitrogen Gas Technique

In this technique the nitrogen gas is being used to remove the moisture inside the oil. First of all, the synthetic ester oil is taken from the drum. The amount of ester oil that been taken is 500 ml and been measured by using beaker. This beaker that contains 500 ml is heated for until the temperature achieved at the 70 ^{0}C. Then after the time is elapse, that oil is poured into the conical flask. This conical flask is special and used for nitrogen gas purposed only. This conical flask that contains synthetic ester oil is closed tightly and the nitrogen gas is allowed to flow inside the oil for at least 1 hour. The hose that carry the nitrogen gas must be soaked inside the oil and this reaction will cause bubble gas containing air and water to escape from the hole on that flask. After the process is done, then that oil is stored inside the amber bottle to avoid the moisture from the environment from entering the oil which can damage the sample. This sample is tested its moisture content by using Karl Fisher Coulumetric to see the changes of its water contents value.

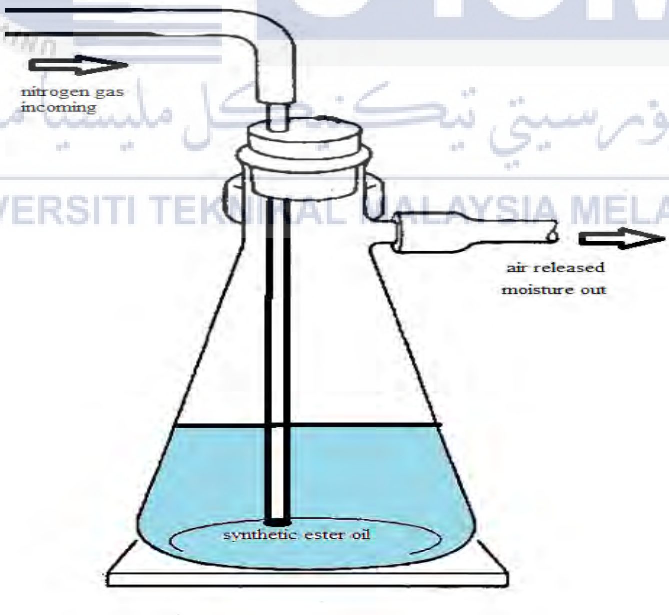

Figure 3.6: Process of removing moisture by using nitrogen gas

3.5.2 Vacuum Technique

In this technique that is by using the vacuum, the oil taken from the drum is degassed using vacuum oven. The quantity of synthetic ester oil that has been prepared is 500 ml for each sample. There are 4 samples is prepared for this vacuum technique. In this experiment, first of all after all the samples had been put inside the vacuum oven, temperature is set at 80^{0}C. Then when the set temperature is achieved, the vacuum process is begun by starting the motor to suck the air inside the vacuum oven until the pressure less than 1kPa [7]. When the pressure is achieved, then turn off the motor and let the oil inside the vacuum in that condition for 48 hour. Then those samples is taken out when the 48 hours' time is elapsed and put it inside the amber bottle and closed tightly to make sure that there will be no surrounding air entering inside the sample. The surrounding air with high humidity can affect the properties of the samples if not securely closed. Then those samples can be used to test its moisture contents by using Karl Fisher Coulometric device.

Figure 3.7: Process of removing moisture using vacuum oven

3.5.3 Air Ventilation Technique

For this technique, those samples had been put into air ventilated oven. Then the air ventilated oven is set its temperature at 105 ^{0}C and being put for 24 hours. This process is to make sure that the moisture inside the oil can be removed and improved its ratio of water inside the oil in parts per-million (ppm). After the process is done, then the sample is taken out from the air ventilated oven and properly stored inside the amber bottle tightly closed to avoid any moisture from surrounding environment from entering inside those samples. Before stored inside the bottle, the oil is been tested its moisture content by using Karl Fisher Coulometric device.

Figure 3.8: Process of removing moisture by using air ventilation oven

3.6 Inserting the Moisture inside the Oil Samples

The method of inserting the moisture inside the oil is by using syringe and also stirrer. The magnetic stirrer is set to rotate at 700 rpm and the heater rod is set to heat the oil during stirring process at 50^{0}C. The amount of time that been used for 0.1ml of moisture added inside the oil is about 1 hour and when the amount of moisture is increased, then the time taken for stirrer process is also increased. The beaker that used for stirring the oil is sealed with the plastic wrapper to avoid any moisture from surrounding environment entering the oil during stirrer process is being carried out. The oil samples that been taken from the amber bottle which been stored the synthetic ester oil samples from different techniques (vacuum, air ventilated and nitrogen gas) is been undergone this process. That oil is poured into the 500 ml beaker and then the moisture is inserted by using syringe. The amount of moisture that been added is varied (0.1 ml, 0.2 ml, and 0.3 ml) for each samples for different method of moisture removal that been done earlier. The purpose of stirring process is to make sure that the moisture that been added inside the oil is properly dissolve and absorb inside the oil without any bubble of water in order to make sure the result when testing the moisture contents by using Karl Fisher Coulometric device is accurate. After all this process is finish for every sample that need to be added of the moisture contents then the preparation of sampling process is finish and the breakdown voltage can be carried out to test the effect of breakdown measurement when increasing the moisture level from those different moisture removal method.

3.7 Data Analysis

Data analysis is been conducted after all the measurement is completed. The data measurement that been gathered is breakdown voltage measurement and also the moisture content of the synthetic ester oil for different moisture removal treatment. From the gathered data by the experiment that been conducted, it's been tabulated properly and then transform all the data into graphical for better analyzing and comparison. From the graph that been created, the statistical analysis can be carried out which is by looking into the distribution of the breakdown data for different level of moisture towards different moisture removal technique, the minimum and maximum value and also its standard deviation from the specific data that been measured. From this experiment, the correlation study that can be perform is breakdown voltage with different moisture level and also effect of moisture added (ml) towards moisture content inside the synthetic ester oil (ppm).

3.8 Flow of the Project

This section summarizes the flow of the methodology for this project. The flowchart is shown in Figure 3.9.

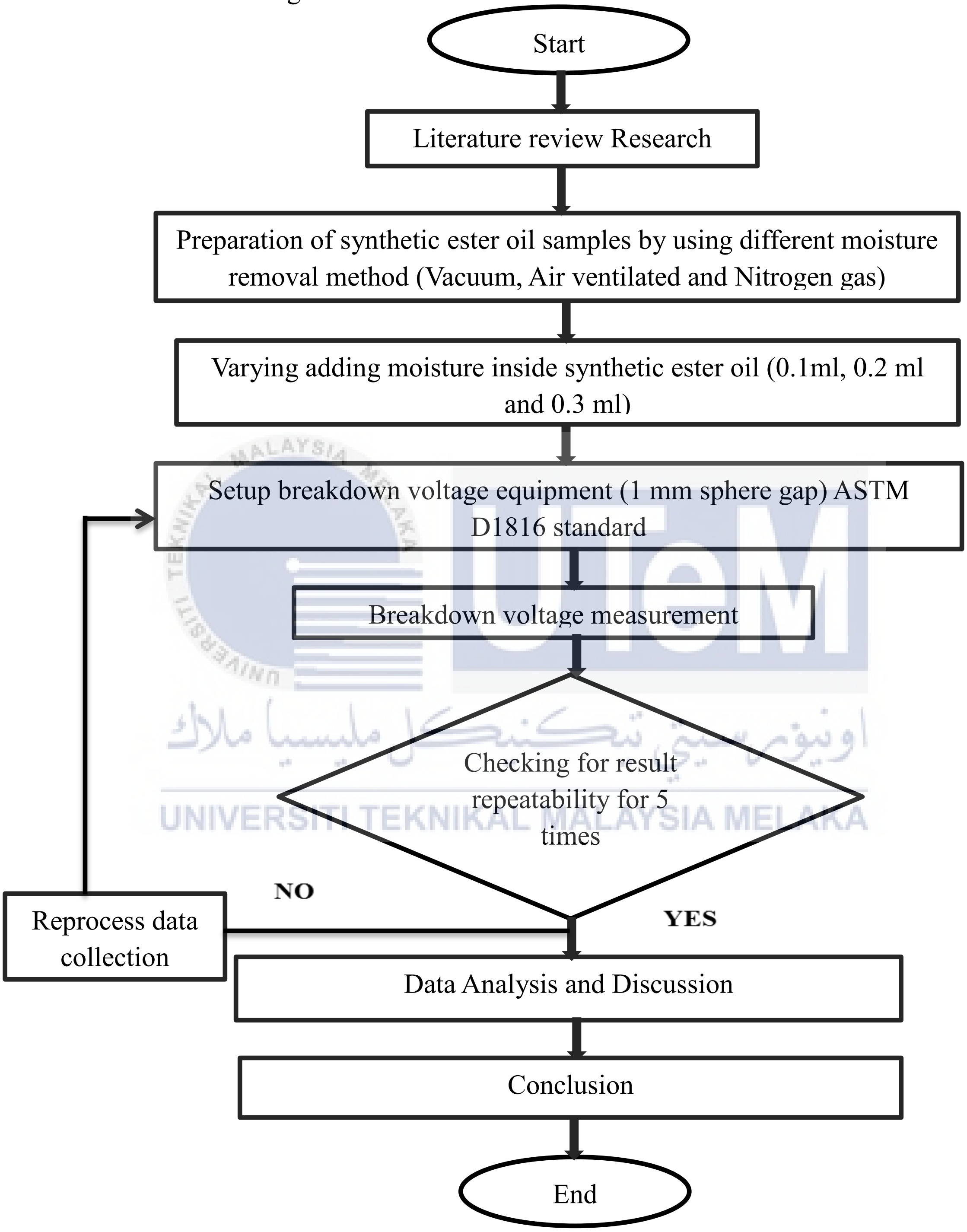

Figure 3.9: Flowchart of the project

3.9 Summary of the Methodology

In this section is discuss about the method that been used and also the preparation of the sample to make the experiment that been studied that is analyzing the different methods of moisture removal treatment on ester oil and the effect of its breakdown measurement for different moisture levels. All of this experiment is done in High Voltage UTeM laboratory which have complete test set in order to carry out the experiment. All the experimental procedure such as preparing the sample for moisture removal and method to adding the moisture inside the ester oil is followed from the previous research and also by referring the appropriate standard. For the testing insulation oil for breakdown test is by following ASTM D 1816.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discusses the result and also analysis of the project. In this chapter, it contains information regarding the research of analyzing the different method of moisture removal for synthetic ester oil and also analyzing the effect of different moisture levels on breakdown measurement.

4.2 Analysis of Moisture Removal Treatment Methods and Effect of Adding Moisture to Moisture Content Measurement

The moisture contents inside the ester oil can influence its dielectric strength as insulation oil. Even though synthetic ester oil has higher capability in absorbing the moisture compared to the well-known transformer oil that is mineral oil but when it achieve its saturation limits, then it can cause the reduction of the dielectric strength. In this experiment, the three method of moisture removal treatment is used in order to improve the quality of the ester oil. This is to make sure the synthetic ester oil can be minimized its moisture contents before prepared it as testing samples. Those samples need to go through this process that is because the synthetic ester oil that been taken from the drum have its moisture contents out from specification range that is more than 400 ppm after being tested by using Karl Fisher Coulometic device. Those three methods are used to compare which one of the technique can remove moisture more efficiently. According to the data that been gathered, the synthetic ester oil that undergo the nitrogen gas treatment have the lowest moisture contents compared to air ventilation and vacuum method. The nitrogen gas treatment gives the moisture contents inside the oil which is originally from 475.9 ppm to become 161.333 ppm compared to air ventilation which only reduce to 387.233 ppm and for the vacuum method gives 801.467 ppm. When the moisture is added to 0.1 ml, the value in synthetic ester oil which is for nitrogen gas, air ventilation and vacuum method is increasing drastically to 695.433, 766.133 and 1116.167 ppm respectively. Then the next sample is increasing the moisture level up to 0.2 ml and its shows that for nitrogen gas method, the value is increasing only by 108.667 ppm to become 804.1 ppm. For air ventilation, it only increased by 70.034 ppm to become 863.167 ppm whereas for vacuum method, it increased to 1355.633 ppm. From the Figure 4.1, it shows the graph of moisture contents is increasing significantly when the moisture is increasing by another 0.1 ml to the nitrogen gas, air ventilation and vacuum treatment of synthetic oil. In this observation, it seems that the vacuum treatment has highest number of moisture contents compared to nitrogen and air ventilation method.

The vacuum method for synthetic oil samples is considering defect in this experiment because it is not reducing the water content inside the oil after the treatment, but it increasing the water inside it. The problem of this causes is still unclear about the increasing of the moisture in this method but it is suspected that this things happen maybe because of during the preparation samples, the amber bottles that been used is not properly dry inside it and it contains some moisture during storing the samples. Table 4.1 shows the moisture contents inside the synthetic ester oil for different moisture levels. The Figure 4.1 shows clearly the trend of the moisture contents in parts per-millions (ppm). The highest moisture content is on the vacuum technique whereas for the lowest moisture content is in nitrogen gas technique. The air ventilation technique is almost same its moisture content with nitrogen gas method when the moisture added is 0.2 ml until 0.3 ml. From the Figure 4.1 it is clearly shows that when the moisture is increasing, the ratio of moisture contents towards synthetic ester oil is also increased and this can give the impact to the performance of the synthetic ester oil of its dielectric strength.

Table 4.1: Result for Different Moisture Levels towards the Moisture Contents inside the Synthetic Ester Oil from the Different Moisture Treatment Method

Moisture level (ml)	Vacuum oven (ppm)	Air ventilation (ppm)	Nitrogen gas (ppm)
0	801.467	387.233	161.333
0.1	1116.167	766.133	695.433
0.2	1355.633	863.167	804.1
0.3	1876.367	1361.033	1214.767

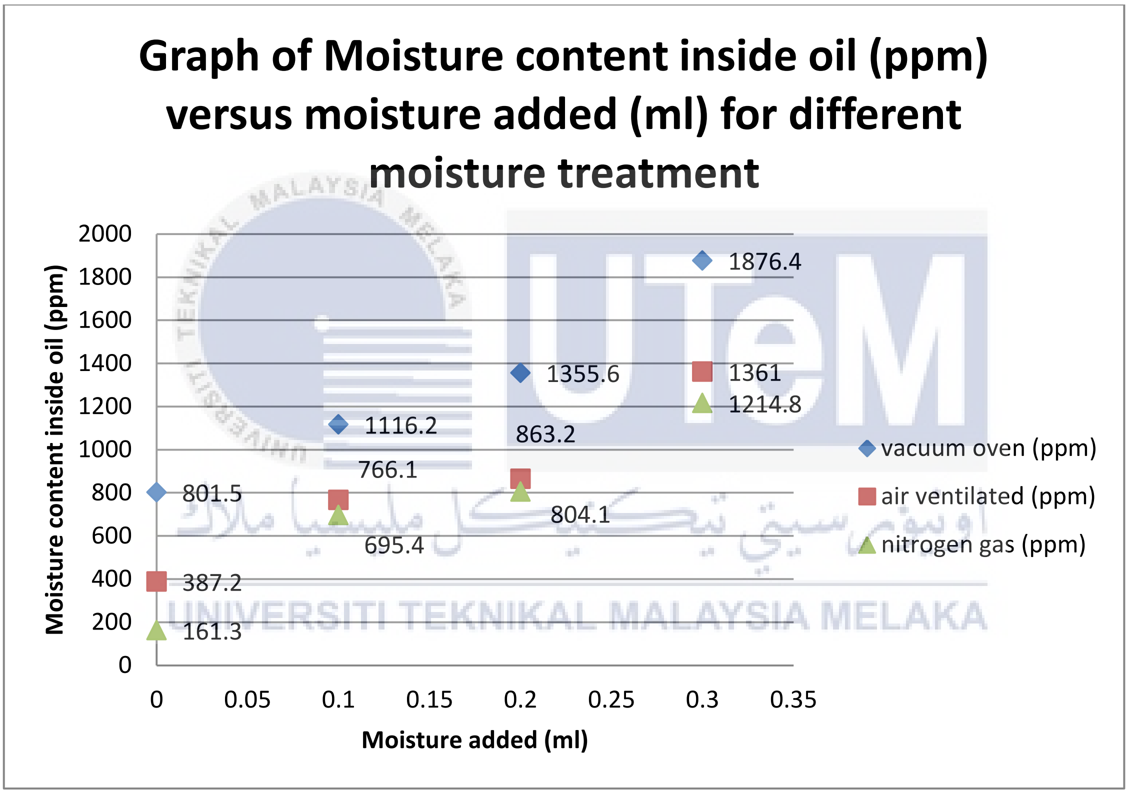

Figure 4.1: Distribution of synthetic ester data for different moisture levels towards moisture contents from different moisture treatment method

4.3 Effect of Adding Moisture to Breakdown Voltage

Moisture is generally can exist in surrounding environment and transformer cannot be avoided from exposed with the condition of high humidity and different levels of moisture when operating at the outdoor area. The moisture surrounding can give the impact of the dielectric intensity of the insulation oil which used to protect the transformer for cooling purposed and from breakdown. In this section, it have been divided to 5 sub-section which will discussed the breakdown voltage data that been gathered from the experiment. For the sub-section of 4.3.1, 4.3.2, 4.3.3 and 4.3.4 is discussing the result of different moisture level towards the breakdown voltage measurement in different moisture removal techniques and 4.3.5 is the analyzing average result for breakdown voltage of the experiment.

4.3.1 Analyzing of Breakdown Voltage Effect without Adding Moisture

Figure 4.2 below shows the distribution graph for breakdown voltage in condition of without moisture added inside the synthetic ester oil for different moisture removal method. From the graph, it shows that by using nitrogen gas, the graph shows obviously high value of breakdown voltage compared to vacuum and air ventilation technique. In nitrogen gas method, it shows that from overall 25 test that been carried out, only 1 test which have the breakdown voltage lower than 20 kV whereas on other 24 test, it shows the breakdown voltage is greater than 20 kV. The maximum of breakdown voltage that had been recorded from this experiment is 52kV whereas the minimum breakdown voltage is 19 kV. The average value for overall test is 43.28 kV and this value can be considered as good insulation oil because it is higher than 20 kV from the allowed specification which is referred ASTM D1816 standard for the 1 mm^2 gap. For the vacuum method which is by referring Figure 4.2, it shows on the distribution graph that this method have the breakdown voltage value within 20 kV. By referring Figure 4.3, the histogram shows that the breakdown voltage frequency is higher at 20 kV to 25 kV. The percentages that cover from overall 25 tests are 48%. The minimum voltage is 15 kV and the maximum is 30 kV whereas the average that been calculated is 21.68 kV.

For the air ventilation method which is by referring Figure 4.2, it shows that the breakdown voltage for synthetic ester oil is barely unstable. But from the overall 25 test, by referring the Figure 4.4, the histogram shows the breakdown voltage is mostly occur at 30 kV to 40 kV which its frequency is 10 out of 25 tests and this value is 40% from the overall test. The minimum breakdown voltage occurs is 16 kV and the maximum is 45 kV whereas the total average that been calculate is 33 kV based on Table 4.2. From the Figure 4.5, it shows the histogram of breakdown voltage frequency for the nitrogen gas method. In this histogram, the highest frequency that been recorded for nitrogen method is at 40 kV to 50 kV scale and its frequency is 17 out of 25 tests and this covers 68% of the overall test. According to the Table 4.2, the uses of nitrogen gas and air ventilation treatment is good in order to improve the breakdown strength whereas for the vacuum treatment is reducing the breakdown of the synthetic ester oil. In terms of the standard deviation it shows that the vacuum treatment breakdown voltage is smaller whereas for air ventilation and nitrogen gas is bigger. From the Figure 4.2, 4.3, 4.4 and 4.5 that been analyze, it shows that the nitrogen and air ventilation methods are comparable in its breakdown voltage strength whereas for the vacuum method, it has the lowest value compared from those two methods.

Table 4.2: The mean, min, max and standard deviation data of the different moisture removal treatment samples without moisture added

Type of Treatment	Mean (kV)	Min (kV)	Max (kV)	Standard Deviation
Vacuum	21.68	15	30	3.717
Air Ventilation	33	16	45	9.908
Nitrogen Gas	43.28	19	52	7.728

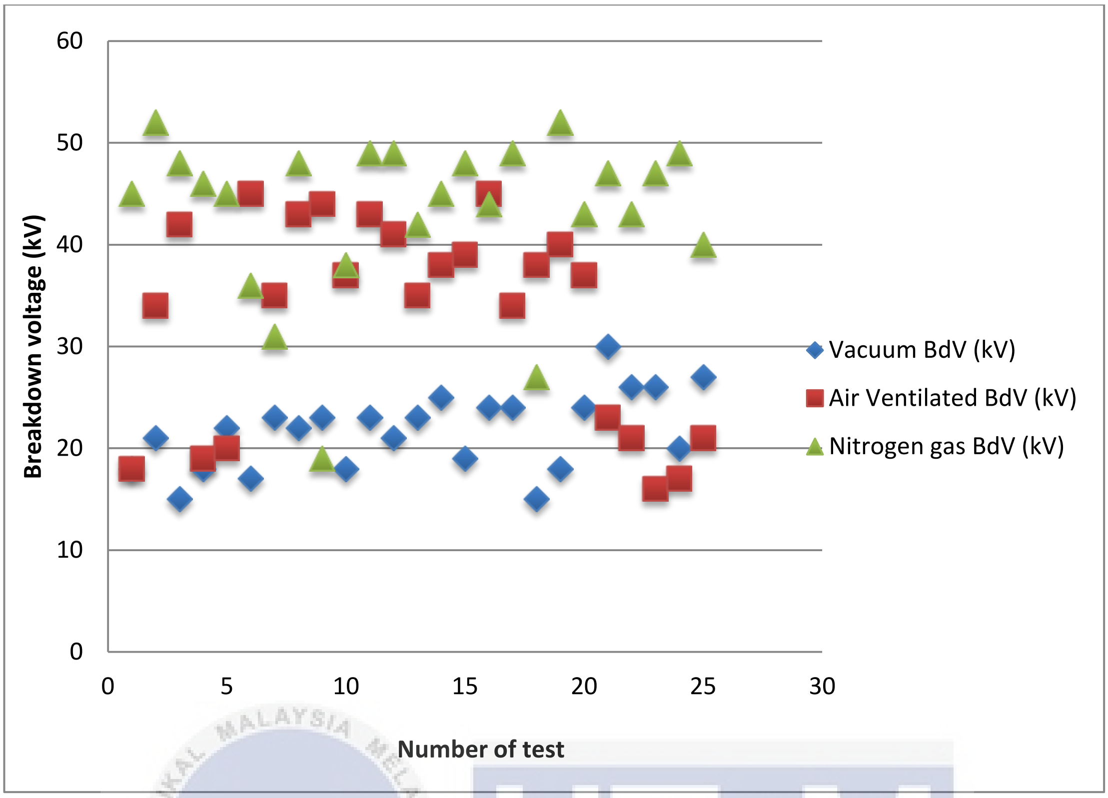

Figure 4.2: Distribution of synthetic ester breakdown voltage data without moisture added for different moisture removal method

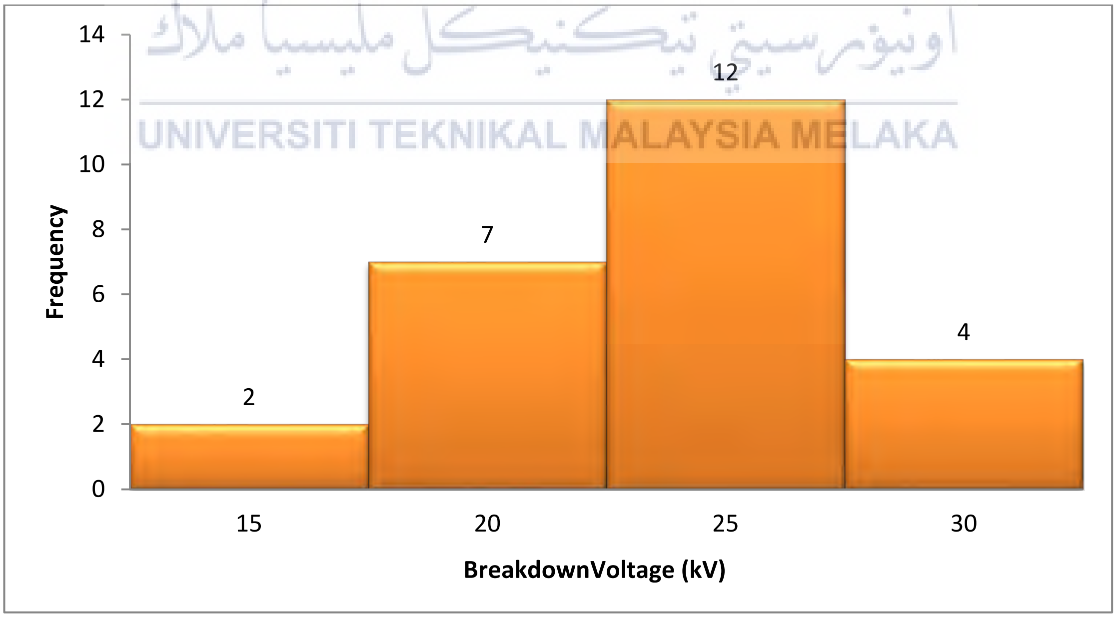

Figure 4.3: Probability density plot of synthetic ester breakdown voltages for vacuum method

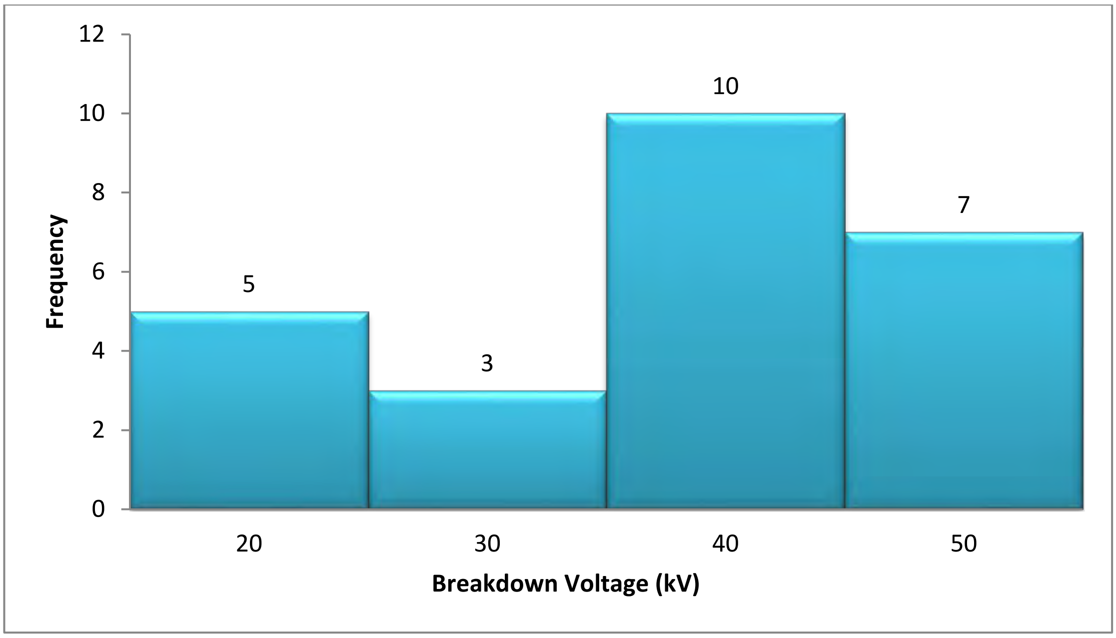

Figure 4.4: Probability density plot of synthetic ester breakdown voltages for air ventilation method

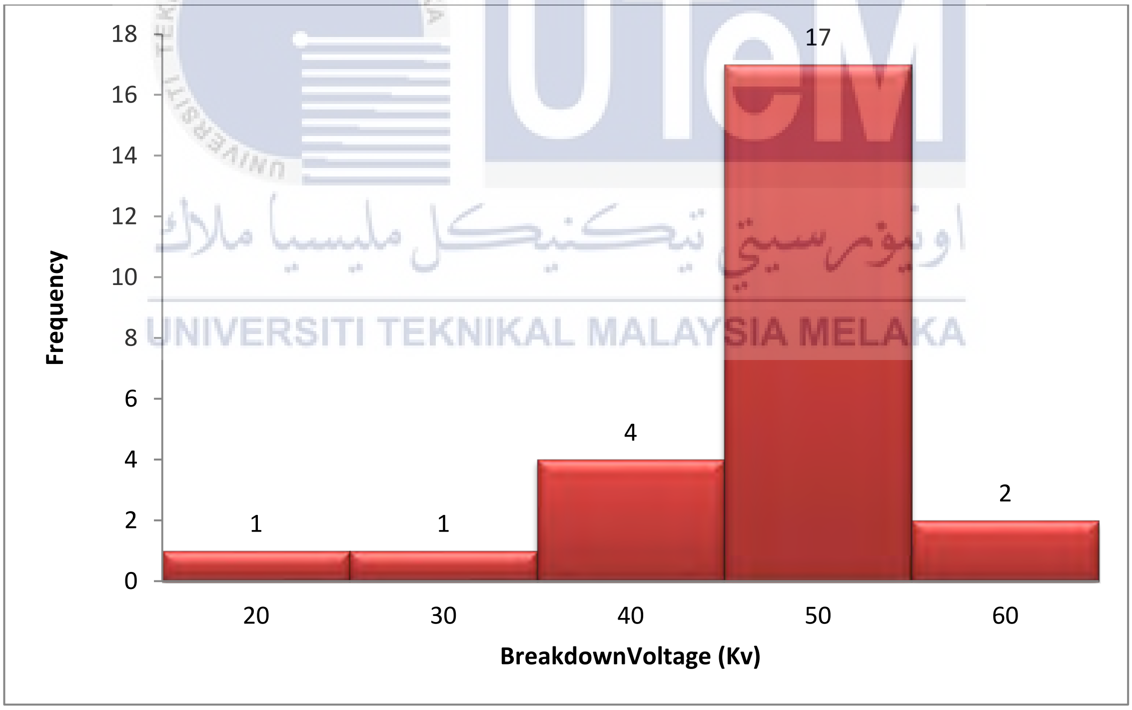

Figure 4.5: Probability density plot of synthetic ester breakdown voltages for nitrogen gas method

4.3.2 Analyzing of Breakdown Voltage Effect by Adding 0.1 ml Moisture

Figure 4.6 shows the distribution graph for breakdown voltage with moisture added 0.1 ml. In this graph, the synthetic ester oil which undergo vacuum treatment have its maximum breakdown voltage occur at 20 kV whereas for its minimum breakdown occur at 9 kV. In this graph, the breakdown voltage that had been carried out is 25 tests and from the 25 test, the maximum frequency is 13 out of 25 tests which are at the range of 10 kV to 15 kV. The second highest frequency is 11 out of 25 tests at range 15 kV to 20 kV which has been shown in Figure 4.7. From the observation, the data for the vacuum when the moisture is added 0.1 ml is more towards below 20 kV which is less than specification for the breakdown voltage to be used as insulation liquid. For air ventilation method, the distribution graph as shown in Figure 4.6 is more stable that is around 25 kV to 30 kV. The highest breakdown voltage that has been measured is 32 kV and whereas for minimum breakdown voltage that been recorded is 19 kV.

By referring the Figure 4.8, it shows that the maximum frequency is 15 out of 25 tests and the range is at 25 kV until 30 kV. By analyzing the data, it can be said that the condition of synthetic ester oil for the moisture 0.1 ml inside the oil is still can be acceptable to be used as insulation liquid because it is over than 20 kV from the allowed ASTM D 1816 specification. For the nitrogen gas method, the distribution data for breakdown voltage from the Figure 4.6 is concentrated at 25 kV to 30 kV that is same as air ventilation technique. The maximum breakdown voltage that been record from all 25 tests is 38 kV which is 6 kV higher than air ventilation method whereas he minimum breakdown voltage is 19 kV which is same value as air ventilation method. From the Figure 4.9, the frequency for that been observed from all 25 tested data is 14 and the range is from 25 kV to 30 kV. From the investigation, it is obviously can be said that the result of breakdown voltage by using air ventilation and nitrogen gas is almost same and still in specification when moisture added is 0.1 ml whereas for the vacuum treatment is out of specification which is its average is only 15.5 kV which is less than 20 kV.

Table 4.3: The mean, min, max and standard deviation data of the different moisture removal treatment samples for 0.1 ml moisture added

Type of Treatment	Mean (kV)	Min (kV)	Max (kV)	Standard Deviation
Vacuum	15.5	9	20	2.844
Air Ventilation	26.44	19	32	2.670
Nitrogen Gas	28.04	19	38	4.331

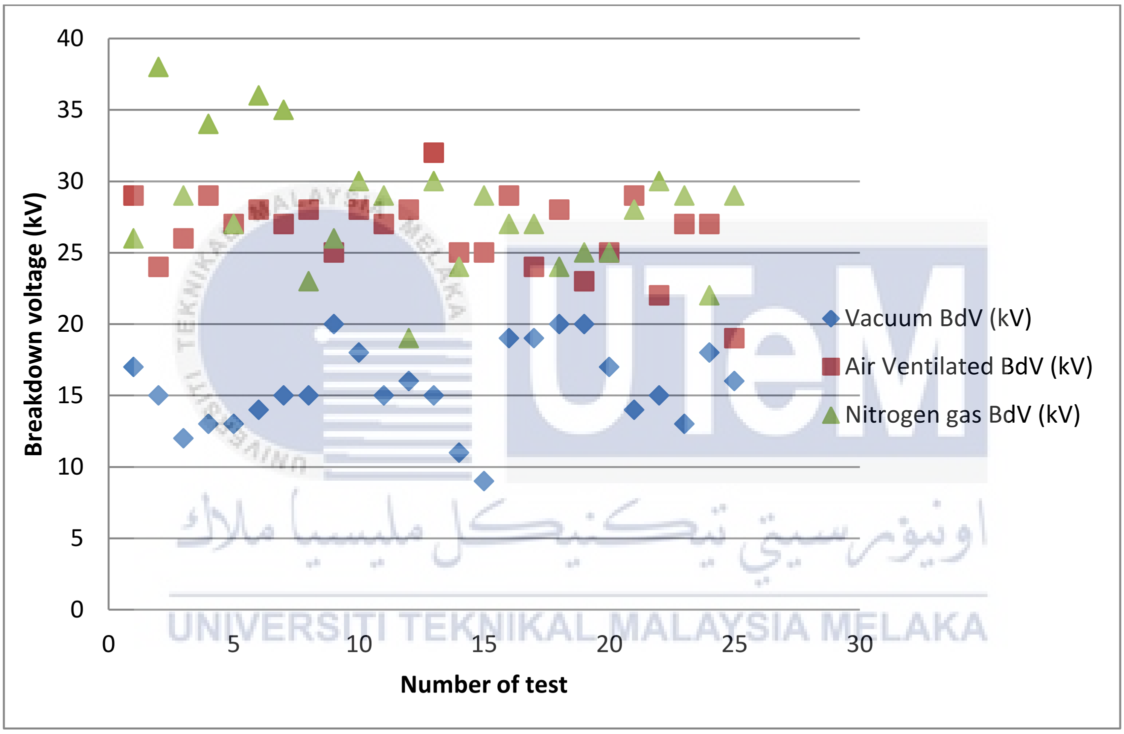

Figure 4.6: Distribution of synthetic ester breakdown voltage data with 0.1 ml moisture added for different moisture removal method

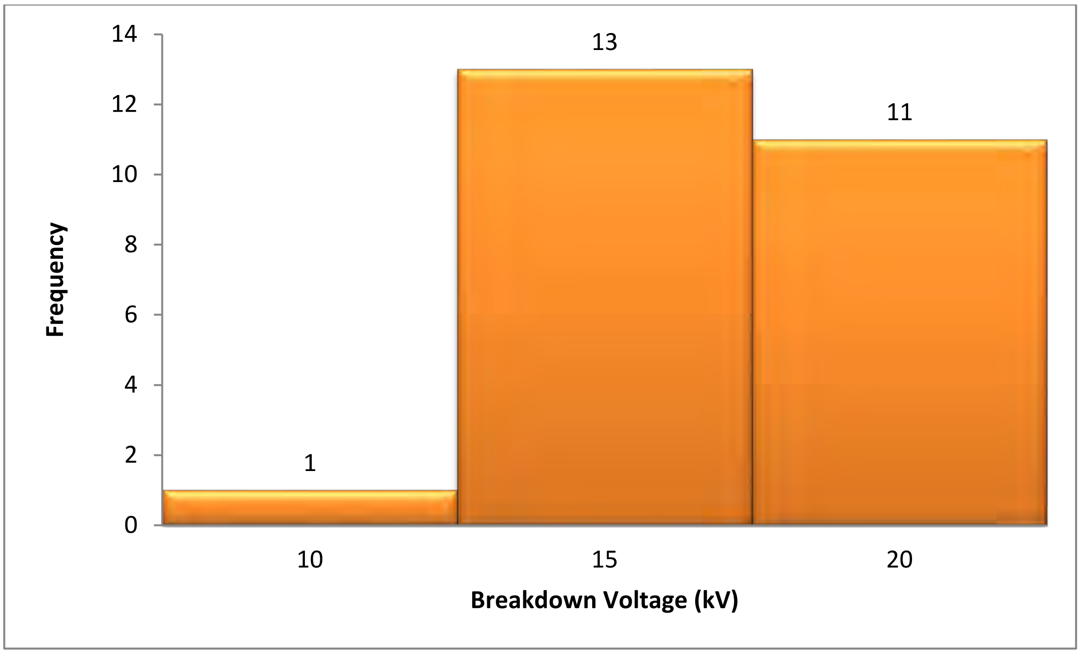

Figure 4.7: Probability density plot of synthetic ester breakdown voltages for vacuum method with 0.1 ml moisture added

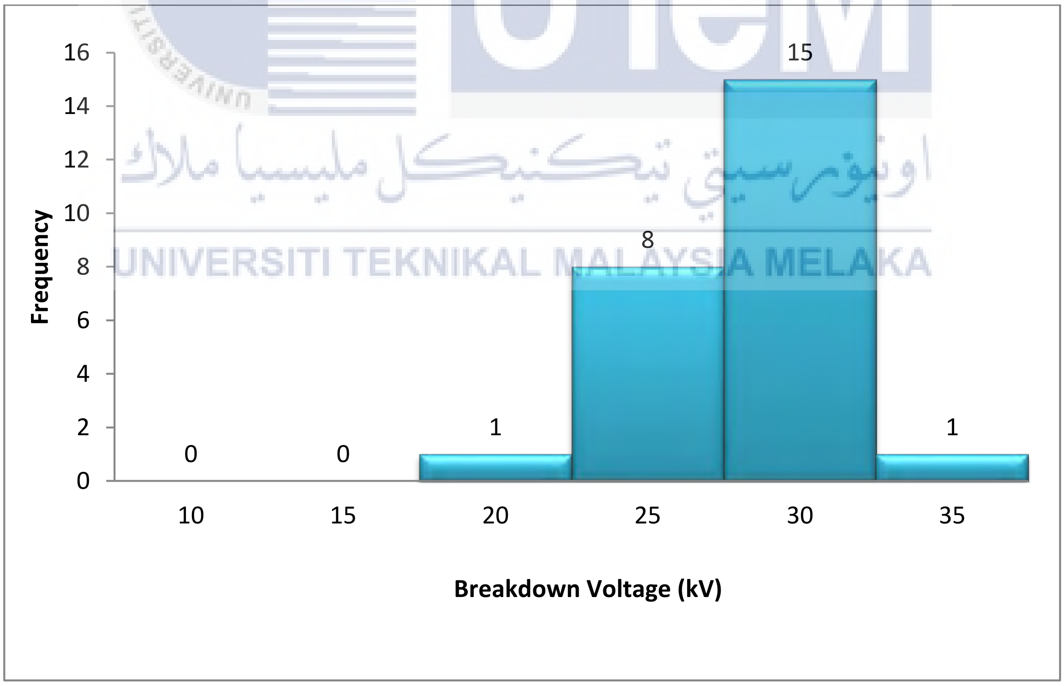

Figure 4.8: Probability density plot of synthetic ester breakdown voltages for air ventilation method with 0.1 ml moisture added

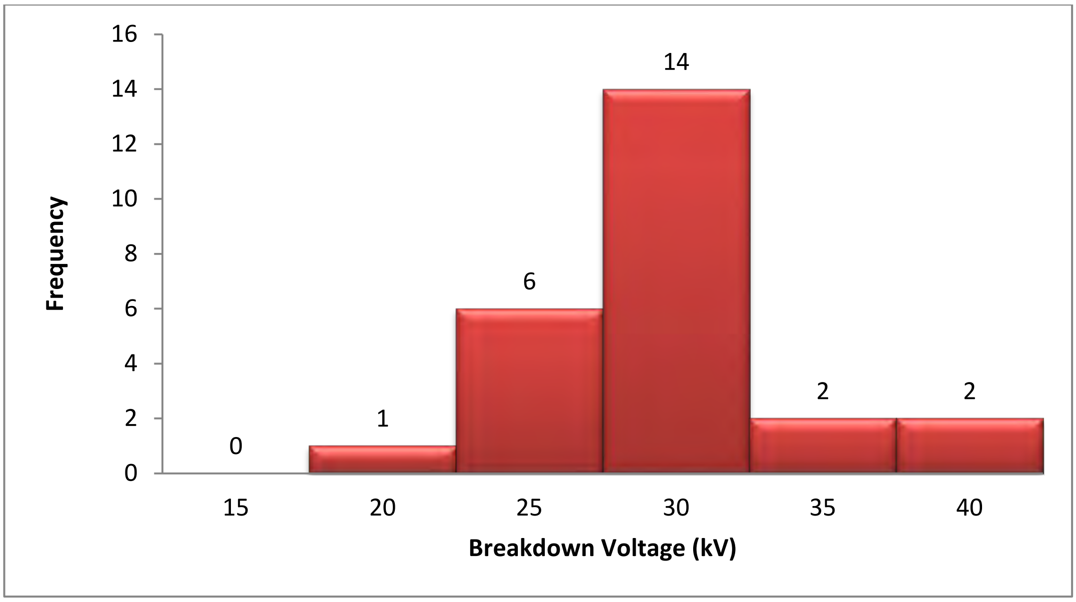

Figure 4.9: Probability density plot of synthetic ester breakdown voltages for nitrogen gas method with 0.1 ml moisture added

4.3.3 Analyzing of Breakdown Voltage Effect by Adding 0.2 ml Moisture

Figure 4.10 is the distribution graph for breakdown voltage for 0.2 ml moisture added. By observing the distribution graph, the rate of breakdown voltage for synthetic ester oil which has undergo vacuum condition is reduced to range 5 kV to 10 kV and the value is concentrated on that range. The minimum breakdown voltage that has been recorded is 7 kV whereas for the maximum is 9 kV. The highest frequency that shown in Figure 4.11 is 22 from the 25 tests that has been carried out and the range of breakdown that been observed is from 7 kV to 8 kV. For the air ventilation method, the distribution graph has shown that the breakdown obviously occur in the range of 10 kV to 20 kV. The maximum of the breakdown voltage is 19 kV whereas the minimum is at 9 kV. From the Figure 4.12, it shows the highest frequency is at range 15 kV to 20 kV which is 11 from the 25 tests. This covers almost 44% from the overall breakdown that occurs during al 25 tests that has been conducted.

In nitrogen gas treatment method for 0.2 ml moisture added, the distribution graph for breakdown voltage which is shown in Figure 4.10 is concentrated at the range of 15 kV to 25 kV. The maximum that been recorded is 27 kV whereas for minimum is 13 kV. From the Figure 4.13, the graph for the frequency of the breakdown voltage is indicated the higher peak at range 20 kV to 25 kV which the frequency is 14 from the 25 times of tested. From the data that been observed, it shows that at the 0.2 ml moisture added, only nitrogen gas method still in specified value for the insulating oil breakdown voltage test in ASTM D 1816. The vacuum and air ventilation methods are below than 20 kV cannot be accepted.

Table 4.4: The mean, min, max and standard deviation data of the different moisture removal treatment samples for 0.2 ml moisture added

Type of Treatment	Mean (kV)	Min (kV)	Max (kV)	Standard Deviation
Vacuum	7.72	7	9	0.665
Air Ventilation	14.36	9	19	3.297
Nitrogen Gas	21.08	13	27	2.925

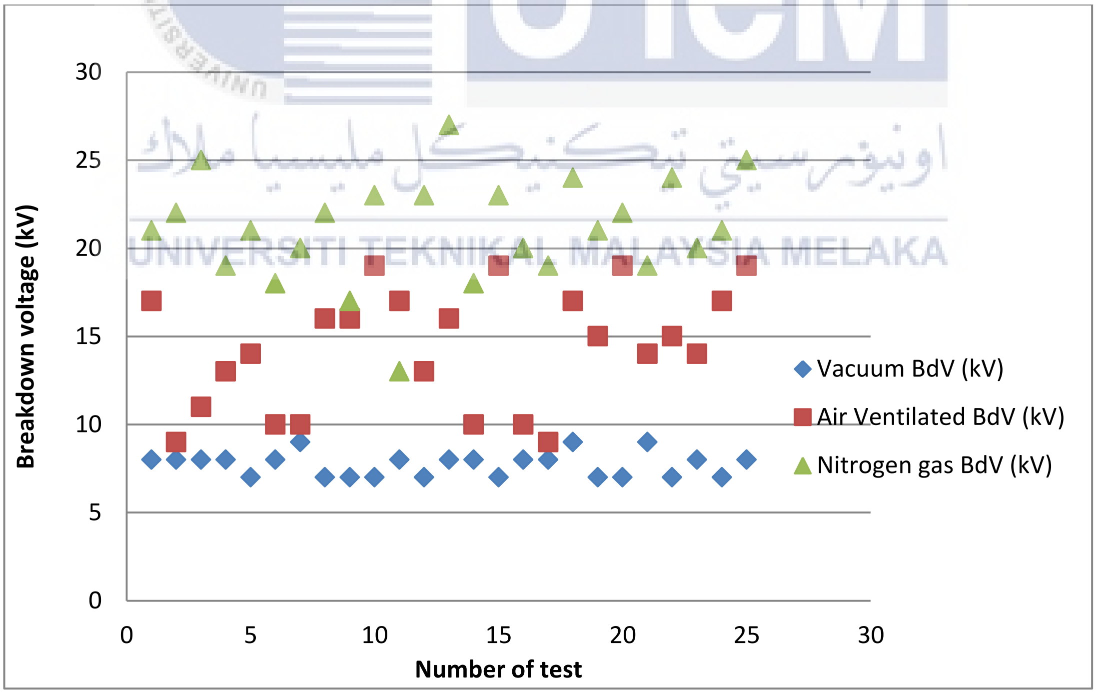

Figure 4.10: Distribution of synthetic ester breakdown voltage data with 0.2 ml moisture added for different moisture removal method

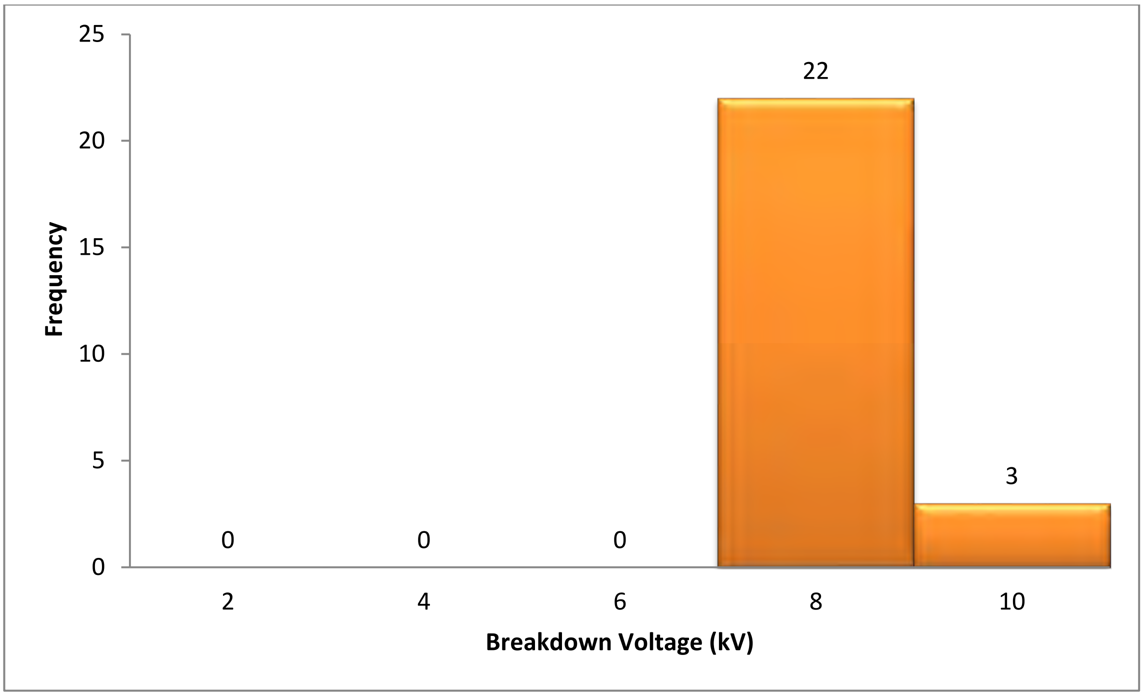

Figure 4.11: Probability density plot of synthetic ester breakdown voltages for vacuum method with 0.2 ml moisture added

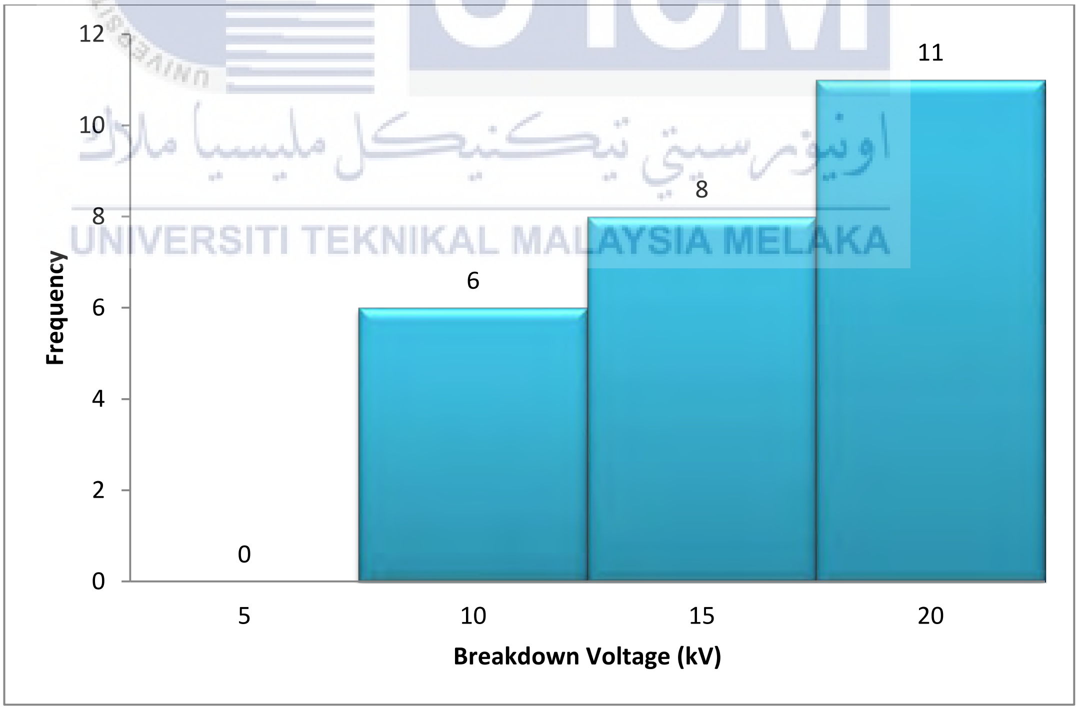

Figure 4.12: Probability density plot of synthetic ester breakdown voltages for air ventilation method with 0.2 ml moisture added

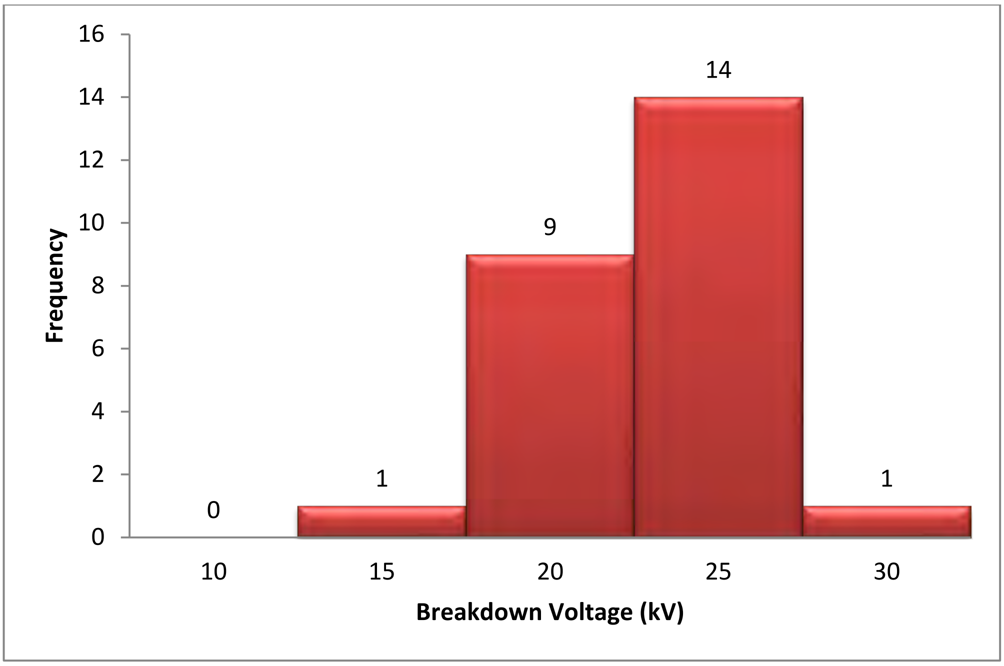

Figure 4.13: Probability density plot of synthetic ester breakdown voltages for nitrogen gas method with 0.2 ml moisture added

4.3.4 Analyzing of Breakdown Voltage Effect by Adding 0.3 ml Moisture

For the moisture adding is 0.3 ml inside the synthetic oil, the result for the breakdown voltage is shown as in Figure 4.14. In the Figure 4.14, it shows the overall breakdown voltage that occurs for vacuum, air ventilation and nitrogen gas treatment method. From the Figure 4.15, the vacuum treatment is at range 7 kV until 10 kV. The maximum value that been recorded is 11 kV whereas for the minimum is 6 kV. From the data, the breakdown voltage is frequently occurred at 6 kV until 8 kV which is 52 % of the overall breakdown voltage occur in 25 tests for vacuum method. For the air ventilation technique, the breakdown voltage is seems to occur at 10 kV to 15 kV as shown in Figure 4.14. Meanwhile, in the same Figure 4.14, the nitrogen gas method is in range 12 kV to 18 kV for its breakdown voltage. The maximum breakdown voltage that been recorded for air ventilation and nitrogen gas is 16 kV and 21 kV respectively. From the Figure 4.15, it shows from the 25 times of testing that been conducted, 16 tests of its breakdown voltage occur at 8 kV to 12 kV which is 64% from the overall test for air ventilation data whereas by referring to Figure 4.17 which is graph for nitrogen gas method, 52 % of the total number of breakdown voltage test is from 10 kV to 15 kV. From the observation by using the data, it can be said that the nitrogen gas technique having higher average of breakdown voltage strength when moisture added is 0.3 ml compared to vacuum and air ventilation. Since, all of the three samples having the average of the breakdown voltage is lower than 20 kV from the specification, the synthetic oil which having 0.3 ml or higher of moisture for 500 ml of synthetic ester oil is cannot be used as insulator. The reason for this situation is because the synthetic ester oil probably has achieved its saturation point in order to absorb free water molecule inside the oil and the free water molecule will form bridge along the sphere gap and this makes conduction is more faster and the breakdown for those samples is become lower than previous moisture added. Furthermore the presence of the contaminants which from the beginning of sample preparation, the oil prone to surrounding environment that contain molecule of dust and humidity in the air can also make the breakdown become more faster, this is because that ester oil didn't undergo filtering process.

Table 4.5: The mean, min, max and standard deviation data of the different moisture removal treatment samples for 0.3 ml moisture added

Type of Treatment	Mean (kV)	Min (kV)	Max (kV)	Standard Deviation
Vacuum	8.48	6	11	1.237
Air Ventilation	11.92	8	16	2.018
Nitrogen Gas	15.08	9	21	2.897

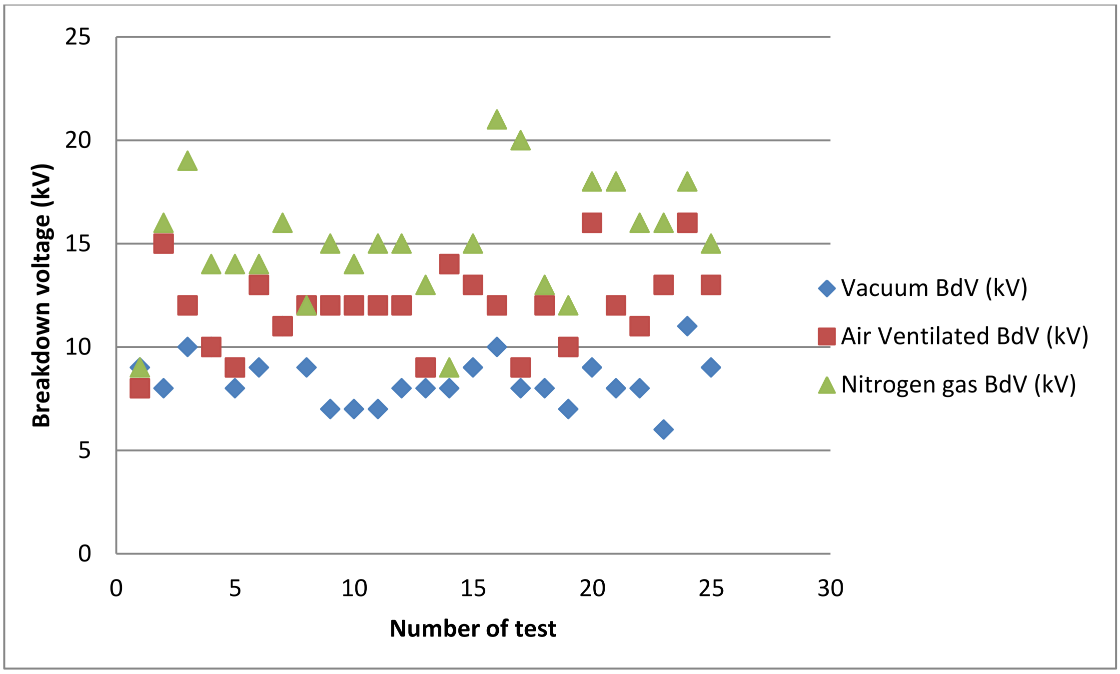

Figure 4.14: Distribution of synthetic ester breakdown voltage data with 0.3 ml moisture added for different moisture removal method

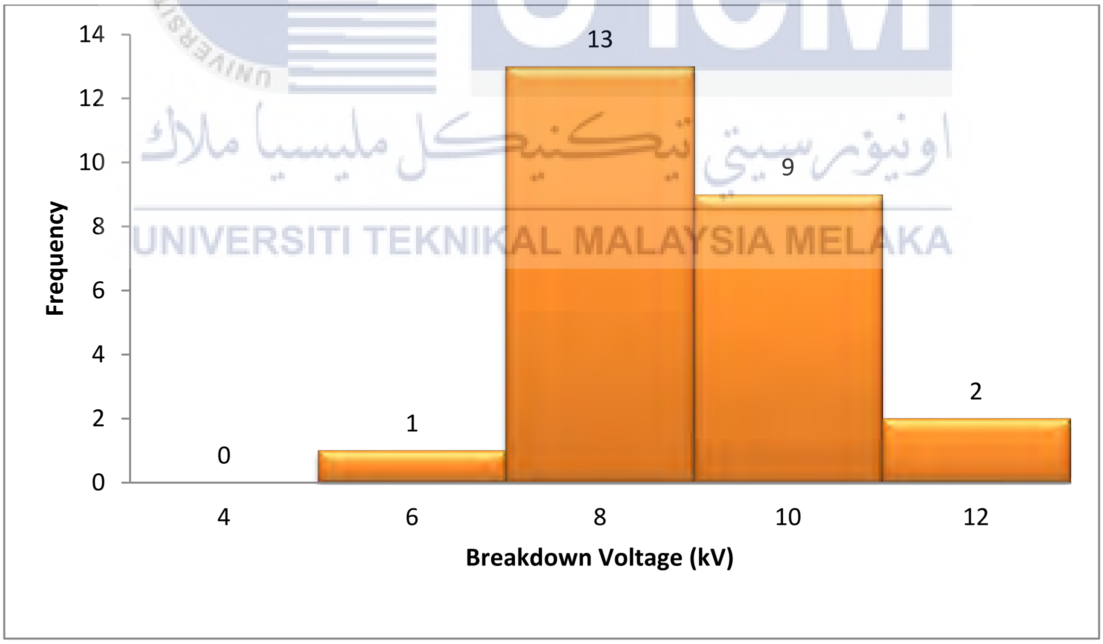

Figure 4.15: Probability density plot of synthetic ester breakdown voltages for vacuum method with 0.3 ml moisture added

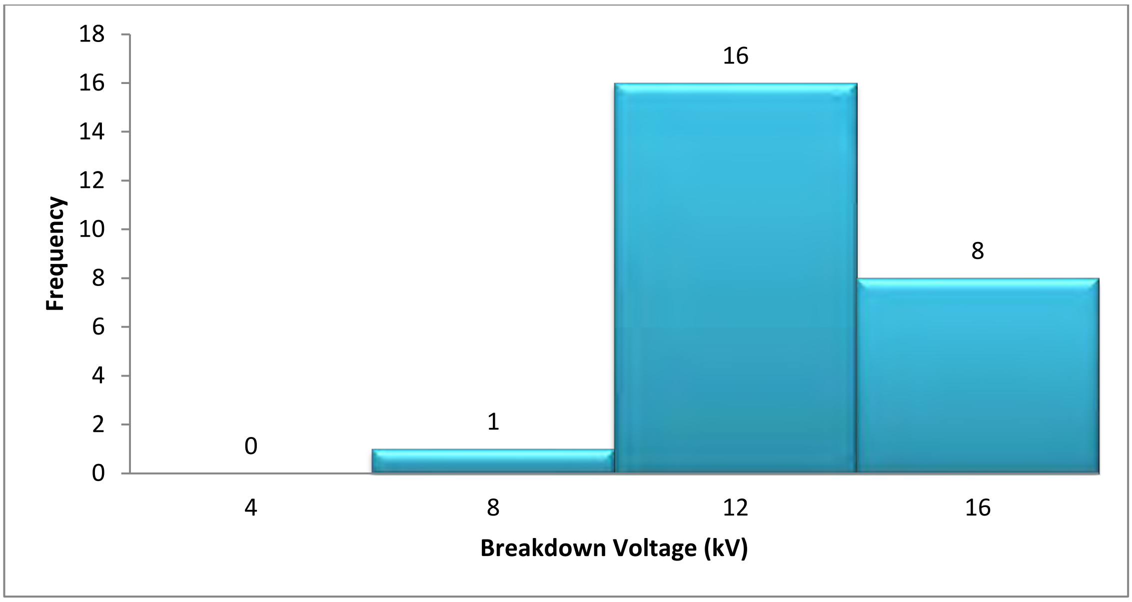

Figure 4.16: Probability density plot of synthetic ester breakdown voltages for air ventilation method with 0.3 ml moisture added

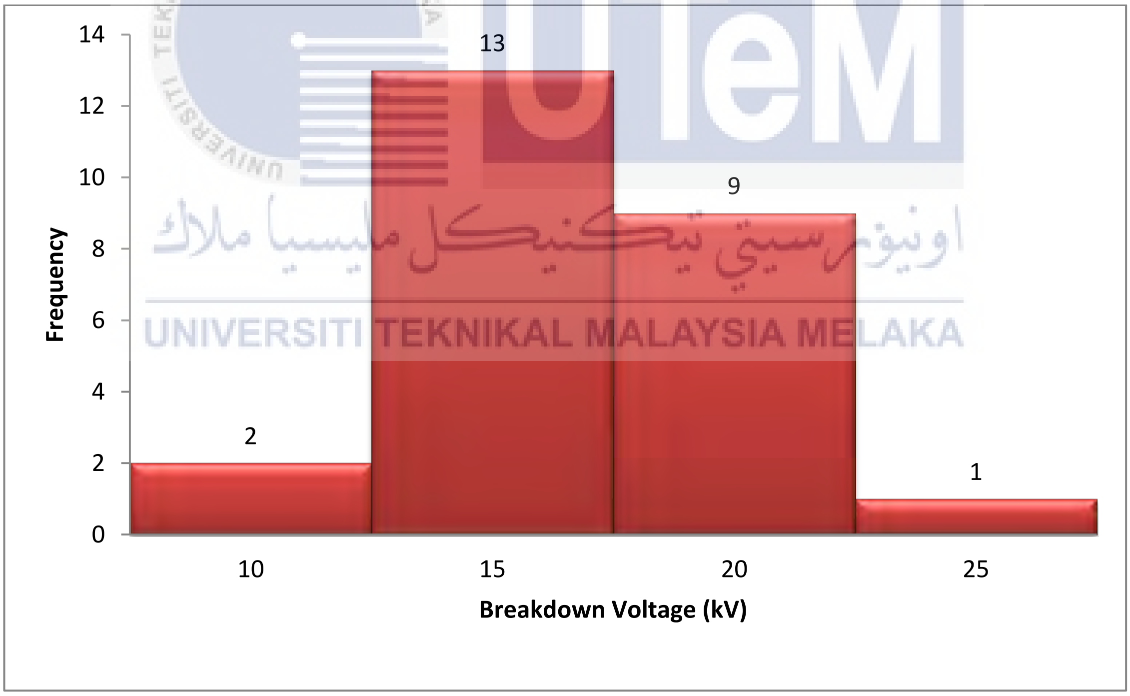

Figure 4.17: Probability density plot of synthetic ester breakdown voltages for nitrogen gas method with 0.3 ml moisture added

4.3.5 Comparison of Average Breakdown Voltage in Different Moisture Levels for Different Treatment Method

From the Table 4.6, it shows that the mean breakdown voltage for vacuum, air ventilated and nitrogen gas. From the Figure 4.18, it clearly shows that the average breakdown for synthetic ester oil which undergoes the nitrogen gas treatment has higher breakdown voltage compared to air ventilation and vacuum method. The second higher is goes to air ventilation method and lastly is vacuum method. When the moisture is been increased for 0.1 ml for each samples, it seems that the breakdown of those samples is decreased gradually. At 0.1 ml moisture added, it seems that the results for breakdown measurement for synthetic ester which undergo nitrogen gas treatment and air ventilation treatment it seem almost near. The difference value is only 1.4 kV. From the results, when the moisture is inserted 0.1 ml to the ester oil which is treated by using nitrogen gas, there is decreasing of breakdown voltage for 15kV to become 28.2kV. Meanwhile for air ventilation treatment, the dielectric strength drop is 10.8 kV, whereas for vacuum treatment is decreasing for 6.4kV to become 15.4kV. When moisture is been increasing to 0.2 ml, the average breakdown voltage for nitrogen, air-ventilation and vacuum samples are 21.2 kV, 14.4 kV and 8 kV respectively For moisture added is 0.3 ml, nitrogen gas is decreased to 15 kV and air ventilation sample is decreased to 12 kV whereas for vacuum is drop to 8.4 kV.

Even though the drop of dielectric strength is bigger on nitrogen gas treatment for the first 0.1 ml moisture added compared with other two treatments, but the breakdown voltage is still higher than both of them. The situation become like this is because maybe there is effect of the humidity from surrounding environment. When the humidity is high, then the oil samples tends to absorb more moisture inside it and this can cause the dielectric strength of the oil become lower. During the process of breakdown test, the humidity of the surrounding is 71%. This humidity is measured by using a humidity and temperature meter. Second which can probably affected the breakdown measurement is the time for stirrer process is not enough in allowing the moisture to spread all over the oil. The time taken for stirring the ester oil which have been put 0.1 ml is more than 1 hour until the bubble of distill water is disappeared. Third is from the contaminated. The oil is not filtered during the preparation samples and the surrounding dusk which entering the oil will make the breakdown strength of the oil is become faster than its dielectric strength capacity. Fourth is during process of pouring the oil samples from amber bottle to breakdown beaker, there is bubble occur when pouring process. Even the oil is pouring very slowly and carefully, but the bubble that form is cannot be avoided. But that bubble is disappear after a few second. From the overall of this measurement, it can be said that when increasing the moisture level, the breakdown strength of the synthetic ester oil will be decreasing. The amount of moisture is influencing the dielectric strength of the synthetic ester oil. Table 4.6 is the average breakdown voltage for those treatment samples when increasing 0.1 ml for each sample up to 0.3 ml. Figure 4.18 is the comparison of the breakdown voltage which clearly shows in graph. From the graph, it shows that the nitrogen gas method is the best which its breakdown is the highest compare to air ventilation and vacuum method.

Table 4.6: Average breakdown voltage result for different moisture level in different moisture treatment for synthetic ester oil

Moisture level (ml)	**Vacuum (kV)**	**Air ventilated (kV)**	**Nitrogen gas (kV)**
0	21.8	37.6	43.2
0.1	15.4	26.8	28.2
0.2	8	14.4	21.2
0.3	8.4	12	15

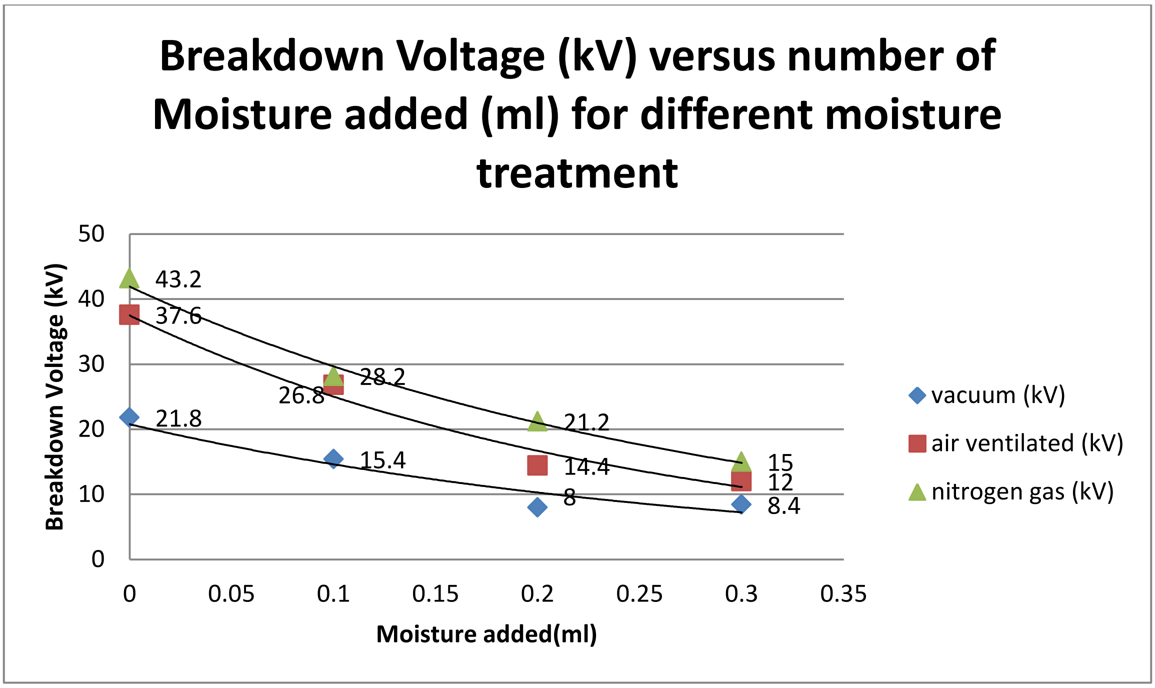

Figure 4.18: Graph of breakdown voltage result for different moisture level in different moisture treatment for ester oil

4.4 Summary of the Analysis

The effect of the moisture can generally degrade the performance of the ester oil in terms of breakdown voltage. From the result that been gathered which can be look at Figure 4.18, it is obviously shows that when the moisture is increasing, then the breakdown will decline steadily. In this study the uses of different method of moisture removal treatment have the effect to the moisture contents inside the synthetic ester oil. From the experiment that been conducted from these three different of moisture removal method, the nitrogen gas treatment is having the most lower moisture content which as shown in Table 4.1 and also Figure 4.1. From the Figure 4.1, it shows the trend of increasing of the moisture content when the moisture is added 0.1 ml until 0.3 ml and from that graph, the method of air ventilation technique and nitrogen gas is comparable its moisture contents when increasing the moisture added 0.1 ml to 0.3 ml. For the vacuum method, the moisture content is not reduced after the treatment. It is probably due to the misconduct during the sample preparation. In terms of breakdown strength, nitrogen gas treatment has good performance compared to vacuum and air ventilation treatment.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

For the conclusion, this project investigates the performance of different methods of removing the moisture. The technique that been used are by using vacuum, air ventilation and nitrogen gas. These methods is applied for the synthetic ester oil in order to reduce the moisture content inside it and also this study is to observe the effect of different moisture levels for the breakdown measurement from the different method of moisture removal techniques. In this study, this experiment is conduct in high voltage lab and all experiment is conduct in room temperature and also by following the standard that is ASTM D 1816 for breakdown voltage testing purpose to make sure the validity of the result is acceptable. The procedure of removing moisture from the synthetic oil is also by following the previous research as guideline for sample preparation. The sample for different removal technique is prepared for testing purpose which is the moisture added is varied. There are 4 samples that been prepared for each of the moisture removal techniques. One of the samples is not adding any moisture inside it and another 3 samples is added the moisture for 0.1 ml, 0.2 ml and 0.3 ml respectively. Karl Fisher titration is used in determining the moisture content inside the oil for each of the sample in order to know the performance of the moisture removal method in reducing the moisture contents inside the synthetic ester oil and also the effect towards the breakdown voltages from those technique that been applied. As from the result that been gathered from the result section, it has been observed that the different technique of removal moisture can make moisture contents inside the oil been improved. From the experiment that been carried out, it shows that from those three methods that been applied which is by using vacuum oven, air ventilation and nitrogen gas, it can be said that the nitrogen gas technique is more efficient in removing the moisture compared by using the air ventilation method and vacuum oven method. The implemented of moisture removal method is very important because to make sure that the ester oil can be performed its dielectric insulation oil inside the transformer in maximum electrical stress. As we know that the synthetic ester oil is still can be considered as good and in specification range below than 400 ppm for the moisture contents compare to the common transformer oil that always been used nowadays that is mineral oil which its moisture contents must not exceed more than 30 ppm.

In this experiment is also to analyze the effect of moisture level for the breakdown voltage of the synthetic ester oil. From this experiment, it can be said that the higher the moisture levels inside the oil, the shorter the value of the synthetic ester oil for its breakdown measurement. Even though that the synthetic ester oil can absorb the moisture contents more from the normal transformer oil that is mineral oil, but when the moisture contents is saturated and the oil cannot absorb more molecule of the water, then there will have free water molecule inside the ester oil molecule which the effect of the those free water molecules tends to weaken the insulation of the ester oil and this water molecule will make the current and voltage to pass easily. When there is a lot of moisture consists inside the oil, the ability of the ester oil as insulation will decrease gradually. Therefore the correlation of this study on testing the different moisture removal method and the effect the different moisture levels towards the breakdown measurement is to see the effectiveness of the moisture removal technique in order to improve the dielectric strength of the synthetic ester oil. By referring the result that been gathered, the overall performance in term of breakdown voltage and also moisture content from those moisture removal technique is been analyze by using appropriate graphical for better observation in making comparison in term of its performance. From the analysis and by overviewing the results, it can be conclude that the nitrogen gas techniques is the best in improving the dielectric strength of the synthetic ester oil which the value of the overall breakdown is the highest and the moisture contents after the treatment is the lowest in part per-million value (ppm).

5.2 Future Works

The study of ester oil is very important because this type of oil have a lot of advantage compare to the common transformer oil that been used nowadays that is mineral oil which have a disadvantage to the environment and also its cost will always increase because the crude oil price is increasing due to depletion of fossil fuel. By doing this study, all the data that been gathered regarding to the ester oil can be used in assist the other study for the appropriate alternative oil to change the function of mineral oil. In this study that is the uses of different technique to treat the ester oil for its moisture contents is to improve the quality of the oil and also to analyze the best method to be implemented. The purpose of this study is also to test the effect on its dielectric strength when reducing the moisture content inside it. The recommendation that can be suggest for the study on the ester oil is there must be conduct more test on this type of oil because ester oil have potential and more advantage compared to the mineral oil. By making further study on the ester oil, it can make this oil to become one of the suitable oil that can be used in order to replace the mineral oil with this alternative renewable oil. For the future work recommendation, this ester oil study can be further its research by studying its permittivity by comparing the mineral with synthetic ester and natural ester oils when moisture is varied. The permittivity analysis is important in order to know the dielectric strength of the insulation oil and also the nature of the oil when the moisture content is at the saturated value. Furthermore the moisture is one of the major problems that can give the impact in degrading the performance of insulation oil.

For the challenges in conducting this study, there is a time constraint in order to study more detail on the ester oil. Then the humidity factor and also contaminants which can degrade the performance of the insulation oil is one of the factor that contribute to the error in measurement and also the sample that has been prepared become corrupted than been expected. For this study with regarding to the alternative insulation oil, it is necessary to give more time for students in order to make research more detail on the capability of ester oil as insulation oil because the time taken in order to prepare the samples is longer than be expected.

REFERENCES

[1] P. S. Pakianathan, “Enhancement of Critical Characteristics of Vegetable Oil and used Mineral Oil of Power Transformer,” *Int. Conf. ICCPCT,* pp. 648–652, 2013.

[2] S. A. Ghani, N. A. Muhamad, I. S. Chairul, and N. Jamri, “A Study of Moisture Effects on the Breakdown Voltage and Spectral Characteristics of Mineral and Palm Oil-Based Insulation Oils,”*ARPN Journal of Engineering and Applied Science,* pp. 1–9, 2015

[3] J. Ulrych, M. Svoboda, R. Polanský, and J. Pihera, “Dielectric Analysis of Vegetable and Mineral Oils,” *Proc. - IEEE Int. Conf. Dielectr. Liq.*, pp. 1–4, 2014.

[4] H. Boris, E. Gockenbach, and B. Dolata, “Ester Fluids as Alternative for Mineral Based Transformer Oil,” *2008 IEEE Int. Conf. Dielectr. Liq. ICDL 2008*, pp. 1–4, 2008..

[5] Midel ® 7131, “ Comparison to Alternative Technologies,” March, pp. 2–3, 2014.

[6] D. Martin, Z. D. Wang, a. W. Darwin, and I. James, “A Comparative Study of the Chemical Stability of Esters for Use in Large Power Transformers,” *2006 IEEE Conf. Electr. Insul. Dielectr. Phenom.*, pp. 493–496, 2006.

[7] X. Wang and Z. D. Wang, “Particle Effect on Breakdown Voltage of Mineral and Ester Based Transformer Oils,” *Annu. Rep. - Conf. Electr. Insul. Dielectr. Phenomena, CEIDP*, pp. 598–602, 2008.

[8] M. Fikri Bin Aziz, “The Experimental Study of Partial Discharge of Malaysian Based Palm Oil,”, 2012.

[9] M. J. Heathcote and D. P. Franklin, “The J & P Transformer Book: A Practical Technology of the Power Transformer,” *J P Transform. B.*, pp. 945, 1998.

[10] T. V Oommen and D. Hanson, “Transformer Fluid : A Powerful Tool for the Life Management of an Ageing Transformer Population by Victor Sokolov Armando Bassetto Ted Haupert,” pp. 1–19.

[11] T. Suzuki, R. Oba, a. Kanetani, T. Kano, T. Tamura, M. Kato, S. Watanabe, Y. Kasahara, and M. Iwahashi, “Consideration on the Relationship between Dielectric Breakdown Voltage and Water Content in Fatty Acid Esters,” *2011 IEEE Int. Conf. Dielectr. Liq.*, pp. 1–4, 2011.

[12] Midel ® 7131, “Moisture Tolerance,” December, pp. 1–2, 2010.

[13] M. Koch, M. Fischer, and P. S. Tenbohlen, “the Breakdown Voltage of Insulation Oil Under the Influences of Humidity, Acidity,Particles and Pressure,” *Int. Conf. APTADM*, pp. 1–6, 2007.

[14] “The Megger guide to insulating oil dielectric breakdown testing.” pp. 1-69, 2003.

[15] N. S. Murad, N. A. Muhamad, A. A. Suleiman, and N. A. M. Jamail, “A Study on Palm Oil-Based Oil Moisture Absorption Level and Voltage Breakdown,” *Electr. Insul. Dielectr. Phenom. (CEIDP), 2013 IEEE Conf.*, pp. 925–928, 2013.

[16] M. Ohlen, “Estimating moisture in Power Transformers Mohammad Tariq , Megger Estimating moisture in Power Transformers - How to Estimate and What to Do,” pp. 1–9, 2006.

[17] ASTM International Standard, “Standard Test Method for Water using Volumetric Karl Fischer Titration,” *Designation E 203-01,* vol. 05, pp. 1–9.

[18] P. Trnka, V. Mentlik, and M. Svoboda, “The Effect of Moisture Content on Electrical Insulating Liquids,” pp. 1–4, 2014.

[19] Matharage, B. S. H. M. S., M. A. R. M. Fernando, M. A. A. P. Bandara, G. A. Jayantha, and C. S. Kalpage. "Performance of Coconut Oil as an Alternative Transformer Liquid Insulation." *Dielectrics and Electrical Insulation, IEEE Transactions on* 20, no. 3 (2013): 887-898, 2013

[20] M. Coulibaly, “Aging Behavior of Cellulosic Materials in Presence of Mineral Oil and Ester Liquids under Various Conditions,” vol. 20, no. 6, pp. 1971–1976, 2013.

[21] D. Martin and Z. D. Wang, “Statistical Analysis of the AC Breakdown Voltages of Ester Based Transformer Oils,” pp. 1044–1050, 2008.

APPENDIX A

3.1 Gantt Chart for Overall Final Year Project Activity

Project Task	Analyze the effect of Moisture Levels in Mineral and Ester Oils on Frequency Domain Spectroscopy (FDS) and Breakdown Measurement						Analyzing the Different Methods of Moisture Removal Treatment on Ester Oil and the effect of its Breakdown Measurement for Different Moisture Levels			
	Final Year Project 1						Final Year Project 2			
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Literature review on knowledge and information of the project										
Selection for the objective and scope of the project										
Sample preparation on breakdown measurement for mineral and ester oil for different moisture levels										
Report writing preparation for FYP 1 and presentation										
Preparation of the samples										
Experimental setup, data collection and data analysis										
Report writing for FYP 2 and preparation for the presentation										

APPENDIX B 1

	Test	BDV (kV)	Remark
1	1	28	RTP: 31^{o}C RH: 67.3% DP: 24.2^{o}C WB: 26^{o}C AVE: **24kV** S: 4.817 S/x: 0.199
	2	20	
	3	30	
	4	19	
	5	24	
2	6	24	RTP: 31^{o}C RH: 64.8% DP: 23.7^{o}C WB: 25.6^{o}C AVE: **25kV** S: 4.669 S/x: 0.184
	7	26	
	8	26	
	9	19	
	10	32	
3	11	31	RTP: 31^{o}C RH: 64.0% DP: 23.4^{o}C WB: 25.4^{o}C AVE: **24kV** S: 7.906 S/x: 0.329
	12	20	
	13	32	
	14	13	
	15	24	
4	16	32	RTP: 31^{o}C RH: 64.8% DP: 23.7^{o}C WB: 25.7^{o}C AVE: **27kV** S: 7.294 S/x: 0.272
	17	33	
	18	31	
	19	17	
	20	21	
5	21	24	RTP: 31.2^{o}C RH: 64.9% DP: 23.9^{o}C WB: 25.9^{o}C AVE: **26kV** S: 2.702 S/x: 0.106
	22	24	
	23	28	
	24	23	
	25	29	

Date: 4/4/2016

Time: 1.47 PM

Type of oil: MIDEL 7131(from Tank)

Humidity: 67.3%

Temperature: 31^{o}C

No. of moisture added: NONE

Karl Fisher test (ppm): 427.5, 475.9 and 443.6

APPENDIX B 2

	Test	BDV (kV)	Remark
1	1	18	RTP: 30.9°C
	2	21	RH: 73.1%
	3	15	DP: 25.5°C
	4	18	WB: 26.9°C
	5	22	AVE: **19kV** S: 2.775 S/x: 0.148
2	6	17	RTP: 31°C
	7	23	RH: 72.6%
	8	22	DP: 25.5°C
	9	23	WB: 26.9°C
	10	18	AVE: **21kV** S: 2.881 S/x: 0.14
3	11	23	RTP: 31.1°C
	12	21	RH: 72.7%
	13	23	DP: 25.7°C
	14	25	WB: 27.8°C
	15	19	AVE: **22kV** S: 2.28 S/x: 0.103
4	16	24	RTP: 31.2°C
	17	24	RH: 72.5%
	18	15	DP: 25.6°C
	19	18	WB: 27°C
	20	24	AVE: **21kV** S: 4.243 S/x: 0.202
5	21	30	RTP: 31.3°C
	22	26	RH: 71.1%
	23	26	DP: 25.5°C
	24	20	WB: 27°C
	25	27	AVE: **26kV** S: 3.633 S/x: 0.141

Date: 5/4/2016

Time: 11.11 AM

Type of oil: MIDEL 7131(Vacuum)

Humidity: 73%

Temperature: 30.9°C

No. of moisture added: NONE

Karl Fisher test (ppm): 813.5, 784.7 and 805.6

APPENDIX B 3

	Test	BDV (kV)	Remark
1	1	18	RTP: 31.4^{o}C RH: 70.8% DP: 25.4^{o}C WB: 27.0^{o}C AVE: **27kV** S: 10.807 S/x: 0.406
	2	34	
	3	42	
	4	19	
	5	20	
2	6	45	RTP: 31.5^{o}C RH: 69.8% DP: 25.2^{o}C WB: 26.8^{o}C AVE: **41kV** S: 4.494 S/x: 0.11
	7	35	
	8	43	
	9	44	
	10	37	
3	11	43	RTP: 31.6^{o}C RH: 70.2% DP: 25.4^{o}C WB: 27^{o}C AVE: **39kV** S: 3.033 S/x: 0.077
	12	41	
	13	35	
	14	38	
	15	39	
4	16	45	RTP: 31.2^{o}C RH: 70.1% DP: 25.3^{o}C WB: 27.1^{o}C AVE: **39kV** S: 4.087 S/x: 0.105
	17	34	
	18	38	
	19	40	
	20	37	
5	21	23	RTP: 30.4^{o}C RH: 65.1% DP: 23.1^{o}C WB: 25.2^{o}C AVE:**20kV** S: 2.966 S/x: 0.151
	22	21	
	23	16	
	24	17	
	25	21	

Date: 5/4/2016

Time: 12.45 PM

Type of oil: MIDEL 7131(Ventilated)

Humidity: 71.3%

Temperature: 31.4^{o}C

No. of moisture added: NONE

Karl Fisher test (ppm): 382.0, 393.0 and 387.4

APPENDIX B 4

	Test	BDV (kV)	Remark
1	1	45	RTP: 30.5^{o}C
	2	52	RH: 66.1%
	3	48	DP: 23.4^{o}C
	4	46	WB: 25.3^{o}C
	5	45	AVE: **47kV** S: 2.95 S/x: 0.062
2	6	36	RTP: 30.6^{o}C
	7	31	RH: 66.7%
	8	48	DP: 23.8^{o}C
	9	19	WB: 25.6^{o}C
	10	38	AVE: **34kV** S: 10.597 S/x: 0.308
3	11	49	RTP: 30.5^{o}C
	12	49	RH: 66.3%
	13	42	DP: 23.4^{o}C
	14	45	WB: 25.2^{o}C
	15	48	AVE: **47kV** S: 3.05 S/x: 0.065
4	16	44	RTP: 30.5^{o}C
	17	49	RH: 66%
	18	27	DP: 23.2^{o}C
	19	52	WB: 25.2^{o}C
	20	43	AVE: **43kV** S: 9.67 S/x: 0.225
5	21	47	RTP: 30.5^{o}C
	22	43	RH: 69%
	23	47	DP: 24.3^{o}C
	24	49	WB: 25.9^{o}C
	25	40	AVE:**45kV** S: 3.633 S/x: 0.08

Date: 6/4/2016

Time: 1.17 PM

Type of oil: MIDEL 7131(Nitrogen)

Humidity: 66%

Temperature: 30.6^{o}C

No. of moisture added: NONE

Karl Fisher test (ppm): 163.5, 159.3 and 161.2

APPENDIX B 5

	Test	BDV (kV)	Remark
1	1	17	RTP:30.7^{o}C RH:68.4% DP:24.1^{o}C WB:25.8^{o}C AVE:**14kV** S:2.00 S/x:0.143
	2	15	
	3	12	
	4	13	
	5	13	
2	6	14	RTP:30.8^{o}C RH:68.9% DP:24.4^{o}C WB:26.1^{o}C AVE:**16kV** S:2.51 S/x:0.153
	7	15	
	8	15	
	9	20	
	10	18	
3	11	15	RTP:30.8^{o}C RH:68.1% DP:24.2^{o}C WB:26.0^{o}C AVE:**13kV** S:3.033 S/x:0.23
	12	16	
	13	15	
	14	11	
	15	9	
4	16	19	RTP:30.8^{o}C RH:69.2% DP:24.5^{o}C WB:26.2^{o}C AVE:**19kV** S:1.225 S/x:0.064
	17	19	
	18	20	
	19	20	
	20	17	
5	21	14	RTP:31^{o}C RH:71.8% DP:25.3^{o}C WB:26.7^{o}C AVE:**15kV** S:1.924 S/x:0.127
	22	15	
	23	13	
	24	18	
	25	16	

Date: 6/4/2016

Time: 2.58 PM

Type of oil: MIDEL 7131(Vacuum)

Humidity: 69 %

Temperature: 30.6^{o}C

No. of moisture added: 0.1ml

Karl Fisher test (ppm):

1) **Before add moisture:** 813.5, 784.7 and 798.2
2) **After add moisture:** 1078.8, 1143.2 and 1093.8

APPENDIX B 6

	Test	BDV (kV)	Remark
1	1	29	RTP:31°C
	2	24	RH:71.5%
	3	26	DP:25.3°C
	4	29	WB:26.8°C
	5	27	AVE:**27kV** S:2.121 S/x:0.079
2	6	28	RTP:30.9°C
	7	27	RH:70%
	8	28	DP:24.8°C
	9	25	WB:26.4°C
	10	28	AVE:**27kV** S:1.304 S/x:0.048
3	11	27	RTP:31°C
	12	28	RH:69.9%
	13	32	DP:24.9°C
	14	25	WB:26.4°C
	15	25	AVE:**27kV** S:2.881 S/x:0.105
4	16	29	RTP:31°C
	17	24	RH:69.8%
	18	28	DP:24.8°C
	19	23	WB:26.4°C
	20	25	AVE:**26kV** S:2.588 S/x:0.10
5	21	29	RTP:30.9°C
	22	22	RH:70%
	23	27	DP:24.8°C
	24	27	WB:26.4°C
	25	19	AVE:**25kV** S:4.147 S/x:0.167

Date: 6/4/2016

Time: 4.08 pm

Type of oil: MIDEL 7131 (Ventilated)

Humidity: 71.3%

Temperature: 31^{0}C

No. of moisture added: 0.1ml

Karl Fisher test (ppm):

1) **Before add moisture:** 382, 393.3, and 387.5
2) **After add moisture:** 776.4, 754.7 and 767.3

APPENDIX B 7

	Test	BDV (kV)	Remark
1	1	26	RTP:31.1°C RH:73.3% DP:25.7°C WB:27.1°C AVE:**31kV** S:5.07 S/x:0.165
	2	38	
	3	29	
	4	34	
	5	27	
2	6	36	RTP:31.1°C RH:73.3% DP:25.7°C WB:27.1°C AVE:**30kV** S:5.612 S/x:0.187
	7	35	
	8	23	
	9	26	
	10	30	
3	11	29	RTP:31.2°C RH:71.3% DP:25.4°C WB:26.8°C AVE:**26kV** S:4.658 S/x:0.178
	12	19	
	13	30	
	14	24	
	15	29	
4	16	27	RTP:31.3°C RH:70.5% DP:25°C WB:26.5°C AVE:**26kV** S:1.342 S/x:0.052
	17	27	
	18	24	
	19	25	
	20	25	
5	21	28	RTP:31.2°C RH:68.3% DP:24.7°C WB:26.4°C AVE:**28kV** S:3.209 S/x:0.116
	22	30	
	23	29	
	24	22	
	25	29	

Date: 19/4/2016

Time: 9.16 am

Type of oil: MIDEL 7131 (Nitrogen)

Humidity: 73.4%

Temperature: 31°C

No. of moisture added: 0.1ml

Karl Fisher test (ppm):

1) **Before add moisture:** 159.9, 165.7, and 162.4
2) **After add moisture:** 683.1, 705 and 698.2

APPENDIX B 8

	Test	BDV (kV)	Remark
1	1	8	RTP:32°C RH:61.8% DP:23.6°C WB:25.9°C AVE:**8kV** S:0.447 S/x:0.057
	2	8	
	3	8	
	4	8	
	5	7	
2	6	8	RTP:32°C RH:63.3% DP:24.1°C WB:26.3°C AVE:**8kV** S:0.894 S/x:0.118
	7	9	
	8	7	
	9	7	
	10	7	
3	11	8	RTP:32.2°C RH:62.5% DP:23.6°C WB:25.9°C AVE:**8kV** S:0.548 S/x:0.072
	12	7	
	13	8	
	14	8	
	15	7	
4	16	8	RTP:32°C RH:62% DP:23.6°C WB:24.8°C AVE:**8kV** S:0.837 S/x:0.107
	17	8	
	18	9	
	19	7	
	20	7	
5	21	9	RTP:32.3°C RH:61% DP:23.6°C WB:25.9°C AVE:**8kV** S:0.837 S/x:0.107
	22	7	
	23	8	
	24	7	
	25	8	

Date: 19/4/2016

Time: 11.52 am

Type of oil: MIDEL 7131 (Vacuum)

Humidity: 62%

Temperature: 31°C

No. of moisture added: 0.2ml

Karl Fisher test (ppm):

1) **Before add moisture:** 842.6, 826.5 and 833.7
2) **After add moisture:** 1382, 1330.6 and 1354.3

APPENDIX B 9

	Test	BDV (kV)	Remark
1	1	17	RTP:30.4^{o}C RH:78.3% DP:26.3^{o}C WB:27.3^{o}C AVE:**13kV** S:3.033 S/x:0.237
	2	9	
	3	11	
	4	13	
	5	14	
2	6	10	RTP:30.6^{o}C RH:78.5% DP:26.4^{o}C WB:27.4^{o}C AVE:**14kV** S:4.025 S/x:0.283
	7	10	
	8	16	
	9	16	
	10	19	
3	11	17	RTP:30.8^{o}C RH:77.3% DP:26.4^{o}C WB:27.4^{o}C AVE:**15kV** S:3.536 S/x:0.236
	12	13	
	13	16	
	14	10	
	15	19	
4	16	10	RTP:30.7^{o}C RH:77.4% DP:26.3^{o}C WB:27.4^{o}C AVE:**14kV** S:4.359 S/x:0.311
	17	9	
	18	17	
	19	15	
	20	19	
5	21	14	RTP:30.7^{o}C RH:77.8% DP:26.4^{o}C WB:27.4^{o}C AVE:**16kV** S:2.168 S/x:0.137
	22	15	
	23	14	
	24	17	
	25	19	

Date: 11/5/2016

Time: 10.15 am

Type of oil: MIDEL 7131 (Ventilated)

Humidity: 78.1%

Temperature: 30.4^{0}C

No. of moisture added: 0.2ml

Karl Fisher test (ppm):

1) **Before add moisture:** 390.2, 387.4 and 389.5
2) **After add moisture:** 788.3, 938.7 and 862.5

APPENDIX B 10

	Test	BDV (kV)	Remark
1	1	21	RTP:31.6^{0}C RH:65.6% DP:24.2^{0}C WB:26.1^{0}C AVE:**22kV** S:2.191 S/x:0.101
	2	22	
	3	25	
	4	19	
	5	21	
2	6	18	RTP:31.6^{0}C RH:65.4% DP:24.3^{0}C WB:26.2^{0}C AVE:**20kV** S:2.55 S/x:0.127
	7	20	
	8	22	
	9	17	
	10	23	
3	11	13	RTP:31.7^{0}C RH:64% DP:23.8^{0}C WB:25.9^{0}C AVE:**21kV** S:5.404 S/x:0.260
	12	23	
	13	27	
	14	18	
	15	23	
4	16	20	RTP:31.7^{0}C RH:63.4% DP:23.8^{0}C WB:25.9^{0}C AVE:**21kV** S:1.924 S/x:0.091
	17	19	
	18	24	
	19	21	
	20	22	
5	21	19	RTP:31.9^{0}C RH:62.6% DP:23.8^{0}C WB:25.9^{0}C AVE:**22kV** S:2.588 S/x:0.119
	22	24	
	23	20	
	24	21	
	25	25	

Date: 19/4/2016

Time: 10.38 pm

Type of oil: MIDEL 7131 (Nitrogen)

Humidity: 66.2%

Temperature: 31.4^{0}C

No. of moisture added: 0.2ml

Karl Fisher test (ppm):

1) **Before add moisture:** 161.7, 202.5 and 187.3
2) **After add moisture:** 826.3, 779.1 and 806.9

APPENDIX B 11

	Test	BDV (kV)	Remark
1	1	9	RTP:32.4^{0}C RH:68.1% DP:25.8^{0}C WB:27.4^{0}C AVE:**9kV** S:1.00 S/x:0.111
	2	8	
	3	10	
	4	10	
	5	8	
2	6	9	RTP:32.3^{0}C RH:66.7% DP:25.4^{0}C WB:27.1^{0}C AVE:**9kV** S:1.673 S/x:0.195
	7	11	
	8	9	
	9	7	
	10	7	
3	11	7	RTP:32.3^{0}C RH:66.6% DP:25.3^{0}C WB:27.1^{0}C AVE:**8kV** S:0.707 S/x:0.088
	12	8	
	13	8	
	14	8	
	15	9	
4	16	10	RTP:32.4^{0}C RH:65.2% DP:24.8^{0}C WB:26.9^{0}C AVE:**8kV** S:1.14 S/x:0.136
	17	8	
	18	8	
	19	7	
	20	9	
5	21	8	RTP:32.4^{0}C RH:64.9% DP:24.9^{0}C WB:26.9^{0}C AVE:**8kV** S:1.817 S/x:0.216
	22	8	
	23	6	
	24	11	
	25	9	

Date: 11/5/2016

Time: 1.08 pm

Type of oil: MIDEL 7131 (Vacuum)

Humidity: 68.5%

Temperature: 32.2^{0}C

No. of moisture added: 0.3ml

Karl Fisher test (ppm):

1) **Before add moisture:** 837.6, 841.5 and 827.9
2) **After add moisture:** 1831, 1922.5 and 1875.6

APPENDIX B 12

	Test	BDV (kV)	Remark
1	1	8	RTP:31.4^{0}C
	2	15	RH:74.7%
	3	12	DP:26.4^{0}C
	4	10	WB:27.6^{0}C
	5	9	AVE:**11kV** S:2.775 S/x:0.257
2	6	13	RTP:31.4^{0}C
	7	11	RH:73.9%
	8	12	DP:26.3^{0}C
	9	12	WB:27.5^{0}C
	10	12	AVE:**12kV** S:0.707 S/x:0.059
3	11	12	RTP:31.4^{0}C
	12	12	RH:72.1%
	13	9	DP:25.9^{0}C
	14	14	WB:27.3^{0}C
	15	13	AVE:**12kV** S:1.871 S/x:0.156
4	16	12	RTP:31.5^{0}C
	17	9	RH:72.1%
	18	12	DP:25.9^{0}C
	19	10	WB:27.3^{0}C
	20	16	AVE:**12kV** S:2.683 S/x:0.227
5	21	12	RTP:32.2^{0}C
	22	11	RH:70.1%
	23	13	DP:26.1^{0}C
	24	16	WB:27.6^{0}C
	25	13	AVE:**13kV** S:1.871 S/x:0.144

Date: 11/5/2016

Time: 12.03 pm

Type of oil: MIDEL 7131 (Ventilated

Humidity: 75%

Temperature: 31.4^{0}C

No. of moisture added: 0.3ml

Karl Fisher test (ppm):

1) **Before add moisture:** 391.7, 386.4 and 389.6
2) **After add moisture:** 1292.3, 1412.3 and 1378.5

APPENDIX B 13

	Test	BDV (kV)	Remark
1	1	9	RTP:31^{0}C
	2	16	RH:77.8%
	3	19	DP:26.6^{0}C
	4	14	WB:27.7^{0}C
	5	14	AVE:**14kV** S:3.647 S/x:0.253
2	6	14	RTP:31.1^{0}C
	7	16	RH:78.3%
	8	12	DP:26.7^{0}C
	9	15	WB:27.8^{0}C
	10	14	AVE:**14kV** S:1.483 S/x:0.104
3	11	15	RTP:31.2^{0}C
	12	15	RH:76.9%
	13	13	DP:26.6^{0}C
	14	9	WB:27.7^{0}C
	15	15	AVE:**13kV** S:2.608 S/x:0.195
4	16	21	RTP:31.2^{0}C
	17	20	RH:76.8%
	18	13	DP:26.6^{0}C
	19	12	WB:27.8^{0}C
	20	18	AVE:**17kV** S:4.087 S/x:0.243
5	21	18	RTP:31.3^{0}C
	22	16	RH:76.6%
	23	16	DP:26.7^{0}C
	24	18	WB:27.8^{0}C
	25	15	AVE:**17kV** S:1.342 S/x:0.081

Date: 11/5/2016

Time: 11.04 pm

Type of oil: MIDEL 7131 (Nitrogen)

Humidity: 77.5%

Temperature: 31^{0}C

No. of moisture added: 0.3ml

Karl Fisher test (ppm):

1) **Before add moisture:** 161.2, 153.4 and 164.7
2) **After add moisture:** 1147.4, 1242.9 and 1254.0