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Signature : .....

Name : FARHAN BIN HANAFFI

Date : 17 June 2016

STUDY OF THERMAL EFFECT ON ESTER OIL DIELECTRIC STRESS USING BREAKDOWN MEASUREMENTS AND TOTAL ACID NUMBER (TAN) TEST

MOHD RODZI BIN ZULKIFLI

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

Faculty of Electrical Engineering

Universiti Teknikal Malaysia Melaka

2016

I declare that this report entitle "*Analyse of thermal effect on ester oil dielectric stress using breakdown voltage and total acid number (TAN) test*" is the result of my own search except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : MOHD RODZI BIN ZULKIFLI

Date : 17 June 2016

To my beloved mother and father

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ABSTRACT

It is well known that power transformer service reliability is largely depending on the condition of the dielectric fluids. The influence of the thermal effect on the dielectric fluid will give important impact on the condition of the transformer themselves. In the real transformer consist of copper winding and pressboard paper that separated the transformer windings. This both materials will become dissolve particle in the insulating oil after long term transformer operation. It can affect the dielectric performance of the insulating oil. This situation can be represents in the experiment by using copper strips and cellulose paper use in insulating oil. Ester oil as alternative oil need to be analyse it thermal performance before applied in industry under this real transformer condition. This study investigates about the thermal effect on ester oil dielectric stress using breakdown voltage and total acid number test. The ester oil condition used is based on the real operating transformer with existing of copper strips and cellulose compared to other both ester oil conditions which is ester oil without particle and ester oil with copper strips. It is because to investigate the deterioration of the ester oil using the breakdown measurement and analyse the effect using total acid number. The entire sample undergoes thermal aging at 120°C for 0, 6, 24 and 48 hours. The breakdown voltage test show that the ester oil for each condition has highest breakdown value during the beginning of the thermal aging and gradually dropped about 25% to 32% from its initial value after achieved 48 hours. While, the total acid number shown the vice versa that ester oil each condition experienced rising of the oil acidity about 60% to 106% from its initial value. Ester oil with cellulose and copper strips has the lowest breakdown voltage because the existing of the cellulose as the impurities that react as the bridging particle for the breakdown to happens quickly. While, for total acid number, ester oil with copper strips show the highest value due to the chemical reaction that make the copper strips react as the catalyst for process of oil oxidation. Relation between total acid number and breakdown voltage is higher the total acid number in the ester oil will cause low breakdown voltage. This is because the oil has been oxidized by acid that reduce the dielectric performance.

ABSTRAK

Seperti yang diketahui umum bahawa kebolehupayaan fungsi transformer amat bergantung pada keadaan cecair dielektrik. Pengaruh kesan haba ke atas bendalir dielektrik akan memberi kesan yang ketara terhadap keadaan transformer. Dalam kondisi transformer sebenar terdapat lilitan logam dan kertas keras yang digunakan untuk memisahkan lilitan transformer. Kedua bahan ini akan larut dalam cecair penebat selepas transformer beroperasi dalam jangka masa yang lama. Ia dapat memberi kesan buruk terhadap prestasi dielektik penebat cecair. Situasi ini boleh digambarkan dalam eksperimen dengan menggunakan logam dan kertas selulosa dlam cecair penebat Kajian tesis ini mengkaji tentang kesan haba ke atas minyak ester terhadap tekanan dielektrik dengan menggunakan ukuran kerosakkan voltan and jumlah nilai acid dalam minyak ester. Minyak ester yang digunakan sebagai sample berdasarkan keadaan sebenar kondisi dalam transformer dengan kehadiran kepingan logam dan selulosa dan dibandingkan dengan minyak ester tanpa zarah dan minyak ester dengan hanya ada kepingan logam. Hal ini bertujuan untuk mengkaji kemerosotan minyak ester menggunakan ukuran kerosakaan voltan dan menganalisa keadaan minyak menggunakan jumlah nilai acid yang terkandung dalam minyak ester. Semua sample perlu menjalani proses penuaan haba pada suhu 120°C selama 0, 6, 24 dan 48 jam. Ujian kerosakkan voltan menunjukkan bahawa minyak ester pada setiap kondisi mencatatkan bacaan tahap kerosakkan voltan paling tiggi pada permulaan proses penuaan haba dan ia mula menunjukkan penurunan berkala sebanyak 25% ke 32 % daripada nilai bacaan permulaan proses selepas 48 jam. Manakala, jumlah nilai acid menunjukkan keputusan kajian sebaliknya di mana minyak ester dengan kepingan logam mencatatkan bacaan tertinggi sebanyak 60% ke 106% daripada bacaan permulaan. Minyak ester dengan selulosa dan kepingan logam pula mencatatkan bacaan paling redah untuk kerosakkan voltan kerana selulosa menyebabkan kehadiran bendasing dalam minyak akan bertindak sebagai jambatan zarah untuk berlakunya kerasokkan voltage pada minyak. Sementara itu, untuk ujian jumlah nilai acid, minyak ester dengan adanya kepingan logam mencatatkan bacaan paling tinggi berbanding sample minyak ester yang lain kerana disebabkan tindak balas kimia yang menjadikan logam sebgai pemangkin untuk proses oksidasi minyak. Hubungan antara nombor jumlah acid dan kerosakkan voltan adalah nombor jumlah acid tinggi dalam cecair penebat akan menyebabkan kerosakkan voltan menjadi rendah. Hal ini kerana cecair telah dioksidasi oleh acid yang merendahkan prestasi dielektik.

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ABBREVIATION

TAN	total acid number
ASTM	american society for testing and materials
NKC	naphthenic Karamay 25 + copper
NK	naphthenic Karamay 25
PKC	paraffinic Karamay 25 + copper
PK	paraffinic Karamay 25
IEC	international electrotecnical commission
TBAH	tetrabutylammonium hydroxide
KOH	sodium hydroxide
IPA	isopropanol
KHP	potassium acid phthalate
DI	distilled water

CHAPTER 1

INTRODUCTION

1.1 Project Background

The transformer is vital equipment in the electrical power system to increase and reduce voltage to desire requirement. In manufactured, the cost to build the power transformer is very expensive. Therefore, transformer breakdown will cause economic losses and can affect power electrical system. Generally, the reliability of the transformer operates around 25 to 30 years. In practical, the life of the transformer can be as long as 60 years with appropriate maintenance[1]. However, poor service and maintenance can shorten the transformer life.

The power transformers in the power system network are mostly liquid-filled transformer. Transformer with liquid-filled contain insulating oil to serve as electrical insulation and heat transfer medium. It is well known that petroleum-based mineral oil is widely used as insulating liquid in the high voltage transformers. Mineral oil is used due to the excellent dielectric properties with low dielectric losses, high electric field strength, and good long-term performance. However, despite having these advantages, petroleum-based mineral oil also gives some critical effect to the environment. It happens when the transformer is exploding or burning where it will release the substances that will bring environmental damage to the ecosystem. Other than that, mineral oil is non-renewal sources as it extract for the petroleum. For that reason, a research should be conducted to find the alternative fuel to replace petroleum-based oil.

Ester oil has a capability as the alternative sources for transformer insulation oil. The most priority factor to choose ester oil is due to the non-toxic material characteristic which did not produce harmful material during a fire. It only releases carbon dioxide and water during the degradation process. In addition, ester oil possesses less flammable characteristic which higher high flash point above 300°C. Before it consider as alternative insulating oil to replace mineral oil, a few study must carried out to analyse the ability of the ester oil as the insulating oil in term of dielectric stress under thermal effect. In the

transformer, the copper and cellulose will become as a part of the insulating oil particle under long term transformer operation. These particles will act as impurities in the oil and will cause deterioration on the insulating oil then reduce its dielectric performance. The previous study has found that insulating oil with existence of cellulose and copper under thermal effect will gradually drop the dielectric performance due to several factors such as moisture, oxidation and impurities. Therefore, this experiment will using breakdown measurement and total acid number test for study the ester oil dielectric performance under thermal stress involving existence of copper and cellulose paper.

1.2 Problem Statement

Insulation component plays an important role in the life expectancy of the transformer. One of the insulation components is the insulation fluid used in the transformer. As well known, mineral oil is the most common oil used in the transformer for purpose of cooling and insulation. Mineral oil which derived from crude petroleum is widely used due to its low cost and its good dielectric properties. However, the performance of mineral oil starts to be limited due to the poor capability of fire safety and new requirement of environmental concerns. Mineral oil facing critiques from the electrical power industry in term of thermal performance because it has relatively low flashpoint (180°C) and fire point that will tend to the transformer burning if having fault[2]. This type of fluid is not suitable in cases in which fire risk is an important concern. Besides that, for environmental factor the mineral oil is less biodegradable, toxic in nature and hazardous in the soil and water. Extend studies has been carried out to find suitable insulating oil for electrical application. Ester oil is known as biodegradable, readily available and fire safe. It is because ester oil has high fire point (>300°C) which can reduce transformer burning during having fault. This oil also has excellent dielectric performance compared to mineral oil in term of breakdown measurement. But, before it start to applied as the insulating oil in the transformer a few experiment need to be carried out to analyse its thermal effect under real transformer condition with existing of particles such as copper and cellulose paper after the transformer has been operates in the long time. This process called thermal aging process. The purpose of the experiment is to determine its dielectric stability under thermal aging process in term of thermal performance.

1.3 Objectives

The objectives of this thesis are:-

1. To investigate the thermal effect on ester oil dielectric stress using breakdown measurements.
2. To analyse the ester oil dielectric stress under thermal effect using total acid number (TAN) test.
3. To compare the relation of thermal effect on ester oil dielectric stress under breakdown voltage and total acid number (TAN).

1.4 Project Scope

In this experiment, the scope is focusing on ester oil as insulating oil sample which is synthetic ester oil (Midel 7131). Ester oil sample used is based on the real transformer condition which existing of copper strips and cellulose pressboard. Copper strips used in the insulating oil provide information about the winding of the transformer. In this experiment, copper strips used are based on ASTM D1934 which provides 15cm length and 0.05cm thickness. While, cellulose pressboard used as the existence of the impurities that comes from the pressboard paper located between transformer winding. For this experiment, the proportion between cellulose and ester oil is 1:100 which is 5 gram for 500ml of ester oil. The ester oil taken from the barrel in the laboratory contains higher moisture level. Therefore, it needs to be removed using Karl Fisher titration method first before carried out an experiment. The experiment conducted is to study the thermal effect on ester oil dielectric stress using breakdown voltage and total acid number (TAN) test. The ester oil samples divided into three different sample conditions which are ester oil without particle, ester oil with copper strips and ester with cellulose and copper strips. Each sample has 500ml of ester oil and consists of 0, 6, 24 and 48 hour of thermal aging process at 120°C. Each hour has three different type of sample condition. After sample undergo thermal aging process, breakdown voltage was carried out based on the ASTM D1816 standard. This standard provided the experiment set up for breakdown test using electrode with gap distance of 1mm. The amount of sample used is 450ml for breakdown test and the rest is used for the next test. Then, the next test is total acid number test which conducted using IPA and KOH solvent. The procedure of this test is explained detailed in methodology part.

1.5 Significant of the study

The study is to analysing the thermal effect on ester oil under real transformer condition with existence of copper and cellulose pressboard. The sample used is divided into three groups which are ester oil without particles, ester oil with copper and ester oil with both copper and cellulose. The all sample will go through thermal aging process with different temperature. Thermal stress used for oil degradation to analyse its effect under different condition of ester oil in transformer by measuring dielectric strength and oil acidity. Thermal aging process will degrade the oil quality and reduce the performance of the transformer. It is because the thermal aging is exposing the oil to oxidize. The oxidation caused the change of oil properties where can lead to the degradation of the oil. The different period of thermal aging is used to ensure how the ester oil goes degradation process through the time. While, the sample with different condition used to measure the characteristic of the particles that will affect the breakdown voltage and oil acidity after the oil put under thermal aging process.

1.6 Thesis Outline

In this report consist of five chapters which are the introduction, literature review, methodology, result and discussion, and also the conclusion and recommendation. The first chapter is introduction including objective, problem statement of the study, experimental scope, and significant of the study. This chapter will describe the starting of the experiment procedure which is crate goal, and then a boundary of the experiment and the way of the experiment will be. The second chapter is the literature review. The related experimental topic that has been done by previous researchers is stated in this chapter. The literature was written in a simple explanation of the others study with related to the topic. The third chapter is the flow of the experimental process. It stated the overall preparation of the experiment until obtains the result. This topic is very necessary to guide a student on an experimental procedure. Next, the fourth chapter is the outcome of the experiment and the detail explains of the result obtained. The results are described in the graph and figure for better understanding. Last but not least, chapter five is conclude all the experimental results and give a suggestion on what need to for improving the experimental study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Power transformer are basic and costly electrical parts in a power system network, and the safe operation of transformers is very imperative significant to keep up the dependability of the electrical supply[3]. Power transformer's life is supposed to be extended as possible to reduce of cost money by replacing them over the years. An ideally power transformer can operate up to 40 years before failure. [4, 5]. Since the lifetime of the transformer is directly depended to the insulation's quality and it's appeared as the important issues nowadays, therefore in this chapter will explain the condition of the insulation material that affect the breakdown voltage and in term of oil acidity by measuring the total acid number[6].

2.2 Transformer oil

Transformer in electric power delivery system around the world is mostly loaded by the insulation of fluid type. As the electrical insulation fluid it is used to act as heat transfer medium in the transformer. The transformer oils are likely and generally accessible, the most broadly used electrical protecting liquids as a part of the world today and has been for a past century [7]. Almost all insulating liquid used in the transformer is petroleum-based insulating oil. The oil is refining particularly to meet the prerequisites of this application. The oil quality in the transformer is an imperative part to keep the reliability and efficiency of the transformer. Transformer oil is made up by refining hydrocarbon gathered during the distillation of a petroleum crude stock. The boiling range of the gathered part and the kind and specified degree of refining process are selected so that the resulting oil that fall within the limits specified for used in transformer. The other level of boiling fraction are utilized to make other products[8]

Transformer oil or mineral oil is well known as insulating oil because of its accessibility and low cost, and also being a magnificent dielectric and cooling medium. Since the time that the world oil stores were tapped in the 1940s, petroleum products have turn out to be broadly accessible. Petroleum-based products are so crucial matter in today's world that we cannot imagine a time we might not have them effortlessly accessible. Transformer and other oil-filled electrical equipment utilize a little fraction of the aggregate petroleum consumption, yet even this fraction is almost irreplaceable[9]. In spite of their long-time achievement, mineral oil is confronting critiques by the electrical power industry due to the thermal performance which is generally has low flash point and fire point which can exposed to the transformer burn when there occur faults. And ecological issue also be focusing because of mineral oil is less biodegradable and contain toxic in nature which can hazardous in the soil and water when there are transformer leaks. In addition, mineral oil is imperilling near hospital, high rise building and residential areas. By rising the operational temperature of the transformer because of the heavy loads for a risk assessment might cause to fire accidents and damaging large cost of financial and asset. Besides that, increasing operating temperature will cause faster deterioration of the oil/paper insulation, in this way shorting their life[2]. Therefore, a broad study has been done throughout the previous two decades to discover reasonable suitable additional dielectrics oils for electrical applications. They found that, ester oils are biodegradable, promptly accessible and fire safe. Nonetheless, aging process of mineral oil has been widely investigated in term of thermal performance, while performance of ester oil is quite obscure[10].

2.3 Ester oil

The developed of ester fluids meet the major and imperative conditions for new protecting fluids that are ecological friendliness, excellent in dielectric properties of high fire resistance and flash point. In this manner, they are extremely encouraging these fluids for use as cooling and insulating fluid in the transformer and other high voltage equipment. In Europe, synthetic ester name Midel 7131 have proven their advantageous for transformer in term of environmental and aging aspects[11].

Ester is made up from the organic compound. By and large, ester comprises of synthetic and natural ester. Synthetic ester is a product of chemical processes between acid

and alcohols through esterification process while, natural ester base is vegetable oil created from soybean, canola, corn, and so forth[12]. Figure 2.1 show the chemical structure of two type of ester which is synthetic and natural ester. Synthetic ester as shown in Figure 2.1 (a) is indicated by '-COOR' group at the end of cross structure where 'R' stands for multiple organic group and the other four organic group could be same of different. Natural ester consists of triglyceride which is contains a mixture of saturated and unsaturated fatty acid with up to 22 carbon length chains containing 1 to 3 double bonds as shown in Figure 2.1(b).

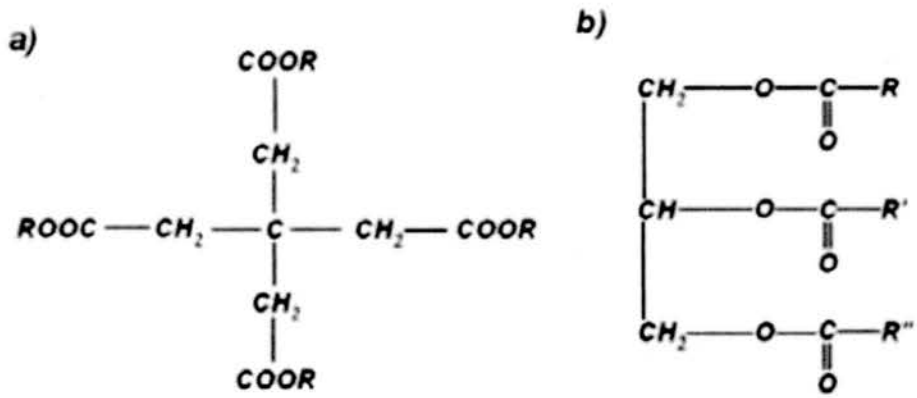

Figure 2.1: The molecular structure of ester (a) synthetic ester (b) natural ester [12]

2.4 Esterification

Esterification is a process for making ester through the chemical reaction. Esterification is the process for produce a compound structure of the R- COOR' where R and R' are from alkyl or aryl groups. The process for making ester is heating a carboxylic acid with an alcohol in the present of acid as a catalyst and removing water from the heating process as shown Figure 2.2 below. A catalyst is needed such as mineral acid for making the reaction occurs at a useful rate. There are many reactions for making ester such as including alcohols and acid chloride or anhydride. Simple alcohols such as methanol and ethanol react very fast with the acid because they are relatively small and contain no carbon atom inside them. Thusly, esterification process can deliver a huge amount of ester for satisfying the solicitation for the chemical and electrical industry[13].

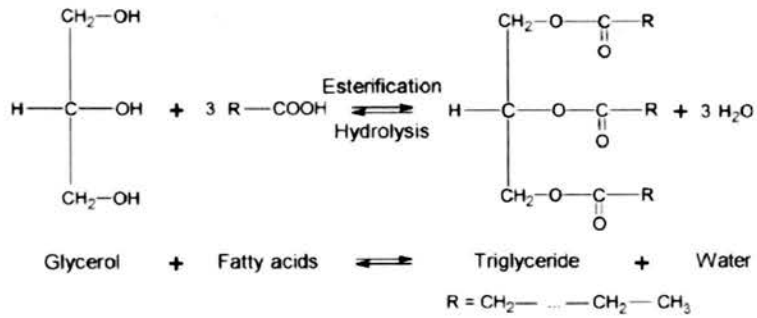

Figure 2.2:Esterification reaction[13]

Producing ester oil is not complete without process of extraction, refining and processing. Nowadays, ester oil has recently been used as a part of power electrical because of the great insulating properties.

Table 2.1 show the properties of the insulating oil for ester and mineral oil. The ester oil offers many advantages to the public society such as fire safety resistance, environment, utility cost and insulation aging advantages over the mineral oil, and is observed to be appropriate for use in transformer insulation system.

Table 2.1: Properties of mineral oil and ester oil

Criteria	**Ester oil properties**	**Mineral oil properties**
Environmental properties	Highly biodegradable, non-toxic materials.	Not degradable because it contains compounds that can hazards to the environment.
Fire risk	Safely for reduce transformer burning due to high fire point.	High probability for transformer fires because of low fire point.
Transformer performance	Can increase the life time of transformer because it ability to slow down the aging rate.	Requires special and expensive processing method to reduce insulation aging rate.
Utility cost	Low price and renewable source give the benefits of	Non-renewable sources need another alternative oil

	longer-term economic.	to replace and require additional investment for maintaining life time of transformer.

2.5 Aging of insulating oil without particles

Insulating oil without particle focus on the insulating oil either mineral or ester oil particle only without any impurities added. The aging of oil particles which exposed to the thermal stress will slowly drop its dielectric strength due to oil is exposed to the ambient surroundings.

2.5.1 Oil acidity measurement

The acidity of insulating oil is indicating the oxidation stability of the oil in the transformer. The higher acidity of oil generally will have lower breakdown due to the oil have been oxidize.

Ruijin Liao et al[14] study of the blend insulating oil comprising ester and mineral oil mixed in percentage. The mixed oil went through aging process to find out the oxidation ability of blend insulating oil. Figure 2.3 shows the acidity of blend oil and mineral oil dependence on aging time. Natural ester oil has higher acidity than mineral oil at normal condition. While mixed insulating oil consist of 20% natural ester and 80% mineral has slightly higher acidity than the new mineral oil. Therefore, this research indicates that the mixed insulating oil have better anti-oxidation ability than mineral oil in the long period of time, which leads to a slower aging rate of mixed insulating oil and a lower oil acidity.

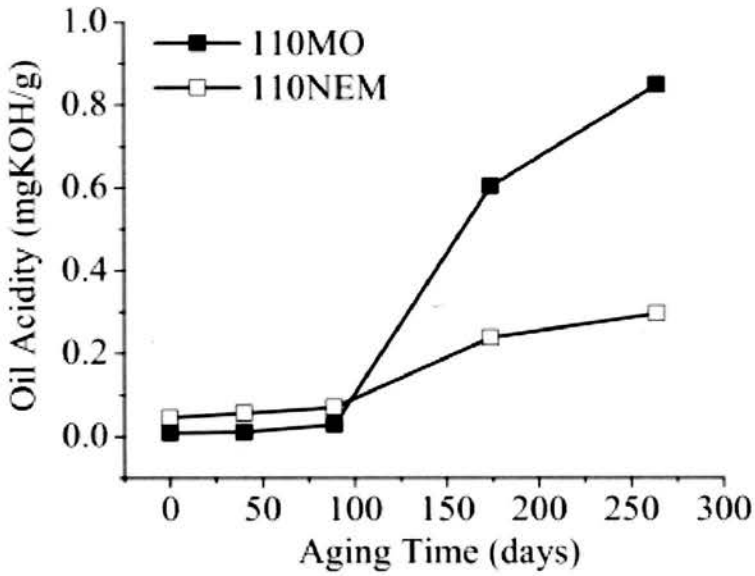

Figure 2.3:Oil acidity on thermal aging process[14]

R. Liao et al[15] discovers that the acidity of the natural ester is dependence to the aging time. The degradation of both natural ester and mineral oil will creates acids through oxidation process, so it is normal to see that the acidity of natural ester and mineral oil will rise with the aging time as shown in Figure 2.4 below. In any case, it is worthy to mention that the acidity of natural ester is extensively higher than mineral oil over the entire aging period. This is due to the natural ester degrades in the different manner to mineral oil.

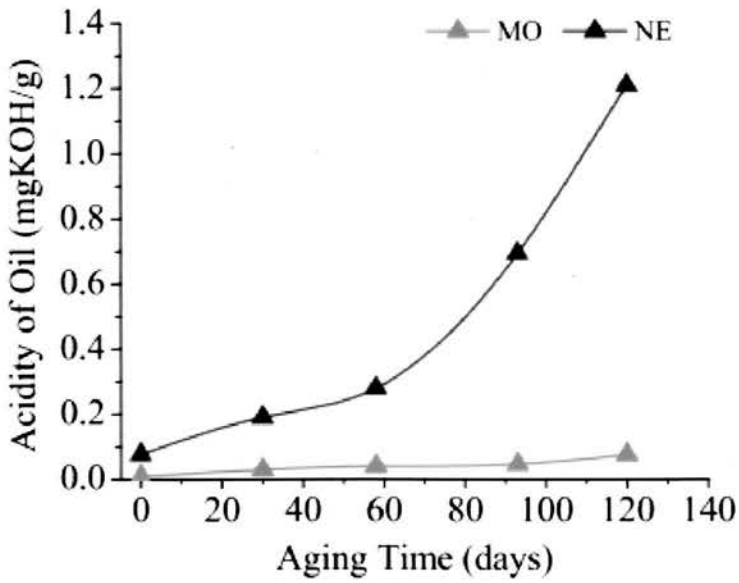

Figure 2.4:Acidity of natural ester and mineral oil in aging process[15].

2.5.2 Oil breakdown voltage

Insulating oil possesses dielectric strength capabilities to withstand on electrical stress. However, they have a limit on it. When the electrical stress breaks the limit of the insulating oil, it will become conductive material. This phenomenon is called breakdown voltage. Therefore, insulating oil, mineral oil and ester also experienced on breakdown voltage.

Based on the Myeong-Seop Shim [16] research, the breakdown voltage of ester oil is higher than mineral oil. It is because the ester oil possesses stronger dielectric strength compared to mineral oil. However, the aging time decrease the breakdown voltage of mineral and ester oil. But, in ester oil the aging oil under accelerated aging process is 15% slower than mineral oil. This because mineral oil has a faster period of decreasing on breakdown voltage with time compared to ester oil. The reason is ester oil possess higher relative boiling point and it causes the ester oil has a slow aging process through a pyrolysis process.

Qingdan Huang et al[17], agree that the aging of oil will reduce the breakdown voltage of insulating oil. Based on the experiment conducted, the mineral oil has lower breakdown voltage than the ester oil during the whole aging process. The experiment uses mixed insulating oil of mineral and ester in percentage. It can be seen that at 10% mixed insulating of ester oil show it similar breakdown voltage with mineral oil at all aged time, while 90% mixed insulating of ester oil show the breakdown voltage similar to ester oil at all aged time. For better understanding, the Figure 2.5 shows the graph of the breakdown voltage against aging time for mixing insulating oil. After aging, the breakdown voltage of ester oil (100%) is decrease about 20% lower than initial value. While mineral oil (0%) is showing the uncertainty graph from its initial value.