INVESTIGATION OF KRAFT INSULATING PAPER PROPERTIES UNDER ACCELERATED THERMAL AGEING ENVIRONMENT

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DECLARATION

I declare that this thesis entitled “INVESTIGATION OF KRAFT INSULATING PAPER PROPERTIES UNDER ACCELERATED THERMAL AGEING ENVIRONMENT is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

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Date : 30 MAY 2019

APPROVAL

I hereby declare that I have checked this report entitled "INVESTIGATION OF KRAFT INSULATING PAPER PROPERTIES UNDER ACCELERATED THERMAL AGEING ENVIRONMENT" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

I dedicate this project to almighty god, Allah S.W.T as always give me inspiration in doing this project. I also dedicate this project to my beloved mother who always encourage me all the way in the project and my studies. Not forgotten, I also would like to dedicate my project to my friends and lecturers that always give me support and sharing idea when implement this project. Lot of love for everyone of you from me. Thank you.

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ABSTRACT

Insulation material in power transformer is very crucial in protecting the material inside the transformer itself. Majority of transformers failure are caused by the insufficient protections that were provided by insulation material itself. When the power transformer operated, presence of moisture content, acidity and oxygen in the transformer can manipulate the properties of the insulation material. Therefore, this project is aim to investigate the most ideal combination between insulating paper and three types of insulating oil types in terms of their acidity, moisture content for insulating oil and tensile strength and colour change for insulating paper after thermal aging process happen. The paper be combines with the different types of insulating oils and be put in the oven to act as accelerated thermal aging process. The accelerated thermal aging be at 110 and 130 degree celcius and were run for 750 hours. The samples with different combination of insulating materials be removed from the oven every 250, 500 and 750 hours. The standards by ASTM were used along this project were implemented as guidance for every tests that had been made. After the samples were collect for different 250 hours duration of time, they go on test to check for their moisture, acidity, UV-Vis for insulating oil while tensile strength and colour changed for insulating paper. After all the samples be removed and tests, the data for the test will be analyze before the combination that have high quality to be the most suitable combination of insulating material will be suggest to be use in the power transformers.

ABSTRAK

Bahan penebat dalam transformer kuasa sangat penting dalam melindungi bahan di dalam transformer itu sendiri. Sebahagian besar kegagalan transformer disebabkan oleh perlindungan yang tidak mencukupi yang disediakan oleh bahan penebat itu sendiri. Apabila pengubah kuasa dikendalikan, kehadiran kandungan kelembapan, keasidan dan oksigen dalam pengubah boleh memanipulasi sifat-sifat bahan penebat. Oleh itu, projek ini bertujuan untuk menyiasat kombinasi paling ideal antara kertas penebat dan tiga jenis minyak penebat dari segi keasidan, kandungan lembapan dan kekuatan tegangan selepas proses penuaan haba berlaku. Kertas akan digabungkan dengan pelbagai jenis minyak penebat dan akan dimasukkan ke dalam ketuhar untuk bertindak sebagai proses penuaan terma yang dipercepatkan. Penuaan terma yang dipercepatkan ialah dalam keadaan 110 dan 130 darjah Celsius dan dijalankan selama 750 jam. Sampel dengan gabungan bahan penebat yang berbeza akan dikeluarkan daripada oven setiap 250, 500 dan 750 jam. Piawaian oleh ASTM digunakan sepanjang projek ini telah dilaksanakan sebagai panduan bagi setiap ujian yang telah dibuat. Setelah sampel dikumpul untuk setiap 250 jam masa yang berlainan, sampel akan menjalani ujian untuk memeriksa kelembapan, keasidan, UV-Vis untuk penebat minyak dan kekuatan tegangan dan perubahan warna untuk penebat kertas. Setelah semua sampel dikeluarkan, data untuk ujian akan dianalisis sebelum kombinasi yang mempunyai kualiti yang tinggi untuk menjadi gabungan bahan penebat yang paling sesuai akan dicadangkan untuk digunakan dalam transformer kuasa.

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LIST OF SYMBOLS AND ABBREVIATIONS

PFAE	-	Palm Fatty Acid Ester
TAN	-	Total Acid Number
ASTM	-	American Society For Testing and Material

CHAPTER 1

INTRODUCTION

1.1 Overview

A research background, problem statement, project objective and scope of the project were discussed in this chapter. The purposed of the project were exposed in the project background. The problem statements were a short brief about the issues what to avoid and to be solved. The purposed and goal of the project were explained in objective and scope of the project.

1.2 Research Background

Nowadays, the electrical power is really important in daily lives to start up the electrical appliance in surrounding. Power transformer is the most valuable appliance in terms of delivering the electrical power. Transformer is device that can changes the level reading of electricity. The lifetime of insulating material in the transformers can affect the electricity that is distributed in the system. Unexpected failure of transformer can occur after long run in-service which can cause highly loss and cost to company that provide the electrical power to consumer.

Thus it is important to slow down the process of aging occur in transformer by study the insulation conditions in the transformer. Insulation can involve in three forms; gas, solid and liquid. This project focuses on liquid and solid insulations in transformer. The function of liquid insulation that is transformer oil is to provide the cooling effect by dissipating the heat between the core and coils to radiator [1].The function of solid insulation or insulating paper is to create turns of wire which can build emf on each turn contributing to the total emf between end terminals.

When in operating condition, power transformers can suffer from the thermal process. The thermal process accelerates the process of aging in the transformer and potentially can be a threat to the safety of the power transformer. Aging process can cause the material properties of the power transformer changed. Generally, the operate temperature of power transformer need to be control by reducing the temperature using different type of insulating oil. The type of insulate paper also need to use different type so that the life span of insulating paper can be increase. So, a study to improve the lifetime of insulating paper needs to carry out by controlling the type of paper and type of oil of the transformer.

1.3 Problem Statement

Damage in power transformer will cause interruption in the process of electrical distribution system network. Mostly of damage in transformer happen because of the insulation problems in the transformer itself. The dielectric insulation problem can be in several factors such as moisture, acidity and many more. This problem can decrease the lifespan of the transformers and the users need to invest lot of money to repair them. Thus this project will focus on comparison of the insulation properties of different type of insulating oil including the tensile strength of the insulating paper. It is quite important to choose the most suitable combination of the insulating material in power transformers because not only it can increase the lifespan, it also can increase the efficiency of the power transformers. Based on the research by Stefan Tenbohlen in 2008, he only focused on different type of insulating oils with a type of insulating paper. Moreover, there are no researcher that making research about which combination of different types of oils and insulating paper is the most suitable to be use in power transformers. Therefore the aging using high temperature are carried out to act as the process of thermal aging in the transformer. The aging process using the Stefan Tenbohlen method were choose before the test on properties of the insulations can be carry on.

1.4 Objective

The purposes of the projects are:

1. To investigate the insulation behavior and properties of insulating materials under accelerated thermal aging process.
2. To analyze the relation in insulation properties between different combination of insulating oil with Kraft paper after different period of aging process in different temperatures.
3. To obtain the optimum combination of insulating material based on tensile strength and structural of the Kraft paper after different period of aging process in different temperatures.

1.5 Scope Of Work

The scopes of the research are:

1. Three different types of insulating oil that are used in this experiment are PFAE, Midel En and Gemini-X while insulating papers that were used was Kraft paper.
2. Accelerated thermal aging process are run for 750 hours at 110 Celcius and 130 Celcius and the sample were collected every 250, 500 and 750 hours.
3. The tests that were done after aging process are to check moisture, acidity and UV-Vis for insulating oils while tensile strength and structural test for insulating paper.

1.6 Research Contribution

The research were expect to help the power transformer user choose the best type of insulating paper and type oil to be used in their transformer in term of solid insulation for winding. The decisions are to compare the insulation characteristic after the aging process using Stefan Tenbohlen technique. The role of temperature was to stimulate the process of aging. When the temperature was increased, the aging process of the insulation materials in transformer also increased including the moisture content. The moisture content can manipulate the properties of oil and degradation rate of paper.

1.7 Thesis Outline

This project report consisted of five chapters. Chapter 1 briefed about the background, problems, objectives and scope of the project. In Chapter 2, the theories and some knowledge that related to the project were explained. Next, Chapter 3 described the methodologies that were used to get the result of the project that were run. Chapter 4 illustrated and interpreted the result that has been received when project were carry on. Lastly, Chapter 5 was the conclusion that has been concluded throughout this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed about theory of power transformer**,** characteristic of insulation material, type of oils that were used in power transformer, type of insulating paper used in power transformer, aging process and method of analysis that were used to monitoring the condition of insulation in power transformer.

2.2 Power Transformer

Power transformer is a device with two or more winding which by electromagnetic induction, transform a system of alternating voltage and current into another system voltage or current with different value but have same frequency for the purpose if transmitting electrical power **[2]**. When electric current flows through a wire, it generates a magnetic field or magnetic flux along the wire. The strength of magnetic flux density is related to the size of the electric current that flow. The bigger the current , the stronger the magnetic field. Current in the wire will generate electric when magnetic exists around a piece of wire. So when there is a second coil of wire next to the first one fluctuating electric current were send into the first coil, we will create an electric current in the second wire. The current in the first coil were called as the primary current and the current in the second wire is the secondary current. What we've done here is pass an electric current through empty space from one coil of wire to another through a process of electromagnetic induction where the current in the first coil induces the current in the second coil. We can make electrical energy pass more efficiently from one coil to another by wrapping them around an iron core. To make a coil of wire, just simply curl the wire round into loops. If the second coil has the same number of turns as the first coil, the electric current in the second coil will have the same size as the first coil. But if primary coil have more of turns in the second coil, we can make the secondary current and voltage bigger than the primary current and voltage. Figure 2.1 shows the structure of power transformer while Figure 2.2 illustrates the winding at a coil of transformer.

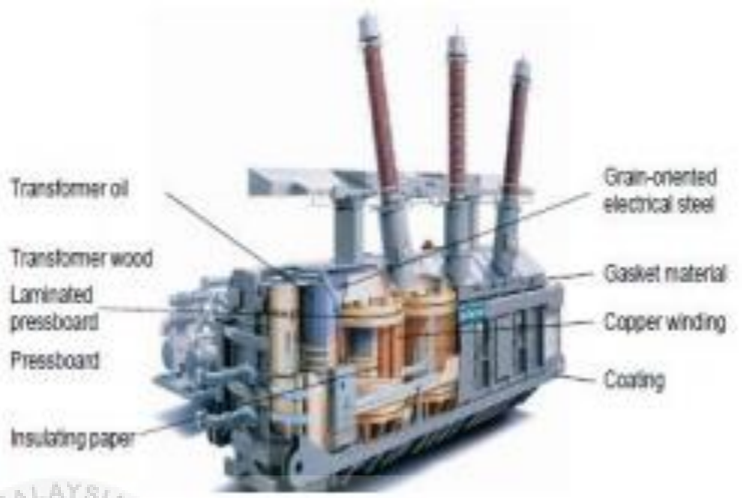


Figure 2.1: The structure of power transformer

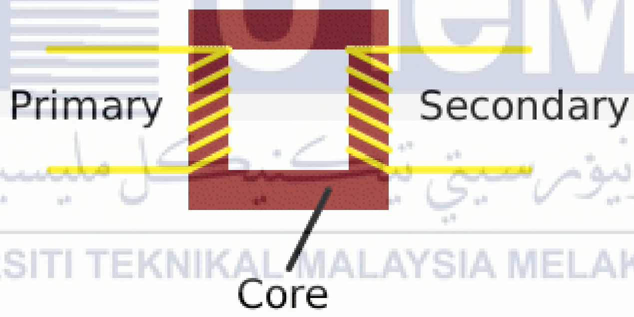


Figure 2.2: The winding at core in transformer

2.3 Insulation Material in Power Transformer

The lifespan of the power transformer depend heavily on the insulation system. The insulation system in power transformer can be consists of liquid, gas and together with the solid material [3]. The insulation material must have good insulating properties to protect the component in the power transformer from damage. The large power transformer is subjected to has different characteristic due to demand of the users. So, the insulation in transformer had to be modeled properly according to the characteristic of the transformer itself

2.3.1 Liquid Insulation

The liquid insulation in transformer is known as the transformer oil. The transformer oil in the power transformer is used to dissipate the heat from the transformer. Oil that used in the transformer are produce from special grade of the petroleum oil and ester oil that had different level of viscosity and specific gravity **[4]**. There are three groups of transformer oil that usually used such as mineral oil, synthetic oil and ester oil as shown in Figure 2.3. This project only focused on mineral oil and two types of ester oil.

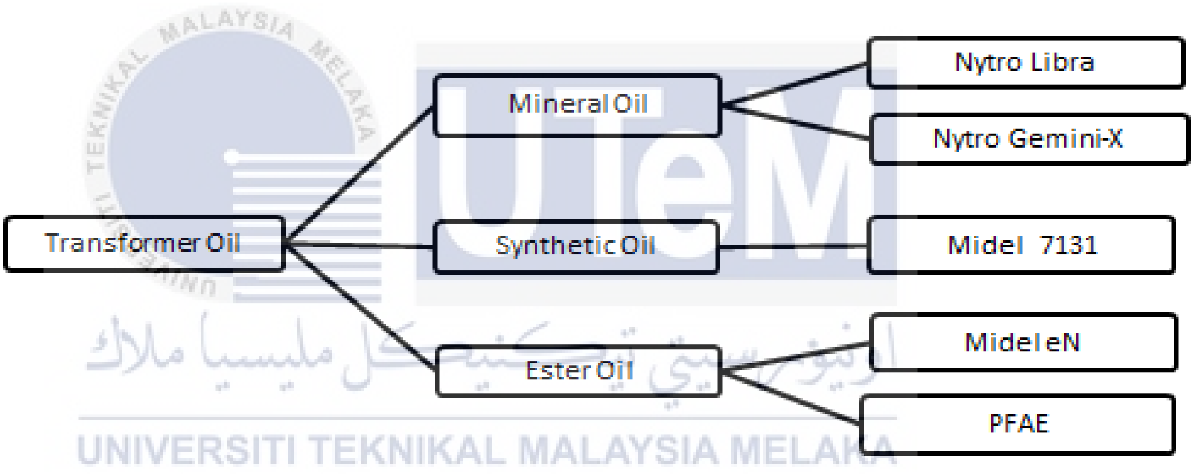


Figure 2.3: Type of transformer oil

2.3.1.1 Mineral Oil

Mineral oil need to be right away refined from the prevalently naphthenic crude oil before it can be used as a part of electrical assembly. Distillates from the crude oil can be refined with different procedure such as dissolvable extraction, hydro treating or hydro cracking. Transformer oil is a mixture of paraffinic, naphthenic, and aromatic hydrocarbons as shown in Figure 2.4 that is prone to oxidation.

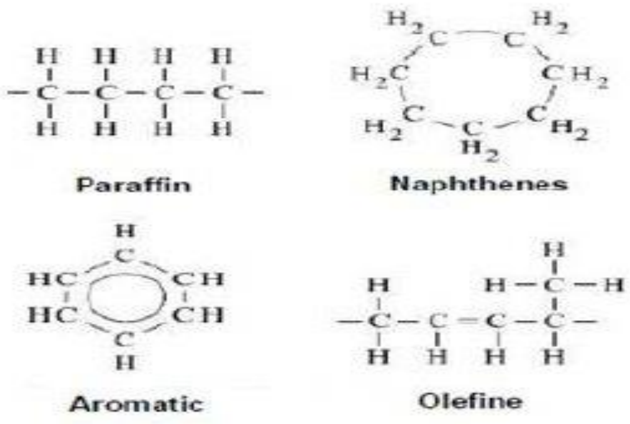


Figure 2.4: Hydrocarbon structure of mineral oil [14]

Oxidation of the oil leads to formation of more polar compound such as acid, ketone and alcohol. These not only can affect the insulating properties of the oil but also will form sludge that can affect the heat transfer properties of the mineral oil. This can manipulate the performance of power transformers including reducing the life span of the power transformer itself **[5]**. So, it is quite important to check the condition of the power transformer by monitor their solid and oil insulation properties. Some example of mineral based insulation oils that available in the market are Hirax, Nytro Libra and Nytro Gemini-X.

2.3.1.2 Natural Ester

Natural Ester is a vegetable oil type. These oils are normally integrated from living life forms and come specifically from soya, sunflower, or rapeseed. In particular, natural esters are made from an esterification response between a tri-liquor and fatty acids. Different procedures permit the last item to be acquired by the trans-esterification response or a blend of mono and tri-esters **[6]**. Since the middle of the 1990 and on account of ecological concerns, a great deal of studies were propel for the advancement of vegetable oils. These days, its utilization begins to be escalating in the distribution transformer market and the test of these in a year from now is to extend its utilization to the power transformer user. In any case, with natural issues now turning out to be critical, the utilization of an item with a high fire point temperature and high biodegradability is turning out to be amazingly appealing.

In this way, the latest accessibility of characteristic ester liquids in view of "renewably sourced" vegetable oils have given another insulating liquid to use with transformers.

2.3.2 Gas Insulation

Gas insulation is air at the atmospheric pressure. Collisional ionization between the free electron and gas molecule will result an occur breakdown in gasses. Insulating gases are chosen based on their chemical inertness and stability. Nitrogen (NS), carbon dioxide (CO_2), Freon (CCL_2F_2) and sulphur hexafluoride (SF_6) are some of insulating gases. A vacuum condition is an ideally condition, where collisional ionization is prevented due to absence of gas molecule. Hence, significantly large breakdown voltages occur for ideally condition [7].

2.3.3 Solid Insulation

A material must have good mechanical and bonding strength before it can be choose as solid insulation in power transformer. There are two type of material that usually used that is organic and inorganic material. Solid insulation inside the power transformer is the largest insulation in electrical equipment. It can be in form of Kraft paper (electro-technical), thermal upgraded paper and pressboard as shown in Figure 2.5. Some of the functions of solid insulation are electrical insulation, direction of oil flow and the mechanical stability. Aging can occur in solid insulation and can affect the electrical and mechanical properties of the transformer. Temperature, water and oxygen are the caused why aging can occur.

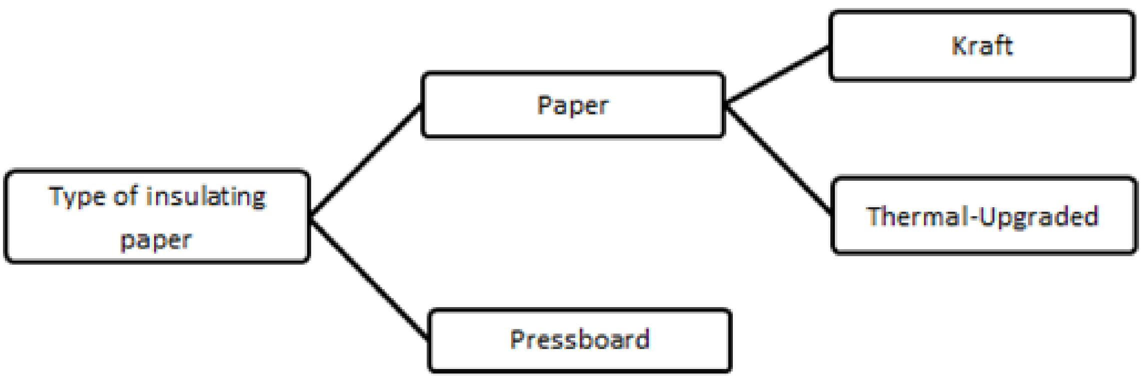


Figure 2.5: Type of insulating paper

Figure 2.6 shows the Kraft insulating paper in transformer that is used to separate each winding and to cover the conductor. Each insulating paper has different densities and structure depends on the type of transformer application while pressboard is used for insulation in high voltage transformer that is filled with liquid insulation **[8]**.

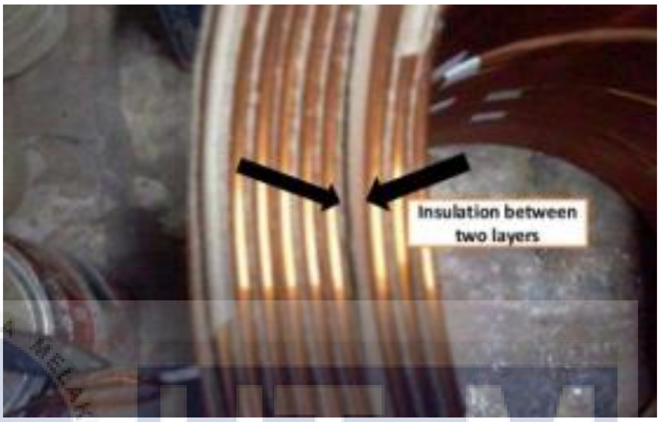


Figure 2.6: Kraft paper insulate in winding

2.4 Transformer Oil Properties

Transformer oil is perfect for supply the cooling performance and minimizing the electrical clearance in an assortment use. It is really important to know the properties and the effect of different factor of transformer oil when making the right decision to be used in the transformer.

2.4.1 Total Acid Number

Transformer oil can oxidize by extreme temperature with the presence of oxygen. This can increase the acidity by creation of carboxylic acid. The acid can degrade the insulating paper in the transformer and form varnish. Oil degradation creates byproduct such as acid and hydro-peroxide as example that can decrease dielectric quality. The oil will starts aging once it is inserts into the transformer. The oil is subject to react with the heat, moisture and oxygen in the transformer. When it is reacts with each other, the oil will oxidized and develop the sludge, acid and oxidation products such as ketone, peroxide and alcohol. Acid content is proportional to the absorbed amount of oxygen by the oil. The peroxide that is form can react with the insulation paper and the oil itself.

2.4.2 Moisture Content

Although in just little amount, moisture is harmful to power transformer due to water is pull into spot of the electrical stress where it has the adverse effect. The deterioration of both insulating oil and insulation material utilizes inside the transformer become quicker with the presence of moisture. More moisture will deliver when the deterioration is start. This is a self-supporting cycle and once the paper has been degraded, it can never come back to its original condition. Moisture either all alone or in conjunction with cellulose particles likewise adverse can affect the dielectric properties of oil. Free water can be produce in the transformer when concentration is sufficiently high and can bring to electrical breakdown. Because the majority if the moisture in the transformer situated in the paper, the removal of moisture quite not effective without remove the moisture in the paper although moisture can be expel from the oil.

2.4.3 UV-VIS

UV-Vis absorption spectroscopy is a measurement of weaken of light after it pass through a sample surface. Light in UV-Vis has energy to promote the outer electron to different energy sublevel. The technique to measure UV-Vis usually was applied to molecules or inorganic complexes in a solution. The measurement of the wavelength can be single or extended spectral range. This measurement was very useful for quantitative measurement of sample identification. Concentration in the solute can be determined by measure the wavelength that were absorb and applying the Beer-Lambert Law [9].This can help to determine the coefficient of the pureness of a substance.

2.5 Tensile Strength

Tensile strength is the maximum load that a material can resist without broken when the force or stress are being exerted on it. The calculation for the tensile strength is load were divided by the cross-sectional area of the material and usually expressed in unit of ppi. A material will change to its original shape when the stress exert on it were less than tensile strength. But, if the stress exert were bigger than the tensile strength, a material can be broken or ductile **[10]**.

2.6 Thermal Aging

The thermal continuance of insulating materials is important for use in any application. Utilization of the particular protection in a specific application must be conformed to the strict temperature administration of electrical equipment. Subsequently the insulating materials characterization into thermal classes and accelerated ageing systems to decide the properties were introduced. Insulating materials amid an operation time are presented to adverse climatic effects, surrounding temperature changes in a generally wide range and temperature brought on by material power losses. Temperature changes influence the mechanical, electrical furthermore another physical and chemical properties of the protecting materials. At much higher temperatures, these materials enter into fluid state. The electrical properties are then generally and electric strength will decrease

Figure 2.7 shows the total acid number (TAN) as a function of aging period using three types of oil, which is natural ester, mineral oil and silicone oil. The sample was subjected to thermal ageing at 120oC and 150oC for 336 hours, 762 hours and 1008 hours aging time [19]. Before aging begins, the acidity of natural ester is the highest among other samples while silicone oils are the lowest. Under thermal aging, the pattern has stayed consistent. After thermal aging occurs at 150oC for 1008 hours, the acidity of natural ester is around 0.5 which is the most higher and the acidity of silicone oil, aged at 120oC at a similar duration is around 0.3 which is the lowest value among the samples.

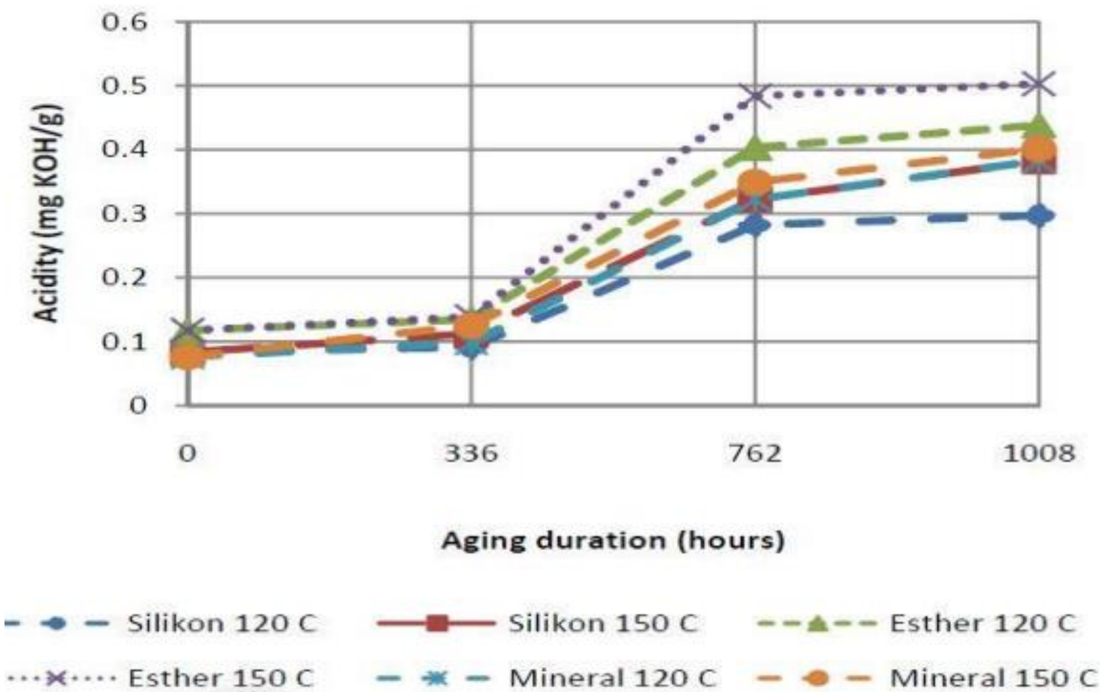


Figure 2.7: TAN to aging period [15]

Figure 2.8 shows the different of moisture content for vegetable oil and mineral oil in with aging time. From the figure, moisture content in vegetable oil is higher than mineral before and after the aging period for 80 days. It is because the vegetable oil has higher moisture than mineral oil [21].

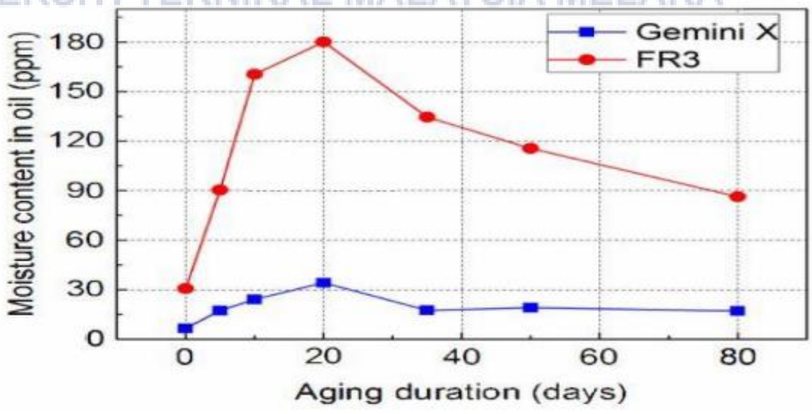


Figure 2.8: Moisture content in oil during aging period [16]

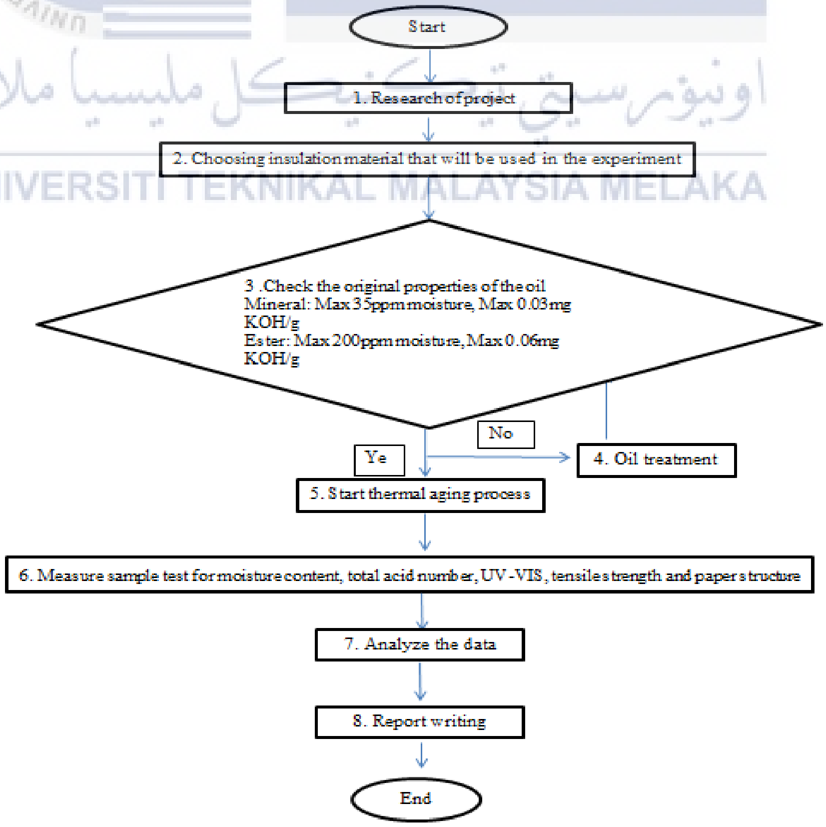
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter were discussed the overall flow when the project was implemented. The flow chart of the project was included as a guideline that leaded to the investigation of project until reached the result of the project. This part discussed about the method that had been suitable utilized to be used as part of the project to conduct experiments on how temperature can affect aging that can manipulate the properties of insulating material in transformer.

3.2 Flowchart of Project



3.2.1 Research of Project

The purposed of this step was to study and collect information about the properties of the insulating materials in transformer included the aging process. There are two type of transformer oil which is mineral oil and vegetable oil that available in our lab facilities. While for the insulating paper, there only had normal Kraft that available in the lab. These insulating materials were going through thermal aging process before it can be test for moisture content, acidity and UV-Vis for transformer oil while tensile strength and structural test for insulating paper. So, this chapter were explained all the actual flew process of the project were implemented.

3.2.2 Choose Insulation Material That Will Be Used in Experiment

There are different types of oils and papers that available in the lab facilities. Each type of oils and papers had different of original insulating properties. There are three types of oil were used that are a type of mineral oil and two type of ester. For mineral oil, Gemini-X was chosen. While for Ester, Midel EN that from vegetable based and PFAE that from palm based were chosen. For insulating paper, normal Kraft paper was chosen to be used in this project.

3.2.3 Check the Original Properties of Oil

Before the thermal aging experiment can be implement, it was really important to check the original properties of the oil that were chosen to be used as sample in the experiment. Although the oils come as fresh oil when it was buy, it actually has been stored unused for a long period of time in the lab. Therefore, the original properties of the oils may not same with the standard and the experiment cannot be proceeds. This situation can happened due to original aging phenomenon or the oils are not seal properly. In order to improve the oils properties as the quality of new oil, oil regeneration process will be a main concern for all specialist **[11]**.

All properties of transformer oil must fulfill the requirement specified by the standard used. This experiment entirely follows the ASTM standard for Water in Insulating Liquids by Coulometric Karl Fischer Titration (ASTM D1533), and Acid and Base Number by Color Indicator Titration (ASTM D974). If there are not satisfied the standard, transformer oil treatment needs to be done. Table 3.1 below shows the original properties of transformer insulating oil.

Table 3.1: Original Properties of Transformer Insulating Oil

Parameter	ASTM D3487	ASTM D6871
	Mineral Oil	Vegetable Oil
Appearance	Clear	Clear
Water Content (ppm)	Max = 35	Max = 200
Acid Number (mg KOH/g)	Max = 0.03	Max = 0.06

3.2.4 Oil Treatment

The oil treatment needs to be process if the oil did not reach the criteria that were set by the ASTM standard. The properties of the oil can changed due to aging and oxidation in the place that the oil was stored. The purpose of the oil treatment was to regenerated the oils go back to their original properties when it was make so that there are no problem occurs when the experiment for aging process were implement.

<u>Procedure for insulating oil treatment</u>

1. Insert the total oil that will be used in the experiment in the beaker.

2. Insert the nitrogen gas into the oil until it has big bubbling.

3. Stay the gas in the oil for 30 minutes.

4. Test the oil for moisture test.

5. If the oil not exceeds the ASTM standard, aging process can be implemented.

6. If the oil exceeds the ASTM standard, repeat the process for 10 minutes until it reach the qualified standards.

Figure 3.1: Nitrogen injection process

3.2.5 Start Thermal Aging Process

Ensured that the oils followed the criteria in ASTM standard before this process be implemented. Each sample for experiment was combined with different type of oils and papers. Each sample will have 100mL of a type of oil, 25cm of Kraft paper, 0.25g of copper, 0.25g of iron, 0.05g of aluminium and 0.05g of zinc. These metal substances were named as the catalyst in the aging process. The samples that contained different combination of insulating material were collected each 250, 500, 750 hours. The experiments were carried out in stages and the procedures for the experiments were prepared so that the flows of the experiment were in the right step. So there are total of 18 samples for this process.

Procedure for thermal aging process

1. Measure 100mL of three different type of oil. Each type of oil need to be measured for six samples.

2. Measure 25cm of Kraft paper. Total of paper need to be used will have 12 samples.

3. Weigh the metal substance and wrap it into same filter paper for each substance so that looks like a tea bag. Do it for 18 samples

.

Figure 3.2: Weigh the metal catalyst

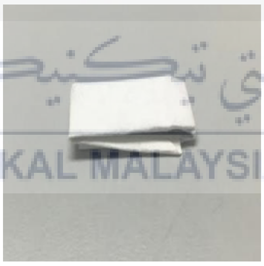


Figure 3.3: Wrap the metal catalyst

4. Put each sample in Step 2 and Step 3 into 400mL borosilicate bottles.

Figure 3.4: Borosilicate bottle

5. Let the mixed samples in the Step 5 in rest condition for at least 24 hours.

6. Insert all the samples into the oven that already heated for 110 and 130 Celcius and were set for 750 hours after the Step 5 has finished.

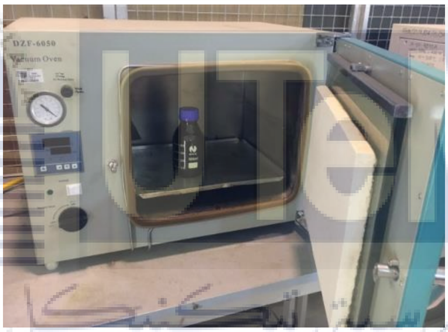


Figure 3.5: Put the sample into oven.

7. Take out the samples that have different combination of insulating material every 250, 500 and 750 hours.

8. Each sample that has been removed from the oven need to be left overnight until it reaches room temperature.

9. The samples are ready to be test after the Step 9 has been finished.

3.2.6 Measure Sample Test for Moisture Content, Total Acid Number, UV-Vis, Structure And Tensile Strength of Paper.

The samples must finish all the procedures in thermal aging process before it can be test in term of their insulating properties. For the oils, it was test on three properties that are moisture content, total acid number and UV-Vis. Meanwhile, the papers are test based on the properties of tensile strength. All tests must follow the standards that were set by ASTM standard.

3.2.6.1 Test for Moisture Content

This method was used to measure moisture contents in the insulating oil by using Karl Fischer titration according to ASTM D1533 standard.

<u>Procedure to measure moisture in insulating oil</u>

1. Fill a syringe with the oil until it is full and make sure no air bubble is presence in the syringe as shown in Figure 3.6.

Figure 3.6: The syringe is full filled with oil

2. The syringe that is filled with oil need to be weight to know the mass of sample used as Figure 3.7.

Figure 3.7: The syringe that is filled with oil were weigh.

3. Add 1mL of oil sample from the syringe into KFC equipment as the equipment show “Conditioning OK” on the screen as shown in Figure 3.8 and Figure 3.9. (*Make sure that the beaker not in contact with the oil sample when insert into the equipment).

Figure 3.8: KFC equipment showing “Conditioning OK”

Figure 3.9: The oil were inject into KFC equipment

4. Weight the syringe after 1mL of oil had been injected as shown in Figure 3.10.

Figure 3.10: Weigh the mass of the syringe after 1mL of oil were inject into KFC.

5. Insert the mass of the oil injected and wait until the KFC equipment shows the moisture content reading at the screen as shown in Figure 3.11.

Figure 3.11: The KFC equipment showing the moisture content at screen.

6. Repeat Step 3 to Step 5 until get three reading of result for each type of oil samples.

3.2.6.2 Test for Total Acid Number

This method was used to measure total acid number or acidity in the insulating oil by using Karl Fischer titration according to ASTM D974 standard.

<u>Procedures to measure total acid number (TAN) in insulating oil.</u>

Before determine the total acid number, the equipment need to calibrate to it original properties first. The steps are:

1) Calibrate the electrode with three types of buffer solution that has different pH values that are 4,7,9.

2) Standardization = to check the original concentration of KOH in IPA 0.1mol/L

3) Blank = to check the acid contain for solvent (20mL IPA)

4) TAN = to check the sample of Total Acid Number (TAN)

<u>TAN procedures:</u>

1. Weight 5g of oil in syringe for each sample as shown in Figure 3.12.

Figure 3.12: 5g of oil were weigh in a syringe

2. Measure 20mL of propanol in beaker as shown in Figure 3.13.

Figure 3.13: 20mL KOH were measured in a beaker.

3. Inject the oil in syringe into beaker contain propanol shown in Figure 3.14.

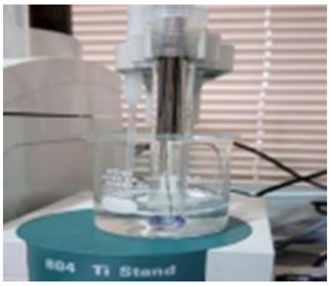


Figure 3.14: The oil was put into beaker contain propanol

4. Choose TAN method at the screen of titration as shown in Figure 3.15.

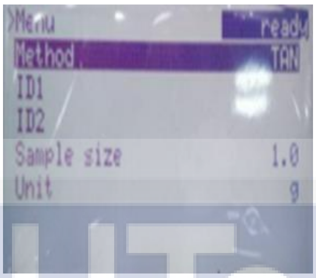


Figure 3.15: Choose TAN method

5. Insert the mass of oil, press start and let it automatically stir as Figure 3.16.

Figure 3.16: The sample were automatically stirred

6. Record the reading for acidity that was shown at the screen as shown in Figure 3.17.

Figure 3.17: The TAN reading for the sample

7. Repeat Step 1 until Step 6 for three reading for each oil sample.

3.2.6.3 Measure Sample Test for UV-Vis

This method was used use to determine the decay in the insulating oil. It can e determined by calculated area under the graph by using trapezium formula.

<u>Procedure to measure UV-Vis</u>

1. Set up UV Spectrophotometer and connect with the computer. (Open UVProbe application).
2. Put the oil sample in the cuvette and insert into UV Spectrophotometer.

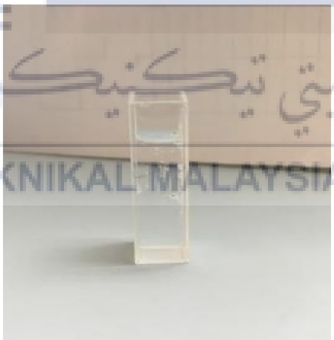


Figure 3.18: Oil in cuvette

Figure 3.19: Cuvette were placed on UV-Spectrophotometer

3. Press start button on the screen and the result were shown in few minutes.
4. Take the reading/measurement.
5. Repeat the step with another oil sample.

3.2.6.4 Measure Sample Test for Tensile Strength og Insulating Paper

This method is used to measure the tensile strength of the papers. All the procedures need to be verified by using the standard that is set by British Standard BS 4415-1

Procedure to measure tensile strength of paper

1. Cut test piece of the paper with a long of 15mm and long enough to be clamped in the clamp.
2. Adjust the clamps to the required initial test length and place the test piece in the clamp.
3. Ensure that test piece is clamped in such manner that parallel to direction of tensile force.
4. Commence test it until the test piece is break.
5. Take the reading how much tensile force need to break the test piece.
6. Repeat this step for all paper sample that going aging process.

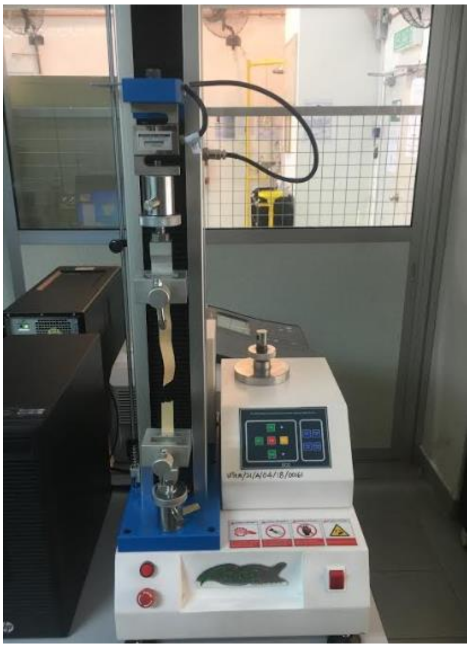


Figure 3.20: Test of tensile strength on insulating paper

3.2.6.5 This test was implemented to compare the changed in colour of insulating paper.

<u>Procedure</u>

1. Cut test piece of the paper with a long of 25cm and long enough to be clamped in the clamper.
2. Adjust the clamps to the required initial test length(20cm) and place the test piece in the clamper.
3. Ensure that test piece is clamped in such manner that parallel to direction of tensile force.
4. Continues test it until the test piece is break.
5. Take the reading of tensile force need to break piece.
6. Repeat this step for all paper sample that going aging process.

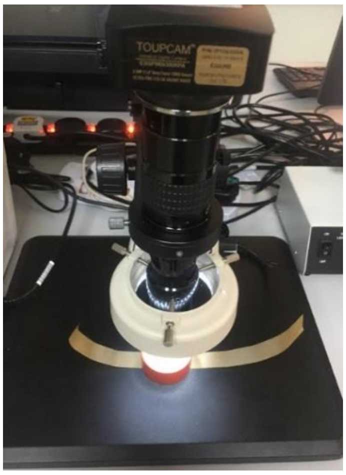


Figure 3.21: Test on structure of insulating paper

3.2.7 Analyzed the Data

The data from the test will be analyzed to determine the effect of thermal aging process on insulating oil and insulating paper based on their moisture content, acidity, UV-Vis and tensile strength. The analysis of the experiment should relate to objective of this research. Then conclusions on which the most ideal combination of insulating material can be made after the result from the sample were compared.

3.2.7.1 Analyzed Data for Insulating Oil

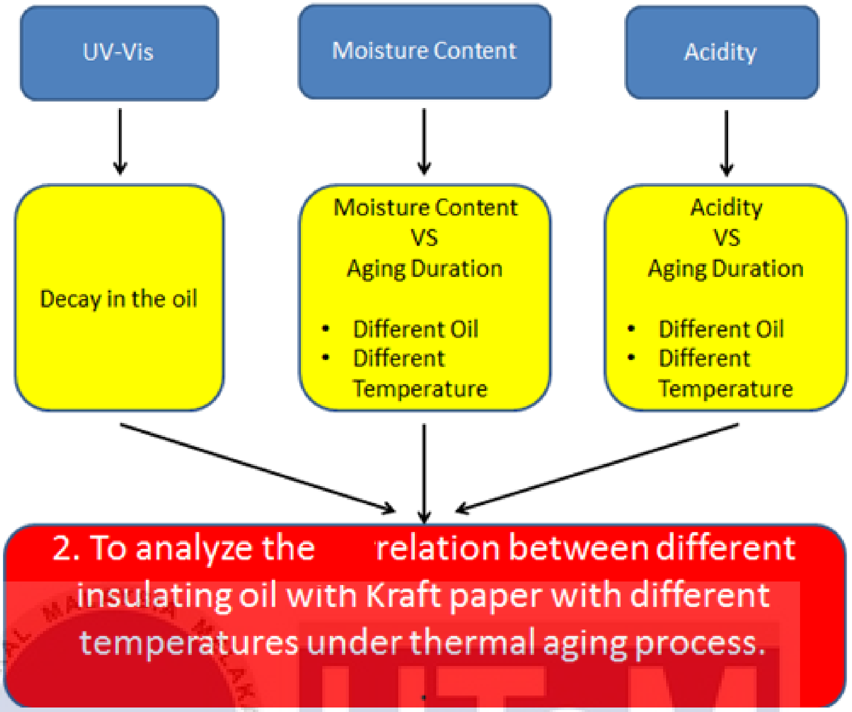


Figure 3.22: Step to analyze data for insulating oil

In UV-Vis test, the oil samples were analyzed for decay in insulating oil after the samples finished the thermal aging process. The decay of the oil can be analyzed by seeing the rate of light absorb by the oil. If the absorbent of light in the oil was high, it means the decay of the oil also high. For moisture content test, the results were put in Moisture Content VS Aging Duration graph. The differences of moisture content can be seen by using the graph. The insulation oil that has low moisture content can be chosen as the most good insulation oil to be used in the transformer. For acidity test, the result was put in Acidity VS Aging Duration graph. The analysis of differences in value of acidity between the insulation oils can be easily seen using the graph. The insulation oil that has low acidity value was the most good insulation oil to be used in the transformer. As conclusion, all of the tests above are to ensure that the tests reached the objective number two of the project that was to analyze the relation between different insulating oil with Kraft paper in thermal aging process with different temperature.

3.2.7.2 Analyzed Data for Insulating Paper

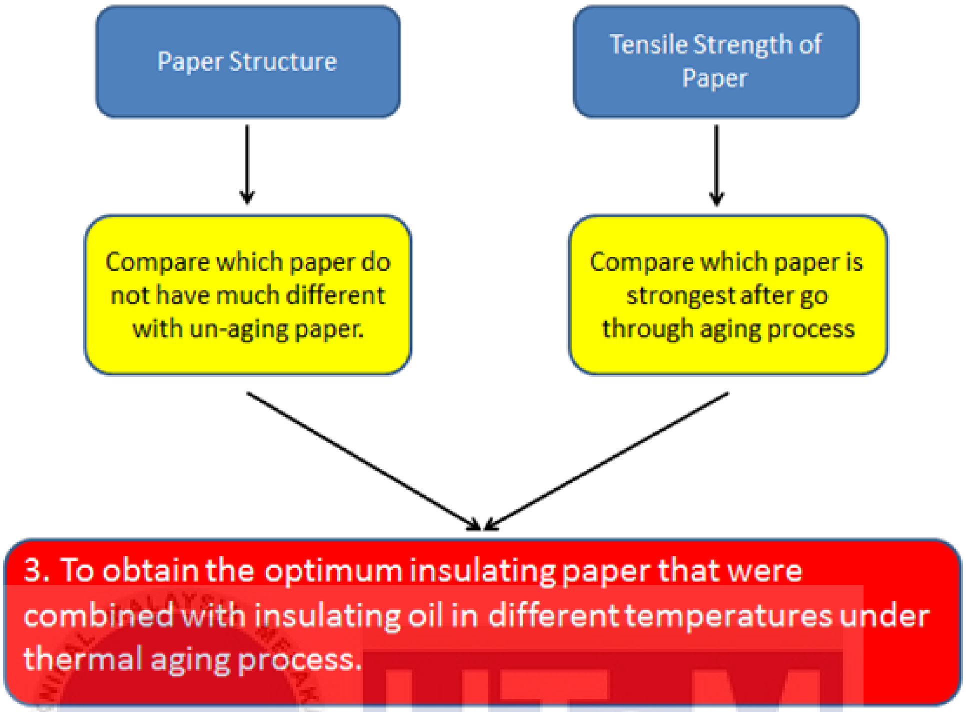


Figure 3.23: Step to analyze data for insulating paper

In Paper structure test, the papers were analyzed for the changing in term of colour of the insulating paper. This test was analyzed by comparing which sample of paper that going for thermal aging do not have much different with the paper that not going for thermal aging process. For tensile strength test for insulating paper, the papers were going on stress-tensile test. All the data that were collected were put in graph so that all the data can be easily analyzed. The type of insulating oil that gave the highest tensile strength of insulating paper to break were chosen as the most good insulation oil to be used to protect the paper insulation from easily broken. As conclusion, all of the tests above are to ensure that the tests reached the objective number three of the project that was to obtain the optimum insulation properties of Kraft paper that were combined with insulating oil under thermal aging process with different temperatures.

3.2.8 Report Writing

The report was completely written after all the process of determined the effect of thermal aging process are complete. The report explained all the step, information and evidence as long as the project was implemented

3.3 Summary

This chapter exposed overall process flow for implementing the project. The overall plan of the project had been summarized through a flowchart so that was easier to be understands. All the procedure during the beginning of this project until the ending of project can be referred here as a guideline. All the result for the test can be seen in the Chapter 4.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the data were recorded and been analyzed based on the experiment that had been completely implemented. To accomplish the objectives of the project, all the tests that were run successfully done and followed the standards according the test. All the data were recorded and has been present in graph and table so that the data can be easily to understand and when making comparison among the data. The analysis of the data from every test had been discussed as followed.

4.2 Achievement of Project and Analysis

All the data are got through the experiment in laboratory. There are three properties of insulating oil that had been measured for data and analyzed that are moisture content, acidity and UV-Vis. Meanwhile, there are two properties of insulating paper that had been measured that are structure of paper and tensile strength. The analysis of the results of experiments was stated as followed.

4.2.1 Measurement for Moisture Content

The data for moisture content for all samples are recorded in table 4.1. Five reading were test for each sample and the data shows the average value for the samples. There was clearly shown that every sample have different value in moisture content according to type of oil, period of aging and temperature.

Table 4.1: Moisture Content for Samples

Type Of Sample	Period Of Aging Process	Moisture Content (ppm)
PFAE 110C		
PFAE 130C		185.62
Gemini-X 110C	0 Hours	
Gemini-X 130C	(Initial)	18.3
Midel En 110C		
Midel En 130C		187.2
PFAE 110C		235.676
PFAE 130C		540.93
Gemini-X 110C		29.0
Gemini-X 130C	250 Hours	34.3
Midel En 110C		325.3
Midel En 130C		614.85
PFAE 110C		357.0
PFAE 130C		564.9
Gemini-X 110C		34.5
Gemini-X 130C	500 Hours	42.3
Midel En 110C		338.533
Midel En 130C		1273.5
PFAE 110C		586.3
PFAE 130C		714.3
Gemini-X 110C		39.033
Gemini-X 130C	750 Hours	105.1
Midel En 110C		827.1

Midel En 130C	750 Hours	1409.83

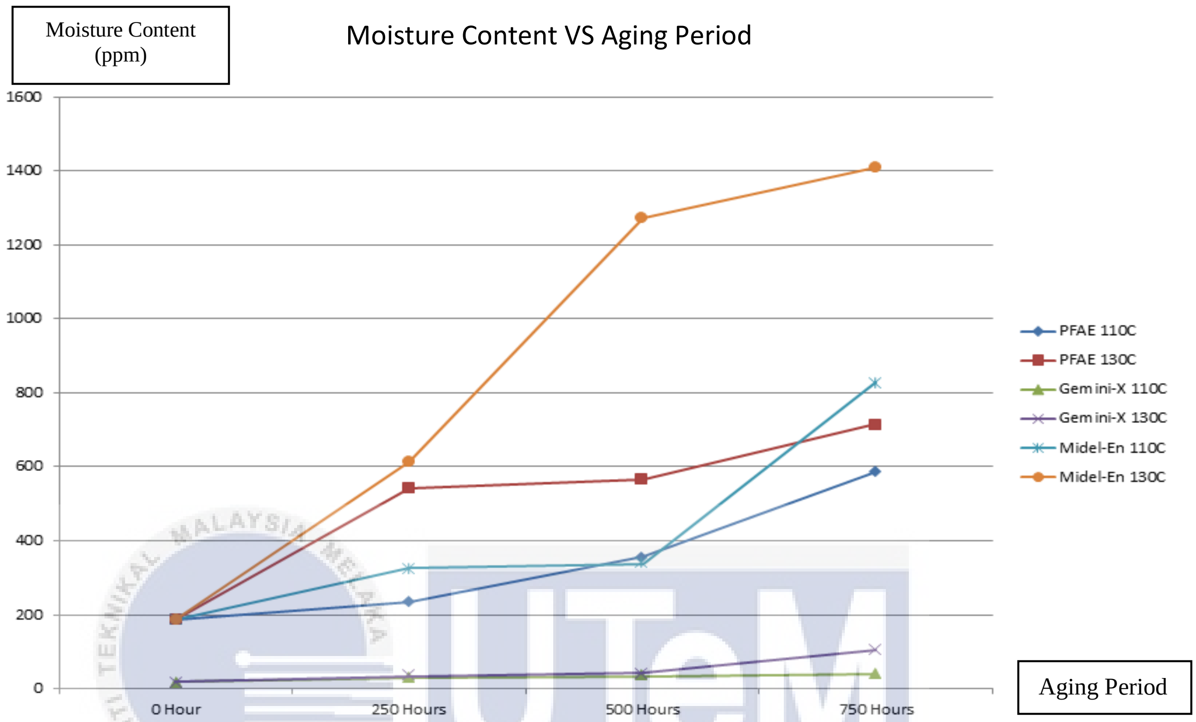


Figure 4.1: Moisture Content VS Aging Period graph

Comparison can be made between the different temperatures and different period of aging. Based on the graph it can be seen that on 750 hours of aging, Midel En 130C has the largest value of moisture content while Gemini-X 110C was the lowest value.

Firstly for PFAE type of oil, it seem that PFAE 130C has the larger value of moisture with 540.3ppm while PFAE 110C was 235.676ppm for 250 hours of aging. For 500 hours of aging, it clearly seen there a rise in moisture for PFAE 110C with value of 357.0ppm while PFAE 130C has small rise with value 564.9ppm. PFAE 110C has lower value than PFAE 130C on 750 hours of aging with different 128ppm in values.

The next type of oil was Gemini-X. On 250 hours of aging, it can be seen that there are tiny rise in moisture content compared to 0 hours of aging with 10.7ppm increase for Gemini-X 110C and 16.0ppm for Gemini-X 130C. The same in pattern of rise also can be seen in 500 hours of aging with Gemini-X 130C has higher moisture content with 42.4ppm in value while Gemini-X 110C was 34.5ppm. Gemini-X 130C shows significant rise in moisture content with value of 105.1ppm while Gemini-X still has small change in moisture content with only 39.033ppm.

The last type of oil was Midel En. Midel En 130C has the highest value of moisture content with value 614.85ppm while Midel En 110C has value of 325.3ppm on 250 hours of aging. Midel En 130C shows drastically change in moisture content from 250 to 500 hours of aging with value of 1273ppm while moisture content for Midel En on 500 hours of aging was 338.533ppm. Midel En 130C has higher value than Midel En 110C on 750 hours of aging with different of 582.73ppm in value of moisture content.

In conclusion, it can be conclude that Gemini-X were the most perfect insulating oil to be used in transformer due to it gave the smallest value of water content among other types of insulating oil.

4.2.2 Measurement for Acidity

The data values for acidity of all samples are recorded in table 4.2. Five reading were test for each sample and the data shows the average value for the samples. There was clearly shown that every sample have different value in acidity according to type of oil, period of aging and temperature.

Table 4.2: Acidity value for Samples

<table>
<tr><th>Type Of Sample</th><th>Period Of Aging Process</th><th>Acidity (mg KOH/g)</th></tr>
<tr><td>PFAE 110C</td><td rowspan="6">0 Hours</td><td rowspan="2">0.05</td></tr>
<tr><td>PFAE 130C</td></tr>
<tr><td>Gemini-X 110C</td><td rowspan="2">0.0442</td></tr>
<tr><td>Gemini-X 130C</td></tr>
<tr><td>Midel En 110C</td><td rowspan="2">0.0146</td></tr>
<tr><td>Midel En 130C</td></tr>
<tr><td>PFAE 110C</td><td rowspan="6">250 Hours</td><td>0.062</td></tr>
<tr><td>PFAE 130C</td><td>0.076</td></tr>
<tr><td>Gemini-X 110C</td><td>0.0499</td></tr>
<tr><td>Gemini-X 130C</td><td>0.0507</td></tr>
<tr><td>Midel En 110C</td><td>0.1976</td></tr>
<tr><td>Midel En 130C</td><td>0.2473</td></tr>
<tr><td>PFAE 110C</td><td rowspan="6">500 Hours</td><td>0.1847</td></tr>
<tr><td>PFAE 130C</td><td>0.2262</td></tr>
<tr><td>Gemini-X 110C</td><td>0.1793</td></tr>
<tr><td>Gemini-X 130C</td><td>0.169</td></tr>
<tr><td>Midel En 110C</td><td>0.6006</td></tr>
<tr><td>Midel En 130C</td><td>2.2277</td></tr>
<tr><td>PFAE 110C</td><td rowspan="6">750 Hours</td><td>0.1123</td></tr>
<tr><td>PFAE 130C</td><td>0.6652</td></tr>
<tr><td>Gemini-X 110C</td><td>0.1137</td></tr>
<tr><td>Gemini-X 130C</td><td>0.8116</td></tr>
<tr><td>Midel En 110C</td><td>0.7592</td></tr>
<tr><td>Midel En 130C</td><td>6.4773</td></tr>
</table>

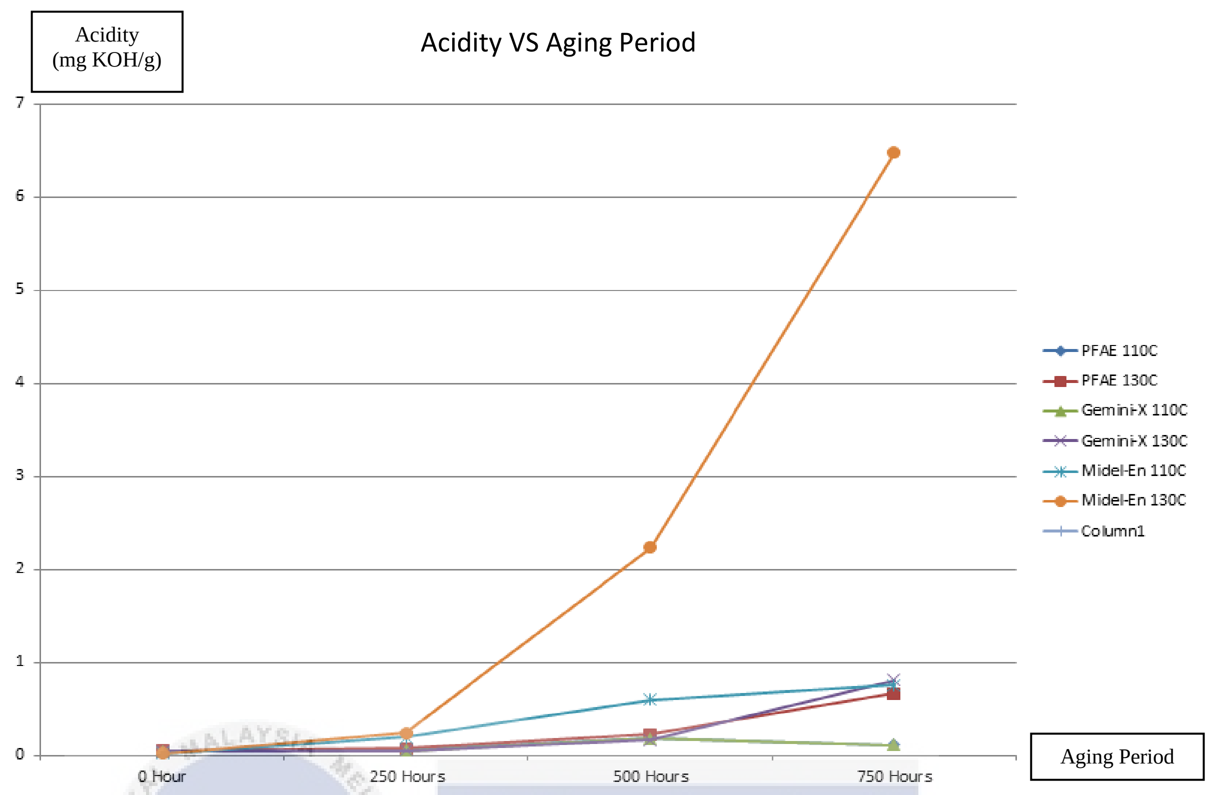


Figure 4.2: Acidity VS Aging Period graph

Comparison can be made between the different temperatures and different period of aging. Based on the graph it can be seen that on 750 hours of aging, Midel En 130C has the largest value of acidity while PFAE 110C was the lowest value.

Firstly for PFAE type of oil, it shows that PFAE 130C has the larger value of acidity with 0.076mg KOH/g while PFAE 110C 0.062mg KOH/g for 250 hours of aging. For 500 hours of aging, there was a rise in acidity for PFAE 110C with value of 0.1847mg KOH/g while PFAE 130C with value 0.2262mg KOH/g. PFAE 110C has lower acidity than PFAE 130C on 750 hours of aging with different 0.5529mg KOH/g in values.

The next type of oil was Gemini-X. On 250 hours of aging, it seem that there are tiny rise in acidity compared to 0 hours of aging with 0.0057mg KOH/g increased for Gemini-X 110C and 0.0065mg KOH/g for Gemini-X 130C. The same in pattern of rise also can be seen in 500 hours of aging with Gemini-X 110C has higher acidity with 0.1793mg KOH/g in value but there was drop on acidity for Gemini-X 130C with 0.169mh KOH/g. PFAE 130C shows significant rise in acidity with value of

0.8116mg KOH/g while Gemini-X 110C still has small change in acidity with 0.1137mg KOH/g only.

The last type of oil was Midel En. Midel En 130C has the highest value of acidity with 0.2473mg KOH/g while Midel En 110C has value of 0.1976mg KOH/g on 250 hours of aging. Midel En 130C shows drastically change in acidity from 250 to 500 hours of aging with value of 2.2277mg KOH/g while acidity for Midel En on 500 hours of aging was 0.6006mg KOH/g. Midel En 130C has higher value than Midel En 110C on 750 hours of aging with different of 5.7181mg KOH/g in value of acidity.

4.2.3 Measurement for UV-Vis

The data for UV-Vis of all samples are were recorded according to the type of oil. This was because the objective of the test was to check the decay in each sample of the oils according to their type. The decay in the oil sample can be determined by seeing the area under the graph of the data. Three reading were test for each sample and the data shows the average value for the samples. There was clearly shown that every sample have different value in decay according to type of oil, period of aging and temperature.

4.2.3.1 PFAE

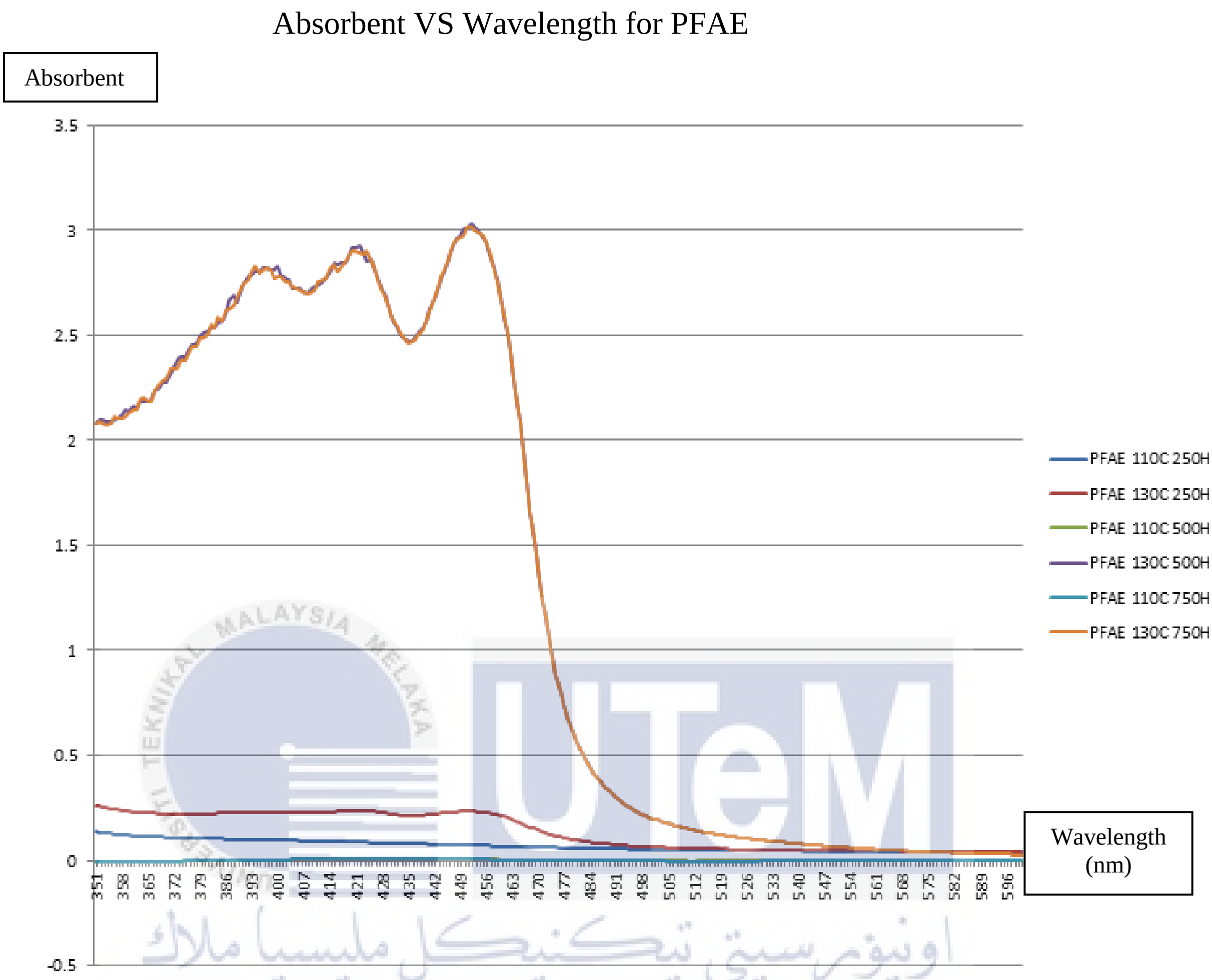


Figure 4.3: UV-Vis Absorbent VS Wavelength graph for PFAE

As the graph above, it can be seen there are low decay in PFAE 110C for 750 hours and likely same with PFAE 110C for 500 hours. Meanwhile, it was different for PFAE 110C for 250 hours because there can be seen that it has highest value of decay for it class in term of temperature. PFAE 130C for 250 hours of aging has the lowest value of decay for their class of temperature. After 750 hours of aging, PFAE 130C shows there are no significant changed as it decay quite similar with 500 hours of aging.

4.2.3.2 Gemini-X

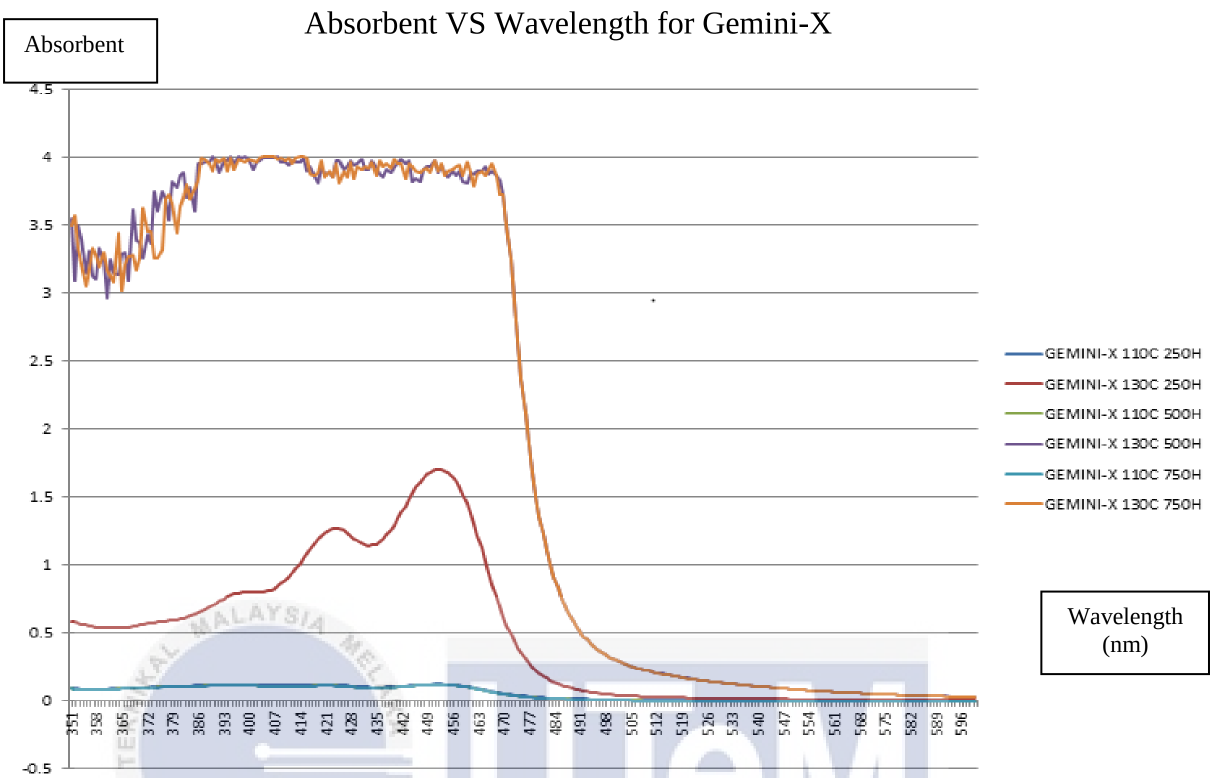


Figure 4.4: UV-Vis Absorbent VS Wavelength graph for Gemini-X

As the graph above, it can be seen there are low decay in Gemini-X 110C for 250 hours and likely same with Gemini-X 110C for 500 hours. Meanwhile, it was different for Gemini-X 110C for 750 hours because there can be seen there was increase in absorbent and it has highest value of decay for it class in term of temperature. Gemini-X 130C for 250 hours of aging has the lowest value of decay for their class of temperature. After 750 hours of aging, Gemini-X 130C shows there are no significant changed as it decays quite similar with 500 hours of aging duration.

4.2.3.3 Midel En

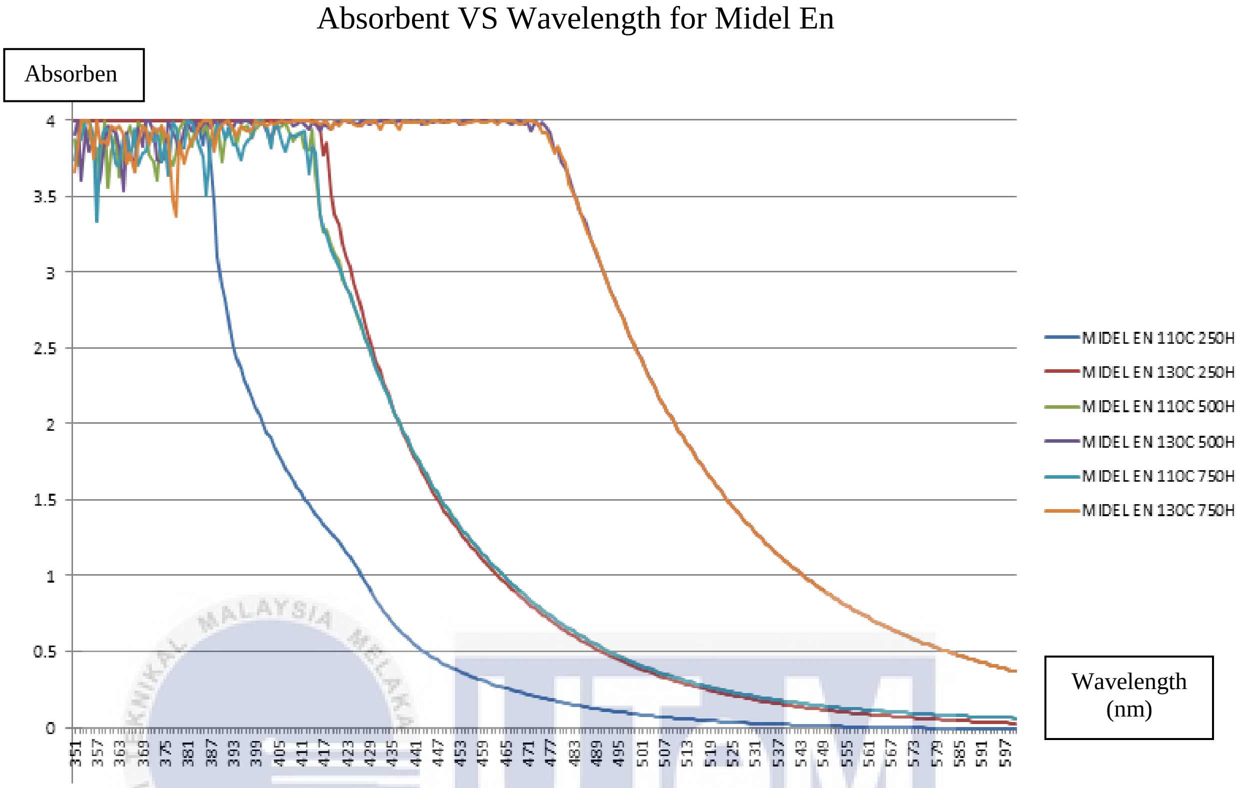


Figure 4.5: Acidity VS Aging Period graph

After 750 hours of aging, Midel En 130C shows there are no significant changed as it decays quite similar with 500 hours aging duration and be the sample that has highest decay among all samples in Midel En class. It can be seen that Midel En 110C on 250 hours of aging has the smallest decay.

4.2.4 Measurement for Tensile Strength of Paper

The data values for tensile strength of all papers samples are recorded in table 4.3. A reading was test for each sample and the data shows value of tensile strength for the samples. There was clearly shown that every sample have different value in tensile strength of paper according to their type of oil, period of aging and temperature. The value of tensile strength for paper that was not going thermal aging process was 86.485MPa.

Table 4.3: Tensile strength value for samples

Type Of Sample	Period Of Aging Process	Tensile Strength (MPa)
PFAE 110C	250 Hours	80.788
PFAE 130C		60.148
Gemini-X 110C		60.615
Gemini-X 130C		79.984
Midel En 110C		63.137
Midel En 130C		57.533
PFAE 110C	500 Hours	74.250
PFAE 130C		40.535
Gemini-X 110C		71.636
Gemini-X 130C		55.758
Midel En 110C		60.055
Midel En 130C		33.624
PFAE 110C	750 Hours	68.273
PFAE 130C		8.779
Gemini-X 110C		69.114
Gemini-X 130C		3.546
Midel En 110C		60.241
Midel En 130C		24.097

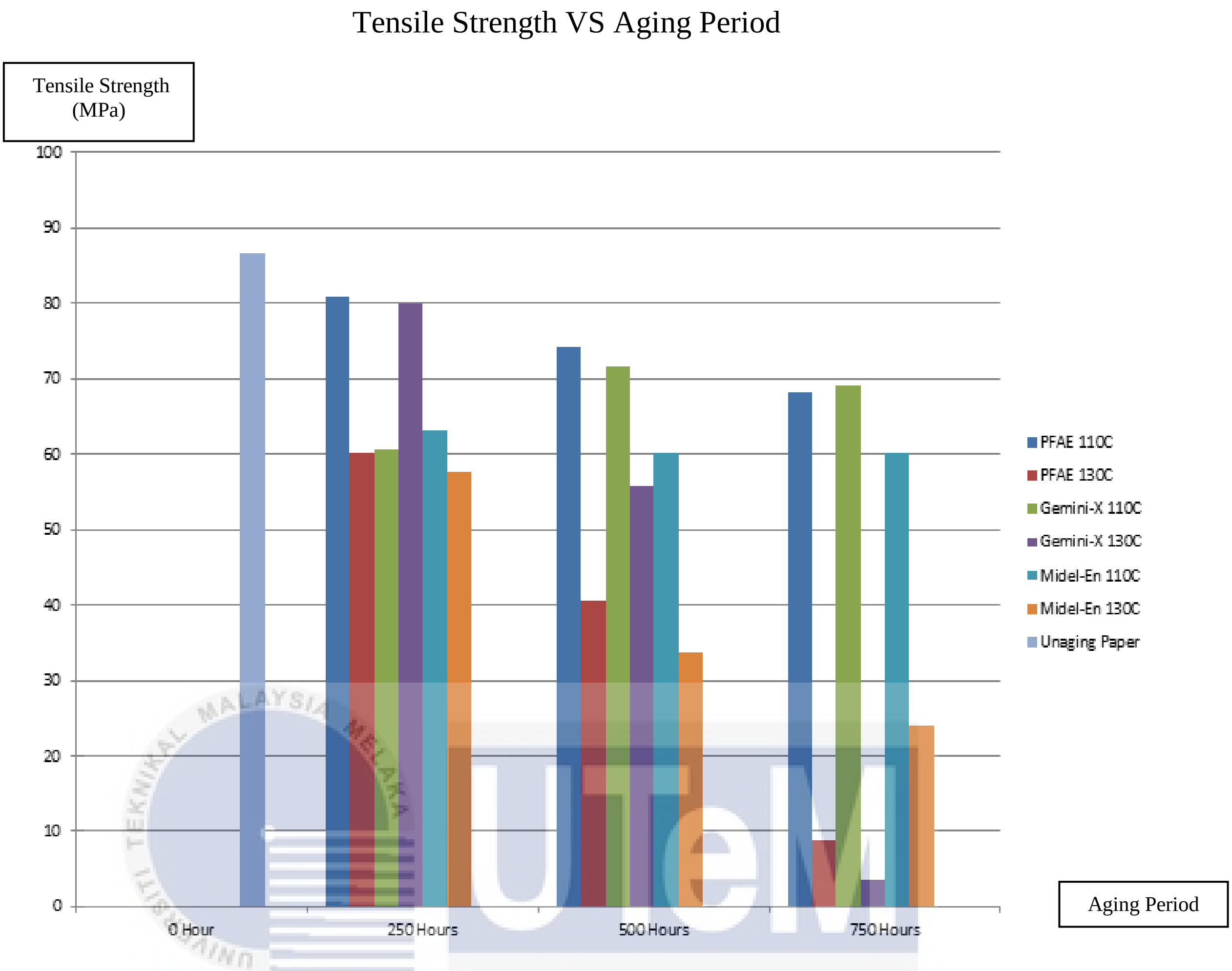


Figure 4.6: Tensile Strength VS Aging Period graph

Comparison for tensile strength the paper can be made by compared the differences of temperatures, types of insulating oil and different period of aging. Based on the graph it shows that on 750 hours of aging at 130C temperature, paper sample from Midel En has the largest value with 24.097MPa of tensile strength while Gemini-X 130C was the lowest with 3.546MPa. Meanwhile for 750 hours of aging on 110C temperature shows that paper sample for Gemini-X was the highest with 69.114MPa of tensile strength followed by PFAE with 68.273MPa and Midel En with 60.241MPa.

In 500 hours of aging at 110C temperature, it can be seen paper sample from PFAE has the highest value of tensile strength with 74.250MPa followed by Gemini-X with 71.636MPa and Midel En with 60.055MPa. For 130C temperature, paper sample for Midel En has the lowest tensile strength that was only 33.624MPa while tensile strength of paper sample for Gemini-X and PFAE are 55.758MPa and 40.535MPa respectively.

For 110C temperature in 250 hours of aging, it can be analyzed that paper sample from PFAE has the highest tensile strength with value of 80.788MPa among others type of oils. Meanwhile, paper sample from Gemini-X on 250 hours of aging has the highest value of tensile strength with 79.984Mpa in term of temperature class among the different period of aging.

4.2.5 Test for Colour of Paper

The data for colour of paper were stated as below. There was clearly shown that every sample have different structure of paper according to their type of oil, period of aging and temperature.

4.2.5.1 PFAE

Figure 4.7: Colour of paper for PFAE 110C

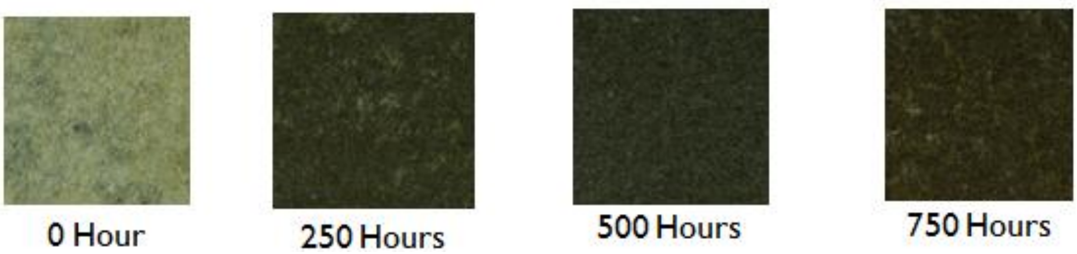


Figure4.8:Colour of paper for PFAE 130C

4.2.5.2 Gemini-X

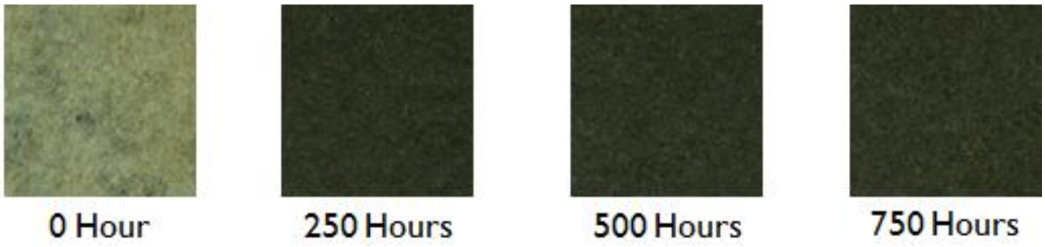


Figure 4.9: Colour of paper for Gemini-X 110C

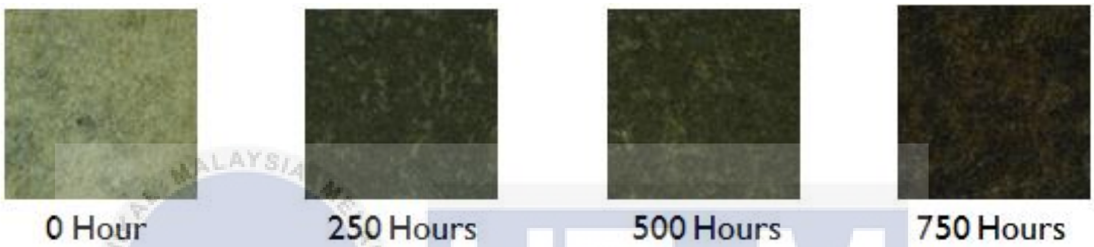


Figure 4.10: Colour of paper for Gemini-X 130C

4.2.5.3 Midel En

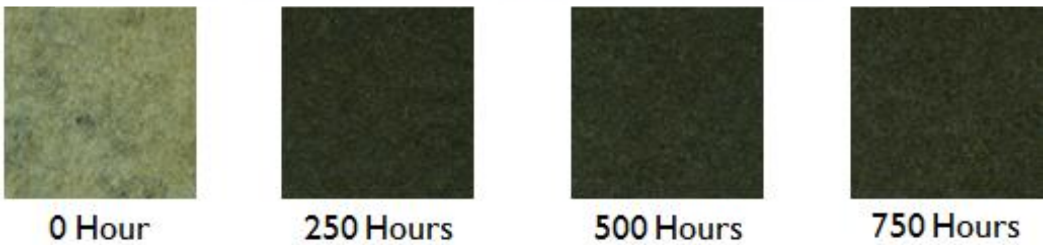


Figure 4.11: Colour of paper for Midel En 110C

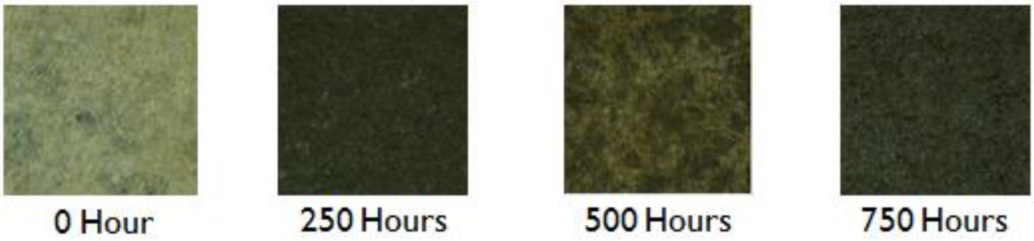


Figure 4.12: Colour of paper for Midel En 130C

Based on the figure above, it can be concludes that the colour of the paper samples were changed accordingly to their period of aging, type of insulating oil and temperature. Based on the results, it can be seen that the colour of the paper structure are obviously changed from the original colour for every type of the oil. All the paper samples became darker than the original paper.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The project was run according to the flowchart successfully. All the tests that had been implemented are following all the standards that were set by ASTM. Among the test that had been implemented are moisture content, acidity and UV-Vis for insulating oil while tensile strength and colour test for insulating paper.By this project, it was proven that value of temperature and period of aging can manipulated the characteristics of the insulating oil and their effect to Kraft paper insulation.

In term of characteristic of the insulating oil, Gemini-X can be choose as the most good insulation oil to be used in power transformer than PFAE and Midel En. This was because Gemini-X shows the lowest value in every type of test about the characteristic of the insulating oil. In term to protect the insulating Kraft paper, Midel En can be choose as the most better type of insulation oil because based on the test for the tensile strength, the paper that were combined with it at 130C shows the highest value that the machine need to break the paper among the others.

As conclusion, it can be said that Midel En was the most perfect insulation oil that need to be combined with Kraft paper in power transformer. This statement was proven by the tensile test that had been done. So, this project had achieved all of the objectives that were state and following all the scopes of the project

5.2 Recommendation

Based on the investigation of the project that had been implemented, it was clearly shows that every type of insulating oils had different value in their characteristic. So their characteristic can influenced the condition of the insulating paper. There are few suggestions that can be used as future plans related to study of this project.

1. Use the suitable equipment during implementing the project.
2. Study the BDV for each type of oil.
3. Compare the result by using the thermal upgraded paper for solid insulation.

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