" I hereby declare that I have read through this report entitle "Weighting Characteristic for Kraft Paper Immersed in Mineral and Vegetable Insulation Oil" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature : .....

Supervisor's Name : .....

Date : .....

WEIGHTING CHARACTERISTIC FOR KRAFT PAPER IMMERSED IN MINERAL AND VEGETABLE INSULATION OIL

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

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

I declare that this report entitle "Weighting Characteristic for Kraft Paper Immersed in Mineral and Vegetable Insulation Oil" is the result of my own research except as cited in the references. The report has not been accepted for any degree and it is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : .....

Date : .....

To my beloved mother, father and siblings

ACKNOWLEDGEMENT

Alhamdulillah, with the willing of Allah SWT, I have successfully completed my Final Year Project, with the title of "Weighting Characteristic for Kraft Paper Immersed in Mineral and Vegetable Insulation Oil". This report was prepared in order to fulfil the requirements of the undergraduate program of degree in Bachelor of Electrical Engineering (Industrial Power) in Faculty of Electrical Engineering, University of Technical Malaysia Malacca (UTeM).

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ABSTRACT

Insulation plays a very important role in an oil-filled transformer. In fact, the importance is undeniable since insulations can determine the lifespan of a transformer. Insulations failure has been reported as the leading cause for transformer failure occurrences. Damage in insulation part might affect the performance of the power transformer and hence the transformer life. Hence having a proper Kraft Paper thickness and insulations oil is the key in obtaining a transformer with great performance and longer lifespan. Thus, this research is particularly purposed to be studied. The objectives of this research are to study the effect of thickness of Kraft Paper with its absorption rate and to verify the absorption rate of Kraft Paper after being immersed in mineral and vegetable insulation oil. The performance of Kraft Paper will be analysed using three different thicknesses which are 0.7mm, 1.4mm and also 2.1mm and two types of insulations oil which are Hyrax Hypertrans a mineral oil and the Palm Fatty Acid Ester (PFAE) a vegetable oil. The performance of the Kraft Paper will be observed by their absorption rate. It is found that the difference in thicknesses do effect the absorption rate of the Kraft Paper, the higher the thicknesses the longer the time taken to reach concentration. In 0.7mm, not many differences were observed in the absorption ratio and the difference can be considered small. However, in 1.4mm, the Kraft Paper has 9.4% higher absorption ratio at the concentration state compared to mineral oil. This is further supported with the higher initial intake for Kraft Paper in PFAE with value of 0.0136%/s compared to 0.0117%/s for Hyrax Hypertrans. In 2.1mm, the absorption ratio of vegetable oil is also higher than mineral by 0.7%.The vegetable oil also achieved concentration faster than mineral oil. This is further supported with higher initial rate intake of vegetable oil with value of 0.0075%/s compared to only 0.0065%/s in mineral oil. Hence it is proven that Kraft Paper immersed in vegetable oil has better performance compared to the one immersed in mineral oil.

ABSTRAK

Penebatan memainkan peranan yang penting terutamanya untuk Transformer yang menggunakan minyak. Malahan, kepentingan penebatan tidak dapat dinafikan memandangkan penebatan dapat menetukan jangka hayat sesebuah transformer. Justeru, penggunaan jenis minyak penabatan dan ketabalan kertas penebatan yang sesuai adalah penting dalam menjamin prestasi dan jangka hayat yang panjang bagi sesebuah transformer. Oleh itu, kajian ini telah dicadangkan untuk dikaji. Objektif kajian ini adalah untuk megkaji perbezaan ketebalan kertas penebatan dan membandingkan kepetusan yang diperolehi dengan kajian terdahulu bagi mendapat keputusan yang sah. Ketebalan yang digunakan adalah 0.7mm,1.4mm dan 2.1mm. Minyak penebatan yang dipilih adalah minyak mineral Hyrax Hypertrans dan minyak sayuran Palm Fatty Acid Ester (PFAE). Prestasi kadar penyerapan kertas penebat akan dinilai menggunakan kaedah pengukuran berat. Perbezaan antara ketebalan akan menyebabkan berlakunya perbezaan kadar penyerapan kertas penebat. Lebih tebal kertas penebat, lebih lama masa yang diambil untuk kertas penebatan menjadi tepu dengan minyak. Bagi 0.7mm, tidak banyak perbezaan dapat dilihat dalam kadar penyerapannya. Walaubagaimanapun, untuk 1.4mm, kadar penyerapan semasa tepu bagi minyak sayuran adalah 9.4% lebih tinggi dari minyak mineral. Minyak sayuran juga mempunyai kadar penyerapan permulaan yang tinggi iaitu 0.0136%/s berbanding hanya 0.0117%/s bagi minyak mineral. Bagi 2.1mm pula, kadar penyerapan semasa tepu minyak sayuran adalah 0.7% lebih tinggi. Kertas penebatan dalam minyak sayuran juga mengambil masa yang lebih singkat untuk tepu. Tambahan pula kadar penyerapan permulaan minyak sayuran adalah 0.0075%/s iaitu lebih tinggi dari minyak mineral yang hanya 0.0065%/s. Justeru, terbuktilah prestasi minyak sayuran adalah lebih bagus.

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LIST OF ABBREVIATIONS

PFAE	Palm Fatty Acid Ester
TNB	Tenaga Nasional Berhad
2FAL	2 Furaldehyde
PEA	Pulse Electro-Acoustic
LODP	Levelling-Off Degree of Polymerisation
DP	Degree of Polymerisation

CHAPTER 1

INTRODUCTION

1.1 Research Background

This research was purposed due to the curiosity of analysing the absorption rate of Kraft Paper when immersed in both mineral and vegetable insulation oil. Even though there is previous research done related to absorption rate of Kraft Paper, there were no research conducted using 0.7mm, 1.4mm and 2.1mm thickness of Kraft Paper.

It is undeniable that insulation is a very important part in the power transformer. In fact, the conditions of the insulation part of a transformer will be able to determine the lifespan of transformer. The main components involved in insulation of a transformer are insulations oil and Kraft Paper. The combination of insulations oil and cellulose products such as Kraft Paper has remained unchanged for the past few decades due to its electric strength and low cost.

The main purpose of Kraft Paper and insulations oil is to help in cooling and also insulating, insulating between turns of windings, coils for windings and cores [1]. These insulating materials will performs better if the absorption rate of the Kraft Paper is higher since the heat can be dissipated faster. Types of insulation oil will usually affect the rate of absorption as different oils will have different chemical structure and viscosity that will contribute to its absorption rate. By having a higher absorption rate, the transformer life can be prolonged (assuming no other problem) since the main cause for paper degradation is due to the heat released by the windings during transformer operations.

1.2 Problem Statement

The insulations are the most important part for the Oil-filled Power Transformer. In fact, insulations failure has been a leading cause for breakdown occurrences and transformer failure. Any unwanted problem that arise in insulation part of a transformer might affect the performance of the power transformer and hence the transformer life. Oil-filled Transformer insulations consist of two main things, which are Kraft Paper and Insulation oil. Degradation of Kraft Paper immersed in insulation oil will affect the level of effectiveness of heat dissipated from transformer core and hence affect the performance of the transformer Thus, the right choice of insulations chosen including the thickness of Kraft Paper and also the type of insulation oil used are important. In this research, the performance of Kraft Paper will be analysed using three different thicknesses which are then immersed in two types of insulations oil which is Hyrax Hypertrans mineral oil and the Palm Fatty Acid Ester (PFAE) vegetable oil. According to the previous research done, vegetable oil will usually have a faster absorption rate with the Kraft Paper but will it performance be the same with different thickness of Kraft Paper. If vegetable oil have higher absorption rate with the Kraft Paper, will it be an advantage or reversal. In order to understand this, the project on analysing the performance of Kraft Paper when immersed in both mineral and vegetable insulation oil will be done

1.3 Objectives

There are three main objectives to be achieved by this research:

i. To study the absorption rate of Kraft Paper in two different insulation oil which are Hyrax Hypertrans mineral oil and the Palm Fatty Acid Ester (PFAE) vegetable oil.
ii. To analyse the effect of thickness of Kraft Paper with its absorption rate towards the performance of the insulation oil.
iii. To verify the absorption rate of Kraft Paper after being immersed in mineral and vegetable insulation oil by performing the experiment for three times and by comparing with previous research.

1.4 Scope of the Project

This research covers two types of oil only, firstly the Hyrax Hypertrans mineral oil and the PFAE vegetable oil. The thickness of the Kraft Paper is limited to 0.7 mm, 1.4mm and 2.1mm. The absorption rate is obtained by measuring the weight of the Kraft Paper immersed in both oil using a digital weighting scale (Shimadzu Model UX 420H). The weight of the Kraft Paper is taken for every interval of six hours for a period of eight days. The reading is recorded and further analysis will be done. The analysis focuses on the absorption ratio of the three different thickness of Kraft Paper in both mineral and vegetable oil.

1.5 Significant of Research

The significant of this project is to study the effect of thickness towards the absorption ratio of Kraft Paper in both mineral and vegetable oil. In Oil-filled Transformer, the performance of the transformer depends on the performance of Kraft Paper in insulation oil. The faster the Kraft Paper became concentrated in oil, the faster the heat in transformer can be dissipated. Hence, this study will show the effect of different thickness of Kraft Paper and their absorption ratio. In addition, the absorption ratio of Kraft Paper in both vegetable and mineral oil will be compared to determine which oil have higher absorption ratio. Hence, it can be seen that Kraft Paper will have a better performance in which type of insulation oil.

1.6 Outline of Report

This progress report consists of five chapters. Chapter 1, the Introduction contains the research background, problem statement, objective, scopes and the outline of the report. Chapter 2, Literature Review, consist of the introduction of the chapter, theory and basic principle, review of the previous related works, summary and discussion of the review and lastly the summary of the chapter. Next, Chapter 3, the Design Methodology consists of the design methodology of the project, project flowchart, experimental set up and also data analysis. Chapter 4, Result and Discussion contains the result and discussion of this project. Lastly, Chapter 5 is about the conclusion obtained and the recommendation of the project to be done in future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focuses on explaining the theory and basic principles used in producing this research. Section 2.2, Section 2.3, Section 2.4, Section 2.5, Section 2.6 and Section 2.7 will explain the theoretical background of materials involve in this research. Section 2.8 will describe all the previous research that had been done that is related to this project. Section 2.9 consists of the overall review of the previous related works focuses on the methodology and the result obtained in that particular research. Lastly, Section 2.10 will explain more on summary and the discussion of the previous related work is done.

2.2 Theoretical Background of Power Transformer

Power Transformer is basically divided into two types which is oil-filled transformer as shown in Figure 2.1 which is mainly used in power system and another one is without oil. The power transformer is the major component of power system which permits a more economical power transmission with high efficiency. Power transformer was first developed in 1885 by William Stanley. The Alternating Current System of the transformer overcome the voltage problem encountered in Direct Current System and hence increases the distance for power transmission. Generation of electrical power is far more cost effective if the power is generated in low voltage level.

However, in order to transmit it, a higher voltage level is needed and hence power transformer is used to step up the voltage level. Moreover when the voltage is increased, the current is decreased and hence having low current will cause less power loss according to the equation of I^2R. Then when the voltage needs to be distributed, again a power transformer is used in order to step down the voltage. These are the contributions of power

transformer. The oil-filled transformer is more favourable since the transformer lifespan is longer and can be reused if the insulations part is replaced with new insulations. The insulations part of an oil-filled transformer is the most important part of the transformer since it will affect the performance and lifespan of the transformer. The main source of heat generated in transformer is usually through the copper loss. Even though there are also other few factor which contributes to the heat loss such as the eddy current and hysteresis but copper loss is still the main contributor in generating heat. If all this heat generated is not released from the transformer, the temperature of the transformer will increase and hence affect the insulation part of the transformer which is the Kraft Paper and also the insulation oil which will then cause damaged to the transformer if this condition prolonged [2]. Having just Kraft Paper and insulation oil is not enough to cool down the transformer, hence, external cooling system is applied to increase the rate of heat dissipated.

Figure 2.1: The oil-filled Power Transformer [3]

2.3 Theoretical Background of Kraft Paper

Kraft Paper is a paper that is used in transformer as an electrical insulation it is also known as the insulation paper. It is basically made up from cellulose fibre which is then purified for electrical application. The Kraft Paper looks exactly like a normal paper as shown in Figure 2.2. Cellulose is a good isolator with high dielectric constant value which makes it a favourable material in electrical insulator. Kraft Papers are available in variety of forms and grades according to the treatment given to the paper. Kraft Paper is usually upgraded thermally by applying diamond pattern epoxy resin to either one side or both side of the paper [2]. Having been upgraded by this diamond pattern epoxy resin will ensure the long-term mechanical and physical properties of the insulation structure of the transformer. This is because, when exposed to certain temperature, the epoxy-resin would be melted and stick to the adjoining layer of the coil and hence forming a winding section which will prevent displacement of each winding layer during short circuit.

Figure 2.2: Kraft Paper [4]

Kraft Paper has a high dielectric constant value which means that they are a good insulator. Dielectric constant is a ratio of permittivity of a substance to the permittivity of free space. Having high dielectric constant means the Kraft Paper has high ability to store electrical energy in an electric field. As the value of dielectric constant increases the electric flux density increase and if other factor remains unchanged this property will allow the object to hold their electric charge for a long time. Thus, Kraft Paper is considered as a good insulator since it prevent the flow of electric in between the coil and at the same time help in heat dissipation from the transformer.

2.4 Theoretical Background of Transformer Oil

Transformer oil is highly refined oil with high insulation which is used in oil filled transformer. This oil has a property of being able to stable in high temperature and hence it is always use in high capacity power transformer. The transformer oil helps in cooling down the transformer by transferring the heat received from coil of transformer to the surrounding. There are two types of transformer oil that is used currently, which is mineral oil and vegetable oil. However, there are still lots of research and development being done regarding the vegetable oil in order to commercialize the usage of vegetable oil in oil-filled transformer.

Transformer oil is exposed to electrical and mechanical stress from high voltage during operation. The transformer oil are also unprotected from many kind of contamination especially those caused by the interaction of winding and others solid insulation inside the vacuum container. All these exposure may cause the transformer oil to change gradually after many years of usage and hence decreasing its effectiveness. The transformer oil is tested according to certain time interval, for instance every 18 months as being practiced in Malaysia by the one and only electrical company Tenaga Nasional Berhad (TNB) in order to check the conditions of the oil.

The tests that are usually done are dissolved gas analysis, Furan Analysis and other general electrical and physical tests which checks the color and appearance, breakdown voltage, resistivity, density and many more in order to check the lifespan of the oil and

when is the right time to change the transformer oil. The gas analysis test is done using special portable equipment as shown in Figure 2.3. Furthermore, the few parameters that are important in choosing and maintaining the transformer oil are electrical parameters, chemical parameters and also physical parameters. The electrical parameters covers the dielectric strength, specific resistance and dielectric dissipation factor while the chemical parameter involves the water content, acidity and also sludge content. The physical parameters focus on the interfacial tension, viscosity, flash point and pour point [2].

Figure 2.3: The Transport-X a portable device for a gas-dissolved analysis [5]

The insulations oil used in this research are Hyrax Hypertrans mineral oil and the Palm Fatty Acid Ester (PFAE) vegetable oil. The properties of these two oils are stated in Figure 2.4 and Figure 2.5.

Properties	Unit	Value
Purity	%	99.3
Density	(15DegC) g/cm^3	0.86
Flash point	DegC	184
Kinetic viscosity	(40°C) m^2/s	4.6
Moisture content	mg/kg	15
Breakdown voltage	(2.5mm) kV	83
Relative permittivity	(80DegC)	2.95
tanδ	(80DegC) %	0.016
Volume resistivity	(80DegC) Ω·cm	1.80E+13

Figure 2.4: Properties of PFAE vegetable oil [10]

PROPERTY	TEST METHOD	SPECIFICATION		VALUES
		Min	Max	
Function				
Viscosity, cSt at 40 °C	ISO 3104		12	10.4
Viscosity, cSt at -30 °C	ISO 3104		1800	1284
Pour Point, °C	ISO 3016		-40	-60
Water Content, PPM	IEC 60814		30 / 40*	20
Breakdown Voltage, kV	IEC 60156	30 / 70**		60
Density at 20 °C, g/ml	ISO 12185		0.895	0.881
DDF at 90 °C	IEC 60247		0.005	0.0002
Refining /Stability				
Appearance	Visual	Clear & Bright		Clear & Bright
Acidity, mgKOH/g	IEC 6201-1		0.01	0.005
Interfacial Tension, dynes /cm	ISO 6295	No general requirement		45
Total Sulfur Content	BS 20000 Part 373	No general requirement		No general requirement
Corrosive Sulfur	DIN 51353	Non Corrosive		Non Corrosive
Antioxidant Additive, wt %	IEC 60666	Not Detectable		Not Detectable
2-Furfural Content, mg/kg	IEC 61198		0.1	<0.1
Performance				
Oxidation Stability at 120 °C, 164 hrs	IEC 61125 C			
Total Acidity, mg KOH/g			1.2	0.9
Sludge, %			0.8	≤0.8
Health, Safety and Environment (HSE)				
Flash Point, °C	ISO 2719	135		145
PCA Content, %	BS 2000 Part 346			<3
PCB Content, mg/kg	IEC 61619	Not Detectable		Not Detectable

Remark: *30 PPM - Bulk Delivery / 40 PPM- Drum Delivery
**30 kV - Before Treatment / 70 kV- After Treatment

Figure 2.5: Properties of Hyrax Hypertrans mineral oil [11]

2.5 Diffusion Theory

In this part, three theory of diffusion will be discussed which are Molecular Diffusion Theory, Brownian Motion Theory and Fick Law.

2.5.1 Molecular Diffusion Theory

All molecules contain heat, this causes the molecule to keep on moving constantly and randomly. As the molecule moves, it can diffuse or penetrate to another space through a membrane that is penetrate-able. Diffusion occurs when there are differences in concentration gradient, which mean when there are region with higher concentration and region with a lower concentration. The diffusion will have a movement in direction of high concentration to low concentration until no concentration gradient existed. This diffusion occurs in liquid and gaseous state only.

The diffusion is affected by two factors, which are the size of concentration gradient and the surface area of membrane. The steeper the concentration gradient the faster the process of diffusion will occur. Next, the greater the size of membrane or surface for diffusion to occur, the faster the diffusion will occur.

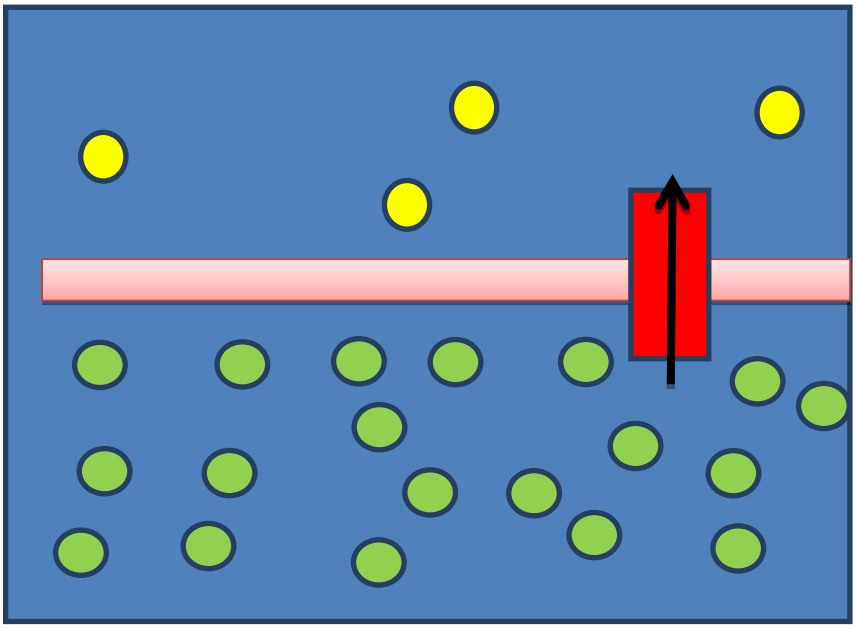

Figure 2.6: Process of diffusion from region of high concentration to low concentration [6]

2.5.2 Brownian Motion Theory

Robert Brown, an English botanist has discovered the Brownian Motion Theory in year 1827. He observed that pollen grain in water was moving constantly. Firstly, he taught there might be something 'alive', but proved that was not so by observing the same kind of motion in inclusions in quartz. He was unable to explain these occurrences.

Albert Einstein then studies the theory and according to Einstein's the movement of the pollen was due to collision with the water molecule that were moving randomly [6]. The concept of atoms and molecules became universally accepted.

The Einstein's theory consists of two parts:

i. The first part is about diffusion equation of Brownian particles as shown in Equation 2.1. In this equation the mean square displacement of a Brownian particle is related to the Coefficient of diffusion.
ii. The second part of the Einstein theory is about the physical quantities that are measurable to the diffusion coefficient.

The p(x, t) is the density, D is the mass diffusivity and t is the time. In this equation, Einstein proved that p(x, t) to be the density of Brownian particles with respect to the change in distance in time.

$$\frac{\mathrm{dp}}{\mathrm{dt}} = \mathrm{D}\frac{\mathrm{d}^2\mathrm{p}}{\mathrm{dx}^2} \qquad [2.1]$$

The theory enables Einstein to calculate the size of the atoms and number of atoms present in a mole and hence the molecular weight of a gas in grams [7].

2.5.3 Fick Law

i) Fick's First Law of Diffusion

$$N_i = -D_i \nabla c_i \qquad [2.2]$$