# FINITE ELEMENT MODELLING OF THERMAL AGEING OF OIL-IMPREGNATED PAPER IN OVEN

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# FINITE ELEMENT MODELLING OF THERMAL AGEING OF OIL-IMPREGNATED PAPER IN OVEN

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## DECLARATION

I declare that this thesis entitled “FINITE ELEMENT MODELLING OF THERMAL AGEING OIL-IMPREGNATED PAPER IN OVEN” is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree

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## APPROVAL

I hereby declare that I have checked this report entitled "FINITE ELEMENT MODELLING OF THERMAL AGEING OIL-IMPREGNATED PAPER IN OVEN" and in my opinion, this thesis is complies the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering with Honour

Signature :

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Date :

**DEDICATION**

To my beloved parents, Hamidah binti Ghani and Zoraimi bin Ali

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## ABSTRACT

A lifetime of a transformer are usually depends on the insulation properties of the solid and liquid insulation through their operations. This two main essential properties plays their roles to protect the transformer mainly from overheating which it may lead to other serious causes of explosion. Unfortunately, this insulation degrade and aged as the transformer works continuously. Therefore, a study on the ageing effect of the insulation properties through simulated experiment are conducted specifically on the cellulose paper within selected hours of operation as to imitate the operation of the transformer in real life. Consequently, thermal properties such as thermal conductivity rate are among the factors that leads to the degradation of the cellulose paper towards different range of the temperature of the operating transformer. Matters of fact, thermal conductivity is generally known of its ability to conduct heat of the material itself. It occurs from the heat transfer operation from the low thermal conductivity to the high thermal conductivity. This can be denotes during the operation of the transformer in which the thermal conductivity properties of the cellulose paper operate as to insulate heat produce by the transformer to overcome the overheating issues. Hence, a development of a simulated model are constructed as to discover the effect of thermal conductivity towards the cellulose paper. Plus, the rate of the thermal conductivity of the cellulose paper are evaluated at different value of temperature oven during the selected hours as to be compared the result in between the standard and the linear value of the thermal conductivity of the cellulose paper itself. In this project, a simulated model are constructed by using COMSOL Multiphysics as to discover the thermal conductivity properties on the cellulose paper. Several data such as ageing hours of 0, 5, 10, 20 and 40 hours and oven temperature of 333.15K, 363.15, 403.15K and 423.15K are set in the simulation along with the linear properties of the thermal conductivity for the cellulose paper. Meanwhile additional properties as well as materials such as copper and transformer oil are added from the COMSOL Multiphysic library itself with its following standard criteria. As a result, during highest temperature oven of 423.15K, the thermal conductivity synchronously are at the highest rate of 0.32 W/m·K at 40 hours taken to be saturate of its operation. It is suggested that, the higher value of the properties of the linear thermal conductivity is applied, the higher rate of the cellulose paper to saturate per duration of its operation. By this, it also indicate that the value of the thermal conductivity are depends on the value of the temperature oven to be set within the hours of operation. Lastly, the result gained from the simulation are then analysed through the output graph on cutline of Y and X axis of the designed model as to closely discover the effect of the thermal conductivity towards each material at different oven temperature.

## ABSTRAK

Jangka hayat pengubah biasanya bergantung pada sifat penebat penebat pepejal dan cecair melalui operasi mereka. Kedua-dua sifat penting ini berperanan untuk melindungi pengubah terutamanya daripada terlalu panas yang boleh menyebabkan berlakunya letupan serius yang lain. Malangnya, kecekapan penebat ini akan merosot dan akan berlaku penuan kerana pengubah berfungsi secara berterusan. Oleh itu, kajian mengenai kesan penuaan sifat penebat melalui eksperimen simulasi dijalankan secara khusus pada kertas selulosa dalam beberapa jam operasi yang dipilih untuk mengimplementasi situasi sebenar opearasi pengubah tersebut. Oleh itu, sifat termal seperti kadar kekonduksian terma adalah antara faktor yang menyebabkan penuan terhadap kertas selulosa ke arah julat suhu pengubah yang berbeza. Tambahan pula, kekonduksian terma umumnya dikenali dengan keupayaannya bahan insulasi untu melakukan pemindahan haba terhadap bahan insulasi itu sendiri. Ia berlaku dari operasi pemindahan haba dari kekonduksian terma rendah hingga kekonduksian terma tinggi. Ini dapat menunjukkan semasa pengoperasian pengubah di mana sifat kekonduksian terma dari kertas selulosa beroperasi sebagai penebat penghasilan haba oleh pengubah untuk mengatasi masalah panas berlebihan. Oleh itu, pengembangan model simulasi dibina untuk mengetahui kesan kekonduksian terma terhadap kertas selulosa. Di samping itu, kadar kekonduksian termal kertas selulosa dinilai pada nilai ketuhar suhu yang berlainan pada jam-jam yang dipilih untuk dibandingkan dengan hasil antara standard dan nilai linear kekonduksian termal terhadap kertas selulosa itu sendiri. Dalam projek ini, model simulasi dibina dengan menggunakan COMSOL Multiphysics untuk mengetahui sifat kekonduksian terma pada kertas selulosa. Beberapa data seperti jam penuaan 0, 5, 10, 20 dan 40 jam dan suhu ketuhar 333.15K, 363.15, 403.15K dan 423.15K ditetapkan dalam simulasi bersama dengan sifat linear kekonduksian terma untuk kertas selulosa. Sementara itu sifat tambahan serta bahan seperti tembaga dan minyak pengubah juga diaplikasikan dari perpustakaan COMSOL Multiphysics dengan kriteria standard yang disediakan. Sebagai kesimpulan, semasa ketuhar suhu tertinggi 423.15K, kekonduksian terma secara serentak berada pada kadar langsung dan menghasilkan nilai kekonduksian terma sebanyak 0.32 W/m·K dengan jangka masa 40 jam yang diambil untuk menjadi tepu terhadap operasinya. Sebagai konklusinya, semakin tinggi nilai sifat kekonduksian termal linier diterapkan, semakin tinggi kadar kertas selulosa menjadi tepu setiap tempoh pengoperasiannya. Dengan ini, ini juga menunjukkan bahawa nilai kekonduksian terma bergantung pada nilai ketuhar suhu yang akan ditetapkan terhadap masa yang tetapkan. Akhir sekali, hasil yang diperoleh dari simulasi kemudian dianalisis melalui grafik output pada garis pintas paksi Y dan X model yang dinilai untuk mengetahui kesan kekonduksian termal terhadap setiap bahan pada suhu oven yang berbeza.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| MO | Mineral Oil |
| NE | Natural Ester Oil |
| SE | Synthetic Ester Oil |
| ASTM | American Society for Testing and Materials |
| IEC | International Electrotechnical Commission |
| WCP | Water Content Pervent |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

This chapter basically elaborates the project background, motivation and problem statement of this research. In addition, the objectives, scope and outline of this project are also explained in this chapter.

## 1.2 Research Background

An efficiency of a transformer is mostly influenced by the insulation system that being applied inside the transformer. In previous research, it is found that transformer life can achieved about 30 years of its operations [1]. If a prompt maintenance is followed, transformer insulation failure can be prevented and operation can be run efficiently without any eruptions. The purpose of electrical insulating materials is to insulate components of an electrical apparatus from each other and from the ground point [2]. Oil-impregnated paper are the most common insulation system that applied inside the transformer. Figure 1.1 shows an overview of a standard transformer that used oil as the liquid insulation.

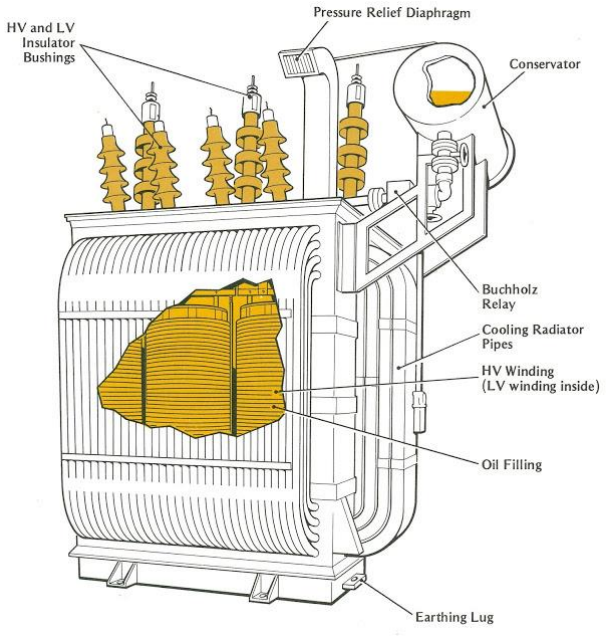


Figure 1.1: The overview of common oil-immersed transformer [3]

Solid insulation in transformer can be represented by the pressboard and cellulose/kraft paper that impregnated with transformer insulation oil. The paper insulation is one of the properties that determined the lifetime of the transformer [4]. It provides excellent dielectric strength and low dielectric loss. Meanwhile, there are 3 types of common insulating oil used inside the transformer which are Mineral Oil (MO), Natural Ester (NE) and Synthetic Ester (SE) [5]. The insulating oil serve dual purposes which are heat dissipator and also as act as an electrical insulation between energized parts. In the long run, ageing escalate and eventually the serviceability become poor and might cause a failure of the operation. Numerous factors that affecting the transformer ageing can be classified through thermally, electrically, mechanically and environmentally[2].

## 1.3 Motivation

Generally, an oil-immersed transformer applied either Mineral Oil or Ester oil (Natural Ester & Synthetic Ester) and cellulose/Kraft paper as their insulating system. As time comes, these insulation systems aged and the ageing process reduce the capability of the insulating oil and the cellulose/Kraft to work on their maximum operation. Eventually, the degradable of the insulation will be affecting the transformer lifetime and decelerate the efficiency of its performance. Main factor affecting the accelerations of ageing of the insulation of a transformer are high temperature, humidity, oxidation and the acidity of its oil [6]. Figure 1.2 indicates additional factors affecting the efficiency and deterioration of transformer oil-paper insulation and the resulting breakdown process.

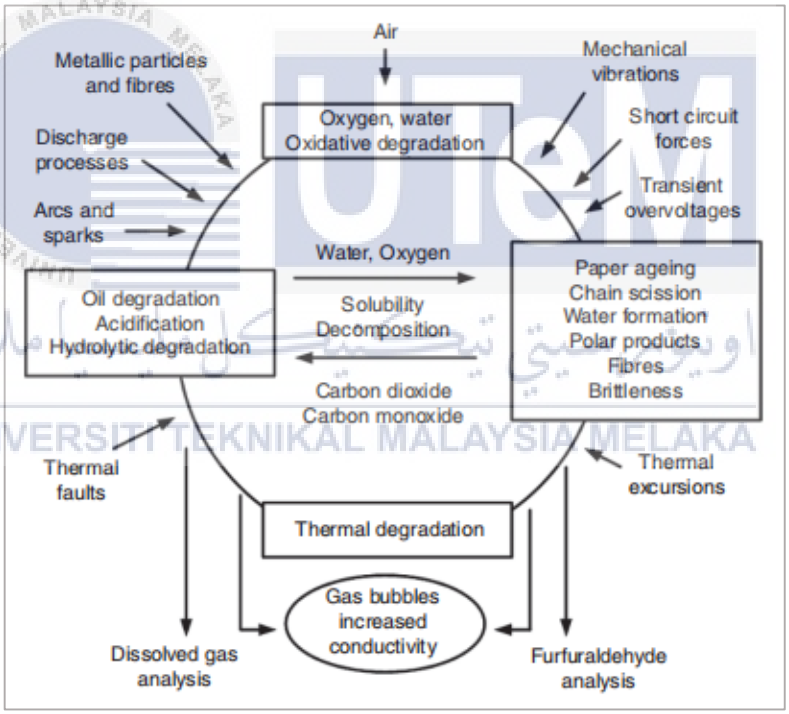


Figure 1.2: Factors that influencing the performance and degradation of transformer oil-paper insulation and resulting breakdown mechanism [5]

Consequently, insulation system of a transformer must acquire high electric strength, high volume resistivity, high thermal conductivity, high specific heat, high flash point, low viscosity, low volatility, and low dielectric dissipation factor as well as high resistance to chemical deterioration, non-flammable, and cost worthy [7]. These criteria need to follow related international standard to be operated as transformer insulation system. This also maintains the mineral oil at the top choice of the insulating oil as almost all the specifications meet the necessary standard. At the same time, studies on various forms of oil, such as natural ester oil, are recommended for preparation when mineral oil is no longer available on the market. Furthermore, initial results related to the necessary parameters of the natural ester oil need to be collected by conducting simulations as one of the methods to identify the thermal conductivity, fluid flow and others before it is applied to the actual situation. It is to ensure that the insulation system of the transformer works according to the information gathered.

## 1.4 Problem Statement

A common solid insulation which is cellulose paper are usually impregnated in the transformer oil and act as the insulation system during the operation of a transformer. With efficient dielectric strength and low dielectric loss, cellulose paper are most preferred solid insulation to overcome heat conduction in between the core of a transformer. Unfortunately, the cellulose paper have its own defect issues such as hygroscopic properties, reactivity with oxygen as well as thermal instability at high temperature. With this issues, it will eventually degrade the quality and the efficiency as a solid insulation within the operating years of transformer. Mere observation on the cellulose paper properties can be conducted by improving the thermal conductivity and study the effect towards the cellulose paper itself at different range of temperature. Basically, accelerated thermal ageing test are one of the experiment that can be conducted to testify the insulating properties of the insulating material of cellulose paper at different temperature. Other experiment that can be performed is by conducting a simulation model in which it is more convenient. The simulation towards improving the thermal conductivity of the cellulose paper can be conducted in a COMSOL Multiphysic software as to forecast the expected result as it can be improved

towards a better efficiency as the insulation system. With this simulation, it can reduce the time and material consuming during the physical experiment. The simulation is conducted on cellulose paper specifically towards on finding of the thermal conductivity rate as to provide preliminary reference for future experiment. Furthermore, it also can help to identifies changes happen during the simulation being conducted. In addition, this simulation includes the designing of the space dimension in a specific discretization of space as it used inside the oven of the accelerated ageing test.

## 1.5 Objective

The objective of this project of the finite element modelling of thermal ageing of oil-impregnated paper in oven are denotes as below:

1. To develop a simulation and discover the effect of thermal conductivity t onwards cellulose paper
2. To evaluate the rate of thermal conductivity of cellulose paper towards different value temperature of oven at different hours.
3. To compare between fix value and linear value of thermal conductivity of cellulose paper within different hours of ageing.



## 1.6 Scope of Work

This research mainly will be focus on:

1. The ageing hours of thermal acceleration experiment and the oven temperature.
2. The rate of thermal conductivity of cellulose paper that will be used for the accelerated thermal ageing test by applying
3. Parameter of the material selection for each element.
4. Essential criteria of the thermal conductivity modelling in COMSOL Multiphysic.

## 1.7 Project Outline

In the next following chapter, the report will be organized as follows:

**Chapter 2:** Brief explanation on the insulating type that being used in most common transformer such as mineral oil, natural ester and synthetic ester. An ageing study are also will be describe as it occurs during the accelerated thermal test. Factors that influencing the ageing process are also to be discovered in this chapter.

**Chapter 3:** Provide method that will be applied on this project. This includes the preparation and procedure before, during and after the accelerated thermal ageing experiment on the vegetables oil. Detailed specification is identified according to the predefined standards.

**Chapter 4:** Provide preliminary result to the vegetables oil modelling to be used as an insulation for the transformer. Further discussion on thermal conductivity of the CO and PO will be discovered in this chapter. It also includes the predetermined result for the final modelling test for future reference.

**Chapter 5:** Comprises of conclusion of the preliminary result obtained from the experiment. A recommendation for future is also to be mention in this chapter as further improvement in this project as it has to be implemented near the future.