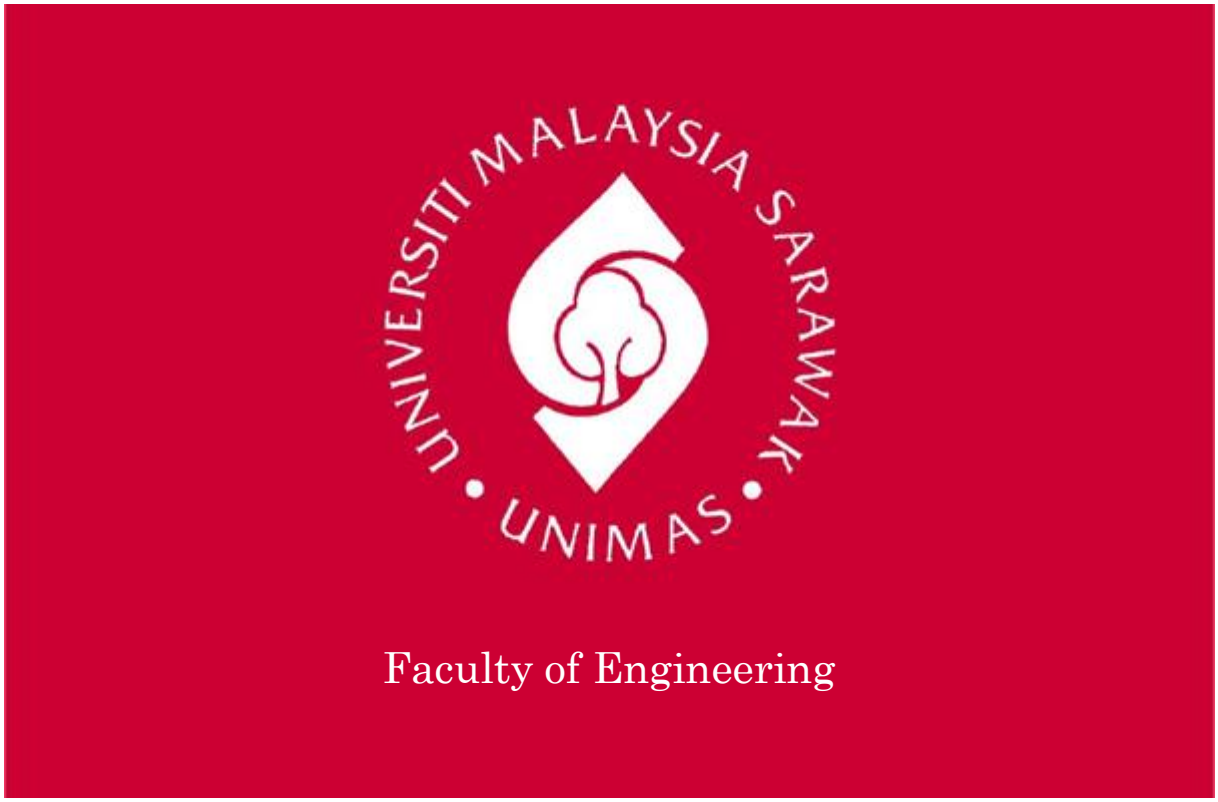


# EXPERIMENTAL INVESTIGATION OF THERMAL AGING AGAINST BREAKDOWN VOLTAGE OF PALM-BASED NANOFLUID

Syed Hazim Fawwaz bin Wan Razali

Bachelor of Engineering

Electrical and Electronics Engineering with Honours

2023

**UNIVERSITI MALAYSIA SARAWAK**

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Final Year Project Report ☑

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# EXPERIMENTAL INVESTIGATION OF THERMAL AGING AGAINST BREAKDOWN VOLTAGE OF PALM-BASED NANOFLUID

## Experimental Investigation Of Thermal Aging Against Breakdown Voltage Of Palm-Based Nanofluid

SYED HAZIM FAWWAZ BIN WAN RAZALI

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering
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# ABSTRACT

The use of mineral oil as an insulating oil in transformers is well-known, and it thus dominates the global market as a commercial transformer oil. Furthermore, because to its wide availability and low cost, mineral oil is the single and significant alternative for enterprises to consider. Transformer insulating oil is crucial in ensuring that the function of the transformer is working well and that it is kept in optimum condition so that it does not influence the entire electrical power system and causes other components to malfunction. However, this idea providing a new alternative technique to replace mineral oil with greener and eco-friendly insulating oil. This is due to the growing demand for greener technology in all areas. In this project, a biodegradable oil (palm oil) sample will be used to produce a reaction between biodegradable oil, alcohol (methanol), and potassium hydroxide (KOH) as a catalyst. This is known as the transesterification process. Next, in a means to enhance its dielectric properties, nano powder (nanosilica) is added to the sample and this addition is known as nanofluids. There are still few studies using this form of insulating oil, as most are focused on nano-based mineral oil and raw biodegradable oil. As a result, this project is mainly focused on nano-based palm ester oil, which may provide a superior outcome in terms of dielectric characteristics. Aside from that, past study indicates that it has great breakdown voltage (BDV) strength and may entirely decay in a short period, which would be a benefit when compared to commercial mineral oil. Throughout the procedure, the produced sample will be subjected to a series of standard tests to assess its performance. Characterization tests utilising a Scanning Electron Microscope (SEM) and Fourier Transform Infrared (FTIR) were performed at the UNIMAS Chemical Lab, while the remaining testing was performed at a licenced lab in Kuching, Sarawak. The oil samples were evaluated in terms of particle characterisation, breakdown voltage (BDV), which were then compared to commercial insulating oil and palm-based ester insulating oil. The result reveals that palm oil methyl ester with 0.05g/L CNT nanofluid has the best breakdown voltage after 50 hours. All breakdown voltage of the sample has been carried out.

# ABSTRAK

Penggunaan minyak mineral sebagai minyak penebat dalam transformer terkenal, dan dengan itu ia menguasai pasaran global sebagai minyak transformer komersial. Tambahan pula, kerana ketersediaannya yang luas dan kos rendah, minyak mineral merupakan alternatif tunggal dan penting untuk dipertimbangkan oleh perusahaan. Minyak penebat transformer adalah penting dalam memastikan fungsi transformer berfungsi dengan baik dan ia disimpan dalam keadaan optimum supaya ia tidak mempengaruhi keseluruhan sistem kuasa elektrik dan menyebabkan komponen lain tidak berfungsi. Walau bagaimanapun, idea ini menyediakan teknik alternatif baharu untuk menggantikan minyak mineral dengan minyak penebat yang lebih hijau dan mesra alam. Ini berikutan permintaan yang semakin meningkat untuk teknologi yang lebih hijau dalam semua bidang. Dalam projek ini, sampel minyak biodegradasi (minyak sawit) akan digunakan untuk menghasilkan tindak balas antara minyak biodegradasi, alkohol (metanol), dan kalium hidroksida (KOH) sebagai mangkin. Ini dikenali sebagai proses transesterifikasi. Seterusnya, dalam cara untuk meningkatkan sifat dielektriknya, serbuk nano (nanosilica) ditambah kepada sampel dan penambahan ini dikenali sebagai cecair nano. Masih terdapat beberapa kajian yang menggunakan minyak penebat bentuk ini, kerana kebanyakannya tertumpu pada minyak mineral berasaskan nano dan minyak terbiodegradasi mentah. Hasilnya, projek ini tertumpu terutamanya pada minyak ester sawit berasaskan nano, yang mungkin memberikan hasil yang unggul dari segi ciri dielektrik. Selain itu, kajian lepas menunjukkan bahawa ia mempunyai kekuatan voltan pecahan yang hebat dan mungkin mereput sepenuhnya dalam tempoh yang singkat, yang akan memberi manfaat jika dibandingkan dengan minyak mineral komersial. Sepanjang prosedur, sampel yang dihasilkan akan tertakluk kepada satu siri ujian standard untuk menilai prestasinya. Ujian pencirian menggunakan mikroskop elektron pengimbasan (SEM) dan Fourier Transform Infrared (FTIR) dilakukan di Makmal Kimia UNIMAS, manakala ujian selebihnya dilakukan di makmal berlesen di Kuching, Sarawak. Sampel minyak dinilai dari segi pencirian zarah, voltan pecahan (BDV), yang kemudiannya dibandingkan dengan minyak penebat komersial dan minyak penebat ester berasaskan kelapa sawit. Keputusan menunjukkan bahawa ester metil minyak sawit dengan cecair nano 0.05g/L CNT mempunyai voltan pecahan yang terbaik selepas 50 jam. Semua voltan pecahan sampel telah dijalankan.

# TABLE OF CONTENTS

## LIST OF TABLES

**Table** **Page**

# LIST OF FIGURES

**Figure** **Page**

# LIST OF ABBREVIATIONS

| | |
|---|---|
| BDV | Breakdown Voltage |
| POME | Palm Oil Methyl Ester |
| PO | Palm Oil |
| CNT | Carbon Nanotube |
| RBDPO | Redefined Bleach Deodorised Palm Olein |
| OIP | Office of Infrastructure Protection |
| PKO | Palm Kernel Oil |
| FAME | Fatty Acid Methyl Ester |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Breakdown voltage insulation oil is a new type of oil that can help protect electronic equipment from sudden and accidental overloads. Unlike traditional electrical oils, breakdown voltage insulation oil is designed to protect equipment from a short circuit. So, if the power supply suddenly shorts out, or if there is a power surge, this breakdown voltage insulation oil will protect the equipment from being damaged. A transformer is the most crucial piece of equipment in an electrical power supply network. A transformer is a device that, depending on the circumstances, converts high voltage to low voltage. During operation, the winding and core of a transformer generate heat. This heat can affect transformer efficiency and life expectancy. To prevent these issues, transformer oil is utilised as a cooling medium and as an electrical insulator.

The first section shows the most important papers that looked for palm oil (PO)-based as an alternative to biodegradable oil insulation and the effect of thermal ageing on the breakdown voltage of palm-based methyl ester. The main thing that causes insulation to age is heat, which makes it less strong and less good at conducting electricity [1]. So, figuring out the condition of OIP by looking at its dielectric properties is important for the safe operation, planned maintenance, and replacement of transformers.

## 1.2 Problem Statement

For decades, power generation industry has commercialised the mineral insulating oil. However, mineral oils are obtained from non-renewable and non-sustainable sources, which is unfavourable. The spilled mineral oil from the leakage and the combustion product will contaminate the air, water, and soil. For power transformer with nominal voltage of 110 kV require 7-8 kg of insulating oil while 400 kV need 80 thousand kilogram which raise the hazard. The disposable process relatively high cost as only small

part of the mineral oil will self-degradation over time. Vegetable insulating oil has a high viscosity, which reduces the cooling effectiveness of power transformers by causing a slow flow rate. Next, commonly insulating oil that are used is from petroleum which is non-renewable source which cannot be replenished in a brief of time [2].

Furthermore, the presence of CNT nanoparticles in the oil may influence its dielectric properties and breakdown voltage performance. However, the specific impact of thermal aging on the breakdown voltage of transformer oil with CNT nanofluid has not been thoroughly examined.

## 1.3 Objectives

The purpose of this research is to explore and experiment more about the palm-based ester insulating oil. Other than that, the further research will be continue with the present of the nanofiller. This nanofiller will be added into palm-based insulating oil and the dielectric properties of the sample will be identify.

The objectives of this study are to

1. To prepare 0.01g/L, 0.02g/L, 0.05g/L and 0.10g/L of CNTs in POME sample.
2. To analyse the breakdown voltage of palm-based ester nano silica insulating oil after 50 hours.
3. To determine which sample has better insulating oil properties with different amounts of nanoparticles.

The thermal aging process, which the transformer oil is subjected to during operation, can potentially affect its breakdown voltage characteristics. This study is to investigate the effect of thermal aging on the breakdown voltage of transformer oil incorporated with carbon nanotube (CNT) nanofluid. The thermal aging process, which the transformer oil is subjected to during operation, can potentially affect its breakdown voltage characteristics.

## 1.4 Project Scope

The project background of the study is covered in the first chapter of this thesis, which also goes into more detail regarding the history of mineral oil use as insulating oil in transformers. In addition, this chapter describes a new type of insulating oil that uses

biodegradable oil. The description of nano-based insulating oil is expanded upon. Palm based cooking oil will be used as base oil in this experiment. Nanoparticles that will be used is carbon nanotubes and which undergo the addition of nanofluid process. The problem definition and the project objectives come next. Finally, this chapter also wraps up this thesis' project outline.

## 1.5 Project Outline

The summary of the report as explained below:

### 1.5.1 Chapter 1: Introduction

This chapter is mostly about explaining what the project is all about. It has sections on the research background, the problem statement, the project's goals, and its scope. It gives a general overview of the need for biodegradable insulating oil to replace mineral oil that can be bought in stores. It also explains why the right number of nanoparticles is important to improve biodegradable insulating oil.

### 1.5.2 Chapter 2: Literature Review

This chapter is about the most recent research articles or ideas about insulating oil, which is a commercial good, and its biological oil predecessors, which are now called palm oil. All the dielectric properties will be talked about in depth. This chapter also talked about how nanoparticles can be used on natural esters. It also talked about the standard concentration that can show the best concentration of nanoparticles to make the dielectric properties better.

### 1.5.3 Chapter 3: Methodology

This chapter tells in depth about the methods used in this experiment. The procedure focuses on making natural esters and adding nanoparticles, which is what this study found. After that, insulating oil is put through a test in a lab to compare all its dielectric properties.

### 1.5.4 Chapter 4: Result and Discussion

This chapter examine and analyse the result of the tests. The result compiled and expressed in graph to make is easier to understand and compared with the standard commercially available insulation oil or with its standard. It is important to justify the

result to make sure how much improvement or how far it is from the standard as an insulation oil.

### 1.5.5 Chapter 5: Conclusion

This chapter summarise the result and method for synthesising of the sample. Any problems or obstacles is explained extensively while various countermeasures to solve the problems are discussed too. It also shows the compatibility of the sample to be insulation oil.

# Chapter 2

# LITERATURE REVIEW

## 2.1 Overview

Mineral oil has been widely utilised as a liquid insulator in power transformers because it is cheaply accessible and has excellent dielectric characteristics. On the other hand, petroleum reserves are dwindling, indicating that mineral oil will become increasingly scarce. Multiple causes, such as electrical arcing, thermal ageing, and oxidation, will deteriorate the qualities of insulating oils, according to the general rule [1]. Transformer insulating oils have a critical temperature that must not be exceeded to prevent electrical failures. Beyond this temperature, the oil will progressively deteriorate, and its insulating characteristics will be lost owing to heat processes. Therefore, the goal of this study is to investigate the effect of thermal aging against breakdown voltage with carbon nanotube as nanoparticle [3]. Vegetable insulating oil is considered an environmentally favourable type of insulating oil since it is biodegradable, eco-friendly, and possesses a respectable amount of breakdown voltage. Transesterification process will be done to reduce the viscosity of refined bleached deodorised palm olein (RBDPO), resulting in the creation of palm oil methyl ester, to address this issue (POME). In accordance with the IEC60156 standard, electrical breakdown voltage tests were carried out [2]

## 2.2 Transformer oil

Transformer in one of the main components and it is an important part in electrical distribution and transmission power system. It operates by transferring electrical energy by electromagnetic induction between two or more circuits. A different current in one of the transformer coils generates a different magnetic field and thus, it will induce a variable electromotive force/voltage in the second coil [4]. When a transformer is working, it makes a lot of heat which the main things that cause heat in a transformer are core losses,

copper losses in the windings, and stray losses caused by a leakage current field. All these losses cause heat, which must be removed so that the transformer will not get too hot [5]. As a result, a cooling system in the transformer is required to avoid the heat, or the transformer will eventually become hot enough to stop working. Transformer oil functions as a cooling mechanism to balance the transformer's heating. The insulating oil fills the pores in the fibrous insulation and the crevices between the tank's windings. The heated oil will then go to the radiator and gently cool, cooling the transformer winding as well [6]. During the process, however, some eddy current flows through the magnetic core. As a result, the core will generate heat, which may disrupt the performance. A liquid is applied in the transformer to ensure proper transformer operation. Insulating oil is the name given to the liquid.

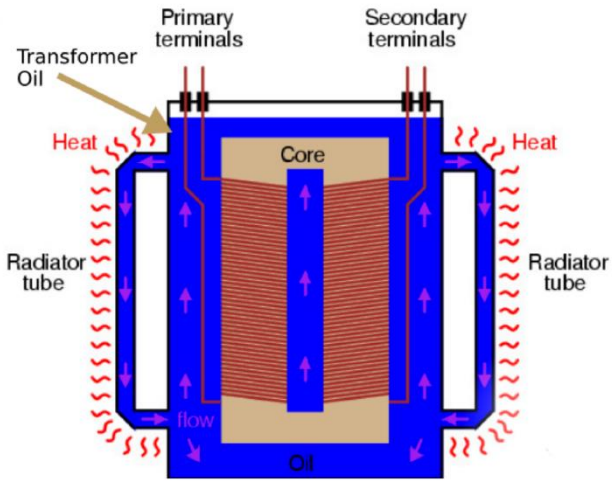


**Figure 1** : Cross-sectional of Transformer [4].

## 2.3 Vegetable Palm Oil

Due to its availability, good cooling, and dielectric quality, mineral oil has been utilised as an electrical insulator for ages. Nevertheless, petroleum sources are non-renewable and diminishing. Vegetable insulating oil is an option since it is renewable, eco-friendly, biodegradable, has a high ignition temperature, and a high electrical breakdown voltage. These characteristics allow vegetable insulating oil to serve as a substitute for mineral oil, the availability of which may soon be restricted.

**Table 1** : Description of the types of Palm Oil [7].

| Type of Palm Oil | Description | References |
|---|---|---|
| Crude Palm Oil | Can be obtained from the mesocarp of the palm nut by sterilization, purification, stripping and extraction process. | [8],[9],[10] |
| Palm Kernel Oil | Can be produced by drying and separation process. | [8],[9],[10] |
| Redefined, Bleached and Deodorized Palm Oil | Can be processed through under degumming, bleaching and deodorization technique. Also, can be separated through fractionation process to produce the RBDPO Olein | [9],[10],[11] |
| PKO Alkyl Ester | Can be made by transesterification, epoxidation, and acid-catalysed ring opening reaction | [9],[10],[11] |
| Palm Fatty Acid Ester | Can be made by molecular design and the transesterification of fatty acid methyl ester and alkyl alcohol from unsaturated fatty acids in palm oil. | [12],[13] |

## 2.4 Mineral Oil

Petroleum, a non-renewable energy source, is used to produce mineral oil. When spills occur because of mistakes made by humans or other shortcomings, its non-biodegradable qualities cause contamination of the water and land [14]. The oil is stable at low temperatures, but as the temperature rises, its properties start to deteriorate. Biodiesel is thought to replace mineral oil under those circumstances [15], [16]. The recent demand for the generation of renewable energy, particularly biodiesel, is highly interesting. Biodiesel is more environmentally friendly, biodegradable, and non-combustible than mineral oil. Higher than 300°C is the flash point and fire point. Its fireproof qualities can lower the cost of maintenance, the risk of a transformer explosion, and the need to put out fires [17].

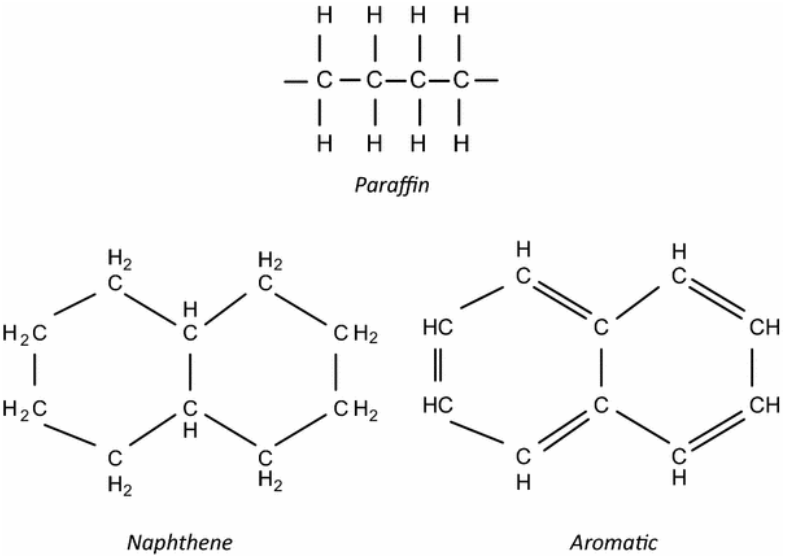


**Figure 2** : Hydrocarbon of mineral oil [18].

## 2.5 Nanofluid

A nanofluid is a liquid in which particles of the nanometre scale are suspended. Particle suspension can be aided by surface-active chemicals in these fluids, which may or may not be present. The thermal conductivity of nanoparticles is significantly greater than that of the basic fluids. Since the addition of nanoparticles to nanofluids enhanced their compressive strength, a wide variety of oxides, metals, nitrides, and nonmetals, such as carbon nanotubes, can be employed as nanoparticles [19]. Various fluids, including water, ethylene glycol, and oils can serve as bases. There have been varying reports about

the rate of progress. Particle size, temperature and pH are only few of the variables that contribute to the observed range in thermal conductivity [20]. To prepare nanofluids, nanoparticles must be chosen with care. Nanoparticles are typically chosen based on their basic properties of permittivity and conductivity. As a result, one should first analyse all the material's properties, which will aid in increasing the dielectric strength and thermal characteristics of the fluid. The nanoparticles are broadly classified into three categories which are shown in Table 2.

**Table 2**: Categories of nanoparticle.

| Type | Nanoparticle | Reference |
|---|---|---|
| Conductive | $Fe_2O_3$, ZnO | [21] |
| Semi conductive | $TiO_2$, $CuO_2$ | |
| Insulating | BN, $SiO_2$ | |

To create the nanofluids, different nanoparticles which are $Al_2O_3$, CuO, $TiO_2$, and ZnO were mixed into transformer oil to the desired concentration of 10% (w/v). The nanofluids' AC and positive dielectric breakdown strengths were compared to those of pure oil using IEC standards, and it was discovered that all the samples had higher AC and positive dielectric breakdown than pure oil.

### 2.5.1 Carbon Nanotubes Nanoparticle (CNT)

A carbon nanotube (CNT) is a tube made of carbon with diameters typically measured in nanometres. There are some similarities between single-walled carbon nanotubes (SWNTs) and multi-walled carbon nanotubes (MWNTs), but also significant variances [22]. Like fullerenes, SWNTs are an allotrope of sp2 hybridised carbon. The structure can be visualised as a cylindrical tube made of graphite-like 6-membered carbon rings. MWNTs are a collection of these tubes arranged in a series of concentric cylinders. As seen in Figure 4, MWNTs can be conceptualised as a collection of single wall tubes nested inside one another. These concentric walls could number as few as 6 or as many as 25. Therefore, MWNTs may have diameters as large as 30 nm as opposed to 0.7 to 2.0 nm for conventional SWNTs. Carbon nanotubes (CNTs) have been investigated as

potential additives or nanoparticles for transformer oil to enhance its properties and performance.

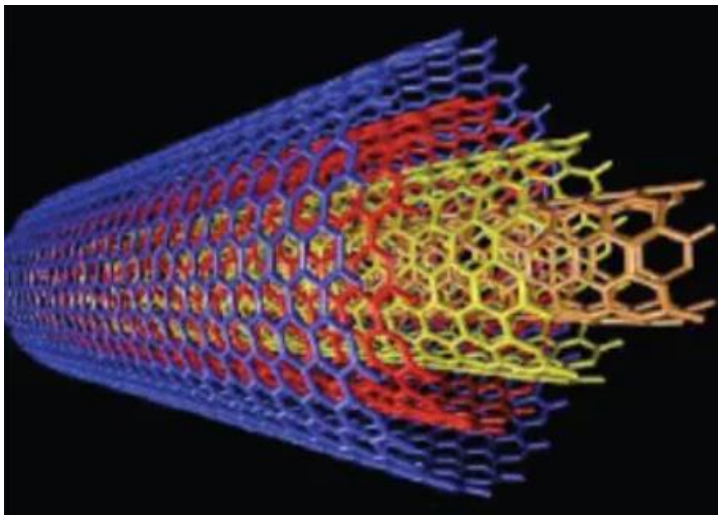

**Figure 3** : Multi-walled Carbon Nanotubes [23].

Polymeric composites' thermal stability, hardness, and electrical conductivity are all improved by CNTs [24]. Additionally, it alludes to carbon allotropes having nanostructures that can have a length-to-diameter ratio of more than 1,000,000. Arc discharge, laser ablation, and chemical vapour deposition are a few methods that have been developed to create nanotubes in significant quantities [25]. CNTs are desirable platforms for the treatment of various diseases due to their exceptional thermal, and electronic properties as well as their tubular shape, which offers a high surface area [23].