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PHYSIOCHEMICAL AND ELECTRICAL PERFORMANCE OF KENAF FIBER AS INSULATING PRESSPAPER IMPREGNATED WITH MINERAL OIL

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PHYSIOCHEMICAL AND ELECTRICAL PERFORMANCE OF KENAF FIBER AS INSULATING PRESSPAPER IMPREGNATED WITH MINERAL OIL

Physiochemical And Electrical Performance Of Kenaf Fiber As Insulating Presspaper Impregnated With Mineral Oil

FATINI IZZATI BINTI KIP

A dissertation submitted in partial fulfilment
of the requirement for the degree of
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May the individuals be bestowed with prosperity and prestige in their endeavours by divine intervention.

ABSTRACT

Cellulose-derived materials, including paper, board, and wood structures are frequently employed in power transformers for their dual functionality as electrical insulation and mechanical reinforcement. Historically, cellulose insulation has been treated with mineral oils, resulting in advantageous effects on ageing indicators, ageing velocities, and water distribution in oil-paper systems.

The evaluation of kenaf's performance as an electrical paper insulation is essential in determining its suitability. The objective of this study is to examine the impact of the ageing process on kenaf paper insulation in mineral oils through fibre characterization (FESEM), Fourier transforms infrared spectroscopy (FTIR), tensile strength and AC breakdown voltage.

The experimental methodology entailed the exposure of kenaf paper to thermal ageing at 90°C, ageing with mineral oil (Nynas) for 240, 480, and 720 hours. The assessment of the oil-impregnated paper's breakdown voltage strength was conducted following the IEC 60243-1 standard. Tensile strength measures the resistance of the material to strain or stretching. The morphological and structural changes of fibres in both types of paper insulation were examined using FESEM, while FTIR is a method for identifying organic, polymeric, and sometimes inorganic compounds.

The findings of the research demonstrate an inverse relationship between the temperature of ageing and the breakdown voltage, implying that a rise in temperature results in a reduction of the breakdown voltage. Furthermore, it was observed that the extent of the amorphous region in kenaf paper. The results revealed that the tensile strength and AC breakdown voltage reflect to the ageing process. The tensile strength and AC breakdown voltage decreased with increased the ageing process.

This study proves kenaf mineral oil-impregnated paper insulation works. The results underscore the importance of accounting for the ageing effect on kenaf insulating potential and improve understanding of paper insulators' physical, mechanical, and electrical properties.

ABSTRAK

Meneliti prestasi kenaf sebagai penebat kertas elektrik adalah penting dalam menentukan kesesuaiannya untuk tujuan ini. Matlamat penyelidikan ini adalah untuk menyiasat bagaimana proses penuaan mempengaruhi penebat kertas kenaf dalam minyak mineral, menggunakan pencirian gentian (FESEM), spektroskopi inframerah transformasi Fourier (FTIR), kekuatan tegangan, dan voltan kerosakan AC.

Penemuan penyelidikan menunjukkan korelasi songsang antara suhu penuaan dan voltan kerosakan, menunjukkan bahawa suhu yang lebih tinggi membawa kepada penurunan voltan kerosakan. Selain itu, diperhatikan bahawa tahap kawasan amorfus dalam kertas kenaf mempunyai kesan ke atas prestasinya. Keputusan menunjukkan bahawa kedua-dua kekuatan tegangan dan voltan kerosakan AC mencerminkan proses penuaan, kerana ia berkurangan dengan peningkatan tempoh penuaan. Pendekatan eksperimen melibatkan penundaan kertas kenaf kepada penuaan terma pada 90°C, serta penuaan dengan minyak mineral (Nynas) untuk tempoh 240, 480, dan 720 jam. Kekuatan voltan pecahan kertas yang diresapi minyak telah dinilai mengikut piawaian IEC 60243-1. Kekuatan tegangan mengukur keupayaan bahan untuk menahan ketegangan atau regangan. FESEM digunakan untuk mengkaji perubahan morfologi dan struktur dalam gentian kedua-dua jenis penebat kertas, manakala FTIR membenarkan untuk mengenal pasti sebatian organik, polimer, dan kadangkala bukan organik.

Bahan selulosa, seperti kertas, papan, dan struktur kayu, telah lama digunakan dalam pengubah kuasa untuk kefungsian dwinya iaitu menyediakan penebat elektrik dan tetulang mekanikal. Secara tradisinya, penebat selulosa telah dirawat dengan minyak mineral, yang didapati mempunyai kesan positif terhadap penunjuk penuaan, kelajuan penuaan, dan pengagihan air dalam sistem kertas minyak.

Kajian ini memberikan bukti tentang keberkesanan penebat kertas yang diresapi kenaf dalam minyak mineral. Hasilnya menggariskan kepentingan untuk mempertimbangkan kesan penuaan ke atas keupayaan penebat kenaf dan menyumbang kepada pemahaman yang lebih baik tentang sifat fizikal, mekanikal dan elektrik penebat kertas.

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FTIR	Fourier Transform Infrared Spectroscopy
FESEM	Field Emission Scanning Electron Microscopy
MO	Mineral oil
TGA	Thermogravimetric analysis
BDV	Breakdown voltage
DP	Degree of polymerization
IEC	International Electrotechnical Commission

CHAPTER 1
INTRODUCTION

1.1 Background

Presspaper, pressboard, and mineral oil have been indispensable insulating materials in the power transformer for decades [1]. The presspaper used to insulate the transformer's winding conductor prevents electrical shorts and breakdowns. Simultaneously, the liquid insulation provided by mineral oil performs the cooling process by transferring the heat from the transformer's interior to its exterior.

Wheat straw, rice straw, sugarcane straw, bamboo, and kenaf are just a few of the many non-wood fiber sources used to create paper. In addition, kenaf fiber has been recognized as a non-wood fiber with the potential for paper manufacturing comparable to the quality of paper produced using wood fiber [2]. According to its scientific name, the plant known as kenaf, or Hibiscus cannabinus L., is a member of the Malvaceae family and has a short-day length. Because of having high fiber strength, using kenaf as an alternative fiber source can indirectly lessen humans' environmental impact. It also offers inexpensive production costs for goods based on pulp [3], [4].

As a means of enhancing the material's mechanical, physical, and electrical properties, treatments have been applied to the fibers or materials themselves. Poor physical properties will reduce fibers' strength and shelf life because they affect fibers' dimension stability, especially lignocellulosic materials [5].

The purpose of this investigation is to evaluate how the ageing time influences the physical, mechanical, and electrical characteristics of kenaf fiber as insulating press paper impregnated with mineral oil. The research reveals the findings of experiments about the AC breakdown strength of impregnated paper. Also, physical, and mechanical measurements, such as Field emission scanning electron microscopy (FESEM), Fourier transform infrared spectroscopy (FTIR), and tensile strength have been explored.

1.2 Problem Statement

There is a growing apprehension among power industries worldwide regarding the power system network that employs oil-filled apparatus, which comprises cellulose as its paper insulation. Cellulose exhibits commendable insulating properties while maintaining a cost-effective price [6]. Nevertheless, the escalating demand for cellulosic insulation in Malaysia is posing a significant challenge because of the scarcity of softwood pulp. Moreover, this circumstance is likely to result in an increased deforestation rate owing to the elevated paper production, thereby adversely impacting the environment. Due to rising energy needs worldwide, high-capacity power transformers are being manufactured rapidly, and using kraft paper and other materials is not enough to protect transformers.

Malaysia is a significant manufacturer of electrical transformers. Presently, the nation predominantly engages in the importation of kraft presspaper, which serves as an insulator in transformers. The present dependence on imported kraft presspaper poses a susceptibility for the electrical transformer sector in Malaysia. In the event of a disturbance in the supply of kraft presspaper, the industry may experience significant repercussions. The establishment of a domestic presspaper industry for Kenaf in Malaysia could potentially enhance the self-sufficiency of the country by decreasing its dependence on foreign materials. Additionally, this could bolster the durability and adaptability of the nation's electrical transformer sector.

In the electrical industry, Kraft presspaper and pine presspaper are the most used insulating presspaper. The disadvantages of these materials include their sensitivity to moisture, flammability, and lack of resilience. Kenaf is a natural fibre with numerous advantages over kraft and pine presspaper. Kenaf is resistant to moisture, and flame durable, and sustainable. Kenaf presspaper is a promising new insulating presspaper alternative. It could enhance the efficacy and dependability of electrical transformers. Presspaper made from kenaf could reduce the risk of combustion in electrical transformers and could enhance the moisture resistance of electrical transformers. Kenaf presspaper also could enhance the durability of electrical transformers and it’s a sustainable and renewable material. Therefore, introducing a new kenaf (Hibiscus cannabinus) improved power transformer system necessitates regular, time-consuming, and money-consuming insulating paper replacement.

Kenaf is one of the non-wood plant fibers that can be utilized as reinforcement or filler in traditional Asian and African crops after wood and bamboo. Four to five months after sowing, kenaf's sponge-like cells grow swiftly. 35% of the kenaf stalk's dry weight is a bast fiber used to make paper, textiles, and cordage. 65% of kenaf fiber is used for animal bedding and potting material. A plant with a diameter of its base between 3 and 5 cm can grow over three meters tall [7]. The long fiber is harvested from the kenaf plant's long stem. In contrast, the kenaf stem has two layers of fiber: bast fiber on the outside and core fiber on the inside [8].

In addition, non-ferrous cells make up a thin layer of pith near the tree's center. Several research indicates that the bast fiber, used to make paper, textiles, and cordage, accounts for around 35% of the dry weight of the kenaf stalk. The core of the kenaf plant is used for various purposes, including animal bedding and potting soil.

The tensile strength of kenaf or epoxy composites had the highest ultimate tensile strength. All composite power gradually increased when the fiber increased [9]. Concerning tensile modulus, kenaf fibers have a higher value than bamboo and jute. The average tensile modulus of kenaf is 5.52GPa, which is 35.1% higher than bamboo and 38.2% higher than jute [10]. Kenaf fiber composite seems stronger. Kenaf fiber gets the lowest elongation at fracture of 2.9%, which means that the Kenaf fiber composite is more brittle. Kenaf fiber has a higher tensile modulus and strength than other natural fibers. The reason kenaf fibre-reinforced composites have better tensile properties may be found in the SEM micrographs. Furthermore, kenaf fibers have higher characteristics than other natural fibers, i.e., longer fiber length and a smaller diameter. These shall be why kenaf fibers showed better tensile properties than other natural fibers [10].

The purpose of this investigation is to evaluate how the ageing time influences the physical, mechanical, and electrical characteristics of kenaf fiber as insulating presspaper impregnated with mineral oil (Nynas Nytro Libra). The research was done to investigate the suitability of the kenaf-based paper insulation as an electrical paper insulation, notably under accelerated aging experiments.

1.3 Objectives

This study's main aim was to investigate kenaf fiber's performance as an insulating presspaper impregnated with mineral oil. Can be achieved through the following set of objectives:

i. To determine the mechanical properties of kenaf fiber insulating papers.
ii. To evaluate kenaf fiber insulating papers' physiochemical performance.
iii. To interpret the kenaf fiber insulating papers' electrical performance.

1.4 Scope of work

The scope and limitations of this experiment are as follows:

This study focuses on the effects of aging on paper insulation that has been soaked in mineral oil (Nynas Nytro Libra). This mineral oil is because Nytro Libra was explicitly designed for use in oil-filled electrical equipment, which is why it is being used. Additionally, it is constructed and configured in such a way as to provide excellent resistance to oil degradation. In addition, it has good oxidation stability, resulting in an increased transformer life and decreased maintenance. The experiment was conducted at temperatures of 90°C and for a predetermined time for 240 hours, 480 hours, and 720 hours. An investigation was done into how the aging process affected the paper insulation.

Tensile strength was measured to determine fiber strength, fiber length, and bonding paper insulation. The Field Emission Scanning Electron Microscope (FESEM) and Fourier Transform Infrared Spectroscopy (FTIR) were then utilized to acquire information regarding the material characteristics of the paper insulation). Finally, the breakdown voltage of the paper insulation was measured.

1.5 Thesis Online

Included in the three chapters that make up this thesis are the following:

- Chapter 1: Introduction
- Chapter 2: Literature Review
- Chapter 3: Methodology
- Chapter 4: Results and Discussion
- Chapter 5: Conclusion and Recommendations

Kenaf fiber as insulating presspaper impregnated with mineral oil, solid and liquid insulation, and presspaper are all introduced in Chapter 1's research summary. The problem, scope, and the study's goals are here.

Later, in Chapter 2, learn about the history of the transformer, insulation in transformer, paper aging mechanism, and paper aging assessment techniques and application of kenaf fiber in industry.

Chapter 3 discusses the specifics of the IEC standard-compliant experimental procedure for assessing the longevity of various materials. Paper insulation products are put through their paces under identical laboratory conditions to perform better. The purpose of this is to enhance reliability. The insulations will be subjected to the testing conditions at 90°C with several days of impregnation for 240 hours, 480 hours, and 720 hours with the same type of mineral oil (Nynas Nytro libra), and the same environment.

The present of Chapter 4 presents the results and subsequent discussion of a comprehensive account of the conclusive outcomes of the Kenaf paper insulation. Additionally, the materials address the methods of data analysis that are conveyed through the utilization of tables and graphs.

Finally. Chapter 5 of this study presents the concluding remarks and recommendations based on the findings of the research. The present chapter provides a summary of the study and concludes the overall research, while also offering recommendations for future research endeavours about the assessment of ageing.

1.6 Summary of the Chapter

Chapter 1 is to find an overview of the study, a declaration of the problem, a description of the study's goals, and an outline of the thesis. The studies/project's purviews are outlined as well. According to the research, there is a pressing need for automation in the seeding process to ensure that it is conducted correctly and efficiently, saving time and effort. As a result, the introduction of kenaf fiber as the insulating paper has helped to increase the use of paper insulation for transformers because of its low price, high strength paper, quick generation cycles, and abundant supply.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the project's literature analysis and background research for the project. A literature review is essential to developing a successful system since it helps uncover problems that may have emerged with the prior system. Aside from that, it helps choose the best strategy to achieve the project's objective based on study findings. This chapter focuses on the research of portal usability comparisons to prior studies.

2.2 Transformer

Presspaper, pressboard, and mineral oil have been indispensable insulating materials in the power transformer for decades [1]. The presspaper used to insulate the transformer's winding conductor prevents electrical shorts and breakdowns. Simultaneously, the liquid insulation provided by mineral oil performs the cooling process by transferring the heat from the transformer's interior to its exterior.

The power transformer is one essential machinery in charge of power transmission and distribution. Therefore, it is necessary to guarantee that the power transformer operates at its optimum level to provide an adequate electricity supply to utilities. Power transformers have a life expectancy of more than 30 years; however, a massive portion of failures don't occur until after they have been in use for more than 20 years, either because their components have worn out or because the transformer itself has developed flaws [11]. The transformer insulation system, consisting of transformer insulation oil and transformer insulation paper, is one of the primary elements that make up a power transformer. The insulation system of a power transformer comprises insulation paper and insulation oil, and it is one of the primary components of the device (transformer oil). The insulation system in a power transformer experiences a variety of reactions because of the thermal and electrical force imposed on it during normal operating conditions [12]. These reactions lead to problems in the power transformer, which in turn causes the insulating system to wear after only eight years of continuous operating [13]. Therefore, keeping an eye on the state of the transformer and paying particular attention to the insulation system is essential if want the machinery to last if possible. Views of transformer insulation are shown in Figures 2.1 and Figure 2.2. In Figure 2.1, cross sections of a big transformer with a shell and a core reveal the transformers' pancake' and 'disc' oil architectures, respectively. Figure 2.2 depicts the layer-wound coil used for LV insulation in distribution and small power transformers [6].

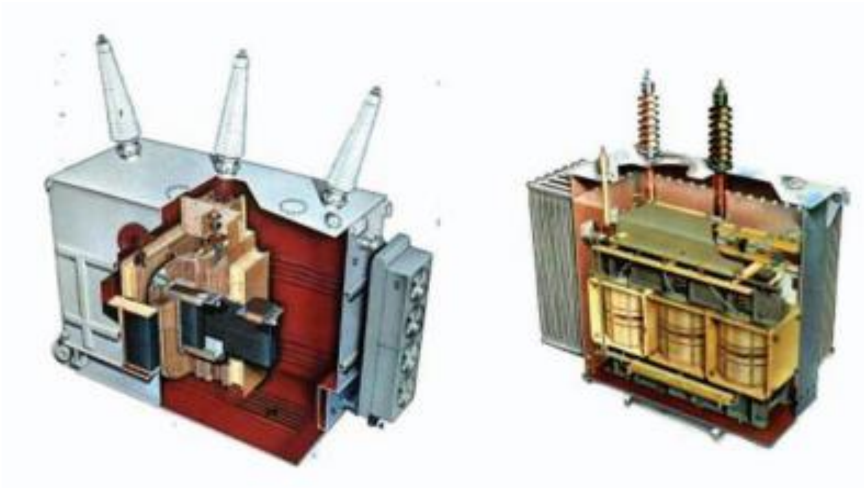

Figure 2.1 Transformers with a cut-out shell and core [6]

Figure 2.2 High voltage insulation, power transformer distribution from ABB (Brochure republished with permission) [6]

2.3 Insulation in Transformer

While early transformers employed asbestos, cotton, and subpar pressboard in the air, modern transformers are virtually filled with oil. The development of shellac-insulated paper in the late nineteenth century was a considerable advancement. In 1906, mineral oil was first used to insulate and cool transformers. Water-filled cooling tubes were put into the transformer tank to cool the oil, which was then chilled. The newly created oil-filled transformers' thermal capabilities were incomparable to those of the shell-impregnated paper. These insulation systems made use of pressboard and kraft paper. When used with transformer oil, paper and pressboard make up most of the insulation used in power transformers. However, they are not amazingly effective dielectrics when used without oil. Thermally enhanced paper and diamond-dotted paper are diverse types of paper that are used. Wood is the following most popular material. Since the latter half of the nineteenth century, petroleum oils have been utilized in electrical machinery. As early as 1891, Ferranti recognized the advantages of the transformer. These mineral oils are still used, albeit with improved selection and refinement [14]

Figure 2.3 Transformer insulation [15].

2.3.1 Liquid Insulation

There are two significant categories of transformer insulation oil: mineral-based oil and vegetable-based. The former has been the industry standard for many years. In contrast, the latter was developed to overcome the shortcomings of mineral-based insulating oil, such as low fire resistance, reliance on petroleum sources, and harmful effects on soil and water during leakage [15]. In addition to the technological drawbacks, the rising cost of traditional insulating oil and the resulting environmental impacts have spurred the investigation of vegetable oil as a substitute.

Transformers used mineral oil as liquid insulation to dissipate heat to the outside of the device. There are two significant categories of mineral oil: naphthenic and paraffinic. Naphthenic oil contains a higher concentration of paraffinic hydrocarbons, while naphthene oil contains a higher concentration of paraffinic hydrocarbons [16]. Naphthenic oil oxidizes faster than paraffinic oil, shortening its working lifespan —naphthenic oil forms more sludge than paraffinic [17]. Naphthenic oil dissolves muck better than paraffinic. This oil prevents transformer windings from overheating and maintains optimal insulation oil temperature [18]. Since it is denser than naphthenic, paraffinic oil can control the amount of ice that floats in low-temperature transformers.

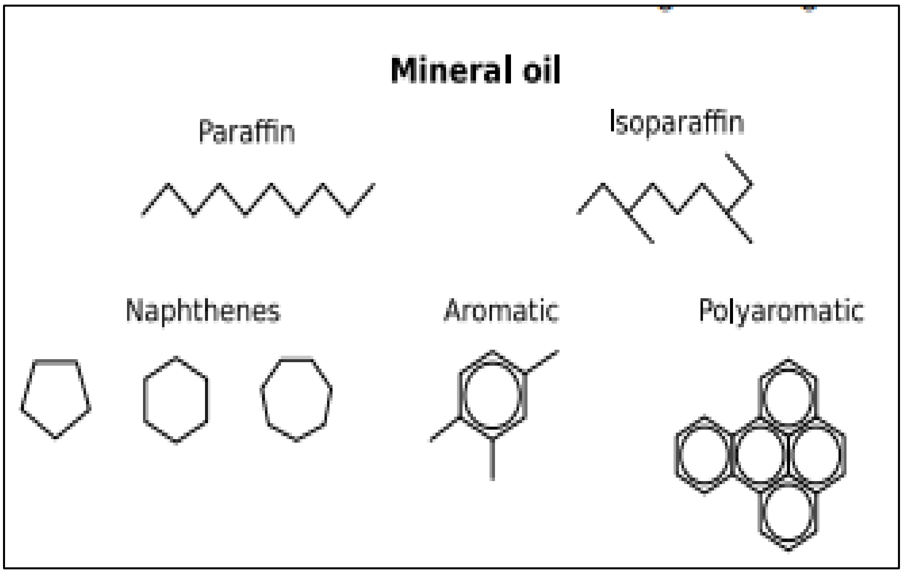

Figure 2.4 The rudimentary carbon structures in a molecule of mineral oil [19].

2.3.1.1 Mineral oil (Nynas Nytro Libra)

Oil in a transformer is used primarily for thermal management and electrical insulation. It is commonly known that the viscosity of a liquid is one of the influencing parameters that affect heat exchange. Therefore, when designing a power transformer's cooling system, it is essential to consider how the viscosity of the insulating oil varies with temperature. Nynas Nytro Libra is a mineral oil variant that has been tailored to meet the specific requirements of electrical transformers. The oil in question exhibits superior dielectric characteristics,