UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF KENAF BAST FIBER-BASED INSULATION PAPER FOR POWER TRANSFORMER APPLICATIONS

MUHAMMAD UMAIR

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DEVELOPMENT OF KENAF BAST FIBER-BASED INSULATION PAPER FOR POWER TRANSFORMER APPLICATIONS

By

MUHAMMAD UMAIR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF KENAF BAST FIBER-BASED INSULATION PAPER FOR POWER TRANSFORMER APPLICATIONS

By

MUHAMMAD UMAIR

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Chair : Norhafiz Bin Azis, PhD
Faculty : Engineering

Due to the shortage of wood for paper and other applications, non-wood fibers such as Kenaf are utilized for papermaking. Kenaf bast fiber is known as one of the common non-wood fibers used for this purpose. Currently, there are only a few studies that are carried out for Kenaf papers as solid insulation in transformers. Furthermore, the impact of beating and Polyvinyl Alcohol (PVA) on Kenaf paper is quite limited, necessitating further investigation into its feasibility to improve the physio-mechanical and electrical properties.

First, the Kenaf bast fibers were collected locally and pulping was carried out using soda pulping methods. The resulting Kenaf pulp was then subjected to various beating revolutions to improve the pulp's strength properties. The beating process was carried out at 3,000, 6,000, 9,000, and 12,000 beating revolutions. PVA was added to the Kenaf pulp after 12,000 beating revolutions. The internal PVA was carried out by adding PVA at weight percentage concentrations of 3%, 6%, 9%, and 12% after the beating stage. The external PVA was obtained by coating the Kenaf paper with 12,000 beating revolutions with PVA at weight percentage concentrations of 2%, 4%, and 6%. Next, the Kenaf papers with different treatments were examined for the physio-mechanical and electrical performances. Apparent density, Tensile Index (TI), Burst Index (BI), and Tear Index (TeI) measurements were carried out to observe the impact of beating and PVA on the physio-mechanical properties of Kenaf paper. Surface resistivity and dielectric constant were measured to determine the dielectric properties of Kenaf paper. An oil-impregnated Kenaf paper was prepared in Mineral Oil (MO) for the measurement of AC breakdown voltage and Partial Discharge (PD) activities. The AC breakdown voltage measurement was carried out based on spherical electrodes with a diameter of 12.5 mm, with both sides facing each other. A Scanning Electron Microscopy (SEM) image was obtained after the AC

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breakdown voltage to observe the effect of electric discharge on Kenaf bast fibers. The maximum PD amplitude and PD repetition rate were measured based on a needle-plane electrode configuration at a gap distance of 50 mm for an applied voltage of up to 30 kV. The Partial Discharge Inception Voltage (PDIV) was obtained at different voltage levels.

It is observed that beating improves the apparent density, TI, and BI of Kenaf paper due to enhancement of fibrillation in Kenaf bast fibers. The beating decreases the average surface resistivity while the average dielectric constant and AC breakdown voltage increase. The PDIV of Kenaf paper decreases as the beating revolutions increase, while the maximum PD amplitude and repetition rate increase. The addition of internal and external PVA further improves the apparent density, TI, and BI of Kenaf paper. The surface resistivity, dielectric constant and AC breakdown voltages, and strength of Kenaf paper are also enhanced with the internal and external PVA. The PDIV of Kenaf paper slightly decreases with the internal and external PVA. The maximum PD amplitude and PD repetition rates of Kenaf paper slightly increase with internal PVA at all applied voltages but decrease with external PVA at voltages of 20 kV, 25 kV, and 30 kV. The TI and BI of the Kenaf paper increased by 197% and 364% with 6% external PVA. Similarly, the highest AC breakdown voltage is observed for the 3 layers of Kenaf paper with 6% external PVA with a value of 36.30 kV. The highest improvement of dielectric constant can be up to 211% for the Kenaf paper with 12% internal PVA. The findings of this study present the minimum thickness, apparent density, and TeI requirements for solid insulation materials in power transformers. However, the TI of Kenaf paper is slightly lower than the required criteria for power transformers, which can be improved with enhancement materials. On the other hand, the AC breakdown strength of Kenaf paper is higher than Kraft paper, while the dielectric constant is comparable. Based on mechanical and electrical properties, Kraft paper has a potential that can be explored further for use in power transformers.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN KERTAS PENEBAT BERASASKAN GENTIAN BAST KENAF UNTUK APLIKASI PENGUBAH KUASA

Oleh

MUHAMMAD UMAIR

Januari 2022

Pengerusi : Norhafiz bin Azis, PhD
Fakulti : Kejuruteraan

Disebabkan oleh kekurangan kayu untuk kertas dan aplikasi lain, gentian bukan kayu seperti Kenaf digunakan untuk pembuatan kertas. Gentian kulit kayu kenaf diketahui sebagai salah satu gentian bukan kayu yang biasa digunakan untuk tujuan ini. Pada masa ini, hanya ada beberapa kajian yang dijalankan untuk penggunaan kertas Kenaf sebagai penebat pepejal dalam pengubah. Tambahan pula, kesan rentakan dan Polivinil Alkohol (PVA) pada kertas Kenaf agak terhad, yang memerlukan penyelidikan lebih lanjut mengenai kebolehlaksanaannya untuk meningkatkan sifat fisio-mekanikal dan elektrikal.

Pertamanya, gentian kulit kayu Kenaf dikumpulkan di sini dan pembuatan pulpa dilakukan menggunakan kaedah soda pulping. Pulpa Kenaf yang dihasilkan kemudian mengalami berbagai putaran rentakan untuk meningkatkan sifat kekuatan pulpa. Proses rentakan dilakukan pada 3,000, 6,000, 9,000 dan 12,000 putaran rentakan. PVA ditambahkan kepada pulpa Kenaf selepas 12,000 putaran rentakan. PVA dalaman dilakukan dengan menambahkan PVA pada kepekatan peratus berat iaitu 3%, 6%, 9%, dan 12% selepas tahap rentakan. PVA luaran diperoleh dengan melapisi kertas Kenaf dengan 12,000 putaran rentakan dengan PVA pada kepekatan peratus berat iaitu 2%, 4%, dan 6%. Seterusnya, kertas Kenaf dengan rawatan yang berbeza diperiksa untuk prestasi fisio-mekanikal dan elektrikal. Pengukuran ketumpatan ketara, Indeks Tegangan (TI), Indeks Pecah (BI) dan Indeks Koyak (TeI) dilakukan untuk melihat kesan rentakan dan PVA terhadap sifat fisio-mekanikal kertas Kenaf. Keberintangan permukaan dan pemalar dielektrik diukur untuk menentukan sifat dielektrik kertas Kenaf. Kertas Kenaf yang disi tepu dengan minyak disediakan dalam Minyak Mineral (MO) untuk pengukuran aktiviti voltan pemecah arus ulang alik (AU) dan Pelepasan Separa (PD). Pengukuran voltan pemecah AU dilakukan dengan elektrod sfera yang berdiameter 12.5 mm, dengan kedua sisi

saling berhadapan. Imej Mikroskopi Elektron Pengimbasan (SEM) diperoleh selepas voltan pemecah AU untuk memerhatikan kesan pelepasan elektrik kepada gentian kulit kayu Kenaf. Amplitud maksimum PD dan kadar pengulangan PD diukur berdasarkan konfigurasi elektrod satah jarum pada sela jarak 50 mm untuk voltan kenaan hingga 30 kV. Voltan Permulaan Pelepasan Separa (PDIV) diperoleh pada tahap voltan yang berbeza.

Diperhatikan bahawa rentakan meningkatkan ketumpatan ketara, TI dan BI kertas Kenaf disebabkan oleh peningkatan fibrilasi pada gentian kulit kayu Kenaf. Rentakan mengurangkan purata keberintangan permukaan sementara purata pemalar dielektrik dan voltan pemecah AC meningkat. PDIV kertas Kenaf menurun ketika putaran rentakan meningkat, sementara amplitud maksimum dan kadar pengulangan PD meningkat. Penambahan PVA dalaman dan luaran meningkatkan lagi ketumpatan ketara, TI dan BI kertas Kenaf. Keberintangan permukaan, pemalar dielektrik, voltan pemecah AC dan kekuatan kertas Kenaf juga ditingkatkan dengan PVA dalaman dan luaran. PDIV bagi kertas Kenaf sedikit menurun dengan PVA dalaman dan luaran. Amplitud maksimum PD dan kadar pengulangan PD bagi kertas Kenaf sedikit meningkat dengan PVA dalaman pada semua voltan kenaan, tetapi menurun dengan PVA luaran pada voltan 20 kV, 25 kV, dan 30 kV. TI dan BI bagi kertas Kenaf meningkat sebanyak 165% dan 217% dengan 6% PVA luaran. Begitu juga, voltan pemecah AC tertinggi diperhatikan untuk tiga lapisan kertas Kenaf dengan 6% PVA luaran iaitu 36.30 kV. Peningkatan pemalar dielektrik tertinggi boleh mencapai 210% untuk kertas Kenaf dengan 12% PVA dalaman. Kajian ini membentangkan ketebalan minimum, ketumpatan ketara, dan keperluan TeI untuk bahan penebat pepejal dalam pengubah kuasa. Walau bagaimanapun, TI bagi kertas Kenaf adalah lebih rendah sedikit daripada kriteria yang diperlukan untuk pengubah kuasa, yang boleh diperbaiki dengan bahan penambahbaik. Sebaliknya, kekuatan pecahan AC bagi kertas Kenaf lebih tinggi daripada kertas Kraft, manakala pemalar dielektrik pula adalah setanding. Berdasarkan sifat mekanikal dan elektrik, kertas Kraft mempunyai potensi yang boleh diterokai lebih lanjut untuk digunakan dalam pengubah kuasa.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Norhafiz bin Azis, PhD
Associate Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Jasronita binti Jasni, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Rasmina Binti Halis, PhD
Associate Professor, Ts.
Faculty of Forestry and Environment
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 19 May 2022

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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Signature:	
Name of Chairman of Supervisory Committee:	Assoc. Prof. Dr. Norhafiz Azis
Signature:	
Name of Member of Supervisory Committee:	Prof. Dr. Jasronita Jasni
Signature:	
Name of Member of Supervisory Committee:	Assoc. Prof. Ts. Dr. Rasmina Binti Halis

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TABLE OF CONTENTS

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LIST OF TABLES

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LIST OF FIGURES

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LIST OF ABBREVIATIONS

NaOH	Sodium Hydroxide
PVA	Polyvinyl Alcohol
AC	Alternating Current
PD	Partial Discharge
PDIV	Partial Discharge Inception Voltage
MO	Mineral Oil
TI	Tensile Index
BI	Burst Index
TeI	Tear Index
SEM	Scanning Electron Microscopy
DDF	Dielectric Dissipation Factor
OH	Hydroxyl
CH2OH	Carboxyl
EFPB	Empty Fruit Palm Bunch
OD	Oven Dry
TAPPI	Technical Association of Pulp and Paper Industry
IEC	International Electrotechnical Commission
IMC	Impedance Matching Circuit
VNA	Vector Network Analyzer
CSF	Canadian Standard Freeness

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CHAPTER 1

INTRODUCTION

1.1 Research background

Kraft paper has been used for decades as insulation materials in transformers owing to its good physio-mechanical properties [1]. Kraft paper can withstand the high electrical and physical stresses experienced around core and windings in transformers [2].

Kraft paper is produced from wood fibers, which are sustainable but can be subjected to shortages under severe deforestation [4]. The principal component for wood and non-wood fibers is cellulose, which is widely used in electrical machines for centuries [4, 5]. The length of wood fibers is slightly longer than non-wood fibers [6]. The morphological properties and chemical composition, such as fiber length and width determine the paper quality [7]. The average length of non-wood fiber plants ranges between 0.6 mm and 30 mm [8, 9]. Lumen width and cell wall thickness affect the rigidity and strength of non-wood fiber papers [6]. Fibers with large lumens and thin walls could be flattened after the pulping [9]. The process of pulping enhances the contact between fibers, which leads to an increase in the strength of paper. Nowadays, papermaking based on non-wood fibers has attracted demands in a wide range of applications. Previously, the usage of non-wood fibers is mainly for writing papers. However, in recent years, its applications have expanded in other areas such as tissue, printing papers, and corrugated boards.

Significant efforts have recently been made to investigate the feasibility of non-wood fibers for electrical insulation purposes [10]. Currently, non-wood fibers have been mainly used in the pulp and paper industries. Although the mechanical strength of non-wood-based papers is inferior to wood-based papers, its strength can be improved by several treatments [11]. Several non-wood plants have been utilized by papermaking industries to make papers, such as Kenaf, bamboo, bagasse, jute, and cereal straws. As an alternative, non-wood fibers including cotton, manila, hemp, and flax have been utilized as insulation materials in various electrical insulation applications [11, 13]. Previously, cotton rag, silk, jute, and asbestos are used for different purposes of electrical insulation [11-14]. A blend of Kraft wood and manila hemp fibers has been utilized as insulation material for telephone insulation in 1920 [12]. The electrical grade papers are mainly used for cables and capacitors before being mainly utilized as the primary insulation in transformers [13]. Linen has been used as insulation in capacitors until the 1920s. Resin impregnated paper is introduced for transformer application in the early 20th century which was later dominated by oil-impregnated paper. Non-wood fibers are strong, low-cost, and

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have good elasticity and flexibility. Cotton fiber has been employed in transformer insulation; however, it has low thermal capacity and are very absorbent of moisture. On the other hand, flax fiber has been utilised for capacitor insulation. The mixture of manila hemp and wood fibers have also been utilised for insulation in telephones [12].

The production of papers from non-wood fibers is carried out using the two steps. The first step is to convert the fibrous raw materials into pulps. The second step is to convert the pulps into papers [9]. The pulping process separates fibers from dust and other unwanted substances [14]. The fiber network is stretched out on a thin sheet of paper and compressed to increase density. The fiber network is further dried to extract residual moisture [9]. The beating process increases the bonding between fibers by fibrillation, thus increasing the fiber surface contact area.

The pulping of non-wood plants can be carried out based on Kraft and soda processes. The soda process is mostly preferred for the pulping non-wood fibers since it requires only Sodium Hydroxide (NaOH) and the production time is shorter than the Kraft process. The soda process can produce high yields, without affecting the overall quality of the end products [15]. This process results in pulps with high insoluble carbohydrates. It is also found that the strength and lignin contents of pulps made from the soda process are almost identical to the Kraft process [16].

Kenaf is a non-wood plant that has been utilized in the manufacturing of animal bedding, twine, coarse cloth, rope, packaging, and paper [16]. The mechanical properties of Kenaf fibers depend on the physical composition, environmental condition, place of origin, and the methods of storing fiber. Due to its high strength characteristics, Kenaf fibers have also been used for writing papers, bonds, surface sizes, and newsprints [17]. The core and bast fibers of Kenaf plants are short and long, respectively. The length of bast fibers ranges from 1.15 mm to 4.03 mm. Bast fibers have a large cell wall and small lumen width, which are favorable to have high strength properties in paper [18]. The long fibers play an essential role in determining the paper's mechanical strength. The mechanical strength is the prime requirement for transformer insulation papers to resist the possible mechanical movements and heat while in operations. Since bast fibers are long fibers, the paper produced from bast fibers has higher mechanical strength.

The strength properties of Kenaf paper can be enhanced using the introduction of chemical additives [19]. There are 2 types of chemical additives known as functional and process chemicals. The functional chemicals directly improve paper qualities while process chemicals influence operations on or near paper machines [20]. Process chemicals include retention aids, biocides, dispersants, and defoamers, whereby functional chemicals include fillers, sizing agents,

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dyes, optical brighteners, and wet-strength/dry-strength additives. The functional chemicals can be added internally in pulp or applied externally on the surface of the paper [5, 22-24]. Hydrogen bonds and friction forces between fibers are the main forces that determine the strength of fiber interactions in the papers whereby it can be improved by the functional chemicals.

Polyvinyl Alcohol (PVA) is one of the chemical additives which can be utilized in pulping and papermaking industries to improve the properties of pulp and paper [24]. It is a common synthetic polymer that is subjected to partial or complete polyvinyl acetate hydrolysis to remove the acetate groups, whereby other vinyl polymers are produced via polymerization of its constituent monomers. PVA has been extensively utilized in a variety of industries including textiles, papermaking, and pulping industries. PVA may improve the resistance of paper to oils and fats. Since it has excellent hydrophilic properties and structural compatibility, it has also been employed with biopolymers and hydrophilic polymers to improve the mechanical strength and electrical properties of paper.

1.2 Problem statement

Kraft insulation paper is made of wood fibers, joined with hydrogen bonds, which are broken by heat and electrical stress during transformer operation. Kraft insulation paper must have strong mechanical and electrical properties to withstand the insulating safety of power transformers. Due to the increasingly industrialized environment and demand, the availability of wood fibers may be limited in the future. There is a need to find an alternate source that can meet the increasing demand for transformer insulation and improve transformer insulation with alternative materials. Non-wood fibers provide the suitable option as the source for pulp and papermaking which can act as an alternative for wood fibers due to the strong mechanical strength of fibers. Currently, the application of non-wood fibers such as Kenaf as insulation material in transformers has yet been highlighted in previous studies.

One of the main issues with the development of insulation paper for transformer application is its ability to be impregnated with insulation oil. The insulation paper must have good Alternating Current (AC) breakdown strength and Partial Discharge (PD) characteristics after impregnation in oil. The current process of Kenaf papermaking does not consider this requirement, which is crucial to ensure the electrical performance, would not be affected due to the insufficient impregnation procedure. Furthermore, there is no investigation related to the impact of chemical additives such as PVA on the oil impregnation process of Kenaf paper.

Currently, several studies have been carried out to examine the physio-mechanical properties of Kenaf paper. However, no investigation has been

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carried out to examine the physio-mechanical properties of Kenaf paper in the presence of PVA concerning transformer requirements. The physio-mechanical properties of insulation paper are important for transformers since the insulation paper is expected to withstand the movement either due to faults or power system events.

Apart from physio-mechanical properties, a good insulation paper should possess good electrical properties to avoid any instantaneous failure. At the moment, there is no comprehensive study that has been performed on Kenaf paper with and without PVA concerning the electrical properties including the AC breakdown voltage, PD characteristics, and dielectric constant.

By addressing the stated issues, it is anticipated that the suitability of Kenaf paper as electrical insulation for transformers can be further explored which provides exciting potential applications in the future.

1.3 Research objectives

The main aim of this research is to develop and examine the physio-mechanical and electrical properties of Kenaf paper for transformer insulation with consideration of PVA. Several objectives are devised to achieve the primary objective.

1. To develop Kenaf paper with and without PVA for electrical insulation application in transformers.
2. To analyze the physio-mechanical and morphological properties of Kenaf paper with and without PVA.
3. To evaluate the electrical properties, AC breakdown voltage, and Partial Discharge (PD) characteristics of Kenaf paper with and without PVA.

1.4 Scope of work

The scope and limitations of this research are as follows.

1. The type of insulation fluids examine in this research is Mineral Oil (MO). MO is the common insulation fluid used in transformers.
2. This research only examines bast fibers for the development of Kenaf paper for electrical insulation purposes in transformers. Bast fibers are chosen due to long fiber characteristics which can contribute to high tensile strength.

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3. This research only considers PVA as the enhancement material for the Kenaf paper, because PVA is a semi-crystalline polymer with plenty of Hydroxyl (OH) groups that form intramolecular hydrogen bonds with cellulose. Since, both PVA and cellulose are hydrophilic polymers, they form strong molecular interactions through van der Waals forces, resulting in high paper strength. PVA has strong cohesive forces with fibers as compared to other chemical additives.

4. The percentage concentration of internal PVA for Kenaf paper ranges from 0% to 12% with a 3% interval, while the percentage concentration of external PVA ranges from 0% to 6% with a 2% interval. The addition of PVA up to 10% to the pulp improves the mechanical and dielectric properties of paper.

5. The research only focuses on Tensile Index (TI), Burst Index (BI), Tear Index (TeI), apparent density, Scanning Electron Microscopy (SEM), AC breakdown strength, dielectric constant, surface resistivity, and PD properties of Kenaf paper with and without PVA. These properties are commonly associated with the insulation paper used in transformers.

1.5 Contribution of research

The details of the contributions of this research study are as follows:

1. The process to develop the Kenaf paper for electrical insulation purposes in transformers can be used and replicated by the relevant industries for mass production.
2. The knowledge on the physio-mechanical and electrical properties of Kenaf paper can be further utilized for research and development to improve its competitiveness as compared to Kraft paper
3. Papermaking manufacturers can further utilize the techno information on the PVA's role for process optimization to cope with the increasing need for electrical insulation industries.

1.6 Thesis organization

This thesis consists of seven chapters, namely, the introduction, literature review, methodology, Kenaf pulp characteristics, physio-mechanical properties of Kenaf papers, electrical properties of Kenaf papers, conclusion, and recommendations for future work.

Chapter 1 introduces the study's background and problem statement. The objectives, scope, limitations, and contributions of the research are described.

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Chapter 2 provides a thorough overview of related research, including insulations in transformer, non-wood fibers for pulp and papermaking, Kenaf fiber characteristics, physio-mechanical and electrical properties of Kraft paper, and chemical additives for the paper strength.

Chapter 3 describes the procedure of the development of Kenaf paper and the experimental workflow. The process of pulping Kenaf fibers and papermaking is discussed in detail. The procedure to develop the Kenaf paper in the presence of PVA is explained in this chapter. The TI, BI, TeI, apparent density measurement, grammage calculation, SEM, AC breakdown voltage and strengths, surface resistivity, dielectric constant, dielectric loss factor, Dielectric Dissipation Factor (DDF), and PD test setup and configuration for measurement of Partial Discharge Inception Voltage (PDIV) are explained in detail.

Chapter 4 presents the morphological analysis of Kenaf pulp, which is used to produce Kenaf papers. The effect of beating and PVA on the Kenaf pulp is observed using SEM imaging.

Chapter 5 presents the physio-mechanical properties of Kenaf paper with beating revolutions and with internal/external PVA. The experimental results on the apparent density, TI, BI, and TeI of Kenaf paper are discussed.

Chapter 6 presents the experimental results and discussions on the surface resistivity, dielectric constant and DDF, AC breakdown voltage and strengths, PDIV, maximum PD amplitudes, and repetition rates of Kenaf paper with beating revolutions and internal/external PVA. After the results and discussion, chapter 7 presents the conclusion and recommendations for future work.

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REFERENCES

[1] Hao, J., Liao, R., Chen, G., Ma, Z. and Yang, L. (2012). Quantitative analysis ageing status of natural ester-paper insulation and mineral oil-paper insulation by polarization/depolarization current. *IEEE Trans. Dielectr. Electr. Insul.*, *19(1),* 188–199. doi: 10.1109/TDEI.2012.6148518.

[2] Moravej, Z. and Bagheri, S. (2015). Condition monitoring techniques of power transformers : A review. *J. Oper. Autom. Power Eng., 3(1),* 71–82.

[3] Aripin, A. (2014). *Potential of non-wood fibres for pulp and paper-based industries.* Johor, Malaysia: Universiti Tun Hussein Onn Malaysia.

[4] Lawson, W.G., Simmons, M.A. and Gale, P.S. (2016). Thermal ageing of cellulose paper insulation. *Conf. Rec. 1976 IEEE Int. Symp. Electr. Insul. ISEI 1976*, no. 1, (pp. 14–18). doi: 10.1109/EIC.1976.7464159.

[5] Jusner, P., Schwaiger, E., Potthast, A. and Rosenau, T. (2021). Thermal stability of cellulose insulation in electrical power transformers – A review. *Carbohydr. Polym.*, *252,* 117196. doi: 10.1016/j.carbpol.2020.117196.

[6] Youngquist, J.A., English, B.E., Scharmer, R.C., Chow, P. and Shook, S. R. (1994). Literature review on use of nonwood plant fibers for building materials and panels. Retrieved from http://128.104.77.228/documnts/fplgtr/fplgtr80.pdf.

[7] Law, K.N., Daud, W.R.W. and Ghazali, A. (2007). Morphological and chemical nature of fiber strands of oil palm empty-fruit-bunch (OPEFB). *BioResources*, *2(3),* 351–362. doi: 10.15376/biores.2.3.351-362.

[8] Abdul Khalil, H.P.S., Siti Alwani, M., Ridzuan, R., Kamarudin, H. and Khairul, A. (2008). Chemical composition, morphological characteristics, and cell wall structure of Malaysian oil palm fibers. *Polym. Plast. Technol. Eng.*, *47(3),* 273–280. doi: 10.1080/03602550701866840.

[9] Wan, J., Yang, J., Ma, Y. and Wang, Y. (2011). Effects of pulp preparation and papermaking processes on the properties of OCC fibers. *BioResources*, *6(2),* 615–1630.

[10] Schaible, M. (1987). Electrical insulating papers - An overview. *IEEE Electr. Insul. Mag.*, *3(1),* 8–12. doi: 10.1109/MEI.1987.290616.

[11] Mcshane, C.P., Rapp, K.J. and Luksich, J. (2003). Aging of cotton / kraft blend insulation paper in natural ester dielectric fluid degree of polymerization. Retrieved from https://www.yumpu.com/en/document/read/45687912/aging-of-cotton-a-kraft-blend-insulation-paper-in-natural-ester.

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[12] Sheppard, H.R. (1986). A century of progress in electrical insulation. *Electr. Insul. Mag. IEEE*, *2(5),* 20–30. doi: 10.1109/MEI.1986.290490.

[13] Prevost, T.A. and Oommen, T.V. (2006). Cellulose insulation in oil-filled power transformers: Part I - History and development. *IEEE Electr. Insul. Mag.*, *22(1),* 28–34. doi: 10.1109/MEI.2006.1618969.

[14] Peng, P. and She, D. (2014). Isolation, structural characterization, and potential applications of hemicelluloses from bamboo: A review. *Carbohydr. Polym.*, *112,* 701–720. doi: 10.1016/j.carbpol.2014.06.068.

[15] Wanrosli, W.D., Zainuddin, Z., Law, K. N. and Asro, R. (2007). Pulp from oil palm fronds by chemical processes. *Ind. Crops Prod.*, *25(1),* 89–94. doi: 10.1016/j.indcrop.2006.07.005.

[16] Sellers, T., Miller, G.D. and Fuller, M.J. (1993). Kenaf core as a board raw-material. *For. Prod. J.*, *43(7–8),* 69–71.

[17] Ramesh, M. (2016). Kenaf (Hibiscus cannabinus L.) fibre based bio-materials: A review on processing and properties. *Prog. Mater. Sci.*, *78–79,* 1–92. doi: 10.1016/j.pmatsci.2015.11.001.

[18] Udohitinah, J.S. and Oluwadare, A.O. (2011). Pulping properties of kraft pulp of Nigerian-grown kenaf (Hibiscus cannabinus L.). *BioResources*, *6(1),* 751–761. doi: 10.15376/biores.6.1.751-761.

[19] Mossello A.A., Jalaludin, H., Tahir, P.M. and Resalati, H. (2010). A review of literatures related of using kenaf for pulp production (beating, fractionation, and recycled fiber). *Mod. Appl. Sci.*, *4(9)*. doi: 10.5539/mas.v4n9p21.

[20] Auhorn, W.J. (2006). Chapter 3 - Chemical Additives. In Holik, H. (ed.), *Handbook Paper Board* (pp. 62–149). doi: 10.1002/3527608257.ch3.

[21] Environmental Protection Agency (1993). Papermaking additives 1, No. 3.

[22] Anderson, J.E., Kim, B.R., Mueller, S.A. and Lofton, T.V. (2003). Composition and analysis of mineral oils and other organic compounds in metalworking and hydraulic fluids. *Crit. Rev. Environ. Sci. Technol.*, *33(1),* 73–109. doi: 10.1080/10643380390814460.

[23] Hubbe, M. (2006). Bonding between cellulosic fibers in the absence and presence of dry-strength agents – A review. *BioResources*, *1(2),* 281–318. doi: 10.15376/biores.1.2.281-318.

[24] An, Q., Li, F., Ji, Y. and Chen, H. (2011). Influence of polyvinyl alcohol on the surface morphology, separation and anti-fouling performance of the composite polyamide nanofiltration membranes. *J. Memb. Sci.*, *367(1–*

© COPYRIGHT UPM

2), 158–165. doi: 10.1016/j.memsci.2010.10.060.

[25] Chandrashekar, R., Chaudhari, S.E. and Bajpai, P.K. (2011). Developments in insulating paper for power transformers. *J. Chem. Eng.*

[26] Ming, L., Jaksts, A., Liu, R., Owman, F. and Leijon, M. (2000). Recent trends within insulation systems for transmission and distribution apparatus. *Proc. IEEE Int. Conf. Prop. Appl. Dielectr. Mater.*, *2,* 849–855. doi: 10.1109/ICPADM.2000.876362.

[27] Lecuna, R., Delgado, F., Ortiz, A., Castro, P.B., Fernandez, I. and Renedo, C.J. (2015). Thermal-fluid characterization of alternative liquids of power transformers: A numerical approach. *IEEE Trans. Dielectr. Electr. Insul.*, *22(5),* 2522–2529. doi: 10.1109/TDEI.2015.004793.

[28] Van Bolhuis, J.P., Gulski, E. and Smit, J.J. (2002). Monitoring and diagnostic of transformer solid insulation. *IEEE Trans. Power Deliv.*, *17(2),* 528–536. doi: 10.1109/61.997930.

[29] Hill, D.J.T., Le, T.T., Darveniza, M. and Saha, T. (1996). A study of the degradation of cellulosic insulation materials in a power transformer. Part III: Degradation products of cellulose insulation paper. *Polym. Degrad. Stab.*, *51(2),* 211–218. doi: 10.1016/0141-3910(95)00204-9.

[30] Jalbert, J., Rodriguez-Celis, E., Duchesne, S., Morin, B., Ryadi, M. and Gilbert, R. (2015). Kinetics of the production of chain-end groups and methanol from the depolymerization of cellulose during the ageing of paper/oil systems. Part 3: Extension of the study under temperature conditions over 120ºC. *Cellulose*, *22(1),* 829–848. doi: 10.1007/s10570-014-0516-8.

[31] Shroff, D.H. and Stannett, A.W. (1985). A review of paper aging in power transformers. *IEE Proc. C Gener. Transm. Distrib.*, *132(6),* 312. doi: 10.1049/ip-c.1985.0052.

[32] Suleiman, A.A., Nazri, F., Muhamad, N.A., Bashir, N. and Mohamad, Z. (2014). Wetting characteristics for kraft paper immersed in mineral and biodegradable insulation oils. *Proc. 2014 IEEE 8th Int. Power Eng. Optim. Conf. PEOCO 2014*, October 2015, pp. 194–198. doi: 10.1109/PEOCO.2014.6814424.

[33] Saha, T.K. and Purkait, P. (2017). Chapter 1 - Transformer Insulation Materials and Ageing. *Transformer Ageing: Monitoring and Estimation Techniques*. Singapore: Wiley. pp. 1–33. doi: 10.1002/9781119239970.ch1.

[34] Marković, M. and Ćućić, B. (2018). Transformer lifetime management through solid and liquid insulation assessment. *Euro TechCon 2018*, pp. 1–25. Retrieved from

© COPYRIGHT UPM

https://www.researchgate.net/publication/330925194_Transformer_Lifetime_Management_through_Solid_and_Liquid_Insulation_Assessment.

[35] Emsley, A.M. and Stevens, G.C. (1994). Review of chemical indicators of degradation of cellulosic electrical paper insulation in oil-filled transformers. *Sci. Meas. Technol. IEE Proc.*, *141(5),* 324–334. doi: 10.1049/ip-smt:19949957.

[36] Darveniza, M., Hill, D., Le, T. and Saha, T.K. (1991). Studies of the condition of insulation in aged power transformers. 2. Fundamental electrical and chemical considerations. *Proceedings of the 3rd International Conference on Properties and Applications of Dielectric Materials*, pp. 1120-1123. doi: 10.1109/ICPADM.1991.172273.

[37] Richards, H.L., Baker, P.G.L. and Iwuoha, E. (2012). Metal nanoparticle modified polysulfone membranes for use in wastewater treatment: A critical review. *J. Surf. Eng. Mater. Adv. Technol.*, *02(03),* 183–193. doi: 10.4236/jsemat.2012.223029.

[38] Hollertz, R. (2017). Preparation, morphology and structure of cellulose nanocrystals from bamboo fibers. *Cellulose*, *19(5),* 1527–1536.

[39] Selyanchyn, O., Selyanchyn, R. and Lyth, S.M. (2020). A review of proton conductivity in cellulosic materials. *Front. Energy Res., 8.* doi: 10.3389/fenrg.2020.596164

[40] Jalbert, J., Gilbert, R., Tétreault, P., Morin, B. and Lessard-Déziel, D. (2007). Identification of a chemical indicator of the rupture of 1,4-β-glycosidic bonds of cellulose in an oil-impregnated insulating paper system. *Cellulose*, *14(4),* 295–309. doi: 10.1007/s10570-007-9124-1.

[41] Emsley, A.M. (1994). The kinetics and mechanisms of degradation of cellulosic insulation in power transformers. *Polym. Degrad. Stab.*, *44(3),* 343–349. doi: 10.1016/0141-3910(94)90093-0.

[42] Brito, B.S.L., Pereira, F.V., Putaux, J.L. and Jean, B. (2012). Preparation, morphology and structure of cellulose nanocrystals from bamboo fibers. *Cellulose*, *19(5),* 1527–1536. doi: 10.1007/s10570-012-9738-9.

[43] Mahjoub, R., Yatim, J.M., Mohd Sam, A.R. and Hashemi, S.H. (2014). Tensile properties of kenaf fiber due to various conditions of chemical fiber surface modifications. *Constr. Build. Mater.*, *55,* 103–113. doi: 10.1016/j.conbuildmat.2014.01.036.

[44] Syamani, F.A., Kurniawan, Y.D. and Suryanegara, L. (2014). Cellulose fibers from oil palm fronds reinforced. *Proceeding ASEAN Conf. Sci. Technol.*, pp. 1–5.

[45] Bajpai, P. (2018). Pulping Fundamentals. *Biermann's Handbook of Pulp*

© COPYRIGHT UPM

and Paper (Third Edition). Elsevier Inc.

[46] Arsène, M.A., Bilba, K., Savastano Jr, H. and Ghavami, K. (2013). Treatments of non-wood plant fibres used as reinforcement in composite materials. *Mater. Res.*, *16(4),* 903–923. doi: 10.1590/S1516-14392013005000084.

[47] Abdelmalik, A.A. (2015). Analysis of thermally aged insulation paper in a natural ester-based dielectric fluid. *IEEE Trans. Dielectr. Electr. Insul.*, *22(5),* 2408–2414. doi: 10.1109/TDEI.2014.004824.

[48] Krause, C. (2012). Power transformer insulation - History, technology and design. *IEEE Trans. Dielectr. Electr. Insul.*, *19(6),* 1941–1947. doi: 10.1109/TDEI.2012.6396951.

[49] Timberlake, A. (2013). Grammage of paper and paperboard (weight per unit area) (Revision of T 410 om-08). Retrieved from https://www.tappi.org/content/tag/sarg/t410.pdf

[50] Fithriyah, N.H. and Erdawati (2014). Mechanical properties of paper sheets coated with chitosan nanoparticle. *AIP Conf. Proc.*, 1589, 195–199. doi: 10.1063/1.4868781.

[51] Shim, M.S., Il Jung, J., An, J.S., Choi, S.H., Seo, Y.J. and Huh, C.S. (2010). Tensile strength of electrical insulating paper in natural ester and mineral oil. *PEOCO 2010 - 4th Int. Power Eng. Optim. Conf. Progr. Abstr.*, *8,* 563–565. doi: 10.1109/PEOCO.2010.5559209.

[52] Arroyo, O.H., Jalbert, J., Fofana, I. and Ryadi, M. (2017). Temperature dependence of methanol and the tensile strength of insulation paper: Kinetics of the changes of mechanical properties during ageing. *Cellulose*, *24(2),* 1031–1039. doi: 10.1007/s10570-016-1123-7.

[53] Anna, V. and Hannu, P. (2007). Interfiber bonding and fiber segment activation in paper. *BioResources*, *2(3),* 442–458.

[54] Main, N.M., Talib, R.A., Ibrahim, R., Rahman, R.A. and Mohamed, A.Z. (2015). Linerboard made from soda-anthraquinone (Soda-AQ) treated coconut coir fiber and effect of pulp beating. *BioResources*, *10(4),* 6975–6992. doi: 10.15376/biores.10.4.6975-6992.

[55] Gärd, J. (2002). The influence of fibre curl on the shrinkage and strength properties of paper. Retrieved from http://www.diva-portal.org/smash/get/diva2:1015864/FULLTEXT01.pdf.

[56] Mohd Hassan, N.H., Muhammed, S. and Ibrahim, R. (2014). Properties of Gigantochloa scortechinii paper enhancement by beating revolution," *J. Trop. Resour. Sustain. Sci.*, *2(2),* 59–67. doi: 10.47253/jtrss.v2i2.497.

© COPYRIGHT UPM

[57] Ishak, M.R., Leman, Z., Sapuan, S.M., Rahman, M.Z.A. and Anwar, U.M.K. (2011). Effects of impregnation time on physical and tensile properties of impregnated sugar palm (Arenga pinnata) fibres. *Key Eng. Mater.*, *471–472,* 1147–1152. doi: 10.4028/www.scientific.net/KEM.471-472.1147.

[58] Kamata, Y., Ohe, E., Endoh, K., Furukawa, S., Tsukioka, H., Maejima, M., Fujita, H., Nozaki, M., Ishizuka, F. and Hyohdoh, K. (1991). Development of low-permittivity pressboard and its evaluation for insulation of oil-immersed EHV power transformers. *IEEE Trans. Electr. Insul.*, *26(4),* 819–825. doi: 10.1109/14.83708.

[59] Chen, S., Yue, C., Wang, W., He, D. and Yang, K. (2012). Volume resistivity and PDIV characteristics of polymer materials under electro-thermal aging. *ICHVE 2012 - 2012 Int. Conf. High Volt. Eng. Appl.*, 50977025, 190–193. doi: 10.1109/ICHVE.2012.6357073.

[60] Saha, T.K. and Purkait, P. (2008). Investigations of temperature effects on the dielectric response measurements of transformer oil-paper insulation system. *IEEE Trans. Power Deliv.*, *23(1),* 252–260. doi: 10.1109/TPWRD.2007.911123.

[61] Kohman, G.T. (1939). Cellulose as an insulating material. *Ind. Eng. Chem.*, *31(7),* 807–817. doi: 10.1021/ie50355a005.

[62] Yang, X., Liu, X., Yu, S., Gan, L., Zhou, J. and Zeng, Y. (2019). Permittivity of undoped silicon in the millimeter wave range. *Electron.*, *8(8).* doi: 10.3390/electronics8080886.

[63] Liao, R., Zhang, F., Yuan, Y., Yang, L., Liu, T. and Tang, C. (2012). Preparation and electrical properties of insulation paper composed of SiO2 hollow spheres. *Energies*, *5(8),* 2943–2951. doi: 10.3390/en5082943.

[64] Mo, Y., Yang, L., Zou, T., Hou, W. and Liao, R. (2019). Preparation of composite insulating paper with decreased permittivity, good mechanical and thermal properties by kevlar/nano cellulose fibrils/softwood pulp hybrid. *IEEE Access*, 7, 104258–104268. doi: 10.1109/ACCESS.2019.2930981.

[65] Feng, D., Hao, J., Yang, L., Liao, R., Chen, X. and Li, J. (2020). Comparison of AC breakdown characteristics on insulation paper (pressboard) immersed by three-element mixed insulation oil and mineral oil. *High Volt.*, 5(3), 298–305. doi: 10.1049/hve.2019.0103.

[66] Nor, S.F.M., Azis, N., Jasni, J., Ab KAdir, M.Z.A., Yunus, R., Ishak, M.T. and Yaakub, Z. (2016). A study on the AC breakdown voltages of as-received palm oil and coconut oil under presence of TiO2. *2015 IEEE Conf. Energy Conversion, CENCON 2015*. pp. 354–357. doi:

© COPYRIGHT UPM

10.1109/CENCON.2015.7409568.

[67] Tang, C., Liao, R.J., Yang, L.J. and Huang, F.L. (2010). Research on the dielectric properties and breakdown voltage of transformer oil-paper insulation after accelerating thermal ageing. *2010 Int. Conf. High Volt. Eng. Appl. ICHVE 2010*. pp. 389–392. doi: 10.1109/ICHVE.2010.5640744.

[68] Neusel, C., Jelitto, H., Schmidt, D., Janssen, R., Felten, F. and Schneider, G.A. (2015). Thickness-dependence of the breakdown strength: Analysis of the dielectric and mechanical failure. *J. Eur. Ceram. Soc.*, *35(1),* 113–123. doi: 10.1016/j.jeurceramsoc.2014.08.028.

[69] Liao, R., Lv, C., Yang, L., Zhang, Y., Wu, W. and Tang, C. (2013). The insulation properties of oil-impregnated insulation paper reinforced with nano-TiO_2. *J. Nanomater.*, *2013*. doi: 10.1155/2013/373959.

[70] Dai, J., Wang, Z. and Jarman, P. (2010). Creepage discharge on insulation barriers in aged power transformers. *IEEE Trans. Dielectr. Electr. Insul.*, *17(4),* 1327–1335. doi: 10.1109/TDEI.2010.5539705.

[71] Li, X., Li, J., Xiang, C., Zhang, J., Bao, L. and Ran, H. (2016). The influence of oil-impregnated insulation paper's thickness on electrical breakdown strength. *Annu. Rep. - Conf. Electr. Insul. Dielectr. Phenomena, CEIDP*, 2016-Decem, 392–395. doi: 10.1109/CEIDP.2016.7785511.

[72] Liu, Z., Liu, Q. and Wang, Z.D. (2016). Effect of electric field configuration on streamer and partial discharge phenomena in a hydrocarbon insulating liquid under AC stress. *J. Phys. D. Appl. Phys.*, *49(18).* doi: 10.1088/0022-3727/49/18/185501.

[73] Lesaint, O. and Massala, G. (1996). Transition to fast streamers in mineral oil in the presence of insulating solids. *Conference Record of the 1996 IEEE International Symposium on Electrical Insulation.*

[74] Sun, J., Li, X., Zhu, L., Ji, S. and Cui, Y. (2017). Partial discharge of needle-plane defect in oil-paper insulation under AC and DC combined voltages: Developing processes and characteristics. *Energies*, *10(11).* doi: 10.3390/en10111759.

[75] Gharehkhani, S., Sadeghinezhad, E., Kazi, S.M., Yarmand, H., Badarudin, A., Safaei, M.R. and Zubir, M.N.M. (2015). Basic effects of pulp refining on fiber properties - A review. *Carbohydr. Polym.*, 115, 785–803. doi: 10.1016/j.carbpol.2014.08.047.

[76] Ashori, A. (2006). Nonwood fibers — A potential source of raw material in papermaking. *Polym. Plast. Technol. Eng.*, *45(10),* 1133–1136. doi: 10.1080/03602550600728976.

© COPYRIGHT UPM

[77] Han, J.S. (1998). Properties of nonwood fibers. *Proc. Korean Soc. wood Sci. Technol. Annu. Meet.*, pp. 3–12.

[78] Aruna, M., Pattanshetti, V.V., Ravi, K.N. and Vasudev, N. (2011). Power transformer winding insulation : A review of material characteristics. *Int. J. Mod. Eng. Res.*, *1(2),* 312–318.

[79] Dhamodaran, T.K., Gnanaharan, R. and Pillai, K.S. (2003). Bamboo for pulp and paper - A state of the art review with annotated bibliography. Retrieved from http://www.inbar.int/sites/default/files/resources/inbar_working_paper_no46.pdf.

[80] Van Der Reyden, D. (1992). Recent scientific research in paper conservation. *J. Am. Inst. Conserv.*, *31(1),* 117–138. doi: 10.1179/019713692806156394.

[81] Lahr, F.A.R., Junior, H.S. and Fiorelli, J. (2015). Non-conventional building materials based on agro-industrial wastes. Retrieved from https://sites.usp.br/constrambi/wp-content/uploads/sites/98/2016/03/Non-conventional-Building-Materials_ebook.pdf.

[82] Judt, M. (1993). Non-wood plant fibres, will there be a come-back in paper-making?. *Ind. Crops Prod.*, 2(1), 51–57. doi: 10.1016/0926-6690(93)90011-W.

[83] Ochi, S. (2008). Mechanical properties of kenaf fibers and kenaf/PLA composites. *Mech. Mater.*, *40(4–5),* 446–452. doi: 10.1016/j.mechmat.2007.10.006.

[84] Huang, J., Zhou, Y., Dong, L., Zhou, Z. and Zeng, X. (2017). Enhancing insulating performances of presspaper by introduction of nanofibrillated cellulose. *Energies*, *10(5).* doi: 10.3390/en10050681.

[85] Khudsar, T., Mahmooduzzafar, Soh, W.Y. and Iqbal, M. (2000). Morphological and anatomical variations of Cajanus cajan (Linn.) huth raised in cadmium-rich soil. *J. Plant Biol.*, *43(3),* 149–157. doi: 10.1007/bf03030492.

[86] Edeerozey, A.M.M., Akil, H.M., Azhar, A.B. and Ariffin, M.I.Z. (2007). Chemical modification of kenaf fibers. *Mater. Lett.*, *61(10),* 2023–2025. doi: 10.1016/j.matlet.2006.08.006.

[87] International Electrotechnical Commission (2004). International Standard. Semiconductor devices - Part 16-4: Microwave integrated circuits - Switches consolidated edition. Retrieved from webstore.iec.ch/preview/info_iec60747-16-4%7Bed1.0%7Den.pdf

© COPYRIGHT UPM

[88] International Electrotechnical Commission (1987). International Standard. Amendment 1. Fixed resistors for use in electronic equipment. Part 6: Sectional specification: Fixed resistor networks with individually measurable resistors. Retrieved from https://www.sis.se/api/document/preview/120353/

[89] Huang, J., Zhou, Y., Jin, F., Sha, Y., Zhang, L. and Le, T.H. (2014). Electrical properties of oil-paper insulation affected by water conductivity during paper-making process. *EIC 2014 - Proc. 32nd Electr. Insul. Conf.*, pp. 272–275. doi: 10.1109/EIC.2014.6869390.

[90] International Electrotechnical Commission (1997). Internat-Ionale International. 1(June).

[91] International Electrotechnical Commission (2001). International Standard. Document management – Part 1: Principles and methods. Retrieved from https://webstore.iec.ch/preview/info_iec82045-1%7Bed1.0%7Db.pdf

[92] International Electrotechnical Commission (1983). Amendment 1 - Printed boards. Part 6: Specification for multilayer printed boards.

[94] Aji, I.S., Sapuan, S.M., Zainudin, E.S. and Abdan, K. (2009). Kenaf fibres as reinforcement for polymeric composites: A review. *Int. J. Mech. Mater. Eng.*, *4(3),* 239–248,.

[95] Takagi, H. and Ichihara, Y. (2004). Effect of fiber length on mechanical properties of 'green' composites using a starch-based resin and short bamboo fibers. *JSME Int. J. Ser. A*, *47(4),* 551–555. doi: 10.1299/jsmea.47.551.

[96] Kakoty, A., Sangma, W.S.N., Phukan, A.R. and Kalita, B.B. (2019). Extraction of kenaf fiber and its physico-chemical properties for various end uses. *Int. J. Chem. Stud., 7(3),* 2617–2620.

[97] Nayeri, M.D., Md Tahir, P., Harun, J., Abdullah, L.C., Bakar, E.S., Jawaid, M., and Namvar, F. (2013). Effects of temperature and time on the morphology, pH, and buffering capacity of bast and core kenaf fibres. *BioResources*, *8(2),* 1801–1812. doi: 10.15376/biores.8.2.1801-1812.

[98] Ishak, M.R., Leman, Z., Sapuan, S.M., Edeerozey, A.M.M. and Othman, I.S. (2010). Mechanical properties of kenaf bast and core fibre reinforced unsaturated polyester composites. *IOP Conf. Ser. Mater. Sci. Eng.*, *11,* 012006. doi: 10.1088/1757-899X/11/1/012006.

[100] Kibblewhite, R.P. and Brookes, D. (1977). Fibre, beating, and papermaking properties of kraft pulps from New Zealand beech (Nothofagus) species. *New Zeal. J. For. Sci.*, *7(3),* 425–444.

© COPYRIGHT UPM

[101] Karlsson, H. (2010). Strength properties of paper produced from softwood kraft pulp – Pulp mixture, reinforcement and sheet stratification. Dissertation Chemical Engineering, Karlstad University Studies.

[102] Shakhes, J., Zeinaly, F., Marandi, M.A.B. and Saghafi, T. (2011). The effects of processing variables on the soda and soda-AQ pulping of Kenaf bast fiber. *BioResources*, *6(4),* 4626–4639. doi: 10.15376/biores.6.4.4626-4639.

[103] Yue, F., Chen, K.L. and Lu, F. (2016). Low temperature soda-oxygen pulping of bagasse. *Molecules*, *21(1).* doi: 10.3390/molecules21010085.

[104] Hubbe, M.A., Becheleni, E.M.A., Lewis, A.E., Peters, E.M., Gan, W., Nong, G., Mandal, S. and Shi, S.Q. (2018). Recovery of inorganic compounds from spent alkaline pulping liquor by eutectic freeze crystallization and supporting unit operations: A review. *BioResources*, *13(4),* 9180–9219. doi: 10.15376/biores.13.4.Hubbe.

[105] Ibrahim, N.A., Hadithon, K.A. and Abdan, K. (2010). Effect of fiber treatment on mechanical properties of kenaf fiber-ecoflex composites. *J. Reinf. Plast. Compos.*, *29(14),* 2192–2198. doi: 10.1177/0731684409347592.

[106] Kędzierski, M., Wiejak, A., Janiszewska, J., Wiśniewska, A., Grzywa-Niksińska, I. and Kurzepa, K. (2020). Efficiency of selected biocide compounds in the protection of building coatings against colonization by mold fungi, cyanobacteria and algae. *Polimery/Polymers*, *65(5),* 371–379. doi: 10.14314/polimery.2020.5.5.

[107] Ribeiro, R.A., Colodette, J.L. and Vaz Júnior, S. (2018). Effect of residual effective alkali on eucalyptus kraft pulp yield and chemistry. *Cerne*, *24(4),* 408–419. doi: 10.1590/01047760201824042593.

[108] Ibraheem, S.A., Ali, A. and Abdan, K. (2011). Development of green insulation boards from kenaf fibres part 1: Development and characterization of mechanical properties. *Key Eng. Mater.*, *462–463(April 2015),* 1343–1348. doi: 10.4028/www.scientific.net/KEM.462-463.1343.

[109] Salleh, F.M., Hassan, A., Yahya, R., Mohd Isa, M.R. and Lafia-Araga, R.A. (2018). Physico-thermal properties of kenaf fiber/high-density polyethylene/maleic anhydride compatibilized composites. *High Perform. Polym.*, *30(8),* 900–910. doi: 10.1177/0954008318777574.

[110] Tholibon, D., Sulong, A.B., Muhammad, N., Ismail, N.F., Tharazi, I. and Md Radzi, M.K.F. (2016). Tensile properties of unidirectional kenaf fiber polypropylene composite. *J. Teknol.*, *78(6–9),* 101–106. doi: 10.11113/jt.v78.9153.

© COPYRIGHT UPM

[111] Millogo, Y., Aubert, J.E., Hamard, E. and Morel, J.C. (2015). How properties of kenaf fibers from Burkina Faso contribute to the reinforcement of earth blocks. *Materials (Basel).*, *8(5),* 2332–2345. doi: 10.3390/ma8052332.

[112] Emran Ismail, A., Khalid, S.N.A. and Muhd Nor, N.H. (2017). A review on the perforated impact energy absorption of kenaf fibres reinforced composites. *J. Phys. Conf. Ser.*, *914(1).* doi: 10.1088/1742-6596/914/1/012044.

[113] Jusoh, A.F., Rejab, M.R.M., Siregar, J.P. and Bachtiar, D. (2016). Natural fiber reinforced composites: A review on potential for corrugated core of sandwich structures. *MATEC Web Conf.*, *74,* 7–11. doi: 10.1051/matecconf/20167400033.

[114] Brännvall, E. (2009). Overview of pulp and paper processes. *Pulping Chem. Technol.*, 1–11. doi: 10.1515/9783110213423.

[115] Dwi, D. and Nugroho, P. (2012). Low consistency refining of mixtures of softwood & hardwood bleached kraft pulp: Effects of refining power. Master of Engineering, Asian Institute of Technology.

[117] Kang, T. (2007). Role of external fibrillation in pulp and paper properties. Doctoral Thesis, Helsinki University of Technology.

[118] W. H. Gao *et al.*, “Effects of beating on tobacco stalk mechanical pulp,” *Cellul. Chem. Technol.*, vol. 46, no. 3–4, pp. 277–282, 2012.

[119] N. N. Wai, H. Nanko, and K. Murakami, “A morphological study on the behavior of bamboo pulp fibers in the beating process,” *Wood Sci. Technol.*, vol. 19, no. 3, pp. 211–222, 1985, doi: 10.1007/BF00392050.

[120] Wenhua, G., Chen, K., Zeng, J., Li, J., Yang, R., Yang, F., Rao, G. and Tao, H. (2012). Effects of beating on tobacco stalk mechanical pulp. *Cellul. Chem. Technol., 46(3),* 277-282. doi: 10.1016/j.carbpol.2015.04.005.

[121] Arsène, K., Savastano Jr, M.A., Allameh, H., Ghavami, S.M. and Soboyejo, W.O. (2003). Cementitious composites reinforced with vegetable fibers. *Proc. 1st Interam. Conf. Non-conventional Mater. Technol. Eco-construction Infrastruct.* pp. 13–16. Retrieved from http://www.nku.edu/~allamehs1/Arsene-Natural Fibers fianl IAC NOCMAT.pdf.

[122] Hassan, N.H.M., Muhammed, S. and Ibrahim, R. (2013). Effect of soda-anthraquinone pulping conditions and beating revolution on the mechanical properties of paper made from Gigantochloa scortechinii (Semantan bamboo). *Malaysian J. Anal. Sci.*, *17(1),* 75–84.

© COPYRIGHT UPM

[123] Sandberg, C., Berg, J.E. and Engstrand, P. (2017). Process intensification in mechanical pulping. *Nord. Pulp Pap. Res. J.*, *32(04),* 615–622. doi: 10.3183/npprj-2017-32-04-p615-622.

[124] González, I., Boufi, S., Pèlach, M.A., Alcalà, M., Vilaseca, F. and Mutjé, P. (2012). Nanofibrillated cellulose as paper additive in eucalyptus pulps. *BioResources*, *7(4),* 5167–5180. doi: 10.15376/biores.7.4.5167-5180.

[125] Huber, P., Lyannaz, L. and Carré, B. (2012). Specks masking by the coating layer in coated paper made from deinked pulp. *Nord. Pulp Pap. Res. J.*, *27(2),* 466–471. doi: 10.3183/NPPRJ-2012-27-02-p466-471.

[126] Nikolaeva, M. (2010). Measurement and improvement of wet paper web strength. Master's Thesis, Lappeenranta University of Technology.

[127] Ramezanzadeh, B., Vakili, H. and Amini, R. (2015). The effects of addition of poly(vinyl) alcohol (PVA) as a green corrosion inhibitor to the phosphate conversion coating on the anticorrosion and adhesion properties of the epoxy coating on the steel substrate. *Appl. Surf. Sci.*, *327,* 174–181. doi: 10.1016/j.apsusc.2014.11.167.

[128] Zhang, P., Wang, Q., Guo, R., Zhang, M., Wang, S., Lu, C., Xue, M., Fan, J., He, Z. and Rao, W. (2019). Self-assembled ultrathin film of CNC/PVA-liquid metal composite as a multifunctional Janus material. *Mater. Horizons*, *6(8),* 643–1653. doi: 10.1039/c9mh00280d.

[129] Zhang, C.H., Lin Yang, F., Wang, W.J. and Chen, B. (2008). Preparation and characterization of hydrophilic modification of polypropylene non-woven fabric by dip-coating PVA (polyvinyl alcohol). *Sep. Purif. Technol.*, *61(3),* 276–286. doi: 10.1016/j.seppur.2007.10.019.

[130] Schuman, T., Wikström, M. and Rigdahl, M. (2004). Coating of surface-modified papers with poly(vinyl alcohol). *Surf. Coatings Technol.*, *183(1),* 96–105. doi: 10.1016/j.surfcoat.2003.09.059.

[131] Shokrieh, M.M., Mahmoudi, A. and Shadkam, H.R. (2015). Hybrid polyvinyl alcohol and cellulose fiber pulp instead of asbestos fibers in cement-based composites. *Mech. Compos. Mater.*, *51(2),* 231–238. doi: 10.1007/s11029-015-9494-7.

[133] Abdulkhani, A., Hojati Marvast, E., Ashori, A., Hamzeh, Y. and Karimi, A.N. (2013). Preparation of cellulose/polyvinyl alcohol biocomposite films using 1-n-butyl-3-methylimidazolium chloride. *Int. J. Biol. Macromol.*, *62(September),* 379–386. doi: 10.1016/j.ijbiomac.2013.08.050.

[134] Schuman, T., Wikström, M. and Rigdahl, M. (2003). The effect of hot calendering of the substrate on the barrier properties of poly(vinyl alcohol)-coated papers. *Nord. Pulp Pap. Res. J.*, *18(1),* 81–89. doi:

© COPYRIGHT UPM

10.3183/npprj-2003-18-01-p081-089.

[135] Millon, L.E. and Wan, W.K. (2006). The polyvinyl alcohol-bacterial cellulose system as a new nanocomposite for biomedical applications. *J. Biomed. Mater. Res. - Part B Appl. Biomater.*, *79(2),* 245–253. doi: 10.1002/jbm.b.30535.

[136] Santi, R., Cigada, A., Del Curto, B. and Farè, S. (2019). Modulable properties of PVA/cellulose fiber composites. *J. Appl. Biomater. Funct. Mater.*, *17(1).* doi: 10.1177/2280800019831224.

[137] Liu, D., Sun, X., Tian, H., Maiti, S. and Ma, Z. (2013). Effects of cellulose nanofibrils on the structure and properties on PVA nanocomposites. *Cellulose*, *20(6),* 2981–2989. doi: 10.1007/s10570-013-0073-6.

[138] Leitner, J., Hinterstoisser, B., Wastyn, M., Keckes, J. and Gindl, W. (2007). Sugar beet cellulose nanofibril-reinforced composites. *Cellulose*, *14(5),* 419–425. doi: 10.1007/s10570-007-9131-2.

[139] Bajpai, P. (2015). Green chemistry and sustainability in pulp and paper industry. *Green Chem. Sustain. Pulp Pap. Ind.*, 1–258. doi: 10.1007/978-3-319-18744-0.

[140] Höglund, H. (2009). Mechanical pulping. *Pulping Chem. Technol.*, *7(1990),* 57–90. doi: 10.1515/9783110213423.

[141] Moradbak, A., Tahir, P.M., Mohamed, A.Z. and Halis, R. (2016). Alkaline sulfite anthraquinone and methanol pulping of bamboo (Gigantochloa scortechinii). *BioResources*, *11(1),* 235–248. doi: 10.15376/biores.11.1.235-248.

[142] TAPPI Pulp Properties Committee (1999). Freeness of pulp (Canadian standard method). Retrieved from https://www.tappi.org/globalassets/t227-d-2-sarg.pdf

[143] Rantanen, W. (2001). Fiber length of pulp by projection (Revision of T 232 cm-1). Retrieved from https://www.tappi.org/content/tag/sarg/t232.pdf

[144] TAPPI Pulp Properties Committee (2008). Laboratory beating of pulp (PFI mill method). Retrieved from https://www.tappi.org/globalassets/t248-d-2-sarg.pdf

[145] TAPPI Pulp Properties Committee (2006). Forming handsheets for physical tests of pulp. Retrieved from https://www.tappi.org/content/sarg/t205.pdf

[146] Yang, C.Q. and Xu, G. (2002). Polymer-aldehyde additives to improve paper properties. United States Patent. Retrieved from

© COPYRIGHT UPM

ttps://patentimages.storage.googleapis.com/38/a6/0b/6ed7688660df8e/US6379499.pdf

[147] Botto-Tobar, M., León-Acurio, J., Cadena, A.D. and Diaz, P.M. (2011). *Advances in Emerging Trends and Technologies.* Springer.

[148] School of Industrial Technology (2017). Stock preparation and papermaking. https://indtech.usm.my/index.php/academic-programme/curriculum-structure-bioresource-1718/stock-preparation-andpapermaking#:~:text=Stock%20preparation%20part%20involves%20the,cleaning%2C%20and%20de%2Dinking.

[149] Kanimozhi, K., Khaleel Basha, S. and Sugantha Kumari, V. (2016). Processing and characterization of chitosan/PVA and methylcellulose porous scaffolds for tissue engineering. *Mater. Sci. Eng. C*, *61,* 484–491. doi: 10.1016/j.msec.2015.12.084.

[150] Satvekar, R.K., Phadatare, M.R., Karande, V.A., Patil, R.N., Tiwale, B.M. and Pawar, S.H. (2012). Influence of silane content on the optical properties of sol gel derived spin coated silica thin films. *Int. J. Basic Appl. Sci.*, *1(4).* doi: 10.14419/ijbas.v1i4.292.

[151] TAPPI (1997). Thickness (caliper) of paper , paperboard , and combined board. Retrieved from http://grayhall.co.uk/BeloitResearch/tappi/t411.pdf

[152] Muchorski, D. (2006). Tensile properties of paper and paperboard (using constant rate of elongation apparatus). Retrieved from https://www.tappi.org/content/sarg/t494.pdf.

[153] TAPPI (1997). Bursting strength of paper. Retrieved from https://www.wewontech.com/testing-standards/200328002.pdf

[154] Wistara, N. and Young, R.A. (1999). Properties and treatments of pulps from recycled paper. Part I. Physical and chemical properties of pulps. *Cellulose*, *6(4),* 291–324. doi: 10.1023/A:1009221125962.

[155] TAPPI (1998). Internal tearing resistance of paper (Elmendorf-type method). Retrieved from http://grayhall.co.uk/BeloitResearch/tappi/t414.pdf

[156] Keithley (2001). “Volume and surface resistivity measurements of insulating materials using the 6517B electrometer/high resistance meter volume and surface resistivity measurements of insulating materials using the 6517B electrometer/high resistance meter. Application Note. Retrieved from https://download.tek.com/document/Volume-SurfaceResistivity_AppNote_1KW-61175-0.pdf

[157] Baur, M., Knauel, J., Calcara, L.and Pompili, M. (2017). Insulating liquids breakdown voltage determination: Test method efficiency. *2017 IEEE*

© COPYRIGHT UPM

19th Int. Conf. Dielectr. Liq. ICDL 2017. pp. 1–4. doi: 10.1109/ICDL.2017.8124657.

[158] International Electrotechnical Committee (1993). Insulating liquids - Determination of the partial. https://infostore.saiglobal.com/en-au/standards/iec-61294-1-0-567723_saig_iec_iec_1295861/

[159] International Electrotechnical Committee (2000). High-voltage test techniques - Partial discharge measurements. https://webstore.iec.ch/publication/1247

[160] Riley, A. (2012). Paper and paperboard packaging. In Emblem, A. and Emblem, H. (Eds.), *Packaging Technology.* Woodhead Publishing Limited.

[161] Maharana, M., Baruah, N., Nayak, S.K. and Sahoo, N. (2017). Comparative study of mechanical and electrical strength of kraft paper in nanofluid based transformer oil and mineral oil. *Proc. Int. Symp. Electr. Insul. Mater.*, *2(September),* 646–649. doi: 10.23919/ISEIM.2017.8166573.

[162] Dhar, A. and Alford, T.L. (2013). Effect of silver thickness and annealing on optical and electrical properties of Nb2O5/Ag/Nb2O5 multilayers as transparent composite electrode on flexible substrate. *Earth Environ. Sci. Trans. R. Soc. Edinburgh*, *1552(1),* 101–106. doi: 10.1557/opl.2013.641.

[163] Provencher, H., Noirhomme, B. and David, E. (2009). Effect of aging on the dielectric properties of insulation paper of power transformers. *IEEE Electr. Insul. Conf. EIC 2009*, June, 473–477. doi: 10.1109/EIC.2009.5166393.

[164] Norrman, K., Ghanbari-Siahkali, A. and Larsen, N.B. (2005). Studies of spin-coated polymer films. *Annu. Reports Prog. Chem. - Sect. C*, *101,* 174–201. doi: 10.1039/b408857n.

[165] He, J., Tang, Y. and Wang, S.Y. (2007). Differences in morphological characteristics of bamboo fibres and other natural cellulose fibres: Studies on X-ray diffraction, solid state 13C-CP/MAS NMR, and second derivative FTIR spectroscopy data. *Iran. Polym. J.*, *16(12),* 807–818.

[166] Grzybowski, S. and Zahn, M. (2012). preparation of a vegetable oil-based nanofluid and investigation of its breakdown and dielectric properties. *IEEE Electrical Insulation Magazine, 28(5)*, 43-50. doi: 10.1109/MEI.2012.6268441.

[167] El Mansouri, N.E., Espinach, F.X., Julian, F., Verdaguer, N., Torres, L., Llop, M.F. and Mutje, P. (2012). Research on the suitability of organosolv semi-chemical triticale fibers as reinforcement for recycled HDPE composites. *BioResources*, *7(4),* 5032–5047. doi:

© COPYRIGHT UPM

10.15376/biores.7.4.5032-5047.

[168] Bai, W., Kong, L. and Guo, A. (2013). Effects of physical properties on electrical conductivity of compacted lateritic soil. *J. Rock Mech. Geotech. Eng.*, *5(5),* 406–411. doi: 10.1016/j.jrmge.2013.07.003.

[169] Salman, A., Al-Ramadhan, Z.A., Bakr, N.A. and Nazal, Z.F. (2014). Electrical properties of polyvinyl alcohol (PVA) films doped with $CoCl_2$ salt. *Int. J. Curr. Res., 6(4),* 6225-6227.

[170] Yee, M.J., Mubarak, N.M., Khalid, M., Abdullah, E.C. and Jagadish, P. (2018). Synthesis of polyvinyl alcohol (PVA) infiltrated MWCNTs buckypaper for strain sensing application. *Sci. Rep.*, *8(1),* 1–16. doi: 10.1038/s41598-018-35638-3.

[171] Gutiérrez, M.P., Li, H. and Patton, J. (2002). Thin film surface resistivity. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.528.6542&rep=rep1&type=pdf

[172] Coursehero.com (n.d). Static electricity and charge: Conservation of charge. https://courses.lumenlearning.com/physics/chapter/18-1-static-electricity-and-charge-conservation-of-charge/

[173] Document Center Inc. (2022). ASTM-D2413. Standard Practice for Preparation of Insulating Paper and Board Impregnated with a Liquid Dielectric. https://www.document-center.com/standards/show/ASTM-D2413

[174] Borch, J., Lyne, M.B., Mark, R.E. and Habeger, C. (2002). *Handbook of Physical Testing of Paper, Volume 2*. CRC Press.

[175] Liao, R., Liu, J., Yang, L., Wang, K., Hao, J., Ma, Z., Gao, J. and Lv, Y. (2015). Quantitative analysis of insulation condition of oil-paper insulation based on frequency domain spectroscopy. *IEEE Trans. Dielectr. Electr. Insul.*, *22(1),* 322–334. doi: 10.1109/TDEI.2014.004490.

[176] Okabe, S., Ueta, G. and Tsuboi, T. (2013). Investigation of aging degradation status of insulating elements in oil-immersed transformer and its diagnostic method based on field measurement data. *IEEE Trans. Dielectr. Electr. Insul.*, *20(1),* 346–355. doi: 10.1109/TDEI.2013.6451376.

[177] Tomago, A., Shimizu, T., Lijima, Y. and Yamauchi, I. (1977). Development of oil-impregnated, all-polypropylene-film power capacitor. *IEEE Trans. Electr. Insul.*, *EI-12(4),* 293–301.

[178] Zhao, D., Yang, F., Dai, Y., Tao, F., Shen, Y., Duan, W., Ma, H., Tang, L. and Li, J. (2017). Exploring crystalline structural variations of cellulose during pulp beating of tobacco stems. *Carbohydr. Polym.*, *174,* 146–153.

© COPYRIGHT UPM

doi: 10.1016/j.carbpol.2017.06.060.

[179] Melander, E. (2011). The effect of charged groups on the beatability of pulp fibres. Retrieved from https://www.diva-portal.org/smash/get/diva2:425918/FULLTEXT01.pdf

[180] Oommen, T.V. and Andrady, T.L. (1996). Graft polymerization and other methods to reduce the hygroscopic\nnature of cellulose insulation. *Conf. Rec. 1996 IEEE Int. Symp. Electr. Insul.*, 2, 538–541. doi: 10.1109/ELINSL.1996.549401.

[181] Koch, M. and Krüger, M. (2009). The negative dissipation factor and the interpretation of the dielectric response of power transformers. Retrieved from https://www.omicronenergy.com/download/document/07E16ADB-ACBB-4639-AE5B-1642F15D4734/

[182] Magabane, P., Bokoro, P. and Jordaan, J. (2019). A review of detection and mitigation of negative dissipation factor in high voltage power transformers. *IEEE AFRICON Conf.*, 2019-Septe. doi: 10.1109/AFRICON46755.2019.9134007.

[183] Seong, J.K., Seo, I.J., Hwang, J.S. and Lee, B.W. (2012). Comparative evaluation between DC and AC breakdown characteristic of dielectric insulating materials in liquid nitrogen. *IEEE Trans. Appl. Supercond.*, *22(3),* 3–6. doi: 10.1109/TASC.2011.2178222.

[184] Huang, J., Zhou, Y., Zhou, Z. and Liu, R. (2016). Dramatically enhanced electrical breakdown strength in cellulose nanopaper. *AIP Adv.*, *6(9),* 1–17. doi: 10.1063/1.4964151.

[185] Sinan, S.S., Shawaludin, S.N., Jasni, J., Azis, N., Kadir, M.Z.A.A. and Mohtar, M.N. (2014). Investigation on the AC breakdown voltage of RBDPO olein. *2014 IEEE Innov. Smart Grid Technol. - Asia, ISGT ASIA 2014*, pp. 760–763. doi: 10.1109/ISGT-Asia.2014.6873888.

[186] Yu, Z., Wang, X., Bian, H., Jiao, L., Wu, W. and Dai, H. (2018). Enhancement of the heat conduction performance of boron nitride/cellulosic fibre insulating composites. *PLoS One, 13(7),* 1–10. doi: 10.1371/journal.pone.0200842.

[187] Li, Y., Zhang, Q., Gao, M., Ni, H., Zhao, Y., Liu, G. and Wang, K. (2017). Influence of fiber impurities on DC partial discharge process in oil-pressboard insulation. *2017 IEEE 19th Int. Conf. Dielectr. Liq. ICDL 2017*, vol. 2017-Janua, no. Icdl, pp. 1–5. doi: 10.1109/ICDL.2017.8124660.

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