DIELECTRIC PROPERTIES OF KENAF-BASED KRAFT PAPER FOR HIGH VOLTAGE INSULATION

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By

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LIST OF ABBREVIATIONS

KBKP	Kenaf-Based Kraft Paper
HV	High Voltage
BS	British Standard

SIFAT-SIFAT DIELEKTRIK KERTAS KRAFT BERASAKAN KENAF UNTUK PENEBAT VOLTAN TINGGI

ABSTRAK

Kertas digunakan secara meluas dalam pelbagai aplikasi kejuruteraan kerana sifat fizikal dan cara penghasilannya yang mudah. Oleh itu, kertas telah direka atau dipilih sebagai bahan penebat elektrik untuk bahagian dalam teknologi voltan tinggi. Bagaimanapun, kenaf adalah bahan baru yang baru diperkenalkan untuk bertindak sebagai bahan penebat untuk sistem penebat voltan tinggi. Oleh itu, untuk menggunakan bahan kenaf bagi tujuan elektrik, ciri kenaf perlu dikaji sebelum boleh digunakan dalam peralatan elektrik sebagai sebahagian daripada sistem penebat. Dalam kajian ini, tiga jenis ujian dielektrik akan dijalankan pada 2 mm kertas kraf berasaskan kenaf (KBKP) untuk menentukan sifat-sifat dielektrik berdasarkan British Standard (BS EN 60641-2: 2004) papan tekan dan kertas tekan untuk tujuan elektrik - bahagian 2: kaedah ujian. Ketiga-tiga ujian ini ialah ujian kandungan kelembapan, penyerapan minyak dan kekuatan elektrik dalam udara. Keputusan menunjukkan kandungan kelembapan KBKP ini adalah 3.15% manakala bagi penyerapan minyak adalah 1.88%. Kekuatan elektrik yang diperoleh daripada ujian kekuatan elektrik dalam udara ialah 12.83 kV / mm. Selepas merujuk kepada British Standard (BS EN 60641-3-1: 1994) papan tekan dan kertas tekan untuk tujuan elektrik elektrik - bahagian 3: spesifikasi untuk bahan individu, KBKP ini berkemungkinan sesuai untuk bertindak sebagai bahan penebat untuk sistem penebat voltan tinggi.

DIELECTRIC PROPERTIES OF KENAF-BASED KRAFT PAPER FOR HIGH VOLTAGE INSULATION

ABSTRACT

Paper is broadly utilized in various engineering applications due to its physical properties and ease of manufacture. Therefore, paper has been designed or chosen as an electrical insulation material for parts in high voltage (HV) technology. However, kenaf is a new material that has been newly introduced to act as an insulating material for high voltage insulation system. Therefore, in order to use kenaf material for electrical purposes, kenaf characteristics need to be studied before can be used in electrical equipment as a part of insulation system. In this research, three type of dielectric test will be conducted on 2 mm kenaf-based Kraft paper (KBKP) to determine its dielectric properties based on British Standard (BS EN 60641-2:2004) pressboard and presspaper for electrical purposes - part 2: methods of tests. This three type of test are moisture content, oil absorption and electric strength in air test. The results showed that the moisture content of this KBKP is 3.15 % while for the oil absorbency is 1.88 %. The electric strength obtained from the electric strength in air test is 12.83 kV/mm. After referred to the British Standard (BS EN 60641-3-1: 1994) pressboard and presspaper for electrical electrical purposes – part 3: specifications for individual materials, this KBKP is possible to act as an insulating material for high voltage insulation system.

CHAPTER 1

INTRODUCTION

1.1 Research Background

HV insulation is an electrical insulation designed to prevent breakdown in a circuit operating at high voltages. The common application of this HV insulation is the insulation system of power transformer [1]. Transformers are crucial power system equipment that converts electrical energy from one voltage level into another by electromagnetic induction. It comprises of primary and secondary windings, core assembly and insulators. Current flowing through the conductors in the primary winding produces a magnetic flux in the core and the resulting magnetic field develops an induction current that flows in the conducting wires in the secondary winding. All conducting elements in transformers need to be perfectly insulated for the purpose of maintaining current flow on its desired path as well as insulating them from one another. In order to electrically separate these conducting paths and in oil filled power transformers, kraft paper or pressboard is used.

Kraft paper were broadly used for cables and capacitors before becoming the main solid insulation in transformers [2]. By the late 1920s in Switzerland, Weidmann had produced transformerboard or known as pressboard nowadays. The transformerboard is made from kraft pulp, which could be easily fabricated into formed items, and these were ideal for high-stressed areas. Weidmann also had developed special transformerboard known as precompressed board in the early 1950s. The precompressed board is tougher and denser than the regular calendered board [3].

From the application of transformer insulation, it is proven that kraft papers and pressboards are widely used as an insulation materials used in power transformers system. However, as a new material introduced, KBKP characteristic need to be studied before can be used in electrical equipment as part of HV insulation system. Therefore, in this research, three type of dielectric test is conducted to determine its dielectric properties based on British Standard (BS EN 60641-2:2004) pressboard and presspaper for electrical purposes – part 2: methods of tests. This three type of test are moisture content, oil absorption and electric strength in air test. From the result, KBKP will be compared with the pressboard type B.7.1 (hard calendered pressboard of low porosity usually loaded) according to the BS EN 60641-3-1: 1994 specification for pressboard and presspaper for electrical purposes - part 3: specifications for individual materials and determined whether there is a possibility of using this kenaf as an insulating material for HV insulation system.

1.2 Problem Statement

Kenaf is a new material that has been newly introduced to act as an insulating material in HV insulation systems. There is a research about this material had been used as an insulating material. This research focus on the development of effective green insulation boards by using natural fibres. Many attempts have been made to develop materials that act as insulators. However, some of these materials were found to be hazardous to humans. Therefore, the insulation board was fabricated from polyurethane reinforced with kenaf fibres in order to develop an effective green insulation boards. Another one research is the study on manufacture electric insulating paper and pressboard from non-wood fibres pulp. This research was conducted to find new kind of cellulose material for produce the electric insulating material for high voltage insulation systems. Thus, several tests were conducted to produce the good quality of electric insulator by using cotton fibres and kenaf bast fibres as material. The tests were density, tensile strength, conductivity and ash content test.

From the first research, the dielectric properties of this KBKP need to be studied in order to use it as an insulating material for high voltage insulation systems because this kraft paper is made without mixing with polymer such as polyurethane. There are also some dielectric properties of kenaf fibres had been discussed in the second research but in order to act as a good insulating material, other kenaf's dielectric properties also need to be studied. This study is needed for further development or improvement of the existing kraft paper.

1.3 Objectives of Research

- To determine the dielectric properties (moisture content, oil absorption rate and electric strength in air) of kenaf-based kraft paper.
- To determine whether kenaf is suitable for high voltage insulation system.

1.4 Scope of Research

This project will only cover the dielectric test on KBKP and determination whether the KBKP can be used for HV insulation. Three tests, which are moisture content, oil absorption and electric strength in air test, were conducted. In order to distinguish the suitability of KBKP as an insulating material for HV insulation systems, the test results will be referred with the specification of pressboard type B.7.1 according to BS EN 60641-3-1:

1994. Therefore, this study can be used for further development or improvement of the existing insulating material.

1.5 Thesis Outline

This thesis starts with the second chapter; it is mainly about the insulating material that has been used for HV insulation. The objective of test conducted also discussed in this chapter.

Next, the tests method that involved in this project are presented in Chapter 3. The tests conducted in this work are Moisture Content, Oil Absorption and Electric Strength in air test. All the tests are conducted to obtain the KBKP's dielectric properties. The project flow and test procedures are elaborated in this chapter.

The tests results for KBKP are analyzed in Chapter 4. The results are discussed and elaborated with the help of figures and table. The dielectric properties of KBKP is then compared with the pressboard type B.7.1 according to BS EN 60641-3-1: 1994. The detailed comparison is tabled and provided at the end of this chapter.

The conclusion of the whole project are discussed in Chapter 5. The limitations of the project and its recommendation are listed at the end of this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter consists of three sections, starting from Section 2.1 to Section 2.3. Firstly, Section 2.1 explains the summary of Chapter 2. Section 2.2 will be mainly about the research on kenaf as insulating material. The last section, Section 2.3 will conclude this chapter.

2.2 Research on Kenaf as Insulating Material

2.2.1 Development of Green Insulation Board from Kenaf Fibre and Polyurethane

According to S. A. Ibraheem [4], the purpose of this research was to develop effective green insulation boards fabricated from polyurethane (PU) reinforced with kenaf fibres. This research was conducted because some of the materials that have been used as insulators were found to be hazardous to humans. The example of these materials is asbestos. Many researchers have linked that asbestos exposure have caused numerous diseases. The damage or deterioration over time of asbestos will released the asbestos fibres, which will caused the air become hazardous. These fibres will trapped in the lung tissue and cause scarring, resulting in several diseases such as asbestosis, lung cancer and mesothelioma when they are inhaled [5]. There are about 90 000 asbestos-related deaths globally every year [6].

Therefore, there were attempts to incorporate natural fibres with promising properties into building applications. These attempts is to show that these fibres are feasible alternatives for use in the construction and industrial fields [7]. Researchers have led to fabricate many composite materials containing kenaf as reinforcing fibres because of the mechanical and environmental friendly properties of these natural fibres. Originally, kenaf was considered a promising material for fabricating high-grade printing and writing paper.

Nevertheless, paper industry is not the only kenaf applications. Kenaf fibres have begun to generate interest to use as an insulation material. In order to fabricate insulators successfully, kenaf was mixed with several polymers. Thus, continuous long kenaf fibres was mixed with polyurethane in order to develop effective green insulation boards. Biocomposites having three different weight contents (40/60, 50/50 and 60/40 kenaf/PU weight %) were manufactured.

Flexural test, Scan Electron Microscopy (SEM), thermal conductivity test, Limiting Oxygen Index (LOI) and water absorption test were conducted to determine which weight contents could be an effective green insulation boards. After all the tests have been carried out, S. A. Ibraheem [4] conclude that the optimal performance was observed at a weight of 50 % kenaf fibres. Furthermore, the minimum water absorption percentage, thickness swelling and changing in volume also were recorded at a weight of 50 % kenaf fibres.

2.2.2 Study on Manufacture Electric Insulating Paper and Pressboard from Non-Wood Fibres Pulp

This research was conducted because want to find new kind of cellulose material for produce the electric insulating material as replacing wood. Wood is known as the tradition material of the cellulose of electric insulating paper. However, it takes a long time for the trees to grow up, the forest was exploited a large quantity and the price is raising day by day. Therefore, according to Chen Kuan [8], the purpose of this research was to manufacture electric insulating paper and pressboard from non-wood fibres pulp.

In order to choose the source of new kinds of materials, these factors need to be considered. These factors are the quality of insulating material in technology, cost must be lower than wood and must have a reliable source for material. The nood-wood plants that have been investigated in this research are kenaf bast fibres and cotton fibres. Density, tensile strength, conductivity and ash content test were conducted to determine its suitability to use as electric insulating paper and pressboard. From the research result, it proved that kenaf bast fibres and cotton fibres are possible to use completely or partly to produce insulating pressboard and paper.

2.3 Conclusion

Based on both of the published works, a lot of new and crucial information were obtained. The development of insulation board that fabricated from polyurethane reinforced with kenaf fibres has been studied. The manufacture of insulating pressboard and paper from non-wood plant also has been studied. Thus, both of the published works could be helpful throughout this whole project.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter begins with a brief introduction in section 3.1 that explains the summary of Chapter 3. The work implementation flows are described in section 3.2. Section 3.3 shows the process of moisture content test. Section 3.4 explains the process of oil absorption test. Electric strength in air test is explained in Section 3.5. Lastly, a summary of the entire chapter is in section 3.6.

3.2 Project Implementation Flow

This project consists of two parts. The first part is to determine the dielectric properties of KBKP. Second part is to determine the suitability of KBKP to act as an insulating material for HV insulation systems. The process flowchart of the both part is shown in Figure 3.1.

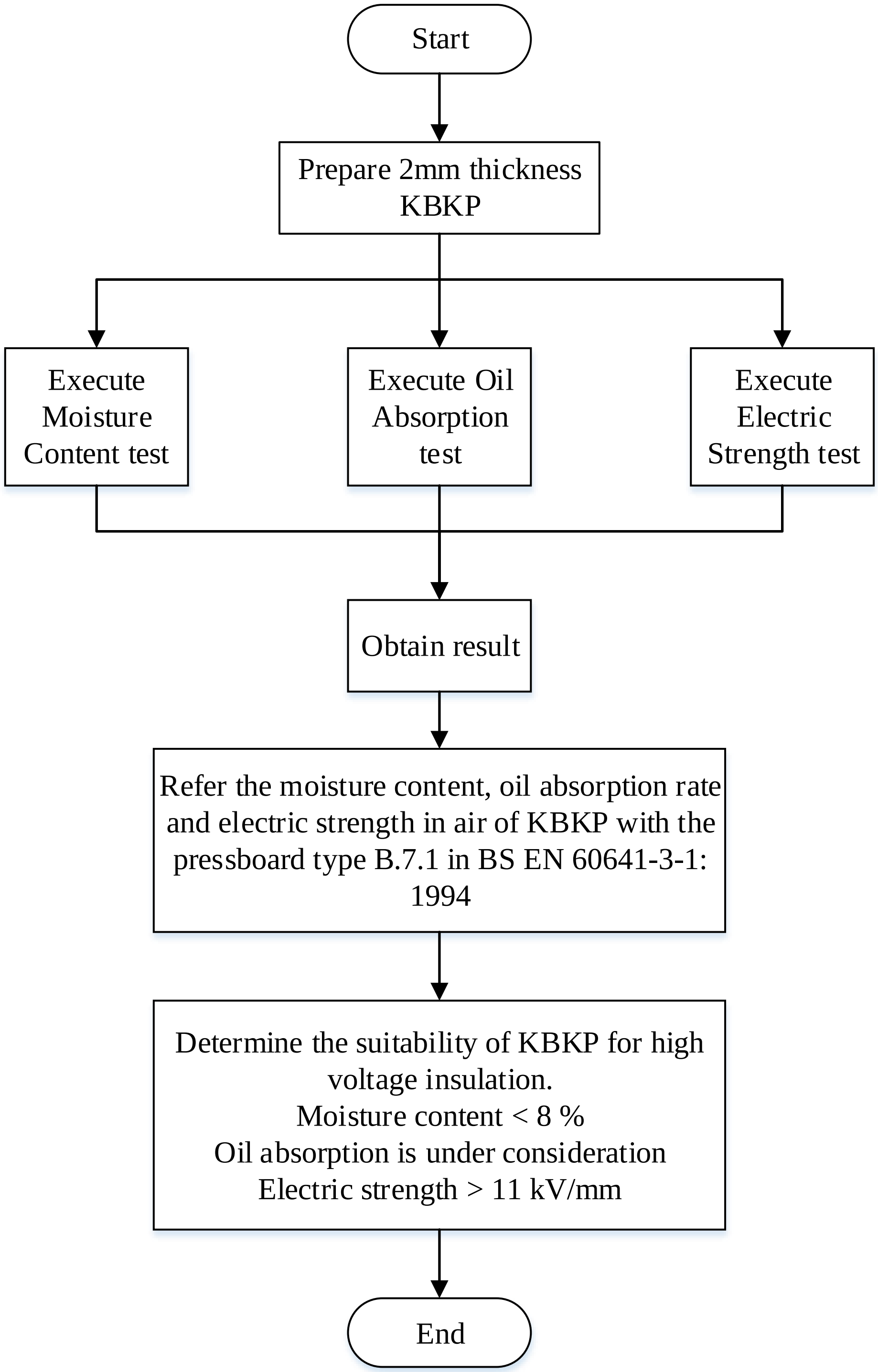


Figure 3.1: Flowchart of project implementation

3.3 Moisture Content Test

The purpose of this moisture content test is to determine the moisture contained in the sample. This moisture content can be obtained by take the weight of water divide by weight of sample and multiplied by 100%. Weight of water is the difference in the weight of the sample before and after drying. Weight of sample is the weight of the sample after it is oven-dry and all water has been removed. The formula of moisture content is stated in equation (3.1) [9].

$$Moisture\ Content = \frac{Weight\ of\ water}{Weight\ of\ sample} \times 100\% \tag{3.1}$$

3.3.1 Experimental Procedure

Figure 3.2 shows the flowchart of moisture content test procedure [10]. This test begins with the preparation of three samples. The sample was cut into three test pieces with its area at least 100 cm^2. All samples were weighed before proceed to the drying process. The mass of the samples were recorded as m_1. Then, all samples were dried according to the drying process. The samples were dried in a ventilated oven at 105 $^oC \pm 5\ ^oC$. Considering that, the thickness of the samples are 2 mm, the period for the drying process was 48 h. After completed the drying process, the samples were weighed again. The mass, m_2 were recorded. Moisture content in percentage (%) was calculated by using the equation (3.2).

$$Moisture\ content = \frac{m_1 - m_2}{m_2} \times 100\ (\%) \tag{3.2}$$

The result was recorded from the average of three samples.

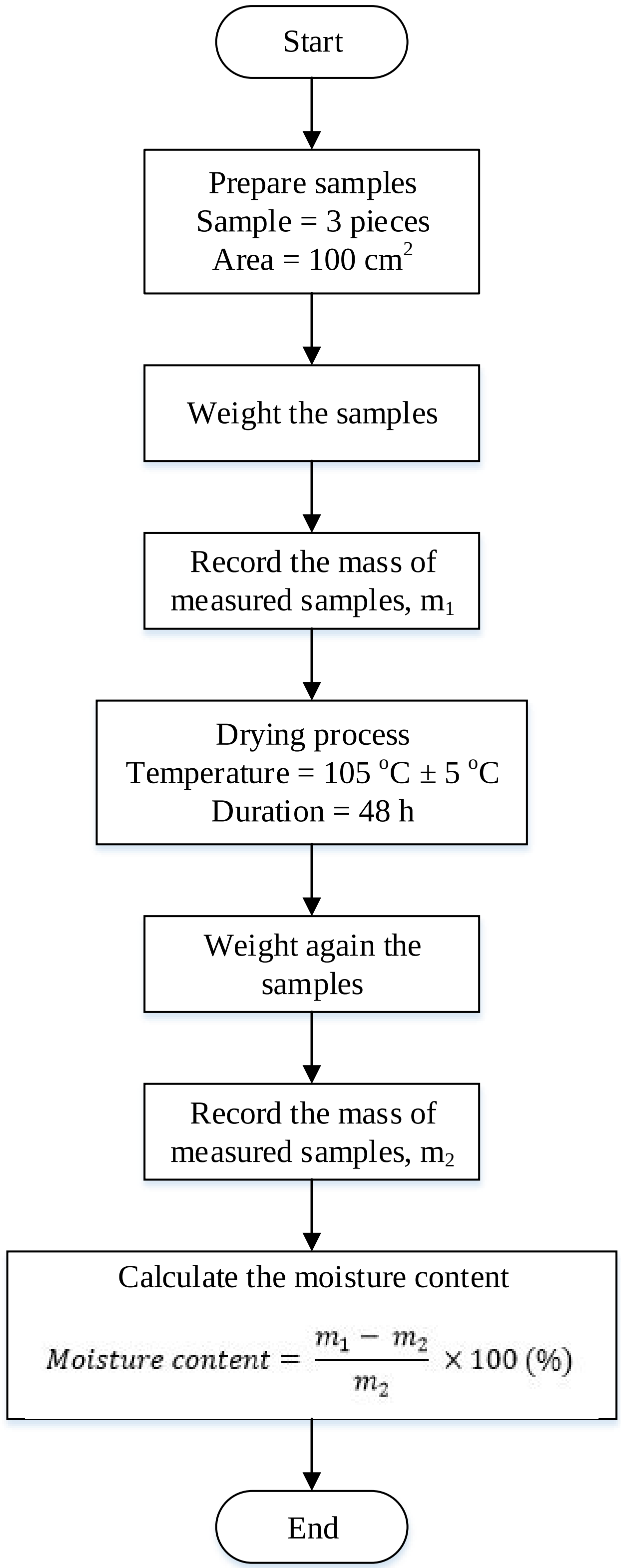


Figure 3.2: Flowchart of moisture content test procedure

This test was proceeded with the extended duration of drying process for sample 3. The extended duration of the drying process were 72 h and 96 h. The purpose is to observe the differences in moisture content value. After obtained the weight of sample 3, sample 3 was immediately placed back into ventilated oven and dried for another 24 h. This has made the total drying process duration for sample 3 is 72 h. Then, the weight of sample 3 was recorded. The same procedure was used for the 96 h of drying process.

3.4 Oil Absorption Test

The purpose of this oil absorption test is to determine the oil absorbency of the sample. This oil absorbency can be obtained by take the weight of oil divide by weight of sample and multiplied by 100%. Weight of oil is the difference in the weight of the sample before and after being exposed to oil. Weight of sample is the weight of sample before it is exposed to oil. The formula of oil absorption is stated in equation (3.3).

$$Oil\ Absorbency = \frac{Weight\ of\ oil}{Weight\ of\ sample} \times 100\% \quad (3.3)$$

3.4.1 Experimental Procedure

Figure 3.3 shows the flowchart of oil absorption test procedure [11]. This test begins with the preparation of three samples. The sample was cut into three rectangular test pieces with an area not less than 100 cm^2. Then, the samples were placed in a vacuum oven for 24 h. Pressure and temperature of the vacuum oven was set at 1.4 kPa and 105 $^oC \pm 5\ ^oC$, respectively. After 24 h, the samples were weighed to determine its mass, m_1. Next, the samples and mineral oil were placed in the vacuum oven. The temperature was increased to 90 ^{o}C and the pressure remained at 1.4 kPa. The temperature and pressure were maintained for at least 2 h.

Then, the samples were submerged completely in the oil. The samples were left in the oil for 6 h. After 6 h, the samples were taken out of the oil and the surplus of oil was removed by using blotting paper. Lastly, the clean samples were weighed and the new mass, m_2 were recorded. The oil absorption in percentage (%) of the mass of the samples before impregnation was calculated by using equation (3.4).

$$Oil\ absorption = \frac{m_2 - m_1}{m_1} \times 100\ (\%) \qquad (3.4)$$

The result was recorded from the average of three samples.

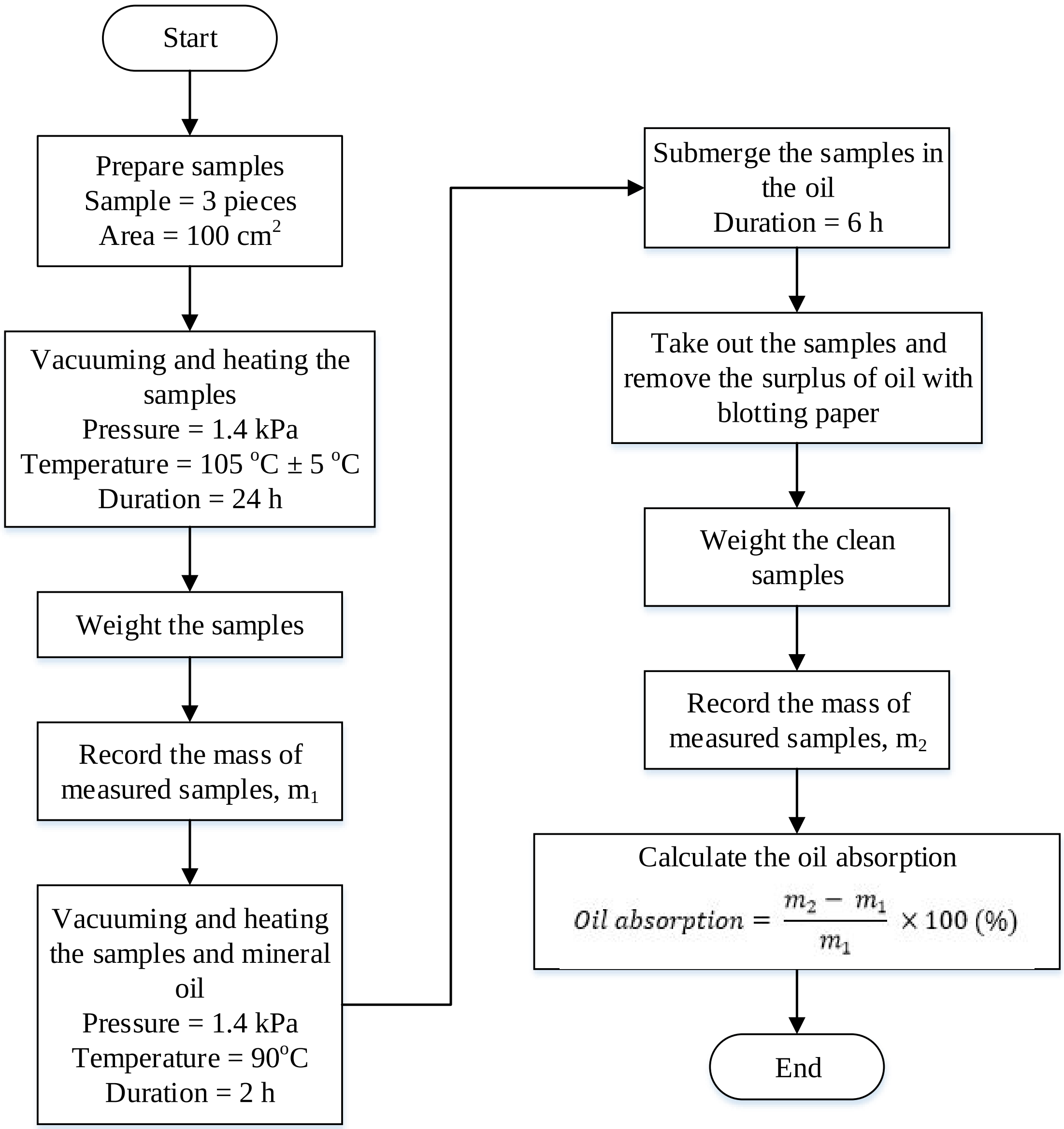


Figure 3.3: Flowchart of oil absorption test procedure

3.5 Electric Strength Test in Air

The purpose of this electric strength test is to determine the breakdown voltage of the sample. The breakdown voltage can be obtained by place the sample between two electrodes and increase the voltage until failure occurs. Type of electrodes used in this test were plane electrodes. The diameter of the two electrodes are 25 mm [12].

The mode of increase of voltage in this test was 20 s step-by-step test [13]. This method started by applied the start voltage of 10 kV. Then, this voltage remained unchanged for 20 s. If the test piece withstands this voltage for 20 s without failure, the voltage shall be increased in incremental of 1 kV. Each increased voltage shall be immediately and successively applied for 20 s until failure occurs.

3.5.1 Experimental Procedure

Figure 3.4 shows the flowchart of electric strength in air test procedure [14]. This test begins with the preparation of three samples. The sample was cut into three test pieces with an area of 49 cm^2. Then, the samples were dried in a ventilated oven at 105 $^{o}C \pm 5$ ^{o}C. Considering that, the thickness of the samples are 2 mm, the period for the drying process was 48 h. After completed the drying process, the electric strength test in air was conducted. The electric strength test in air was done by place the samples between two electrodes and increased the voltage until failure occurs. The result was recorded from the average of three samples. The electric strength test setup was referred to Figure 3.5.

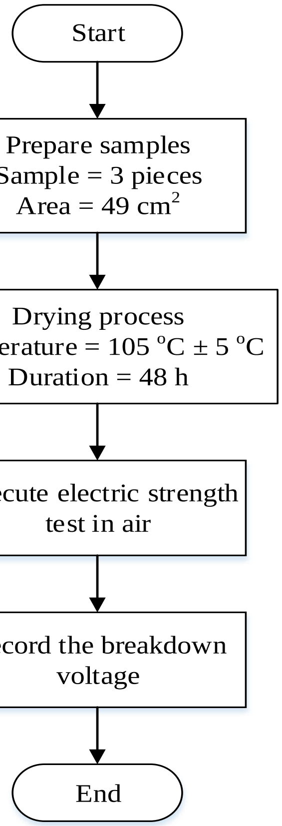


Figure 3.4: Flowchart of electric strength in air test procedure

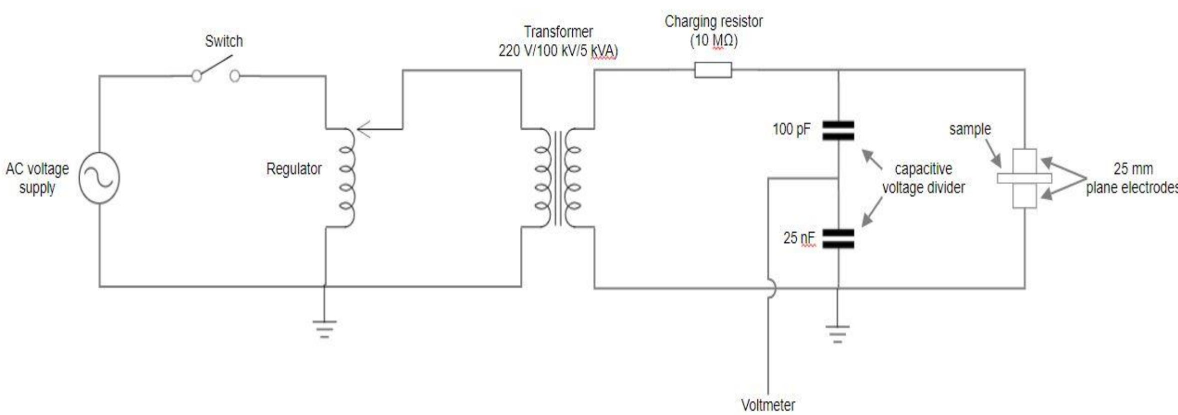


Figure 3.5: Test setup for electric strength in air test

This test was proceeded with the test of electric strength in air of KBKP without drying process. The purpose is to observe the differences in electric strength value. A new sample with same area was prepared to undergo this test. After the sample preparation, the electric strength in air test was directly executed without dry the sample. Similar test setup, type of electrodes and method of increase of voltage were used.

3.6 Conclusion

Throughout this chapter, the overall procedure was fully explained starting with the sample preparation until the result measurement of all tests. The equipment and test setup also was explained in this chapter. Thus, accurate result can be made with the help of the test procedures.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the investigation of dielectric properties (moisture content, oil absorption rate and electric strength in air) of KBKP was discussed. This chapter consists of two sections. The first section commences with the KBKP's dielectric properties (moisture content, oil absorption rate and electric strength air). Then, the results are summarized in second section of this chapter and a better understanding on the dielectric properties of KBKP can be achieved.

4.2 Dielectric Properties

4.2.1 Moisture Content

The result of moisture content of KBKP was analyzed. The content of water inside the KBKP after the drying process are tabulated in Table 4.1. Three samples were used and the result was recorded from the average of three samples. The value of moisture content were calculated by using the equation (3.2). The result shows that the average value of KBKP moisture content after 48 h drying process was 3.15 %. The moisture content value and average moisture content value are shown in Figure 4.1. The picture of KBKP weighing process before and after drying process are shown in Figure 4.2 and Figure 4.3 respectively.

Table 4.1: Moisture content value of KBKP after 24 h drying process

Samples	1	2	3
KBKP weight before dry (g)	19.75	20.62	21.55
KBKP weight after dry (g)	19.15	19.98	20.90

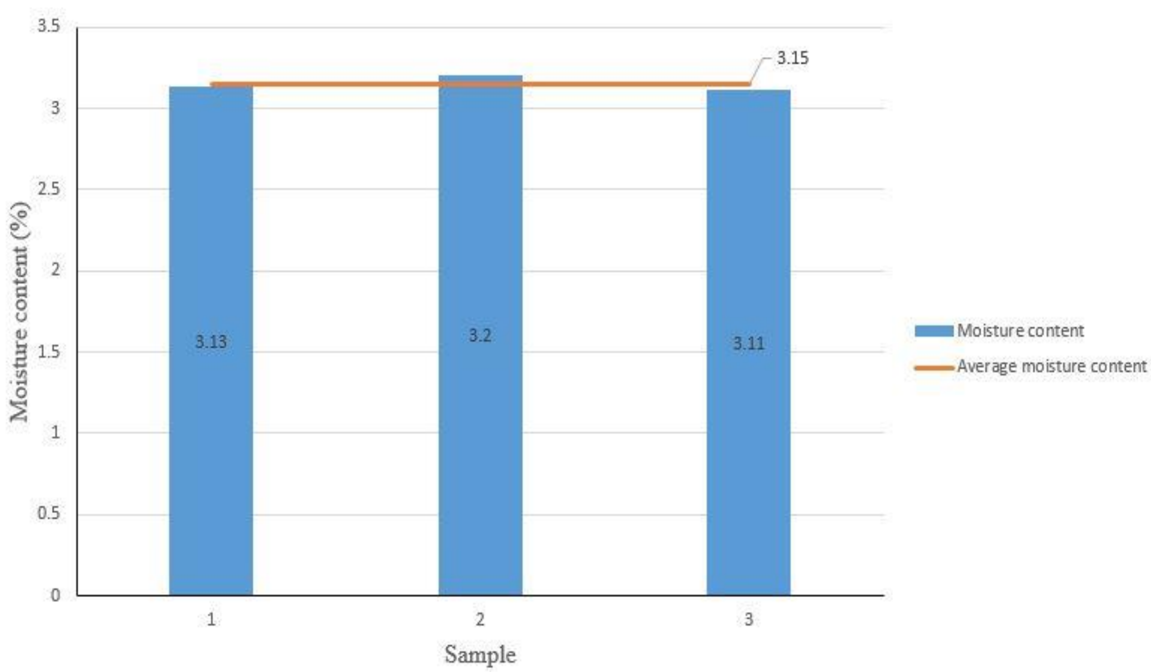


Figure 4.1: Graph of moisture content

(a) (b) (c)

Figure 4.2: Picture of KBKP weighing process before drying process for: (a) sample 1, (b) sample 2, and (c) sample 3.

(a) (b) (c)

Figure 4.3: Picture of KBKP weighing process after drying process for: (a) sample 1, (b) sample 2, and (c) sample 3.

From the results obtained, standard deviation was calculated using the equation (4.1) [15].

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{4.1}$$

Where:

σ = standard deviation

N = number of samples

x = sample values

μ = mean

The standard deviation obtained was 0.0387. This low standard deviation means that the moisture content values tend to be closed to the mean (also called the expected value). The percent error also was calculated using the equation (4.2) [16]. The percent error obtained were tabulated in Table 4.2.

$$Percent\ error = \frac{|\ experimental\ value - expected\ value\ |}{expected\ value} \times 100\% \qquad (4.2)$$

Table 4.2: Percent error of moisture content

Samples	Percent error (%)	Average (%)
1	0.63	
2	1.59	1.16
3	1.27	

The drying process are extended to 72 h and 96 h to observe the differences in moisture content value. This extended drying process was applied to sample 3. After weighing the sample for 48 h drying process, sample 3 was immediately placed back into the ventilated oven and continued the drying process for 24 h. This has made the total drying process duration for sample 3 is 72 h. Then, the weight of sample 3 was recorded. Same process applied to the 96 h drying process, after weighing the sample 3 for 72 h drying process, the sample was immediately placed back into the ventilated oven and continued the drying process for another 24 h. The results of the extended drying process was tabulated in Table 4.3. Graph of KBKP weight against the duration of drying process is shown in Figure 4.4. The moisture content value for 72 h and 96 h drying process was 3.16 %.

Table 4.3: Moisture content value of KBKP after 72 h and 96 h drying process

KBKP weight after 72 h dry (g)	20.89
KBKP weight after 96 h dry (g)	20.89
Moisture content for 72 and 96 h (%)	3.16

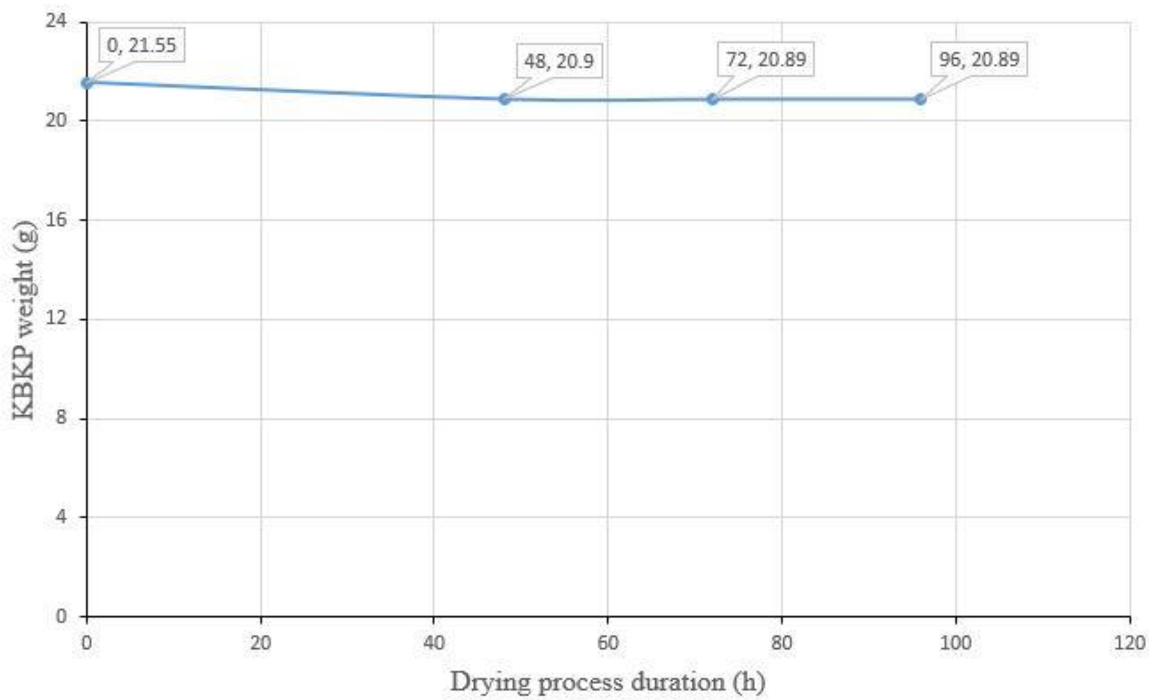


Figure 4.4: Graph of KBKP weight against duration of drying process.

From the result, when the duration of drying process increase, the weight of KBKP is decreased. The weight of KBKP after drying process for 48 h and 72 h were decreased from 21.55 g to 20.9 g and 20.89 g respectively. While, the drying process from 72 h to 96 h, the weight of KBKP remained 20.89 g. The moisture content obtained for 72 h and 96 h of drying process was 3.16 %.

4.2.2 Oil Absorption

The result of oil absorption rate of KBKP was analyzed. The rate of oil absorbed into the KBKP are tabulated in Table 4.4. The value of oil absorbency are calculated by using the equation (3.3). The result shows that the average value of KBKP oil absorption rate was 1.88 %. The graph of oil absorption rate and average oil absorption rate are shown in Figure 4.5. The picture of KBKP weighing process and KBKP with oil weighing process are shown in Figure 4.6 and Figure 4.7 respectively.

Table 4.4: Oil absorption rate value of KBKP

Number of test pieces	1	2	3
KBKP weight (g)	20.36	21.35	21.40
KBKP + oil weight (g)	20.64	21.65	22.01

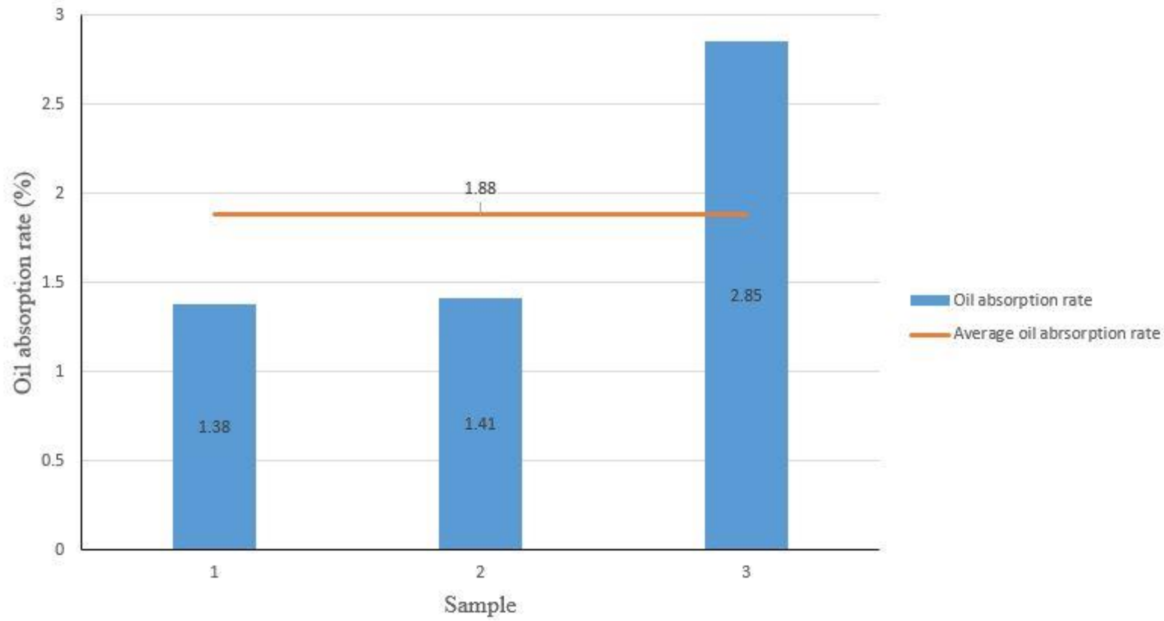
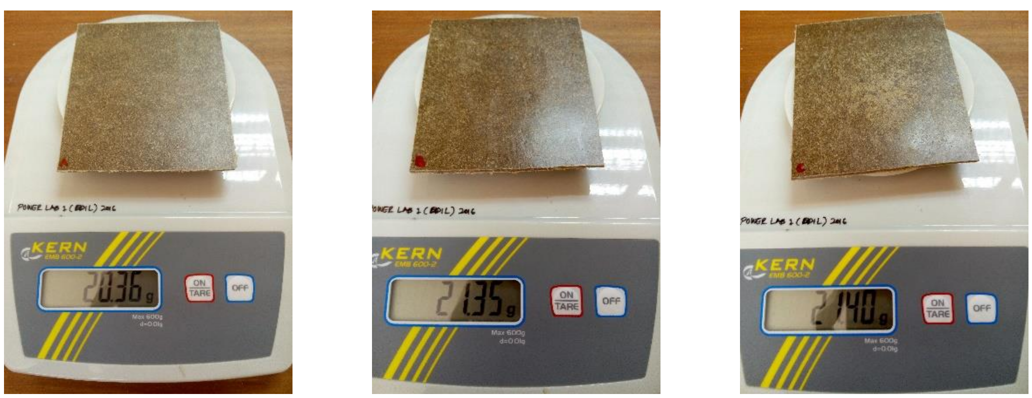


Figure 4.5: Graph of oil absorption rate



(a) (b) (c)

Figure 4.6: Picture of KBKP weighing process for: (a) sample 1, (b) sample 2, and (c) sample 3.