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# Determination of Dielectric Constants through Capacitor Measurement Using Variations in Thickness, Area, Materials, and Density

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## ABSTRACT

In this study, the researchers focused on testing experimental media from Yeti Rusmiati to measure the dielectric constant of capacitors, with variations in thickness, surface area, material, and density. The experimental results show that the thicker the dielectric material, the smaller the capacitance value. This applies to all materials tested, namely mica, silicon, and duplex paper, with errors from largest to smallest being 24.97% duplex, 7.27% mica, and 0% silicon. Measuring the capacitance of parallel plate capacitors with variations in plate area from GRC gypsum, silicon rubber, and mica, it was found that the error from largest to smallest is mica 11.56%. In comparison, silicon rubber and GRC gypsum have an error of 0%. Measurement of capacitance by varying the dielectric material shows that the capacitance value of the capacitor is proportional to the dielectric constant of the material. Among all the 12 materials tested, the highest dielectric constant is banana leaves with a value of $\boldsymbol{\kappa}$ = 12.6 and the smallest flannel with a value of $\boldsymbol{\kappa}$ = 1.02. In contrast, the variation in density shows that the greater the density, the greater the dielectric constant, from the largest to the smallest, the variation in density of leaves steamed with fire, fresh leaves 1 x 24 hours, and dry leaves heated with the sun, respectively 67.51;22.96; 16.57. It can be concluded that Yeti Rusmiati's media can be used in measuring dielectric constant with variations in thickness, area, density, and dielectric material in learning capacitors.



## INTRODUCTION

Electricity and magnetism include materials that are difficult for students to understand. This is supported by a decrease in the results of the National Examination, one of which is in the form of static electricity competency (Jh, 2018). Static electricity is a subject matter taught in phase F of Kurikulum Merdeka. The scope of topics discussed in this material includes Capacitors (Kemendikbudristek, 2022). The learning outcome in phase F requires students to do an experiment with one of the procedural skills to conduct capacitor experiments, including variable measurements related to capacitors, such as the dielectric constant of capacitors.

A learning media is needed so that students are able to easily carry out capacitance measurement experiments. This is in line with Ni Luh Putu Ekayani, 2017 which states that learning media helps students absorb and understand learning topics (Ekayani, 2017). So, it is hoped that students will not encounter difficulties in learning static electricity, especially when the capacitor experiment is carried out.

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One of the media that has been developed is learning media, which Yeti Rusmiati, 2013, has tested. This media can measure the dielectric constant of acrylic at 3.04 using parallel plates (Rusmiati, 2013).

In this study, the capacitor used is a parallel plate capacitor. Capacitors are devices used to store dielectricity-based energy (Meiliyadi et al., 2022). Two capacitor plates, which are conductor materials made of 0.5 mm thick aluminum, are inserted by dielectric materials in the form of duplex paper, nylon PE, pertinax ebonite, mica, silicone rubber, GRC board, Polyvinyl chloride (PVC), dry paper, acrylic resin, EVA foam, flannel, and banana leaves. This study aimed to measure the dielectric constant ($\boldsymbol{\kappa}$) of capacitors with variations in the thickness of the dielectric material (distance between plates), variations in the area of the opposite plates, and variations in dielectric materials, materials variations, and variations in density. Determination of the value of the dielectric constant is done by measuring the capacitance of the capacitor using the following formula (Halliday et al., 2013):

$$C = \kappa \frac{\varepsilon_0 A}{d} \qquad \dots(1)$$

Where $\kappa$ is the dielectric constant, when a dielectric is introduced between the plates, the charge q on the plates increases by a factor $\kappa$. The capacitance created by the presence of a material is directly related to the material's dielectric constant, which is affected by the respective dielectric material (Clipper Control Inc., 2022). Some of the dielectric constants of materials include: 1) duplex paper (aspen wood) 9.4 (Torgovnikov & Torgovnikov, 1993) 2) Nylon PE (*Polyethylene)* 2.2 - 2.4. 3) Pertinax Ebonite 4.7 - 10.9. 4) *mica* 2.6 - 3.2. 5) silicone rubber 3.2-9.8. 6) Gypsum GRC (*cement powder*) 5.0 - 10. 7) *Polyvinyl chloride* (PVC) 3.4. 8) acrylic resin 2.7 - 4.5 (Clipper Control Inc., 2022). 9) EVA *rubber (Ethylene, vinyl, acetate)* 1.43 (Gunasekaran et al., 2008). 10) Flannel 1.3 (Sihono S. and Siti Nurul Khotimah., 2016). 11) Dry paper 3.5 (Halliday et al., 2013).

Then, by analyzing the graph of the relationship between capacitance and plate thickness as well as the graph of the relationship between capacitance and plate area, the value of the dielectric constant of the material is obtained. From the equation, by varying the thickness of the dielectric (d), the dielectric constant can be determined from the *slope of* the graph of the relationship between C and 1/d. Therefore, the following equation is obtained:

$$y\ (slope) = \kappa \frac{\varepsilon_0}{d} \qquad \dots(2)$$

The existence of errors obtained in practicum data can be compared to references and theories using errors. An error in a calculation is defined as the approximation of the value obtained (approximation value) to the theoretical value (actual value) (Soedijono, 2019). If the reference value has a range, then the reference value is taken based on the closest value to the measured value. The error calculation is obtained mathematically as follows (Soedijono, 2019):

$$Rel\ Xa = (Xt - Xa)/\ Xt \qquad \dots(3)$$

Where *Xt* is the measured value, and *Xa* is the reference value. Measurements in this study were carried out using an LCR (inductor, capacitor, resistor) meter in units of nF, which were connected to a series of parallel plate capacitors on the media that Yeti Rusmiati had made. This media can determine the capacitance capacitor and dielectric constant.

In a previous study, this media was tested several times to measure the dielectric constant of acrylic (Nurmasyitah, 2017). In 2016, this media also had been used to measure the dielectric constant of acrylic, styrofoam, flannel, mirror, plywood, and frosted paper, titled Dielectric Constant Determination Experiment of Some Materials Using LCR Meters and Principles Parallel Plate Capacitor worked by Susanti

Sihono and Siti Nurul Khotimah (2016). Vanja Mandric (2018) measured capacitor capacitance and dielectric constant using parallel plates but only using variations of paper material (Mandrić Radivojević et al., 2018). However, the use of conductor plates could affect the capacitance and dielectric constant. Umapati Pattar (2014) mentioned that the dielectric constant of a solid body involves the measurement of the capacitance of a capacitor if its physical dimensions are known, using parallel plate capacitors where the plates are commercially available aluminum panel sheets (APS). The use of APS can seal the material properly and reduce measurement errors due to air gaps (Pattar, 2014).

However, there has been no research in measuring dielectric constant, which not only uses material variations but also variations in thickness, area, and density of dielectric materials. Therefore, the authors would like to conduct an experiment related to measuring capacitance capacitors and dielectric constants in variations of thickness, area, and density. This is intended so that the use of dielectric constant measurement media has variations in measurement so that when applied massively to student learning needs, it can increase knowledge of the variables that affect the dielectric constant of materials.

## METHODS

Before the research was conducted, the tools and materials were designed in such a way that they could be used. Yeti Rusmiati, 2013, made the parallel plate capacitor holder presented in Figure 1. The main material of the holder is wood equipped with four adjustment screws on the right and left sides, which function to make the capacitor plate and dielectric stable, not moving and sticking perfectly.

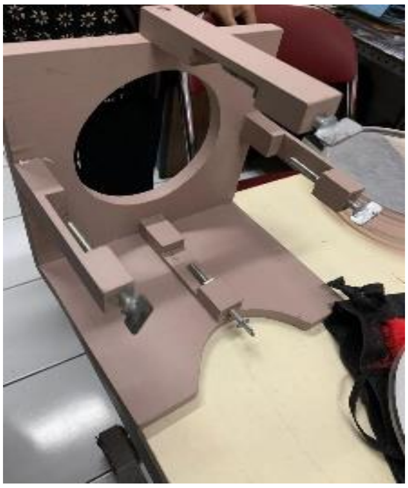


**Figure 1.** Plate Capacitor Holder

Furthermore, the first experiment used thickness as a variation. The material had the same diameter (20 cm) but had a variation in thickness. Materials measured with variations in thickness were mica, silicone rubber, and duplex (aspen wood). The second experiment varied the area of parallel plates (conductors) carried out for three types of materials, namely mica, silicon, and GRC. In the third experiment, dielectric plates were made with the same diameter of 20 cm and the same thickness of 2 mm but had material variations. The variations in these materials include Materials whose capacitance is measured so that the dielectric constant can be determined are duplex paper (aspen wood), Nylon PE (*Polyethylene)*, Pertinax Ebonite, *mica*, silicone rubber, GRC *Gypsum* (*cement powder*), *Polyvinyl chloride* (PVC), acrylic resin, EVA *rubber (ethylene, vinyl, acetate)*, flannel, dry paper, and fresh banana leaves. After that, the banana leaf itself will be varied based on the density value. Banana leaves were given three different conditions, namely dried in the room, steamed over medium heat using fire, and fresh banana leaves with a thickness of 1 mm each with a fixed diameter of 20 cm.

The results of the experiment will be compared to the theory, and an error (error) will be sought to determine the accuracy of the data. In simple terms, the research design can be presented in Figure 2.

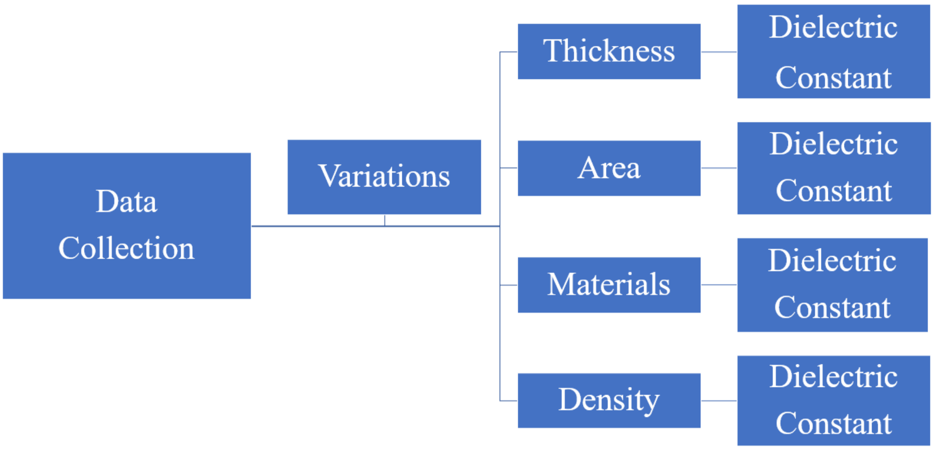



**Figure 2**. Research Design

## RESULTS AND DISCUSSION

### 1. Measurement of the dielectric constant with variations in thickness

Experiments with varying thicknesses were carried out for three types of materials, namely Mica, Silicon, and Duplex. Calculation of the dielectric constant ($\boldsymbol{\kappa}$) is carried out by means of equation (1) and then compared with the value of the reference dielectric constant, and the magnitude of the error is calculated by means of equation (3). Based on the experiments, a graph measuring capacitance against thickness can be made, as shown in Figure 3. The dielectric constant ($\boldsymbol{\kappa}$) can also be determined from the slope of *the* graph in Figure 3 and by using equation (2).

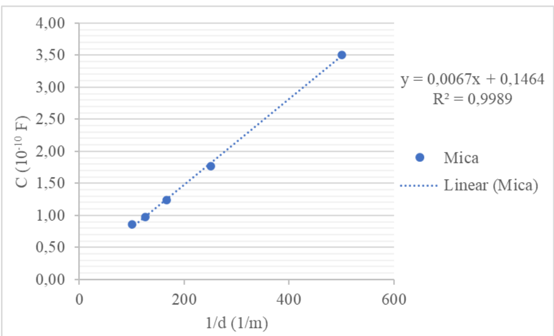



**Figure 3.** Graph of Measured Capacitance against Mica Thickness Variations

The slope obtained based on the graph is $m$ = 0.0067 x $10^{-10}$, so the dielectric constant of Mica material is $\boldsymbol{\kappa}$ = 2.24. The mica dielectric constant value obtained has an error of 7.27% against the reference (2.6-3.2) by taking the nearest reference 2.6. The measurement could be categorized as valid if the accuracy is more than 75% (Supriyadi, 2016). Based on the 7.27% error value, therefore the measurement could be confirmed its validity.

Data and processing of capacitance measurement results for silicon materials with variations in thickness are visualized via the graph in Figure 4(a). The dielectric constant ($\boldsymbol{\kappa}$) can also be determined from the slope of the graph; for silicon materials, the slope of the graph is m = 0.0107 *x*, $10^{-10}$so through equation (2), the dielectric constant value of Silicon material is $\boldsymbol{\kappa}$ = 3.85. The silicon dielectric constant value obtained is included in the dielectric constant reference range of 3.2 - 9.8 so that the error is zero.

Data and data processing of capacitance measurement results for Duplex materials with thickness variations can be visualized in Figure 4(b). For the Duplex materials, the slope of the graph is m = 0.01196 x, *so* that $10^{-10}$ through equation (2), the dielectric constant value of duplex material is obtained by $\boldsymbol{\kappa}$ = 7.05. The duplex dielectric constant value obtained has an error of 24.97% against a reference of 9.4. Due to the error of less than 25% (Supriyadi, 2016), the measurement of the duplex dielectric value could therefore confirm its validity.

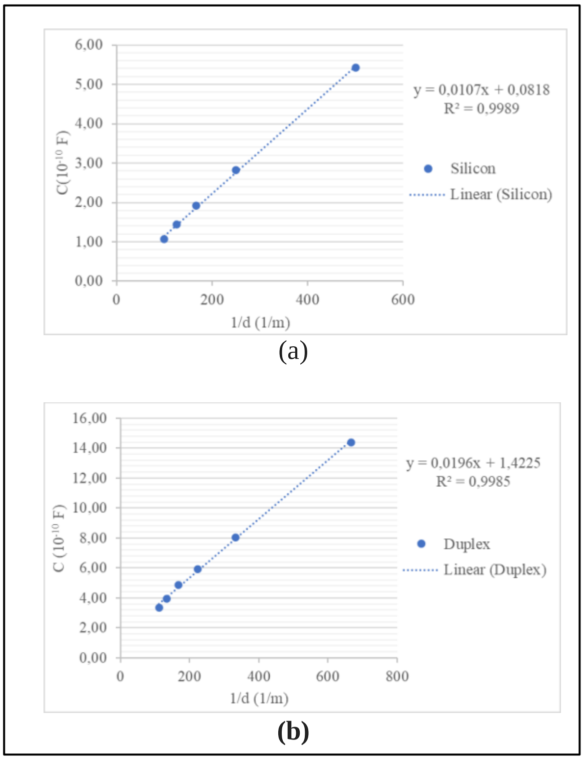



**Figure 4.** Graph of Measured Capacitance against Some Variations: (a) Silicon Thickness Variations, (b) Duplex Thickness Variations

Based on the data, it can be concluded that there is a tendency for capacitance to decrease as the thickness of the dielectric material increases. This is caused by the electric field, which will decrease linearly with the distance between the plates as the dielectric layer thickens due to the constant voltage (Halliday et al., 2013). In simple terms, as long as the voltage difference is constant, the same amount of work is required to transfer the test charge from one plate to the other, which is directly proportional to the distance. So, as the distance increases, the force decreases proportionally. Where the force per unit charge is, by definition, the electric field, and the smaller the value of the electric field, it will directly reduce the capacitance value of the capacitor. In other words, if the distance (d) is enlarged, the charge on each plate gives less pulling force on the other plates, so less charge is pulled, and the capacitance is smaller (Pertiwi, 2016).

Based on the research results, when the thickness was varied with a constant range, namely the addition of 0.002 m for mica and silicon materials and 0.0015 for duplex materials, it was observed that the decrease in the measured capacitance value was not constant, so the dielectric constant value for each variation was different with a certain error. This can be caused by the always-changing capacitance values measured by the LCR meter, so researchers take the largest value that often appears in these measurements. Various limitations of the tools used, the ability to measure officers, and the conditions of terrain will result in results of varying sizes (STPN, 2020).

## 2. Measurement of the dielectric constant with variations in the area of the conductor

Experiments by varying the area of parallel plates (conductors) were carried out for three types of materials, namely Mica, Silicon, and GRC. Data and data processing of capacitance measurement results for Mica materials with variations in the conductor area can be visualized in Figure 5. The dielectric constant ($\boldsymbol{\kappa}$) can also be determined from the slope of the graph in the figure and by using equation (2).

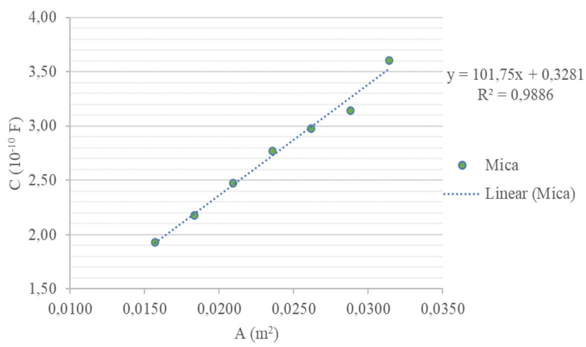



**Figure 5.** Graph of Measured Capacitance against Mica Area Variations

The slope obtained based on the graph is $m$ = 101.75 x $10^{-10}$, so the dielectric constant of Mica material is $\boldsymbol{\kappa}$ = 2.30. The mica dielectric constant value obtained has an error of 11.56% against the reference (2.6-3.2) by taking the closest value of 2.6. Due to the error value being less than 25%, the measurement could therefore be considered valid (Supriyadi, 2016).

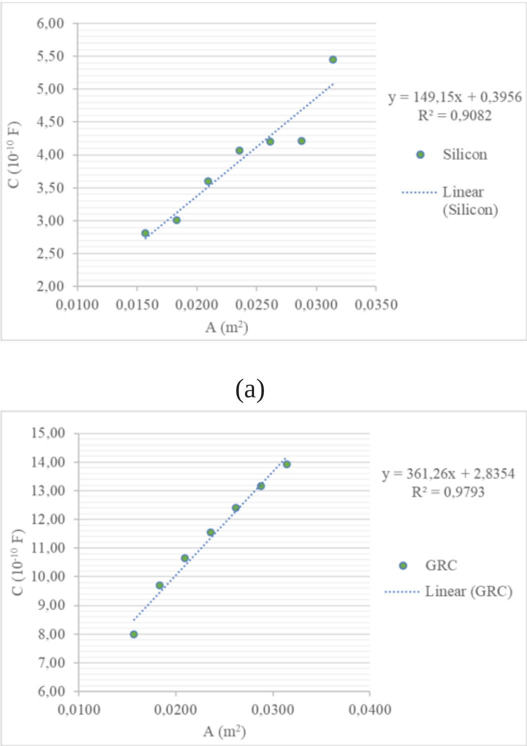



**Figure 6.** Graph of Measured Capacitance against (a) Wide Variation Silicon, (b) Area Variations of GRC

Data and data processing of capacitance measurement results for silicon materials with variations in the conductor area are visualized in Figure 6(a). The dielectric constant ($\kappa$) can also be determined from the slope of the *graph*; for silicon materials, the slope of the graph is *m* = 149.15 x 10-10, so through equation (9), the dielectric constant value of Silicon material is $\kappa$ = 3.37. The silicon dielectric constant value obtained is included in the dielectric constant reference range of 3.2-9.8 so that the error is zero.

Data and processing of capacitance measurement results for cement powder GRC materials with variations in the conductor area are attached in Figure 6(b). The dielectric constant ($\kappa$) can also be determined from the slope of the graph; for GRC materials, the slope of the graph is m = 361.26 $x$, $10^{-10}$, so through equation (2), the value of the dielectric constant of the GRC material is $\kappa$ = 8.61. The GRC dielectric constant value obtained is included in the dielectric constant reference range of 5 - 10 so that the error is zero.

Based on the findings, there was a tendency for the capacitance value to be greater the wider the area of the capacitor plate. This is due to the fact that the width of the capacitor plates affects the electric field flux through the surface and the amount of charge stored in the plates, as well as the function of the capacitor as a charge store (Serway & Jewett, 2018).

Based on the research results, when the conductor area is varied with a constant range, namely a decrease of 1/12 of the overall area, it is observed that the decrease in the measured capacitance value is not constant, especially for GRC materials, so the dielectric constant value for each variation is different with a certain error and even tends to increase for GRC materials. This can be caused by the constantly changing capacitance values measured by the LCR meter, so researchers take the largest value that often appears in these measurements. Also, the thickness of each material is not uniform.

Inconstant values of capacitance can also come from the lead or the meter used because when considering the effects due to resistance in the wires and current through the dielectric material, each of these effects is too small to cause any measurable difference given the materials.

To get a constant capacitance measurement value, it can be done using a different capacitance meter that has better accuracy. Another solution that can be done to ensure that the capacitance measurement results are not constant is not based on the condition of the multimeter that has been examined by five brands of meters and compared with commercial capacitance bridge measurements. Four of the five multimeters use the AC method of measuring capacitance. This AC method applies the same frequency across the capacitor, regardless of capacitance. The fifth multimeter uses the RC timing technique to measure capacitance. The only difference in capacitance readings between the different multimeters is that meters using the RC timing technique give a large zero capacitance offset with no load capacitance (10 nF). If this "zero" capacitance is reduced, the readings of this multimeter are nearly identical to those of any other as well as to a commercial capacitance bridge (Grove et al., 2005).

### 3. Measurement of the dielectric constant with a variety of dielectric materials

The all-dielectric plate thickness is 2 mm. After conducting experiments to obtain the capacitance value of the capacitor after the dielectric is inserted, the author then calculates the dielectric constant based on the measured capacitance value of the capacitor. The dielectric constant value obtained is then compared with the reference value and is summarized in Table 1.

**Table 1.** Dielectric Constants of Various Materials

| No | Material | d(m) | D(m) | C (pF) | Dielectric constant $\kappa$ | | Error (%) |
|---|---|---|---|---|---|---|---|
| | | | | | Experiment | Reference | |
| 1 | Duplex (Aspen) | 0.002 | 0.200 | 1283 | 9,23 | 9,4 | 2 |
| 2 | Nylon PE ( *Polyethylene* ) | 0.002 | 0.200 | 280.04 | 2.02 | 2,2-2,4 | 8 |
| 3 | Pertinax ebonite | 0.002 | 0.200 | 1302 | 9.37 | 4.7 - 10.9 | 0 |
| 4 | Mica | 0.002 | 0.200 | 350,21 | 2.52 | 2.6 - 3.2 | 3 |
| 5 | Silicone rubber | 0.002 | 0.200 | 500 | 3.60 | 3.2 - 9.8 | 0 |
| 6 | Gypsum GRC ( *cement powder* ) | 0.002 | 0.200 | 1352,4 | 9,73 | 5.0-10.0 | 0 |
| 7 | *Polyvinyl chloride* resin (PVC) | 0.002 | 0.200 | 531,29 | 3.82 | 3,4 | 12 |
| 8 | HVS dry paper | 0.002 | 0.200 | 678 | 4.88 | 3,5 | 39 |
| 9 | Fresh banana leaves | 0.002 | 0.200 | 1755,2 | 12,6 | - | - |
| 10 | Acrylic resins | 0.002 | 0.200 | 401 | 2.89 | 2,9 | 0 |
| 11 | EVA ( *Ethylene, vinyl, acetate* ) *rubber* | 0.002 | 0.200 | 200 | 1.44 | 1.43 | 1 |
| 12 | Flannel | 0.002 | 0.200 | 142 | 1.02 | 1,3 | 21 |

The result of the measurement can be seen in Figure 7 (a) and (b). Based on Figure 7, it can be seen that the greater the dielectric constant, the greater the capacitance value measured during the experiment, where the capacitance value of the capacitor is directly proportional to the dielectric constant.

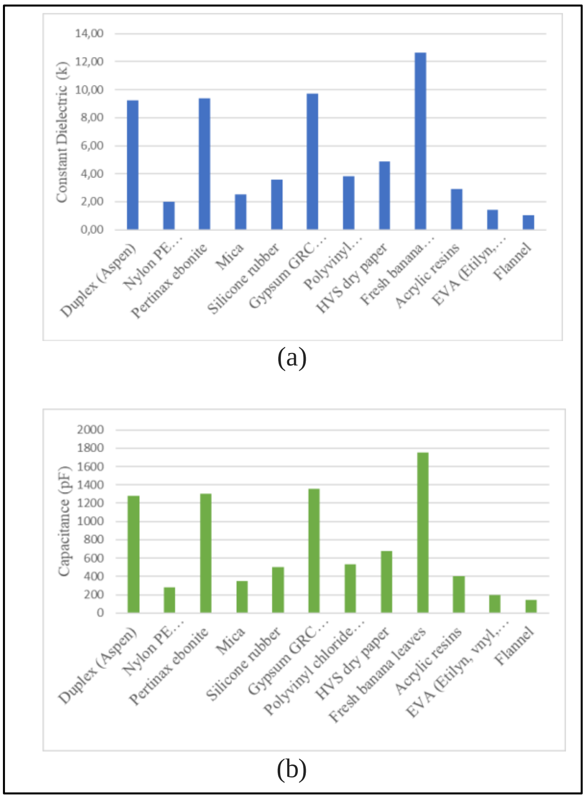



**Figure 7.** Graph of Dielectric Constants and Capacitance of Various Material: (a) Dielectric Constants of Various Materials and (b) Capacitance of Various Materials

This is theoretically in accordance with equation (1). The dielectric constant is influenced by the constituent materials of a material, which in this study comes from a solid dielectric. Solid dielectrics have a greater advantage over other materials because they can self-repair if a discharge occurs (Nurmasyitah, 2017). Dielectric constant ($\kappa$) is a number that relates the ability of a material to flow alternating current in a vacuum to flow alternating current (Clipper Control Inc., 2022). In other words, this constant represents the tightness of the electrostatic flux in a material when given an electric potential (Lide, 2004). So, the greater the constant value, the greater the capacitance value. Where mathematically, the dielectric constant is the ratio of the electrical energy stored in the material if it is given a potential ($\varepsilon_s$) relative to a vacuum (vacuum) ($\varepsilon_0$) (Lide, 2004).

Based on the variation of materials, materials that have capacitance values and dielectric constants from smallest to largest from the study are Flannel, EVA (Etlin, vinyl, acetate) rubber, Nylon PE (Polyethylene), Mica, Acrylic resin, Silicone rubber, Polyvinyl chloride resin (PVC), HVS dry paper, Duplex (Aspen wood), Pertinax ebonite, Gypsum GRC (cement *powder)*, fresh banana leaves. Factors that affect this dielectric constant are the nature of the constituent atoms and molecules, temperature, type of applied voltage, and so on (Nurmasyitah, 2017). Therefore, fresh banana leaves have a large dielectric constant compared to other materials due to the moisture and water stored in the banana leaves. Water has a relatively large dielectric constant because water molecules have a permanent dipole moment due to the presence of OH bonds (de Sousa et al., 2017). Meanwhile, flannel has the smallest dielectric constant because the flannel itself is made of yarn fibers. Flannel has a relatively small dielectric constant due to the degree of tension of the woven yarn, density, and mass of the woven surface (Mustata & Mustata, 2014). Flannel thread material is easy to separate and tends to be brittle so that the bonds between atoms are weak and only able to store a small charge and a small dielectric constant (Summerour et al., 2013).

In summary, the difference in dielectric value is affected by the permittivity of the material. When a dielectric material is inserted between the two capacitor plates, the polarization of the dielectric material will contribute to electric dipoles due to the polarization mechanism and the amount of charge stored in the capacitor, which increases the amount of electric charge stored in the capacitor. In other words, the greater the value of the dielectric constant, the greater the dielectric properties, in the sense of describing the ability of a material to store, transmit, and reflect electromagnetic wave energy (Jumingin & Setiawati, 2016). Materials that have a large dielectric constant have polar bonds, so they are permanently polarized. Meanwhile, materials with a small dielectric constant tend to be non-polar bonds because non-polar dielectric materials do not have a dipole electric moment (Halliday et al., 2013).

### 4. The Measurement of the Dielectric Constant with Variations in Density

The control variables in the fourth experiment were the thickness of 1 mm and the cross-sectional area of a banana leaf of 20 cm. The independent variable is the variation in the density of banana leaves, which are differentiated based on three conditions. The first condition is banana leaves, which are dried in an *indoor environment* for one month and seven days. This is done to avoid excessive shrinkage of the water content in banana leaves so that the banana leaves have an asymmetrical shape when heated in the sun. By drying banana leaves in an *indoor environment*, the symmetrical shape of the dried banana leaf circles can be maintained so that they have a diameter of 20 cm. The second condition is fresh banana leaves without any action. This fresh condition has the criteria that the banana leaf has not been more than 1 x 24 hours when it is picked from the tree. The third condition is that the banana leaves are evaporated over medium heat so that they wither. Using experimental procedures that have been determined in the research design, data on the capacitance values of banana leaf capacitors with variations in density are obtained as follows:

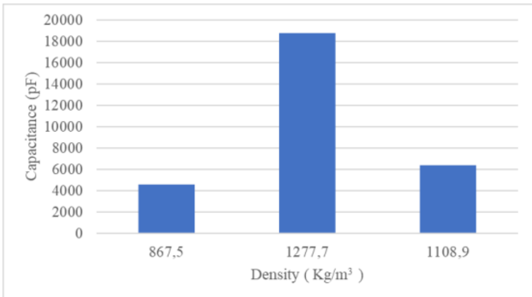
**Table 2.** The Dielectric Constant of Banana Leaf Density Variation

| Mass Type (Kg/m$^3$) | Material | d (m) | D (m) | D$^2$ (m$^2$) | A (m$^2$) | C (pF) | $\kappa$ |
|---|---|---|---|---|---|---|---|
| 867.5 | Dried banana leaves (1 month seven days) | 0.001 | 0.2 | 0.04 | 0.0314 | 4606 | 16.57 |
| 1277.7 | Evaporated by fire | 0.001 | 0.2 | 0.04 | 0.0314 | 18760 | 67.51 |
| 1108.9 | Fresh leaves > 1x24 hours | 0.001 | 0.2 | 0.04 | 0.0314 | 6380 | 22.96 |

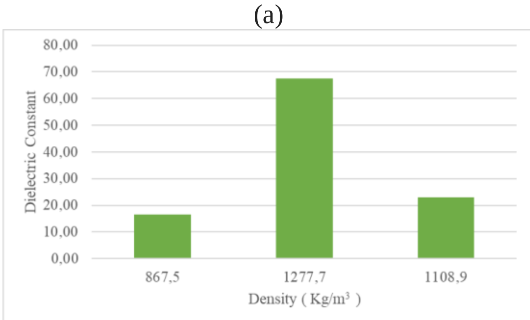
Description of Table 2:
d = thickness (m)
D = diameter (m)
A = Area ($m^2$)
C = Capacitance (pF)
$\kappa$ = Dielectric constant

Based on Table 2, the following graph can be made, which states the effect of the density of the material on capacitance and dielectric constants. Leaves with a large density also have a greater mass because of the large water content. The water content from the largest to the smallest is owned by leaves that are evaporated using fire, fresh leaves, and dry leaves. Leaves steamed with fire have the highest density; this is because the cellulose content in banana leaves is 20.5 - 23.5, and lignin is 4.5 - 10.4 (Wina, 2001). The presence of cellulose and lignin causes high carbon bonds when heated because cellulose and lignin are mostly composed of carbon (Lestari & Priambodo, 2020). Through the process of burning with fire, this carbon composition affects the production of water through the equation CxHy + O2 -> CO2 + H2O + heat. In banana leaves, CxHy is methane $CH_4$ gas, which will produce carbon dioxide, water, and heat when it reacts with oxygen and is heated with fire (Retno Sari, 2014). This causes the water content through the combustion process in banana leaves to be more than the fresh banana leaves themselves, namely the water produced during the combustion process using fire, and results in a large mass of water content, which affects the density of the leaves. Meanwhile, the process of drying the leaves using sunlight will cause the evaporation process on the leaves so that the water content in the leaves will decrease and reduce the density of banana leaves.

Based on the graph of Figure 8, it can be seen that the greater the density value, the more the capacitance value and dielectric constant are also higher. From the largest to the smallest variation in the density of leaves steamed with fire, fresh leaves 1 x 24 hours and dry leaves heated with the sun, respectively, have a dielectric constant of 67.51, 22.96, and 16.57. This is because the dielectric properties are proportional to the mass of water in the sample, which is directly proportional to the density of the sample. The high water content indicates a high relative permittivity of water, which results in a high ability of a material to store energy from the electric field of electromagnetic waves (Sacilik et al., 2006). In addition, the water contained in banana leaves has a polarizing nature. Banana leaves with a large density have a large humidity. The free polarization of water ions on the leaf causes a decrease in the internal electric field and increases the dielectric constant of the dielectric. As the moisture content of the leaves decreases, ion freedom decreases and consequently inhibits polarization and reduces the dielectric constant (Afzal et al., 2010).




(a)




(b)

**Figure 8.** Graph of The Effect of Density: (a) on Capacitance, and (b) on Dielectric Constance

This study has several limitations. Firstly, the results of this study are only limited to measurements for 12 materials, as shown in Table 1, where there is one material whose reference for the dielectric constant is unknown. Secondly, the measurement of these materials uses the same LCR meter measuring instrument. Thirdly, measurements on banana leaf material were only carried out at three different material density conditions.

The research can contribute to determining the dielectric constant of a material in which the dielectric constant is unknown and its relation to area, thickness, and density variables. The tools and methods used in this study can easily be re-tested on several materials and can contribute as good learning media for students at the high school level in learning capacitors.

## CONCLUSION AND SUGGESTION

Based on this research, it can be concluded that by using an LCR meter and a parallel plate capacitor device, the dielectric constant of various types of materials can be determined either by varying the thickness of the dielectric material, the area of the conducting plate, or the density so that the media created by Yeti Rusmiati can be used on a large scale by high school (SMA) students in class XII static electricity discussion.

Regarding the results of previous research and our research using materials that already have references, this dielectric constant measurement learning media can determine the dielectric constant precisely to the reference. Therefore, it is suggested to use other materials that students can easily find, such as various types of leaves with variations in density. Furthermore, this research could be developed to observe the effect of dielectric constant measurement media using problem-based learning, contextual learning, or any learning strategies.

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## AUTHOR CONTRIBUTIONS

SN, JK, and JJ constructed, reviewed, and edited the literature. They also took and processed the data as a group. SK gave the project idea, supervised the experiment, and reviewed the literature and data as the research supervisor. All authors read, approve, and edit the final manuscript.

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