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MODELLING CORONA DISCHARGE THRESHOLD IN COMPOSITE DIELECTRIC PROPERTIES OF EGGSHELL COMPOSITES INSULATORS: A VOLTAGE-BASED STUDY

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ABSTRACT

Corona and flashover threshold voltages are affected by the characteristics of insulator materials, such as chemical composition and thickness, as well as environmental conditions, including humidity and temperature. Eggshell powder is produced from the impact of crushed eggshells; this powder will be used as a substitute and filler (cement) used in the pavement mixture on solid insulators. This study aims to understand the difference in the response of flashover and corona phenomena to increased voltage in composite insulators. Flashovers tend to occur at low voltages and decrease drastically at high voltages, while coronas rarely appear at low voltages but increase and stabilize at high voltages. Flashovers are rare at voltages over 20 kV, but corona is still possible. This suggests that the design of insulators or conductors for high voltages needs to pay attention to the corona effect which can lead to material degradation over time, while the risk of flashover is lower. In this study, the voltage threshold for the emergence of corona is about 20 kV, where the electric field is strong enough to trigger an electrical discharge around the conductor. After crossing this limit, the corona remains at high voltage. Therefore, the design of the material or insulator must consider the constant presence of corona at high voltages to prevent material damage due to the discharge of electrical energy around the conductor.

I. INTRODUCTION

Solid insulators or solid-form electrical insulators are commonly used in a variety of electrical applications to ensure system safety and efficiency. There are several types of solid insulators being researched, especially for high-voltage applications such as transformers [1]. Some of the key materials for solid insulation include thermoplastic polymers, such as polyurethane, which have advantages in dielectric strength and mechanical resistance. It is a good alternative to cellulose-based pressboards for insulators on transformer windings due to their better resistance to high voltages and lower dielectric losses [2].

In the world of materials research, step by step is always taken to find more innovative and sustainable solutions. One of these innovations is the testing of the electrical insulation properties of eggshell mixture materials. As the industry's need for eco-friendly insulator materials increases, researchers are starting to turn their attention to organic waste that was previously considered worthless.

The research also includes important insulating characteristics, such as the material's ability to withstand high stresses without experiencing damage. For example, polymer dielectrics and glass fibers are often tested for their resistance to conditions such as partial discharge and electrical damage due to cracks on the surface of the material. This study is important to improve the performance of insulation materials that are more stable and efficient in the long term. In this study, eggshells were not only tested to see how they can survive under high voltages, but also how their electrical conductivity compares to traditional insulator materials. The biggest challenge is to ensure that the new composite is thermally stable, so that it remains able to protect electrical and electronic devices under extreme conditions.

This research is conducted by testing the high voltage resistance of a process that tests materials to the limit of their natural capabilities. It further looks at how much electricity can be channeled through this material, ensuring that it remains an effective barrier between electric current and vulnerable elements. Thermal stability is something that needs to be considered, seeing how these processed eggshells are able to withstand temperature fluctuations without experiencing deformation or deterioration in quality.

Eggshells, which are organic waste from the food and household industries, have attracted attention as a potential alternative material for a variety of applications. The eggshell is mostly composed of calcium carbonate (CaCO3) with a unique microstructure, which gives it attractive mechanical and thermal properties. In this context, the use of eggshells as a solid insulator material offers various advantages. The use of eggshells helps reduce organic waste that contributes to environmental pollution. Eggshells are easy to obtain because they are abundant waste from various sectors, such as households, restaurants, and food processing plants. As a waste material, eggshells do not require high production costs, so they are more economical than conventional insulator materials. The calcium carbonate content in the eggshell provides sufficient dielectric strength for electrical insulation applications

II. THEORETICAL REFERENCE

Corona discharge is an electrical discharge phenomenon that occurs when the electric field around a conductor reaches a point where the surrounding gas molecules are ionized. This usually occurs at high voltages and becomes more common on non-smooth surfaces, such as wires or insulators. The limit or threshold of corona discharge refers to the minimum voltage that causes an electrical discharge in the form of a corona discharge. This threshold is influenced by factors such as the surface of the material, atmospheric pressure, and the dielectric properties of the material. Dielectric Properties in Insulator Composites, is a mixture of several materials to improve electrical insulation properties. A good composite material will have the property of being resistant to the flow of electric current and be able to reduce leakage.

Eggshells contain calcium carbonate which naturally has good insulating properties. The use of eggshell as a dielectric composite material aims to utilize the abundant and inexpensive material, but still has good performance in high voltage applications. Stress Testing on Composite Materials: Typically, testing is done by applying a gradually increasing voltage to the insulator material to identify the point where corona discharge begins to occur. This is done in a laboratory using a voltage that can be controlled and monitored in real-time. To detect corona discharge at the micro level, ultraviolet cameras and electric current measurement devices are used. It helps identify the distribution of the electric field and detect the discharge point before it reaches a destructive threshold.

The quality and homogeneity of the eggshell distribution in the composite matrix affect the corona stress threshold. Evenly distributed materials tend to have a well-distributed electric field, reducing the possibility of corona discharge. Microstructural effects in composites, such as the presence of small cavities or imperfections (microvoids), can lead to a significant increase in the local electric field, which can lower the corona threshold. Insulators made of eggshell-based composite materials can be a more economical alternative compared to conventional polymer- or ceramic-based insulators. In addition, they can provide comparable performance in terms of high-voltage isolation. Stability to the Environment: In addition to efficiency, eggshell composite insulators also have good resistance to temperature and humidity changes, making them a reliable choice in outdoor applications or in demanding environments.

There have been several previous studies that have addressed the phenomenon of corona and flashover voltage in solid insulators, particularly in the context of high voltages and outdoor applications. These studies show that corona threshold stresses and flashovers are affected by the characteristics of insulator materials, such as chemical composition and thickness, as well as environmental conditions, including humidity and temperature. For example, research focusing on flashover in insulators under vacuum conditions found that parameters such as electric field strength, insulator geometry, and insulator surface smoothness played an important role in preventing flashovers from occurring. This research aims to increase the withstand voltage of the insulator, which ultimately increases the resistance of the insulator to the corona phenomenon at high voltages [3].

Another study examined contaminated insulators in the transmission network. The results show that the presence of contaminants can lower the flashover voltage, so it is important to consider the protection and maintenance of the insulator to improve the reliability of the system [3]. Construction and Building Materials: Research shows that egg shells processed into powder can be used as a partial substitute for cement in the manufacture of concrete or bricks. The addition of eggshells, especially in certain percentages such as 5-10%, can increase the compressive strength of the material, although at higher proportions it will usually decrease. Research at De La Salle University, for example, shows that eggshells can be an alternative to construction materials by using seawater mixtures to reinforce eggshell-based concrete [4].

Eggshells have also been used as adsorbents for the removal of heavy metals and dyes from wastewater, since its main composition, calcium carbonate, has the ability to absorb pollutants. This use offers an environmentally friendly solution for the utilization of eggshell waste, while reducing water pollution and improving clean water quality. Joe, S. Y in This paper discusses the long-term use of temporary FPD, Polymethyl Methacrylate (PMMA) as a temporarily fixed material, and the benefit of eggshell waste to porosity and flexural strength of PMMA materials. The addition of eggshell to PMMA for temporary fixed restoration could decrease porosity and increase the flexural strength of PMMA material because it contains calcium carbonate so that it could be used for the manufacture of provisional fixed restoration which requires long-term useKeywords: temporary fixed denture, polymethyl methacrylate, eggshell, porosity, flexural strength [5].

III. MATERIALS AND METHODS

III.1 MATERIALS

Eggshells are mainly composed of about 94-97% calcium carbonate ($CaCO_3$) which acts as the main component that gives the shell its hard structure, but it also contains a variety of other materials in smaller amounts of Protein Matrix – about 1-2% serves as a binder between calcium carbonate crystals, providing additional strength and elasticity. The composition of egg shells, which is composed mostly of calcium carbonate, makes them a potential material for applications in various industries, such as composite materials, fertilizers, and even solid insulator materials.

The research uses eggshell material, then the ideal proportion of egg shell mixture with resin material is used to produce a high-quality insulator. In this research, the test material used uses a ratio of 60/40 and 2% of the Resin Weight equivalent to 1.2 Grams, the results obtained by the insulator as a test material have perfectly hardening properties, are flame retardant and have a hard texture, the material and insulator used are shown in Figure 1.

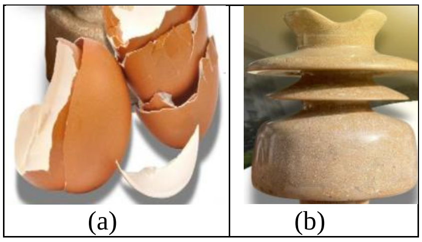

Figure 1: Materials and Testing (a) eggshells as solid insulators (b) Eggshell insulators.
Source: Authors, (2025).

In making eggshell insulators, there are several materials needed, including: polyester resin, eggshells, catalysts, glazes, and methyl methacrylate. Polyester resin is an organic compound that is more volatile or has a higher VOC (Volatile Organic Compounds) content than epoxy resin. So polyester resin has a much stronger odor than epoxy resin. Polyester resins have strong and flammable VOC exhaust gases or vapors. Polyester resin is also one of the types of resin insulators that are often used. This resin has good electrical insulation properties, is resistant to weather, and is resistant to corrosion.

Eggshell powder is a powder produced from the impact of crushed eggshells, this powder will be used as a substitute and filler (cement) used in pavement mixtures. The shell of a poultry egg consists of calcium carbonate of 97% of its mass, glued together with a protein matrix. Without the protein matrix, the egg would become very brittle and would not be able to maintain its shape.

III.2 METHODS

Recent research has explored various methods to model and optimize corona release in composite insulators. Ultraviolet imaging has been used to estimate the magnitude of the emitter, taking into account factors such as observation distance and imager amplification [6]. Derivatives-Free Breakers combined with finite element modeling have been used to optimize corona ring parameters, reducing electric field intensity by up to 66% [7]. The Finite Element Method (FEM) has been proposed as an effective technique for calculating the distribution of potential forces and electric fields along insulators, especially on complex composite fields [8]. In addition, Response Surface Methodology has been applied to optimize the dielectric strength of polymer composites by determining the optimal fill ratio, with commercial wollastonite and alumina trihydrate identified as important factors [9]. This study provides valuable insights into the modeling and optimization of coronal release thresholds in composite insulators.

The breakdown voltage for a solid insulator is the maximum voltage that can be applied to the insulator material before dielectric damage or electrical jumps through the material occur [10]. To find the breakdown voltage equation in solid insulators, there are several theoretical approaches based on the basic laws of electric fields, as well as the material properties of the insulators used. In general, the Vb break-through voltage depends on several factors, such as the thickness of the material d, the strength of the critical electric field Eb, and the material constant of the insulator. The basic equation for the break-through voltage in a solid insulator can be written as:

$$V_b = E_b \times d \qquad (1)$$

Where, = *Electric Field* (kV/cm), V = *Breakout voltage* (kV), d = *material thickness* (cm)

In this study, eggshells were not only tested to see how they can survive under high voltages, but also how their electrical conductivity compares to traditional insulator materials. The biggest challenge is to ensure that the new composite is thermally stable, so that it remains able to protect electrical and electronic devices under extreme conditions.

This research involves testing the high voltage resistance of a process using materials to the limits of their natural capabilities, and ensuring that they remain an effective barrier between electric current and vulnerable elements. Thermal stability is the final highlight, seeing how these processed eggshells are able to withstand temperature fluctuations without experiencing deformation or deterioration in quality. With this approach, eggshell mixed materials can be a pioneer in creating electrical insulators that are not only efficient but also environmentally friendly.

IV. RESULTS AND DISCUSSIONS

In this study, the test was carried out in an insulator in dry conditions using the Insulation Resistance Tester (Megger) testing tool, the circuit used in the test can be seen in figure 1.

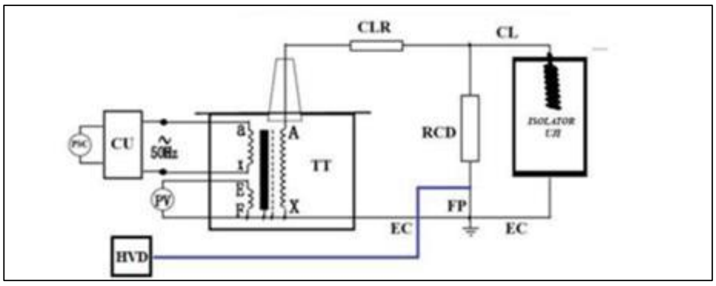

Figure 2: Diagram Rangkaian Pengujian.
Source: Authors, (2025).

By using the test tool as seen in figure 2, the test results obtained are shown in table 1.

Table 1. Isolator Test Results

Test Voltage (kV)	Time (second)	Explanation
5	120	X
10	120	X
15	120	X
20	120	X
30	120	flashover
80	120	flashover

Source: Authors, (2025).

Table 1. Showing the results of voltage tests on insulators in dry conditions to observe flashover and corona phenomena. The electrical voltage applied to the insulator during the test, expressed in kilovolts (kV), ranges from 5 kV to 80 kV. The test time at each voltage level is 120 seconds for each voltage level. At 5 kV and 10 kV, no flashover occurs. At a voltage of 20 kV, there is no flashover at this voltage, which indicates that this voltage is still relatively safe from flashover in dry conditions.

At voltages of 30 kV and 80 kV, the corona phenomenon begins to appear which causes flashovers. The corona phenomenon usually occurs at high voltages where the electric field around the conductor is strong enough to ionize the air without causing a full electrical discharge or flashover. The threshold voltage for flashover in dry conditions is around 15 kV. At this voltage, flashovers sometimes appear and sometimes not, indicating that at voltages above 15 kV, the risk of flashover increases. The emergence of Corona, the corona phenomenon begins to be seen at 30 kV and continues at higher voltages. This is consistent with the theory that corona tends to occur at high voltages when the electric field is strong enough to cause partial ionization.

The results obtained are followed by the relationship between the test voltage and the occurrence of flashover using linear regression. In this context, the free variable (X) is the test voltage (kV). A bound variable (Y), where a flashover occurs, which is usually expressed in binary form (e.g., 0 for no flashover and 1 for flashover). From the data obtained made at voltages below 15 kV, the probability of flashover is low or non-existent.

At voltages of 15 kV and above, the probability of flashover starting to increase or occur consistently at a given voltage. Using simple binary linear regression it is possible to estimate the likelihood of a flashover occurring based on the applied voltage. The Linear Regression model was used to find the relationship between voltage and flashover probability, the results obtained are shown in the graph Figure 3.

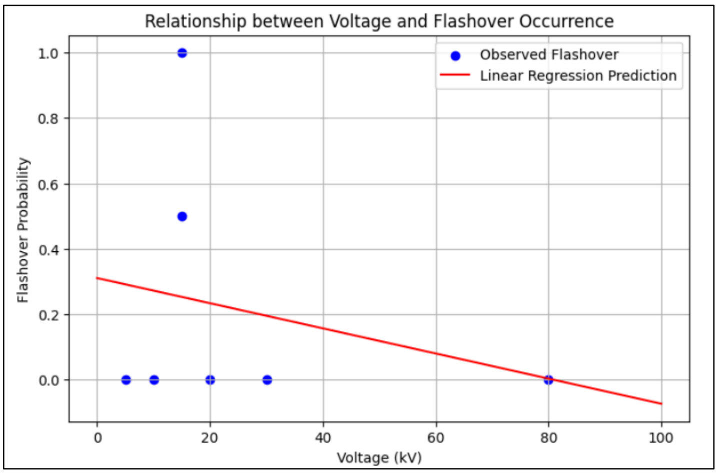

Figure 3: Relationship Between Voltage and Flashover Probability.
Source: Authors, (2025).

From the graph in figure 3, we can see the linear regression relationship between voltage (kV) and flashover probability. Based on the results of the graph in the figure, the linear regression equation is obtained:

$$\textit{Flashover Probability} = -0.0038 \times \textit{Voltage} + 0.3104$$

Where the slope of -0.0038 indicates that with increasing voltage, the probability of flashover decreases slightly linearly in this model. An intercept of 0.3104 indicates the approximate probability of a flashover when the voltage is close to 0 kV. However, this relationship does not appear to show a strong trend due to the variable flashover data at a given voltage (e.g., at 15 kV). The error value generated from this linear regression model, expressed in the form of Mean Squared Error (MSE), is about 0.124. This shows how far the model predicts from the actual flashover data, this model may be less accurate to predict directly.

Furthermore, it describes the relationship between voltage (kV) and the probability of flashover (electrical leap through the surface of the insulator) and the probability of corona (discharge of electrical charge around the conductor) at various voltage levels. The graph of the modeling results using the python programming language is shown in Figure 4

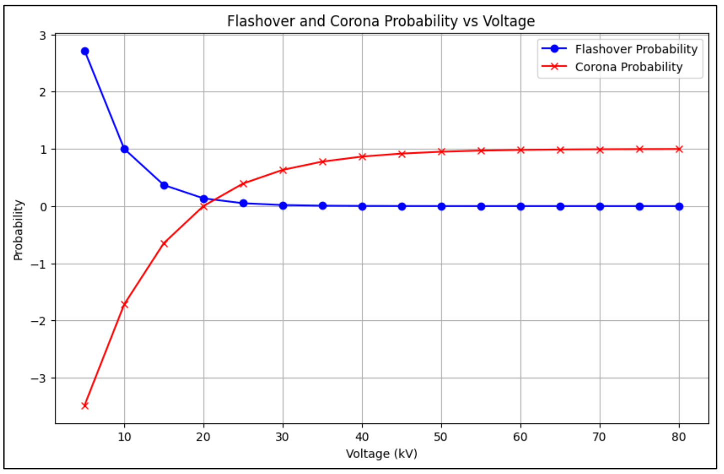

Figure 4: Flashover and Corona Probability and Voltage.
Source: Authors, (2025).

In figure 4. The Y axis indicates the "probability" for two electrical phenomena, namely flashover and corona. Note, however, that the probability value here is not like a regular probability (0 to 1), but rather a relative probability that may be measurable as the intensity or frequency of events under certain experimental conditions. This value can be interpreted as the frequency or rate of flashover and corona events at different voltage levels. X-Axis (Voltage in kV): The X-axis indicates the voltage level in kilovolts (kV), which increases from 0 to 80 kV. Increasing voltages can affect the likelihood of both phenomena, depending on the characteristics of the insulator material or component being tested.

The Flashover Curve (Blue Line with Dots) shows a downward trend: Initially, the probability of flashover is quite high at low voltages (about 10 kV), but then it decreases drastically as the voltage rises to about 20 kV. This may indicate that at low voltages, flashover phenomena occur more frequently, but there is a certain limit where high voltages actually decrease the occurrence of flashovers. Once the voltage reaches about 20 kV, the flashover probability remains stable (close to zero) up to 80 kV. This may be due to the more stable strength of the electric field at high voltages, so flashover does not occur because the insulation is more effective at this level.

The Corona Curve (Red Line with the Cross), has an increasing trend: The probability of the corona starts from a negative value (which may be interpreted as a very low or insignificant event) at low voltages, but gradually increases with increasing voltages. This shows that the corona phenomenon tends to be more dominant at high voltages. Stability at High Voltage: After reaching a voltage of about 20 kV, the probability of the corona remains relatively stable (close to a certain positive value) up to 80 kV. This may indicate that the corona becomes a constant phenomenon that does not increase or decrease significantly at high voltages, but is nonetheless present as an electric field effect.

To find out the relationship between voltage (kV) and corona presence indicators, modeling is needed by showing how the corona phenomenon appears at a certain voltage and remains at a higher voltage, the results obtained are seen in the graph in figure 5.

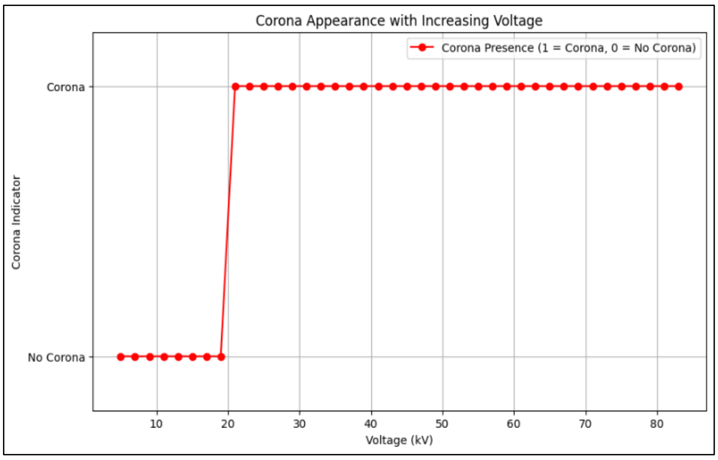

Figure 5: Corona Appearance With Increasing Voltage
Source: Authors, (2025).

This figure 5 graph shows the relationship between voltage (kV) and corona presence indicators. The graph shows how the corona phenomenon appears at a given voltage and remains at a higher voltage. Y Axis (Corona Indicator): The Y axis indicates an indicator of corona presence, with a value of 0 indicating "No Corona" and 1 indicating "Corona Appearing". This indicates whether or not the corona phenomenon occurs at a given voltage. X-axis (Voltage in kV): The X-axis indicates the voltage level from 0 to 80 kV. The higher the voltage, the more likely it is that corona will occur, according to the pattern shown in the graph.

At voltages below 20 kV, the indicator shows no corona (value 0). This means that at low voltages, the corona phenomenon has not yet appeared. The Corona surge occurred at a voltage of around 20 kV. At this point, the graph shows a sharp transition from "No Corona" to "Corona Appears." This shows that the threshold voltage for the appearance of the corona is around 20 kV. After reaching a voltage of 20 kV and above, the corona remains (value 1), and the graph becomes stable. This suggests that once the corona appears, it will remain present at higher stress levels, and the phenomenon becomes constant.

V. CONCLUSIONS

In the research that has been carried out, the results have been obtained, that the flashover and corona phenomena have different responses to increased voltage. Flashover is more likely to occur at low voltages and then decrease drastically at high voltages. In contrast, corona is less frequent at low voltages, but it increases and then stabilizes at high voltages.

At high voltages (more than 20 kV), flashovers are rare, but corona is still possible. This suggests that in insulator or conductor designs for high voltages, the corona effect needs to be specifically considered, while the risk of flashover may be lower. For equipment operated at high voltages, the material and insulator design need to focus on reducing the corona effect, which can lead to material degradation over time. Flashover seems to be a problem at low or medium voltages.

Voltage Threshold that the corona starts to appear at a voltage of about 20 kV. This is the threshold voltage where the electric field is strong enough to cause an electrical discharge around the conductor. After crossing the threshold of 20 kV, the corona does not disappear, but rather remains at a higher voltage. This means that the material or insulator design must consider the constant presence of corona at high voltages to prevent damage or degradation of the material due to the discharge of electrical energy around the conductor.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Samsurizal, Yulisya Zuriatni
Methodology: Samsurizal, Yulisya Zuriatni
Investigation: Yulisya Zuriatni, Andi Makkulau
Discussion of results: Samsurizal, Andi Makkulau
Writing – Original Draft: Samsurizal
Writing – Review and Editing: Samsurizal, Yulisya Zuriatni
Resources: Samsurizal, Yulisya Zuriatni, Andi Makkulau
Supervision: Yulisya Zuriatni, Andi Makkulau
Approval of the final text: Samsurizal

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