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Gum Rosin Characteristics as Alternative Coating Material to Improve High Voltage Outdoor Insulator Performance

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Abstract

Numerous attempts have been made to enhance the performance of ceramic insulators, including insulators' design modification, surface coating application, and regular maintenance improvement. Room Temperature Vulcanized (RTV) silicone rubber, frequently employed as a coating for outdoor ceramic insulators, may deteriorate due to continuous exposure to ozone and ultraviolet (UV) light, resulting in a loss of insulating properties and potential surface cracking. This research aims to investigate the characteristics of new materials intended as additional coating materials for high voltage insulators to improve the performance of ceramic insulators. The proposed material, gum rosin ($C_{20}H_{30}O_2$), is derived from the distillation of pine tree sap and possesses excellent hydrophobicity properties, meeting one of the requirements for an insulator. This research was carried out in two stages, which are characteristic tests of gum rosin as an additional coating material on RTV silicone rubber consisting of hydrophobicity, surface resistivity, relative permittivity (ε_r), and tan delta, followed by a leakage current test of gum rosin and RTV silicone rubber-coated ceramic insulators to validate the insulation performance improvement. The results show that the addition of 5 wt.% gum rosin to the RTV silicone rubber can improve the characteristics of insulator coating material indicated by an increased contact angle of 7.85° and reduced leakage current magnitude up to 9.42% at a relative humidity of 70%, 7.1% at a relative humidity of 80%, and 10.02% at a relative humidity of 90%. These results proved that gum rosin can be used in addition to the conventional RTV silicone rubber coating material to improve the insulation characteristics of outdoor ceramic insulators.

Keywords:

Gum Rosin;

Hydrophobicity;

Surface Resistivity;

Leakage Current;

Coating Insulator.

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1- Introduction

In electric power systems, outdoor insulators have a vital role in ensuring the reliability and stability of electricity distribution by preventing current leakage and flashover. These conditions are usually caused by pollutants and moisture that accumulate [1] and lower the insulator's performance [2, 3]. The surface of ceramic insulators is easily wetted by water; therefore, the insulator surface can be easily coated by conductive contaminants [4]. Leakage current flow on the insulator surface can result from the combination of electrical voltage acting on the insulator and the presence of moisture and impurities. Over time, the insulator surface may

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deteriorate due to the heat from the leakage current. The insulator may experience flashover more quickly as a result of this surface deterioration [5].

Currently, to overcome the weakness of ceramic insulators due to environmental influences, preventive maintenance must be performed by washing the insulator surface, which can reduce the risk of flashover, but this maintenance is very expensive [6–8]. Another method to overcome this problem is to make the insulator surface warmer, so that water or water vapor on the insulator surface can dry quickly. This idea triggered the application of a coating on insulators called semiconducting glaze insulators. Semiconducting glaze insulators were once installed on the island of Bali, Indonesia, and were expected to operate for an extended period to improve the performance of outdoor insulators on the coastline [9]. However, after two years of operation, the insulator suffered damage, cracking, or breaking due to a large leakage current, which in turn caused significant heating on the insulator surface. Therefore, in that case, the semiconducting glaze insulators were no longer installed and were replaced by conventional ceramic insulators.

One promising approach is the use of silicone rubber-based coating materials that have been shown to have high hydrophobic properties, lower leakage current and resistance to UV light [10–12]. These properties are important to reduce the accumulation of water and pollutants on the insulator surface, thereby reducing the risk of flashover [13, 14]. Research by Wang et al. shows that modification of silicone with polyurethane can improve the mechanical and electrical properties of the coating, making it more effective in insulator applications [15]. In addition, the use of superhydrophobic coatings has also been shown to improve insulator performance by reducing ice formation and water accumulation, which are common problems in outdoor insulators [16]. Several other researchers used fillers in silicone rubber such as alumina, chromium oxide, and hafnium oxynitride [17–19] to improve the performance of silicone rubber. However, the relatively high price and dependence on synthetic chemical raw materials have prompted research into more economical and environmentally friendly alternative materials to be the focus of recent research. Such coatings not only reduce Volatile Organic Compound (VOC) emissions but also offer excellent insulation performance [20].

Gum rosin, a natural resin derived from pine trees, possesses excellent potential as an alternative coating material. Gum rosin is rich in resin acids, including abietic acid, which provides natural adhesive and hydrophobic properties. In addition, gum rosin has the advantages of abundant availability, relatively low price, and biodegradable properties, making it more environmentally friendly compared to synthetic materials [21, 22].

Several previous studies have examined the use of gum rosin in various applications, such as antimicrobial coatings, adhesives, and composite materials. However, studies on gum rosin as an outdoor insulator coating material are still very limited. Research by Sha et al. (2024) reported that the combination of gum rosin with specific polymers can improve the mechanical and chemical stability of materials [23]. A related study on coating insulators by Cai et al. (2024) highlighted the importance of coating materials with long-lasting hydrophobic properties to prevent flashover [24]. Other studies have shown that gum rosin can be modified to improve its characteristics, such as resistance to oxidation and solvents [25]. Furthermore, gum rosin also has good adhesion ability, improving the bond between the coating and the insulator surface, thus extending its service life and improving its performance [2, 3].

This study aims to investigate the performance of ceramic insulators by coating the insulator surface using the addition of gum rosin on RTV silicone rubber (RTV SiR) as a more economical and environmentally friendly alternative coating material. From our previous research, the application of gum rosin as an insulator coating can reduce leakage current, but the performance of gum rosin itself is not as optimal as RTV silicone rubber [26]. This study offers a comprehensive analysis of the characteristics of a new material, gum rosin as an additive to silicone rubber to be used as a coating material for ceramic insulators by integrating customized experiments with real outdoor scenarios, providing insights into the effect of humidity and pollutants on the performance of ceramic insulators, as well as providing practical insights through experiments under varying humidity conditions, to investigate the effect of degradation on the performance of ceramic insulators which has not been present in previous studies.

2- Research Methodology

The research methodology, illustrated in Figure 1, outlines the investigation of characteristics of gum rosin as an alternative coating material to improve high voltage outdoor insulator performance.

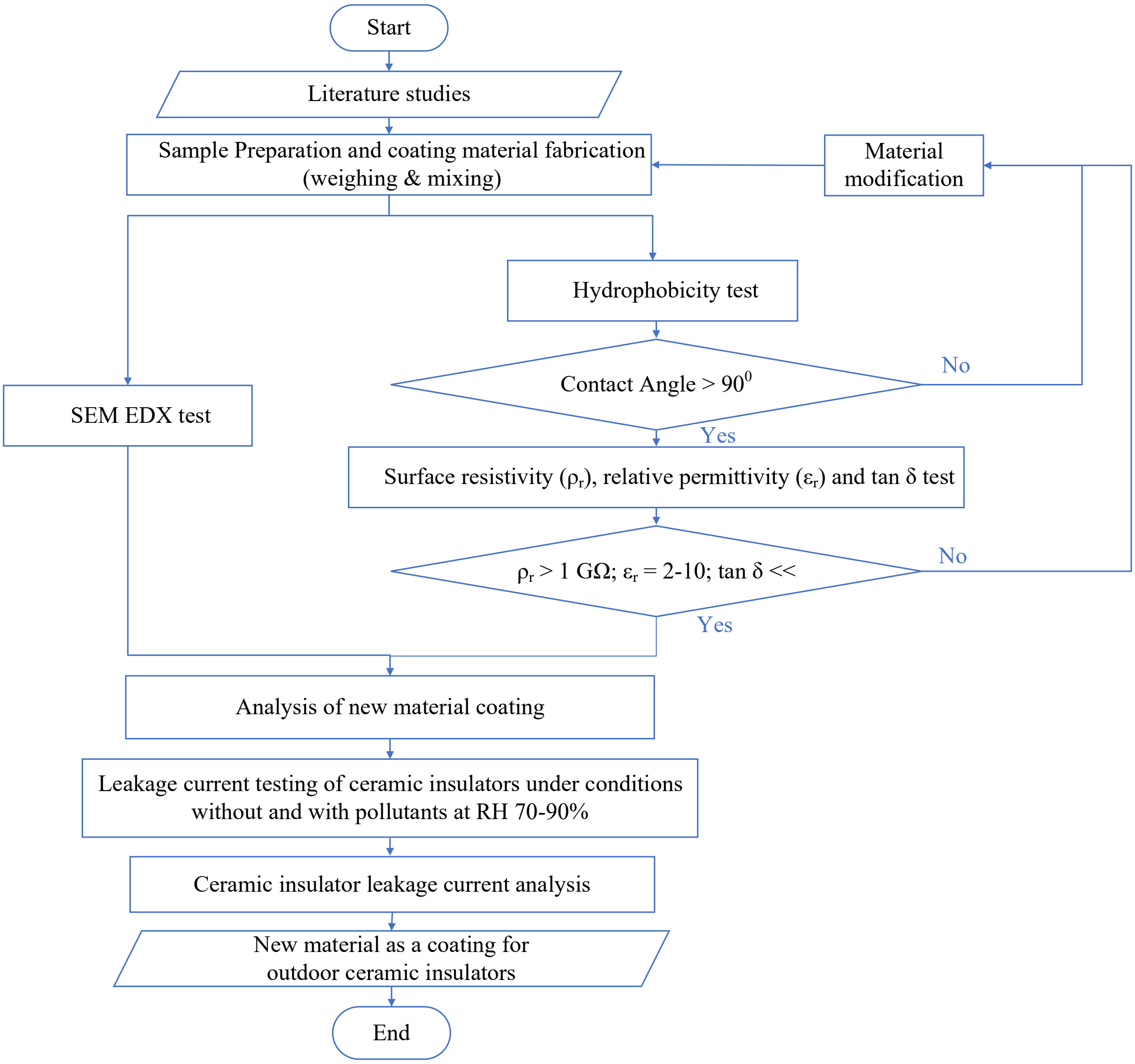


Figure 1. Flow chart of the research method

2-1-Material Test

The coating material used in this research is gum rosin and RTV SiR. Gum rosin results from the distillation process of the sap of tusam or pine trees. The molecular formula for gum rosin is $C_{20}H_{30}O_2$. This substance can be employed as an insulator because of its properties, which include adhesiveness, hydrophobicity, and viscosity booster [27]. Conversely, RTV SiR exhibits excellent dielectric characteristics. It is also very resistant to UV light, chemicals, thermal deterioration, and corona discharge. It can also decrease leakage current. On the other hand, RTV's hydrophobicity is what makes it perfect for use as an insulator because it can regain its hydrophobicity even after a layer of contamination has accumulated on the surface, preventing flashover, arcing, current leakage, and the development of dry band areas [28]. A depiction of gum rosin and silicone rubber chemical structure can be found in Figure 2.

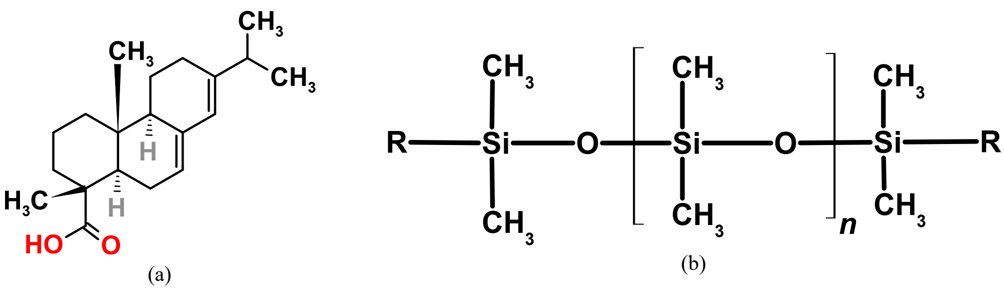


Figure 2. Chemical structure: (a) gum rosin and (b) silicone rubber

A comparison of the characterization of silicone rubber and gum rosin as coating materials can be shown in Table 1.

Table 1. Characterization of silicone rubber & gum rosin as a material coating

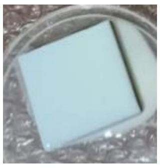
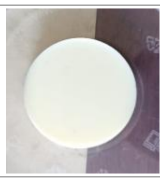
Requirements	Silicone Rubber	Gum Rosin
Hydrophobicity [29]	110^0	68.05^0
Thermal conductivity	0.2 W/m-K [30, 31] 0.180 - 0.200 W/m-K [32]	0.113 ± 0.001 W/m-K [33]
Dissipation factor	0.0000140 - 0.0150 [32]	0.140-0.152
Surface resistivity [34]	1×10^{13} to 1×10^{14} (Ωcm) [35]	1.54×10^{13} Ωcm [36]
Conductivity (σ)	$1.21 \times 10^{-5}(\Omega m)^{-1}$ [37]	0.65×10^{-11} $(\Omega m)^{-1}$ [36]

In the comparison of coating material characteristics in the Table 1, RTV SiR has better coating material characteristics compared to gum rosin, but the performance of RTV SiR can be further improved by adding gum rosin, where gum rosin has hydrophobic properties so that in this study the mixing of the two materials is expected to obtain a better coating material to obtain a suitable coating material.

2-2-Sample Preparation

In this work, the samples were prepared by mixing silicon rubber with 5 wt.% gum rosin as the material coating. This composition is used because this composition has the largest contact angle compared to other gum rosin compositions [38]. The sample is made in three forms: a ceramic specimen (coating layer) to measure static contact angle and SEM EDX, a bulk form to measure permittivity, and a ceramic insulator to measure leakage current (Table 2).

Table 2. RTV SiR and RTV SiR + GR 5wt.% samples

Sample	RTV SiR	RTV SiR + GR 5wt.%
Coated samples in a ceramic specimen (50 × 50 mm)		
Bulk samples (d = 55 mm)		
Coated samples in a ceramic insulator (d = 280 mm)		

2-3-SEM EDX Experimental Setup

Scanning electron microscopy (SEM) and X-ray spectroscopy (EDX) are methods for analyzing surface materials. These methods provide high-resolution surface topography with an excellent depth of field. Primary electrons, with energies ranging from 0.5 to 30 keV, penetrate the surface and induce the emission of secondary electrons. SEM equipped with EDX analysis, offers elemental analysis and quantitative compositional data for small to nano-sized areas of the sample. The electron beam directed at the sample surface generates X-rays that reveal the quantitative characteristics of the material's elements. The SEM/EDX analysis was conducted using a Hitachi SU3500 and the SEM micrographs were captured using a magnification of 1000x and 10-15 kV accelerating voltage, with a 50µm spatial resolution limited by subsurface beam scattering.

2-4-Hydrophobicity Experimental Setup

A digital camera is used to record the contact angle on the test material's surface to quantify hydrophobicity. The purpose of this hydrophobicity test is to determine if the test material's surface is hydrophilic or hydrophobic. When a surface's static water contact angle (θ) is greater than 90°, it is hydrophobic; when it is less than 90°, it is hydrophilic [39]. The contact angle indicates how waterproof the material's surface is; the higher the hydrophobic angle, the better the material's ability to prevent water from penetrating the insulating layer. The IEC TS 62073 standard serves as the foundation for hydrophobicity testing.

To measure the hydrophobicity, use a Socorex pipette to drop 50 µL of mineral water on the insulator specimen's surface once. Take a picture of the water on the surface, then calculate the contact angle. This experiment utilized a Socorex pipette and the contact angle measurement apparatus schematic.

The static contact angle can be calculated using Equation 1 [30]:

$$\text{Contact angle} = \frac{\text{left contact angle} + \text{right contact angle}}{2} \tag{1}$$

2-5-Surface Resistivity, Relative Permittivity, and Tan δ Experimental Setup

The test electrodes used in this research used the JIS K6271 Determination of Resistivity Standard and IEC 62631-3-2-2015 Determination of resistive properties (DC Methods)–Surface Resistance and surface resistivity. Surface resistivity testing was carried out at voltages of 1000 V for 30 minutes. Before being tested, the bulk sample is coated with a silver paste to minimize resistance at the contact surface, leading to more reliable test results. Samples that have been given silver paste are then tested using a high resistance meter test equipment.

To get the surface resistivity value, use Equation 2 as follows.

$$\rho_s = \frac{\pi(D+d)}{D-d} \times R_s \tag{2}$$

where ρ_s = surface resistivity (Ω.m), R_s = surface resistance (Ω), d = primary electrode diameter (m), and D = ring electrode inner diameter (m).

A permittivity test measures a material's ability to withstand electric fields without breaking down. Relative permittivity is defined as the ratio of the material's permittivity to air. The measurement frequency is set at 1 kHz, and the capacitance is measured. Then, the relative permittivity is determined using Equation 3 as follows.

$$\varepsilon_r = \frac{C\,.\,d}{A.\ \varepsilon_0} \tag{3}$$

where ε_r = relative permittivity; C = capacitance (F); d = distance between electrodes (m); A = surface area (m^2); ε_0 = vacuum permittivity (8.8541×10^{-12} F/m).

The relative permittivity and Tan δ testing are carried out at every 0.1 kHz increase with frequency variations starting from 0.1 - 2 kHz using an LCR meter test equipment.

2-6-Leakage Current Experimental Setup

For the first test, the samples are placed in an unpolluted state; the gum rosin and RTV silicone rubber coated samples are placed in a contaminated state. The chamber dimensions are 1.2 × 1.2 × 1.5 cm. A 50 Hz AC high voltage, ranging from 5 kV to 25 kV, was used for the experiment involving changes in humidity. Figure 3 displays the circuit for testing the insulator leakage current and the experimental setup.

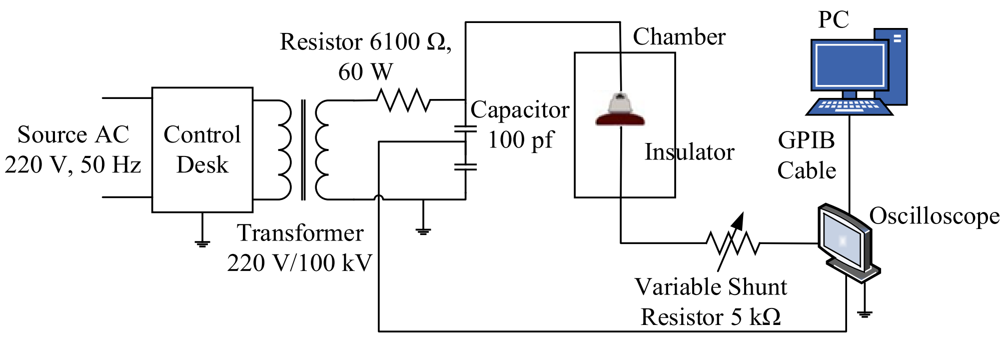


Figure 3. Insulator leakage current test circuit [40]

Conditioning is carried out by applying high pollutants to the insulator samples, based on standards IEC 507:1991 and IEC-TS-60815-1-2008. The pollutant provided is a mixture of salt (NaCl) and Kaolin. This research tested the leakage current in two conditions: unpolluted and polluted clean fog with variations in humidity of 70%, 80%, and 90%.

3- Experimental Results and Analysis

3-1-SEM EDX Experiment Result

Results of the SEM morphology test of gum rosin, RTV SiR and RTV SiR + gum rosin samples with 1000x magnification are shown in Figure 4.

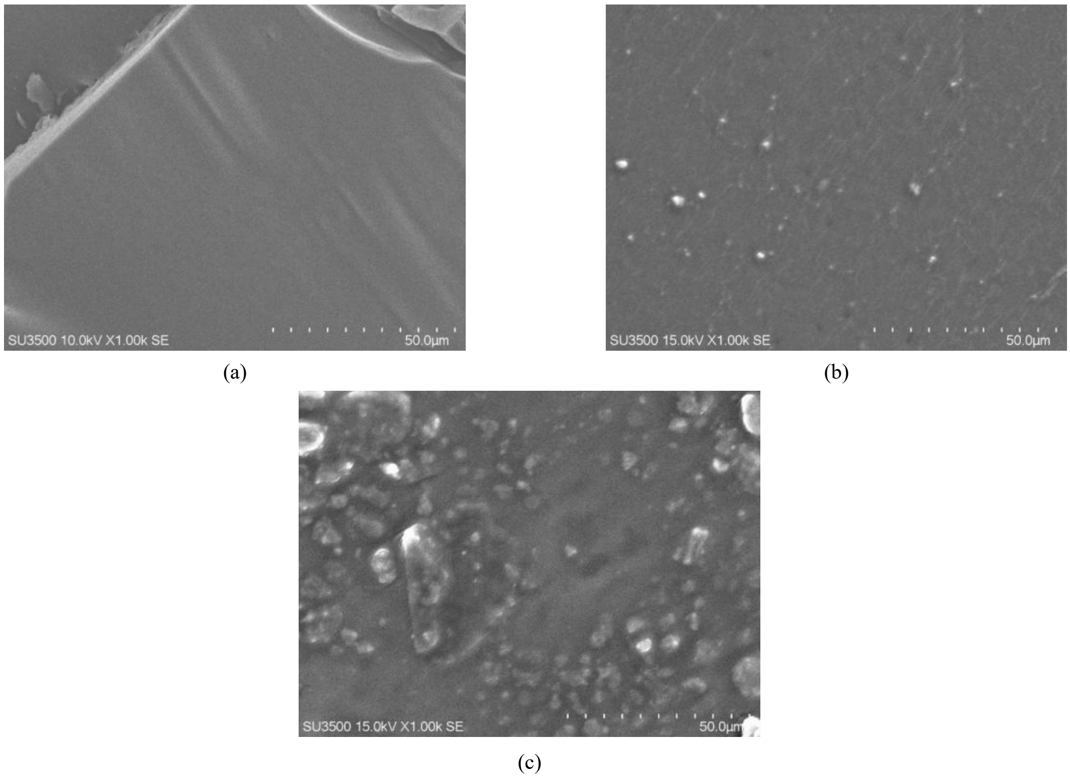


Figure 4. Image of the surface of the sample by using SEM morphology test: (a) gum rosin, (b) RTV SiR and (c) RTV SiR + GR 5 wt.%

From the SEM morphology test, it is known that the surface of gum rosin is porous and rough compared to silicone rubber. However, when this gum rosin is mixed with RTV SiR, the surface becomes even rougher. Meanwhile, the composition characteristics of the gum rosin, RTV SiR, and RTV SiR + gum rosin samples were determined using the EDX (Energy Dispersive X-Ray Spectroscopy) test, as shown in Figure 5.

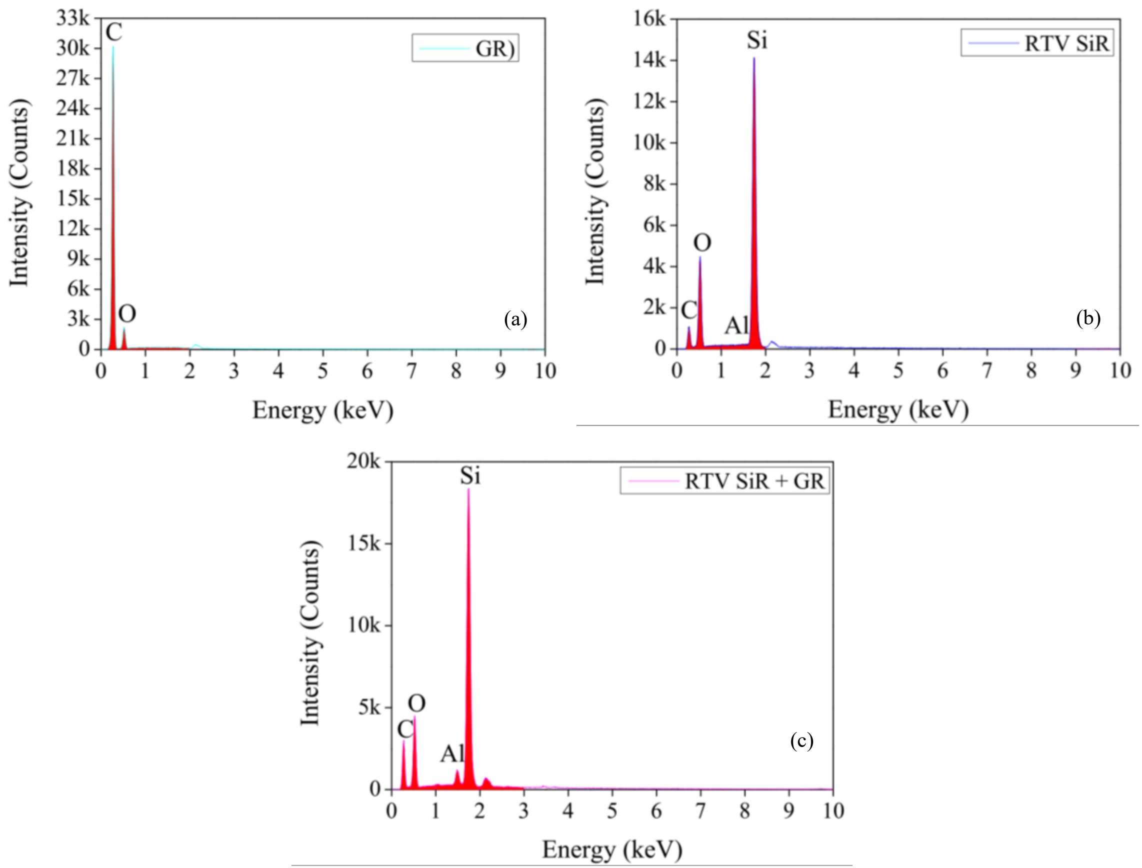


Figure 5. EDX spectrum results: (a) gum rosin, (b) RTV SiR and (c) RTV SiR + GR 5 wt.%

The EDX spectrum, as shown in Figure 5 above, shows the peaks in the spectrum that represent the characteristic energy of the X-rays emitted by a particular element in the sample. A higher peak indicates a higher concentration of that element. The EDX spectrum results on the gum rosin sample in Figure 5 (a) showed a peak at the characteristic X-ray energy at 0.277 keV, indicating the presence of carbon (C) in the sample. The other samples, RTV SiR (Room Temperature Vulcanized Silicone Rubber) in Figure 5 (b) and RTV SiR adding gum rosin in Figure 5 (c), showed a peak at the X-ray characteristic energy at 1.74 keV, indicating the presence of silicon (Si) in the sample.

Gum rosin contains carbon (C) and oxygen (O) elements. These elements indicate the organic nature of gum rosin, consisting mainly of resin acids, which contribute to its hydrophobic and adhesive properties. RTV SiR contains C, O, Si, and aluminum (Al) elements. The presence of Si and Al reflects the composition of RTV SiR, which provides excellent dielectric properties, hydrophobicity, and resistance to UV and chemical degradation. Furthermore, adding gum rosin to silicone rubber can increase the C content due to its organic structure while increasing significant levels of Si and O to maintain good dielectric properties.

The element-composition comparison between gum rosin, RTV SiR and RTV SiR + gum rosin samples were analyzed using EDX results, as shown in Table 3.

Table 3. Comparison of the elemental composition of gum rosin, RTV SiR and RTV SiR + gum rosin

Sample	C (%)	O (%)	Al (%)	Si (%)
Gum Rosin	92.52	7.48		
RTV SiR	35.71	30.19	0,22	33.78
RTV SiR + GR	53.61	19.19	1.16	25.98

From the EDX test, it is known that gum rosin consists of C and O elements. The elements in gum rosin are 92.52% C and 7.48% O. The C-O element in organic compounds refers to the chemical bond between carbon atoms (C) and oxygen atoms (O). These bonds usually occur in organic compounds containing carbon and oxygen, forming an important part of various organic molecules. The C-O element is important because it gives special properties and characteristics to organic compounds. C-O bonds in organic compounds can affect the reactivity, physical properties, and uses of the compound. Meanwhile, for silicon rubber, the composition characteristics of silicon rubber samples show the presence of C (35.71%), Si (33.78%), Al (0,22%), and O (30.19%) elements [31] and for the RT SiR+ gum rosin, the composition characteristics of silicon rubber samples show the presence of C (53.61%), Si (25.98%), Al (1.16%), and O (19.19%).

3-2- Hydrofobicity Experiment Result

Based on the findings of direct observation using a camera, the contact angle between the material surface and the water drop is determined. Then, the hydrophobicity class is determined by the averaged contact angle of the left-side and right-side of water droplets at 10 different points. The result of contact angle measurement on polluted samples can be seen in Figure 6.

(a) Gum rosin (b) RTV SiR (c) RTV SiR + Gum rosin

Figure 6. Hydrophobicity result: (a) Gum rosin; (b) RTV SiR; (c) RTV SiR + Gum rosin

Equation 1 can be used to determine the hydrophobic contact angle. The result of measuring the hydrophobicity is shown in Figure 7.

From the hydrophobicity measurements, the average value of the contact angle measurement results of gum rosin is 68.05°, the contact angle of RTV SiR is 92° and the contact angle of RTV SiR + gum rosin is 96.65°.

According to the findings of the hydrophobicity test, the ceramic insulator's contact angle improved after being coated with gum rosin compared to when it wasn't coated. The results of measuring the contact angle of a ceramic insulator without coating range from 45 to 55° [9].

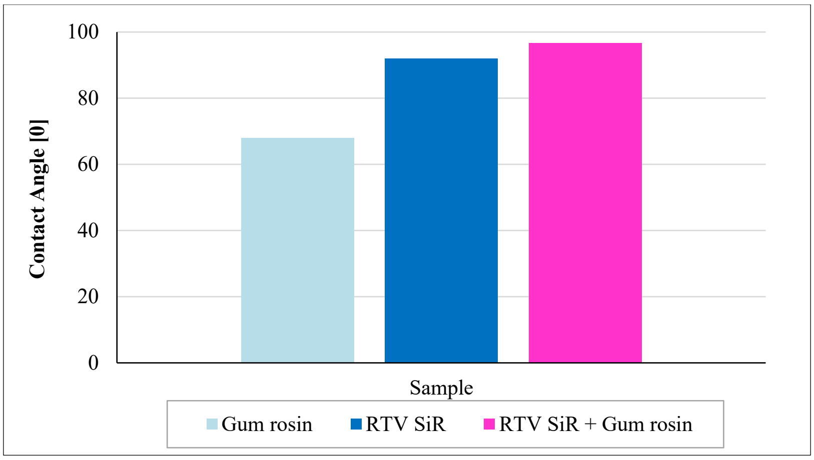


Figure 7. Comparison of contact angle

3-3- Surface Resistivity, Relative Permittivity, and Tan δ Experiment Result

A good insulator material has a high surface resistivity and low dielectric loss/dissipation factor. Materials with good resistivity and tan δ can withstand leakage current better, which means they are more effective in isolating electricity. Surface resistivity testing was carried out at voltages of 1000 V for 30 minutes, with test results as in Figure 8.

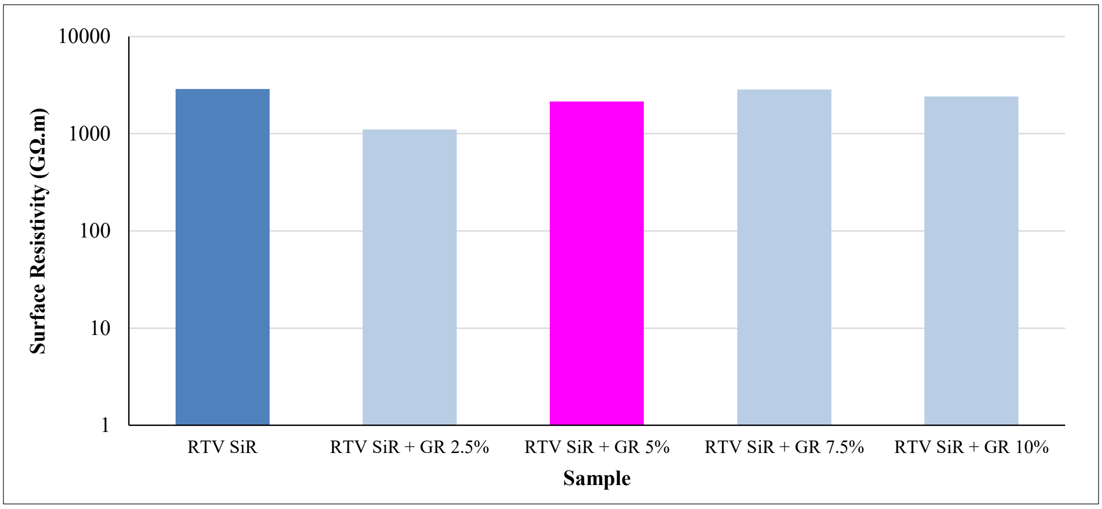


Figure 8. Comparison of surface resistivity result

From the results of the surface resistivity test, it is known that with the addition of gum rosin to RTV SiR, the surface resistivity value is not much different from RTV silicone rubber and still fulfils the specification for electrical insulation coating that the standard surface resistivity for insulating coating materials is more than 1 GΩ based on EDMS 29-300-1 of 2021. A comparison of the relative permittivity and tan δ of each sample at a frequency of 1 kHz can be seen in Figure 9.

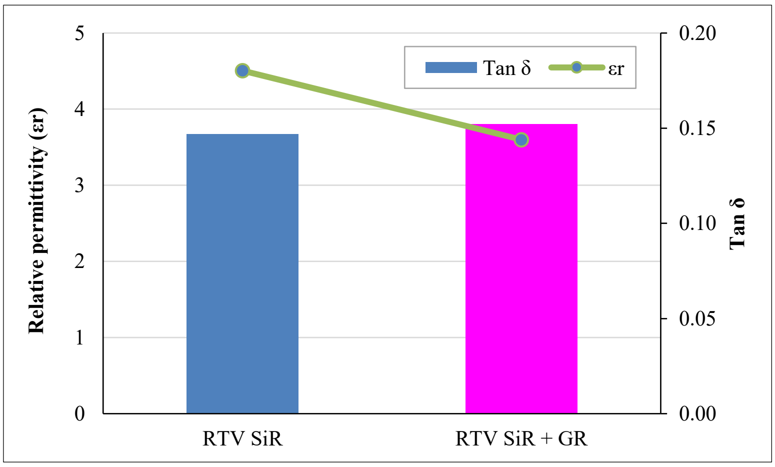


Figure 9. Comparison of relative permittivity and tan δ

The results of the relative permittivity test of gondorukem (gum rosin) + RTV is 3.5-3.6. This value is smaller than the relative permittivity of silicone rubber which is around 4.5. The permittivity decreases with the mixing of gum rosin and RTV silicone rubber. Meanwhile, tan δ has no significant change ranging from 0.140 to 0.152. Based on EDMS 29-300-1 of 2021 concerning the Specification for electrical insulation coating, the permittivity meets the standard and the tan δ value shows a small dielectric loss value.

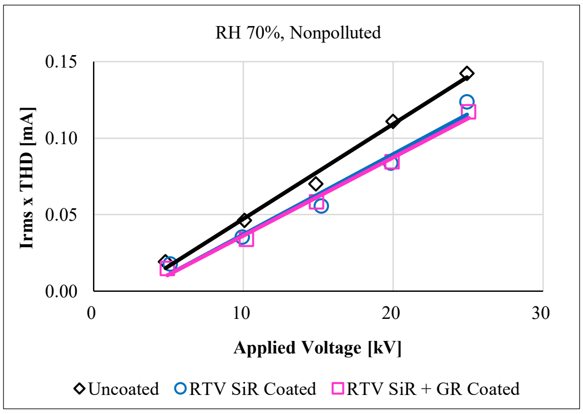
3-4- Leakage Current Experiment Result

Figure 10 provides a visual image of the application of pollutants to ceramic insulators. Leakage current was tested in two conditions, nonpolluted and highly polluted, based on standards IEC 507: 1991 and IEC-TS-60815-1-2008, with variation humidity of 70%, 80%, and 90%.

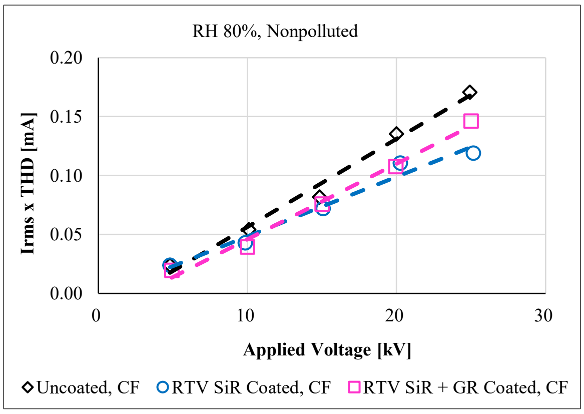
Condition	Ceramic Insulator		
	Uncoated	RTV SiR	RTV SiR + gum rosin
Polluted			

Figure 10. The visual image of ceramic insulators without and with coated

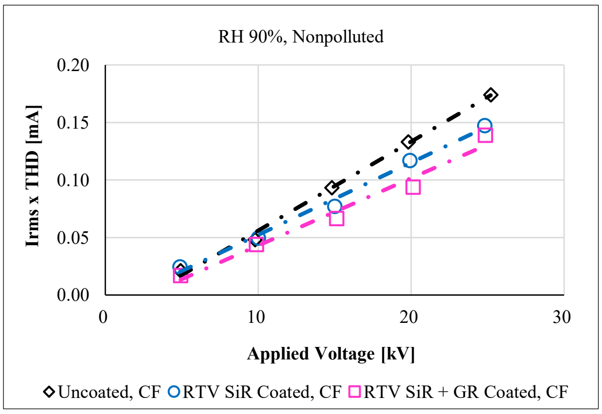
A comparison of the cross-products of leakage current (I_{rms}) and THD for nonpolluted and polluted with variation humidity can be seen in Figures 11 and 12. Compared to leakage current or THD parameters alone, this cross-product of the two is thought to be better for diagnosing insulators since it has a greater correlation factor with the severity of the insulator issue [41].



(a) RH 70%, Nonpolluted



(b) RH 80%, Nonpolluted



(c) RH 90%, Nonpolluted

Figure 11. Comparison of the cross-products of leakage current (I_{rms}) and THD nonpolluted condition

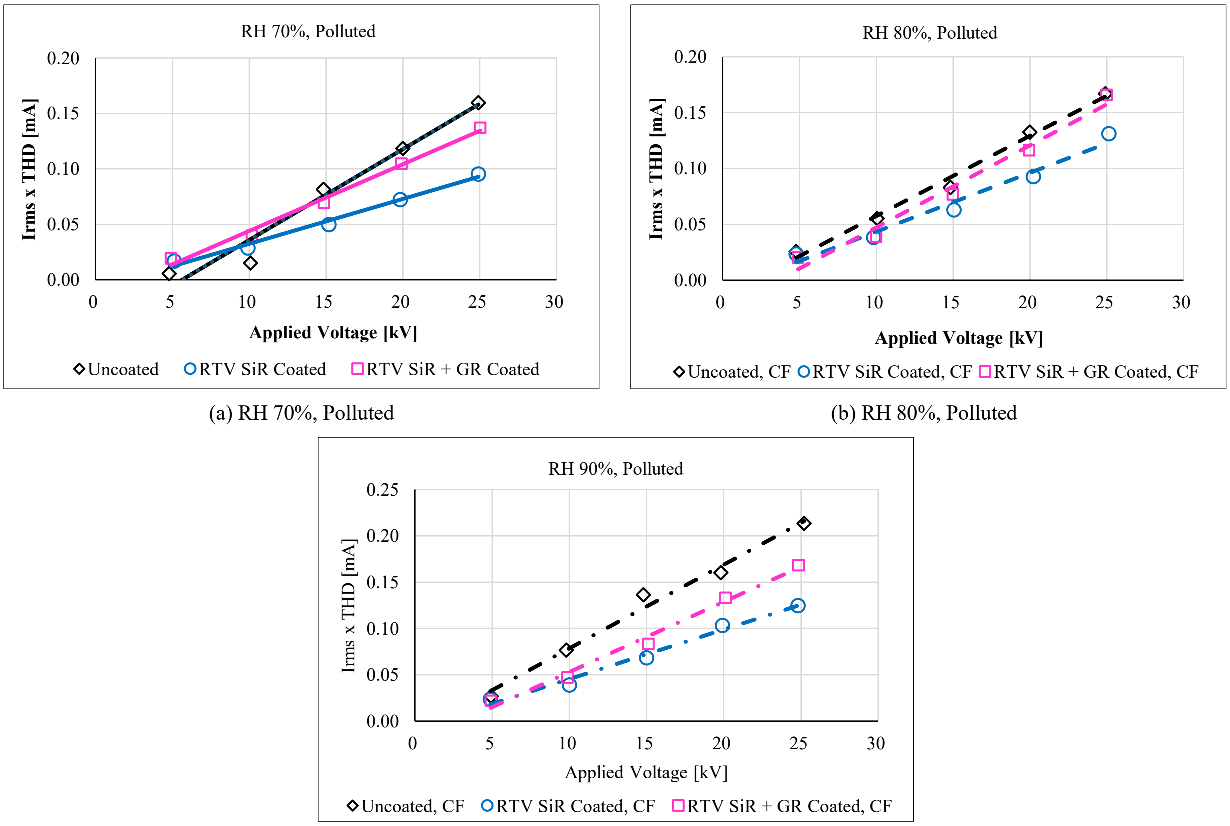
Figure 11 (a) shows the cross-product graph of leakage current (I_{rms}) and THD at 70% humidity under conditions without pollutants. From the figure, it can be seen that giving a coating to the insulator can reduce the leakage current. Adding gum rosin to silicone rubber can reduce the leakage current better although not too significant, ranging from 17-27% while silicone rubber alone is about 7-25%. Figure 11 (b) shows the cross-product graph of leakage current and THD at 80% humidity under conditions without pollutants. From the figure, it can be seen that the addition of gum rosin to silicone rubber can reduce the leakage current better up to a voltage of 10 kV (about 18-27%), above 10 kV is not better when compared with silicone rubber alone, where the decrease in leakage current is about 7-21% while silicon rubber alone decreases about 12-30%. Figure 11 (c) shows the cross-product graph of leakage current and THD at 90% humidity under conditions without pollutants. From the figure, it can be seen that the addition of gum rosin to silicone rubber can reduce the leakage current, which is greater, ranging from 9-29%, while silicone rubber alone is about 0-17%.

Table 4 shows the percentage reduction cross-product of leakage current (I_{rms}) and THD in the nonpolluted conditions of each insulator after applying RTV SiR and RTV SiR + gum rosin coating.

Table 4. Reduced cross-products of leakage current (I_{rms}) and THD nonpolluted conditions

Voltage (kV)	Humidity					
	70%		80%		90%	
	RTV SiR Coated	RTV SiR + Gum rosin Coated	RTV SiR Coated	RTV SiR + Gum rosin Coated	RTV SiR Coated	RTV SiR + Gum rosin Coated
5	7%	23%	0%	18%	-	19%
10	24%	27%	20%	27%	-	9%
15	20%	17%	12%	7%	17%	29%
20	25%	24%	18%	21%	12%	29%
25	13%	18%	30%	14%	15%	20%

The above results show that in conditions without pollutants with variations in humidity, the addition of gum rosin to silicone rubber is effective at high humidity, as in environmental conditions in mountainous areas. This is because the addition of gum rosin to silicone rubber can increase its hydrophobicity, making this coating material effective in high humidity.



(a) RH 70%, Polluted

(b) RH 80%, Polluted

(c) RH 90%, Polluted

Figure 12. Comparison of the cross-products of leakage current (I_{rms}) and THD polluted condition

Figure 12 (a) shows the cross-product graph of leakage current and THD at 70% humidity in polluted conditions. From the figure, it can be seen that adding gum rosin to silicone rubber can reduce the leakage current when compared to an uncoating insulator, but is not better when compared to a silicone rubber coating alone. With the addition of gum rosin, the leakage current can be reduced by up to 15%, while the silicone rubber alone can reduce the leakage current by up to 40%. Figure 12 (b) shows the cross-product graph of leakage current and THD at 80% humidity in polluted conditions. Similar to 70% humidity, adding gum rosin to silicone rubber can reduce the leakage current when compared to an insulator uncoating, but is not better when compared to a silicone rubber coating alone. With the addition of gum rosin, the leakage current can be reduced by 1-29%, while the silicone rubber alone can reduce the leakage current by 8-30%. Figure 12 (c) shows the cross-product graph of leakage current and THD at 90% humidity under polluted conditions. As in 70% and 80% humidity, adding gum rosin to silicone rubber can reduce leakage current when compared to insulators uncoating, but not better when compared to silicone rubber coating alone. With the addition of gum rosin, leakage current can be reduced by 17-39%, while silicone rubber alone can reduce leakage current by 13-50%.

Table 5 shows the percentage reduction cross-product of leakage current (I_{rms}) and THD in the polluted conditions of each insulator after applying RTV SiR and RTV SiR + gum rosin coating.

Table 5. Reduced cross-products of leakage current (I_{rms}) and THD polluted conditions

Voltage (kV)	Humidity					
	70%		80%		90%	
	RTV SiR Coated	RTV SiR + Gum rosin Coated	RTV SiR Coated	RTV SiR + Gum rosin Coated	RTV SiR Coated	RTV SiR + Gum rosin Coated
5	-	-	8%	21%	13%	19%
10	-	-	30%	29%	49%	39%
15	39%	15%	24%	8%	50%	39%
20	39%	12%	30%	12%	36%	17%
25	40%	14%	21%	1%	42%	21%

The results above show that in polluted conditions, where the pollutant given is a high pollutant (IEC-TS-60815-1-2008), the addition of gum rosin to silicone rubber does not improve the reduction in leakage current when compared to those without gum rosin (silicone rubber alone). This condition applies to all humidity from 70% to 90%. Although the addition of gum rosin to silicone rubber can increase hydrophobicity, when there are pollutants, the hydrophobic properties of the coating material become ineffective and become more conductive.

From the results of the leakage current test, it is known that the greater the voltage applied, the greater the leakage current. This is because the voltage is directly proportional to the current. It can also be seen that coating the ceramic insulator can reduce the leakage current compared to those without a coating. Adding gum rosin to silicone rubber at 70% and 90% humidity can reduce the leakage current better than without gum rosin. This is because gum rosin has hydrophobic properties, which can reduce leakage current. While at 80% humidity, gum rosin in silicone rubber can reduce leakage current better up to a voltage of 10 kV. However, this does not apply to polluted conditions, with gum rosin in silicone rubber, it is not better to reduce the leakage current. With the presence of pollutants and the increasing level of pollutants, the leakage current can increase because the higher the pollutant, the higher the level of conductivity, thus making the leakage current also more excellent.

4- Analysis and Discussion

Organosilane molecules found in RTV silicone rubber have the unusual capacity to create covalent connections between inorganic and organic (Si-O) atoms. RTV silicone rubber can increase the thermal stability of thermosetting epoxy because the Si-O functional group is covalently bonded and the bond energy required to break the Si-O covalent bond is relatively high in comparison to other functional groups C-C or C-O in epoxy resin. As a result, the temperature required for the material degradation process is also relatively high. The thermal stability increases with the addition of weight% RTV silicone rubber [42].

The comparison between C/O and Si/Al components can be used as a degradation assessment parameter in the insulator. This is because the presence of oxygen on the surface of the insulator and the decrease in carbon content result from extensive oxidation (degradation) on the surface of the insulator. Thus, the ratio between O/C elements increases while the Si/Al ratio decreases in samples that experience degradation (aging) [43]. Although in gum rosin the O/C element ratio value is 0.081, whereas in silicon rubber is 0.85 and RTV SiR+ gum rosin is 0.36, which means that the level of degradation in silicon rubber is higher compared to gum rosin and RTV SiR+ gum rosin.

From the results of contact angle testing using 10 measurements, gum rosin's average contact angle was 68.05^0. This result shows that gum rosin has better hydrophobicity characteristics when compared to uncoated ceramic specimens with a contact angle of about <55° [44]. The results of testing the contact angle of RTV SiR obtained an average contact angle (hydrophobicity) of RTV SiR of 92°. The results obtained are the same as research that has been done previously [44]. These results indicate that RTV SiR has good hydrophobic characteristics. From hydrophobicity testing, it is known that gum rosin can increase the hydrophobicity of ceramic insulators, but it is still below 90°, which means it is still hydrophilic. When compared with RTV SiR, its hydrophobicity is better. This is because RTV SiR is located in the LMW bond of the methyl group (CH_3), silicon (Si), oxygen atoms (O), and alumina trihydrate that make up the insulator housing. The chemical bonds of Si-O chemical silicon rubber can be broken down by heat, UV, and corona activity [45], when this functional group is easily separated, it means that the main chain in the insulator will easily be separated so that the structural strength of the insulator will decrease, this will result in the insulator being easily degraded [46, 47].

From the results of the hydrophobicity test, adding gum rosin to RTV SiR can increase the hydrophobicity of RTV SiR from 92° to 96.65°. Meanwhile, from the gum rosin side, the addition of RTV SiR can increase the hydrophobicity of gum rosin, which was originally $68{,}05^0$ to 96.65^0. This shows that the combination of gum rosin with specific polymers can improve the mechanical and chemical stability of materials [23]. Based on IEC TS 62073 hydrophobic classification, the results of measuring the hydrophobicity of RTV SiR + gum rosin have class 1 of hydrophobicity. RTV SiR + gum rosin produces better hydrophobicity compared to RTV SiR. Still, in a limited composition because when the composition of gum rosin increases, the coating does not dry out, so it can be concluded that RTV SiR is the base coat and gum rosin is the composite material.

Based on EDMS 29-300-1 of 2021 concerning Specifications for electrical insulation coating, for surface resistivity values based on IEC 60093 & ASTM D257 standards, a good surface resistivity for insulator coating material is more than 1 GΩ and from the results of the gum rosin surface resistivity test meets these standards and the results are not much different when compared to RTV SiR. Research [7, 25] states that adding gum rosin to RTV SiR can increase surface resistivity. From insulation characteristics, gum rosin has good insulating properties. When mixed with RTV SiR, they form an additional insulating layer on the material's surface. This reduces electrical conductivity and increases surface resistivity. From the surface polarization side, gum rosin can modify the surface of RTV SiR. When the surface of a material is more polar, it is more difficult for electric charges to move through the material, so surface resistivity increases. From the dielectric effect side, gum rosin acts as an additional dielectric material on the RTV SiR surface. Dielectrics are materials that separate electrical charges and affect the material's ability to store electrical energy. With the addition of gum rosin, the dielectric capacity of RTV SiR can be increased, and through structural stabilization, gum rosin can reduce the structural instability of RTV SiR.

By mixing gum rosin and RTV SiR, the permittivity decreases. Permittivity is the ability of a material to withstand an electric field. The greater the relative permittivity, the greater the material as a dielectric. From the test results, the relative permittivity of RTV SiR + gum rosin is 3.5-3.6. This value is smaller than the relative permittivity of silicon rubber which is around 4.5. Meanwhile, for tan δ there was no significant change, ranging from 0.147 to 0.152. Based on EDMS 29-300-1 of 2021 regarding Specification for electrical insulation coating, for the permittivity value based on the ASTM D150 standard, the good constant permittivity/dielectric for insulator coating material is 2-10 and from the results of RTV SIR + gum rosin surface resistivity testing meets these standards and the tan δ value indicates a small dielectric loss value.

An insulator's electrical capability is stated to be good when it has considerable insulation resistance, high dielectric strength, high arcing resistance, low dielectric loss/dissipation factor, high thermal conductivity, and does not contain gas-filled pores so that partial discharge does not occur.

Insulators are designed to have a breakdown voltage value greater than the flashover voltage, because breakdown voltage can cause malfunction of the insulator, unlike flashover voltage which can be prevented by coating with filler. This flashover voltage is a limit for determining the dielectric strength of an insulator [48].

The leakage current test results show that using coatings on the insulator surface can reduce the leakage current. In conditions without pollutants, the addition of gum rosin to silicone rubber proved effective in reducing leakage current compared to without the addition of gum rosin, especially at 90% humidity. This is because gum rosin has hydrophobic properties so that it can reduce leakage current. This is because adding gum rosin to RTV SiR has better hydrophobic properties than gum rosin alone or RTV SiR alone, as seen in the contact angle test above. While at 80% humidity, gum rosin in silicone rubber can reduce the leakage current better up to a voltage of 10 kV. When applied to polluted conditions, with the presence of gum rosin in silicone rubber, it is not better at reducing leakage current. With the presence of pollutants and higher levels of pollutants, the leakage current can increase because the higher the pollutants, the higher the level of conductivity, thus making the leakage current also greater. This is because RTV SiR is located in the LMW bond of the methyl group (CH_3), silicon (Si), oxygen atoms (O), and alumina trihydrate that make up the insulator housing. The chemical bonds of Si-O in silicon rubber can be broken down by heat, UV light, and corona activity [45]. When this functional group is easily separated, it indicates that the main chain in the insulator can also be easily cleaved, leading to a decrease in the structural strength of the insulator; this results in the insulator being more susceptible to degradation [46, 47].

However, this does not apply to polluted conditions. The presence of gum rosin in silicone rubber is not better for reducing leakage current than silicone rubber alone. However, compared to uncoating insulators, it can still reduce leakage current in polluted conditions. This shows that with the addition of organic material, namely gum rosin, which is a cheap and environmentally friendly coating material, the results are not much different from silicone rubber filler nano silica which is also more effective in conditions without pollutants compared to pollutants [49] so that gum rosin can be considered as an alternative additional material that is cheap and environmentally friendly.

5- Conclusion

In this study, the characteristics of gum rosin as a mixture material of RTV silicone rubber were tested. This research investigates the SEM EDX test, hydrophobicity test, surface resistivity test, relative permittivity (εr), tan δ, and leakage current testing of ceramic insulators coated with RTV SiR and gum rosin. The conclusion of this study shows that the addition of gum rosin to RTV silicone rubber significantly improves the performance of ceramic insulators. This study revealed that the mixture of RTV silicone rubber with 5 wt.% gum rosin increased the surface hydrophobicity, which was shown by an increase in contact angle from 92° to 96.65°. Higher hydrophobicity helps prevent water absorption on the insulator surface, which is important for reducing leakage current.

In addition, SEM EDX test results show that adding gum rosin increases the carbon content of the blend, which contributes to an increase in surface resistivity. Higher surface resistivity indicates that the insulator surface becomes less conductive, which reduces the leakage current that can flow through it. Leakage current testing demonstrates that the silicone rubber RTV blend with gum rosin can decrease the leakage current by 9.42% at 70% relative humidity, 7.06% at 80% relative humidity, and 10.02% at 90% relative humidity under unpolluted conditions. Although there was a reduction in leakage current in polluted conditions, the effectiveness of these mixtures was not as good as in non-polluted conditions. However, adding gum rosin to RTV silicone rubber improves the hydrophobicity, surface resistivity, and thermal and chemical stability, all contributing to reducing leakage current in ceramic insulators. Thus, gum rosin can be an effective additive to improve the performance of low-cost and environmentally friendly RTV silicone rubber coated ceramic insulators.

6- Declarations

6-1- Author Contributions

Conceptualization, R.A.D., U.K., and S.; methodology, R.A.D., R., and S.; software, R.A.D.; validation, R.A.D., R., and S.; formal analysis, R.A.D.; investigation, R.A.D.; resources, R., U.K., and S.; data curation, R.A.D.; writing—original draft preparation, R.A.D.; writing—review and editing, R.A.D., R., U.K., and S.; visualization, R.A.D.; supervision, R., U.K., and S.; project administration, U.K. and S.; funding acquisition, U.K. and S. All authors have read and agreed to the published version of the manuscript

6-2- Data Availability Statement

The data presented in this study are available in the article.

6-3- Funding

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6-4- Institutional Review Board Statement

Not applicable.

6-5- Informed Consent Statement

Not applicable.

6-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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