

The Performance of High Voltage Insulator Based on Epoxy-Polysiloxane and Rice Husk Ash Compound in Tropical Climate Area

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Abstract This paper presents the effect of natural aging upon the performance of the polymeric insulation materials made from Epoxy resins, Polydimethylsiloxane (PDMS), and Rice husk ash compound. The samples of epoxy resin insulation material consist of Diglycidyl Ether of Bisphenol A (DGEBA), Meta Phenylene Diamine (MPDA) as curing agent, and 325 mesh Rice Husk Ash (RHA) as filler, treated with variation of PDMS content. The research aims are to observe the Equivalent Salt Deposit Density (ESDD), critical leakage current, and flashover voltage on the insulation material surface that has undergone a natural aging. Experimental method was carried out through the following procedure. The samples were placed outdoor for natural aging test, outside the building of electrical engineering and information technology of Gadjah Mada University in Indonesia. Then the ESDD, critical leakage current, flashover voltage on the sample surface was measured every 2 weeks. The experiment results show that the performance of insulator material fluctuates during 52 weeks. The higher PDMS with RHA filler content the lower ESDD and surface leakage current. Furthermore the flashover voltage increases.

Keywords Epoxy-polysiloxane, Rice Husk Ash, Equivalent Salt Deposit Density, Critical Leakage Current, Flashover Voltage

1. Introduction

The use of epoxy resins as high voltage insulator material is appropriate, because of its high dielectric strength (25-45 kV/mm)[1]. But epoxy resin insulating materials is very sensitive when used in areas with high temperature, high humidity, the existence of pollutants and ultraviolet radiation[2]. The main advantages of epoxy resin over porcelain material as insulator material are that it is much lighter (because of low density), easy handling, easy blending with additives, and having hydrophobicity.

Many researchers revealed that the first generation polymeric insulator material of epoxy resin based on bisphenol A with silica sand filler for outdoor insulators had satisfactory performance in normal air conditions. But, for long term outdoor service, their performance was unsatisfactory. There was a crack on the surface because it was not resistant to ultraviolet radiation[3]. The next

generation is the cast epoxy resin cycloaliphatic. It shows good performance under normal atmospheric condition, but the performance will be decreased under polluted atmospheric condition[4,5]. The weakness of the cast epoxy resin cycloaliphatic is the impurity of its filler, Alumina Trihydrate (ATH), which may consist of Sodium Oxide (Na₂O) and Potassium Oxide (K₂O). Those two alkali oxide along with water will form Alkali Hydroxyl (NaOH and KOH), a strong electrolyte, which can change dielectric property of cast epoxy resin cycloaliphatic [6].

An aging test to analyze Silicon Rubber (SiR) type polymeric polysiloxane insulator and Ethylene Propylene Diene Monomer (EPDM) insulator performance was held outside Anneberg Bulk Station, West Coast Sweden by observing the relationship between surface condition and performance of polymeric insulator. Six SiR and three EPDM samples were analyzed by using Electron Spectroscopy for Chemical Analysis (ESCA), Attenuated Total Reflection Fourier Transform Infrared (ATR-FTIR), and Scanning Electron Microscopy (SEM). The results conclude the relationship between insulation material surface condition and hydrophobic property, leakage current and voltage resistance. In EPDM insulator, a high magnitude of leakage current and intensity of arc occurs. But, in insulator of SiR only a very

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Published online at <http://journal.sapub.org/eee>

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low leakage current occurs.

Polysiloxane (i.e. silicon rubber) is able to create hydrophobic properties on insulator surface in which prevents water layer formation and leakage current occurrence on its surfaces. Low Molecule Weight (LMW) component is diffused from the bulk of SiR to the outer surface layer. LMW will then film the pollutant and maintain the hydrophobic properties (i.e. prevent water layer formation on insulator surface)[8].

Adding ATH to SiR gives better resistance of erosion and tracking. Surface degradation of elastomeric silicon with lower filler (0-25%) will make tracking phenomenon occurs faster, while higher filler (50%-70%) will delay surface degradation due to dry band arc phenomenon and reduce water absorption[9].

The application of polysiloxane on the mixture of epoxy and rice husk ash as the filler affects the hydrophobic properties. The higher filler content in insulator the bigger contact angle of water droplets on the insulator surface[10].

Insulator contaminations become a troublesome in electrical power system operation. Wet atmospheric condition will form thin water layer on the insulator surface. Then, the present of the contaminant inside the layer will create leakage current on the insulator surface[11]. The contaminant layer accumulation at the surface of the insulator will increase the leakage current in which causes flashover voltage and give damage to insulator[12].

Considering that electrical properties of polymeric insulators are influenced by the type of material and the environmental conditions, therefore this paper will discuss performance of epoxy-polysiloxane polymeric insulator materials with rice husk ash as the filler (EP-RHA) under natural tropical climate. The performance is measured as equivalent salt deposit density, surface leakage current, and the flash-over voltage.

2. Epoxy - Polysiloxane Polymeric Insulator

2.1. Epoxy Resin Polymeric Insulator Material

Epoxy is a thermosetting chemical compound. It consists of oxygen and carbon atomic bond which is generated by chemical reaction between epichlorohydrin and bisphenol A. A complex structure of epoxy resin has molecule bond as shown in Fig. 1.

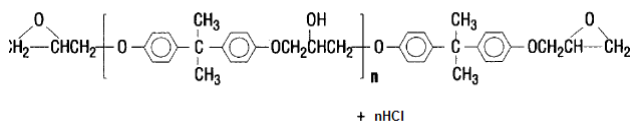


Figure 1. Epoxy resin structure

Epoxy resin will harden when mixed with hardener, catalyst and filler. It is widely used as insulator, house hold equipment, machinery component, automotive, tank, pipe,

aeroplane body part, bridge construction, etc. An epoxy resin formation reaction with MPDA hardener is shown in Fig. 2.

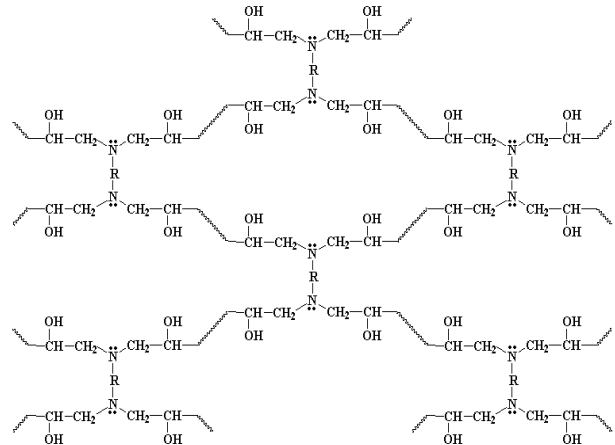


Figure 2. Epoxy resin formation reaction with MPDA hardener

2.2. Polysiloxane Polymeric Insulator Material

Polysiloxane is a polymeric material that consists of silicon and oxygen atom on its main chain. Polysiloxane main chain is more flexible than vinyl polymeric and polyolefin. The chemical structure of polysiloxane is shown in Fig. 3.

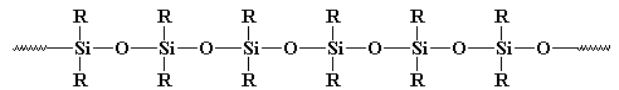


Figure 3. Chemical structure of Polysiloxane

Several applications of polysiloxane are statue and frame moulding material, mixture compound, filler liquid and insulation coating of electrical and electronics equipment, filler compound in polyester, electric insulation material, chemical and ultraviolet radiation proof material for human body treatment product.

Polysiloxane can be formed through addition and condensation polymerization. Polysiloxane, in the addition polymerization is formed at siloxane bonds (Si-O) which have double bond as vinyl (—C=C—) at the edge. While in the condensation polymerization is formed in siloxane bond which has hydroxyl (OH) group at the edge.

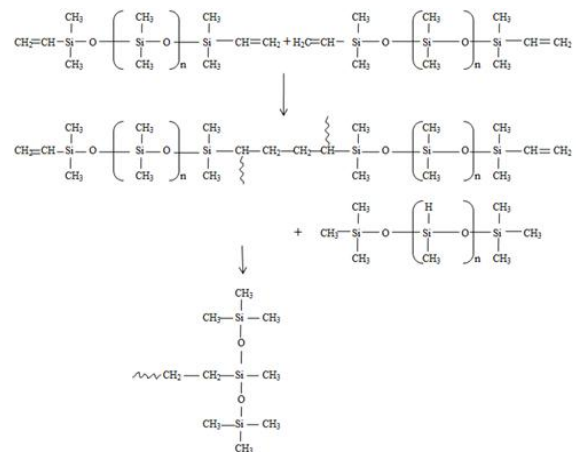


Figure 4. Addition polymerization reaction process resulting PDMS

Addition polymerization reaction of polysiloxane with chloroplatinic acid catalyst creates PDMS as shown in Fig.4.

Thermal stability of Si-O bond is very good, but has a relatively high ionic property. This property makes the bond easily broken on a high concentration of acid or alkali[13]. Strong bond of Si-O gives very high resistance properties of SiR against damage from environment condition or corona phenomenon. This Si-O also has similar property to glass or quartz which will not leave a conductive layer when burnt, e.g. burning caused by arching. Instead of the good thermal properties, SiR has stable elasticity within temperature range of -50°C up to +230°C (long thermal stability). This latest property is the most important property criteria of electrical insulator[14].

2.3. Rice Husk Ash

In Indonesia, rice husk is usually used for main firing material (fuel) in brick industry or as plant seed medium, while its ash is usually used for cleaning-rub ashes or even wasted. Rice husk burning will produce RHA with very high SiO₂ content (>80% from total weight). When continuous burning at 500 to 700°C for 1-2 hours applied, RHA will contain large amount of amorphous silica which can increase mechanical property of cement-RHA mixture at certain dosage[15,16].

3. Insulator Material Performance

3.1. Equivalent Salt Deposit Density (ESDD)

The outdoor insulator surface will be contaminated by pollutant which is carried by the wind. Pollutant materials basically divided as 2 major components: conductive components and inert components. The conductive components mostly consist of ionic salt such as sodium chloride (NaCl), sodium sulphate (Na₂SO₄), magnesium chloride (MgCl₂), etc. Inert components are a solid materials or cations which can not being unravelled to ions in liquid (e.g. kaolin, silica, bentonite, cement, etc). These inert components can create mechanical bond with conductive component particles. Kaolin, cement dust and silica make the insulator surface become hydrophilic, while oil creates hydrophobicity.

Table 1. *b* Factor

θ (°C)	<i>b</i>
5	0.03156
10	0.02817
15	0.02277
20	0.01905

Contamination level which is caused by a certain salt can be measured by using Equivalent Salt Deposit Density (ESDD) method which is expressed in mg/cm². The ESDD procedure includes measuring conductivity of cleaning materials i.e. water and cotton, before and after cleaning. This is

done at certain room temperature and then converted to standard 20°C conductivity by using correction factor as shown in Table 1[17].

The next step is calculation of conductivity by using following equation (1):

$$\kappa_{20} = \kappa_{\theta} [1 - b(\theta - 20)] \quad (1)$$

Where: κ_{20} = standard conductivity in 20°C (μS/cm); κ_{θ} = conductivity at temperature θ °C (μS/cm); θ = temperature of liquid (°C); *b* = correction factor in temperature (θ).

With the value of conductivity at 20°C, salt concentration is calculated (in %) by using following equation (2):

$$D = \frac{(5,7 \times 10^{-4} \times \kappa_{20})^{1,03}}{10} \quad (2)$$

Where: *D* = Salt concentration (%); κ_{20} = Conductivity at 20°C (μS/cm).

The ESDD can be calculated by using following equation (3):

$$ESDD = 10 \times V_{ap} \times \frac{(D_2 - D_1)}{S} \quad (3)$$

Where: *ESDD* = Equivalent Salt Deposit Density (mg/cm²); *V_{ap}* = washing water volume (ml); *D₁* = equivalent salt concentration of water and cotton before washing (%); *D₂* = equivalent salt concentration of water and cotton after washing (%); *S* = washed insulator surface area (cm²).

If the conductivity value, κ_{20} , is only 0.004-0.4 S/m, the following equations are used (eq. 4 and eq. 5):

$$S_a = (5.7 \kappa_{20})^{1,03} \quad (4)$$

$$ESDD = (S_a V) / A \quad (5)$$

Where: *S_a* = salt content at insulator surface in kg/m², *V* = washing water volume in cm³, and *A* = washed insulator surface area.

3.2. Leakage Current on Insulator Surface

Most of high voltage insulator applied outdoor in electrical power transmission systems. Polluted environment will create a long term pollution coating on insulator surface. This pollution coating does not have a detrimental effect when the insulator is dry. The electrostatic field determines the voltage distribution of such a dry insulator and a very small capacitive leakage current flow across the entire insulator. However in the atmospheric condition is wet, the contamination particles on the insulator surface will dissolve into the water and provide a continuous path of conduction between the high voltage electrode and ground.

When an insulator is wet, a resistive leakage current flows in a conducting path on the insulator surface which has greater value than capacitive current (in case the insulator is in dry condition). At this point, the equivalent circuit can be represented by resistance (*R_w*). This leakage current creates in non-uniform heating of the contamination layer that eventually causes dry bands to be formed at the narrow sections where the surface leakage current density is highest.

The voltage distribution along the surface of wet polluted insulators is very non-uniform when a dry band is formed in series with the conductive film. Since the resistance of the

dry band is very high, the whole applied voltage across the insulator appears across the dry band. As a result, the breakdown occurs across the dry band when it reaches the air critical flashover voltage and generates small sparks between the separating moisture films.

The heat resulting from the small sparks creates carbonization and volatilization on the insulator surface which left permanent carbon tracks on the surface. This process will continue until the breakdown happen due to the formation of carbon bridge between electrodes [18]. This phenomenon is usually occurs in wet contaminated insulator surface.

The equivalent circuit after the appearance of dry band is represented by parallel resistance (R_d) and a capacitor (C_d). The leakage current phenomenon on the insulator surface and its electrical model is shown in Fig. 5.

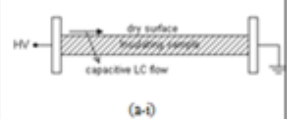
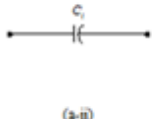
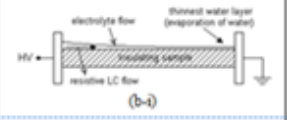
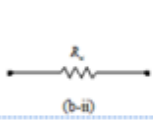
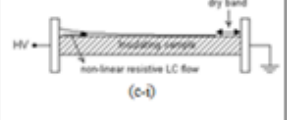
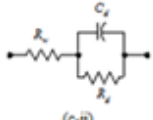
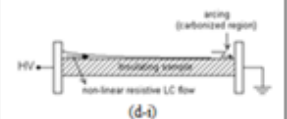
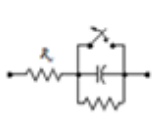
Physical form	The equivalent circuit
(a-i) 	(a-ii) 
(b-i) 	(b-ii) 
(c-i) 	(c-ii) 
(d-i) 	(d-ii) 

Figure 5. Leakage current phenomenon on insulator surface and its electrical model

The relationship between electrical field strength (E) and leakage current (I_{lc}) (eq. 6):

$$\bar{E} = NI_{lc}^{-n} \tag{6}$$

Where: \bar{E} = electric field (kV/cm); (I_{lc}) = leakage current (mA); N = constant which is related with electric field; n = constant which is related with leakage current.

3.3. Flashover Voltage on Insulator Surface

Flashover voltage is an external disturbance on insulator surface or fire arcing process on insulator surface. It may occur in solid surface or gas. Flashover voltage value is smaller than puncture voltage on an insulator. Several factor affect flashover voltage, such as: surface resistance of a material, surface condition and electric field shape between electrodes and insulator.

Flashover voltage on polluted condition follows this following sequence [19,20]:

- 1) Insulator with dry band and conductive pollution layers

are represented as a series of arc path along x (air gap) and resistance of polluted layer at every length unit $R' = R'(I)$, as in Figure 6.

- 2) The surface of insulator between two electrodes is an electric arc which is in series with conductive polluted layer.

- 3) The arcing can extend or shut-off if the electric field strength reaches certain value in dry band, then the electric discharge occurs and initiates flashover.

- 4) Flashover voltage occurs when the arc covers entire dry band and further the entire insulator surface between two electrodes.

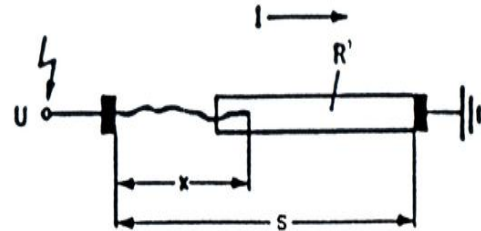


Figure 6. Model of insulator with dry band and contaminated layer to determine critical leakage current (I) and voltage (U)

The relationship between surface conductivity and flashover voltage can be shown in the following equations (eq. 7 – eq. 9):

$$V_{fo} = N \frac{1}{\kappa^{(n+1)}} \frac{-n}{L} \tag{7}$$

$$\frac{V_{fo}}{L} = N \frac{1}{\kappa^{(n+1)}} \frac{-n}{L} \tag{8}$$

$$E = N \frac{1}{\kappa^{(n+1)}} \frac{-n}{L} \tag{9}$$

where: V_{fo} = flashover voltage (kV); E = electric field (kV/cm); κ = surface conductivity due to pollutant ($\mu\text{S}/\text{cm}$); L = length of arcing when the flashover occur (cm).

During the flashover test, the voltage is increased step by step until the critical voltage for every insulator sample reached. The measurement value is then calibrated by using standard value in standard air condition [21] as the following equations (eq. 10, eq. 11):

$$V_s = \frac{V_B}{d} \tag{10}$$

$$d = \frac{b_B}{760} x \frac{273+20}{273+t_B} = \frac{0,386b_B}{273+t_B} \tag{11}$$

Where: V_s = standard flashover voltage (Volt); V_B = measured flashover voltage (Volt); d = relative air density (mmHg/ $^{\circ}\text{C}$); t_B = ambient temperature during test ($^{\circ}\text{C}$); b_B = ambient air pressure during test (mmHg).

4. Experimentation

4.1. Materials and Testing Tools

The materials used in this experimentation consist of: 1) Epoxy resins, with the basic material is Diglycidyl Ether of Bisphenol A (DGEBA) and hardener is Meta Phenylene

diamine (MPDA) (brand name: Eposchon); 2) Silicon Rubber (SiR), type: RTV 585 with catalyst code: 60R (chloroplatinic acid) (brand name: Rhodorsil); 3) Rice husk ash, 325 mesh, type: IR 64, as filler material.

Test sample was made in round shape with 70 mm diameter and 5 mm thickness, and coded as: RTV_{EP1}(filler 10%), RTV_{EP2}(filler 20%), RTV_{EP3}(filler 30%), RTV_{EP4}(filler 40%), and RTV_{EP5}(filler 50%).

The testing tools consist of: 1) Fog chamber with size of 1.2 x 1.2 x 1.2m as testing chamber; 2) High voltage apparatus, transformer 220/100000 volt, 5 kVA, 50 mA current, 4% impedance, 50/60 Hz; 3) Thermometer for temperature, hygrometer for humidity and barometer for air pressure measurement; 4) Oscilloscope, LeCroy 9354 AL, 500 MHz; 5) Conductivity meter, Hanna Instrument HI8633.

All tools are available in the High Voltage Laboratory, Electrical Engineering and Information Technology, Gadjah Mada University, Yogyakarta, Indonesia.

4.2. Testing Procedure

The test samples are installed outdoor, outside Electrical Engineering building, Gadjah Mada University. Samples are placed in support bracket with 45° tilt, flipped every week and taken for performance test every 2 weeks. This procedure applies for 52 weeks experiment period.

The ESDD procedure will follow these steps: 1) Preparing a beaker, measuring cup, and cleaning cotton; 2) Filling a beaker with 200 ml distilled water; 3) putting the cotton inside the beaker, measuring the temperature and conductivity; 4) Separating the pollutant layers from the samples by rubbing the soaked cotton, then putting the pollutant and the cotton into the beaker, and finally stirring them; 5) Measuring the temperature and conductivity of water and cotton mixture. The conductivity with and without pollutant are converted into standard conductivity at 20°C by using b factor based on IEC 507 standard (1991), then calculating salt concentration (in %) by using equation (2). The ESDD can be calculated the by using equation (3).

Leakage current measurement procedure can be explained as following steps: 1) Putting test sample into fog chamber with 70% humidity (after fogging); 2) Applying voltage. Every sample is tested by applying increase voltages with a step of 1.5 kV/sec, from 11.5 kV up to 50% flashover voltage; 3) Recording. Every surface leakage current displayed and recorded by an oscilloscope; 4) Multiplying the voltage value from the oscilloscope with multiplying factor of voltage divider equivalent for obtaining leakage current value; 5) Calculating critical surface leakage current.

Flashover measurement procedure can be explained as following steps: 1) Putting test samples into fog chamber with 70% humidity (after fogging); 2) Applying voltage. Every sample is tested by applying increase voltages with a step of 1.5 kV/sec until flashover occurs; 3) Recording temperature, humidity and air pressure then converting flashover voltage value by using standard value correction factor (as eq. 10 and eq. 11).

The measurement tools arrangement is shown in Fig. 7.

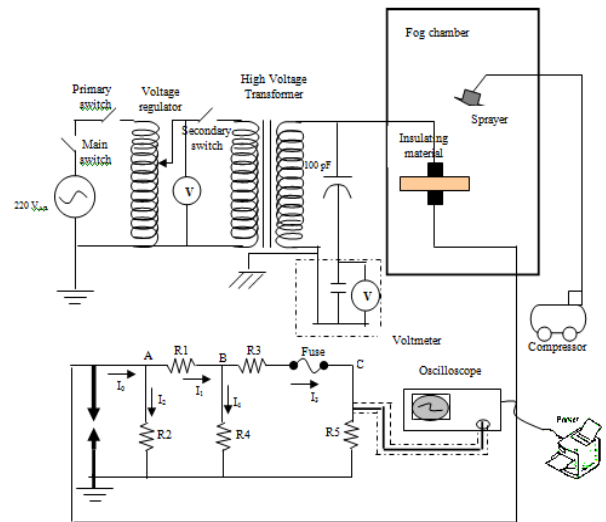


Figure 7. The measurement tools arrangement for leakage current and flashover voltage test

5. Results and Discussion

The following sections below show the performance results of insulator materials of epoxy-polysiloxane with rice husk ash filler for each composition during 52 weeks experimentation.

5.1. ESDD Performance of Epoxy-polysiloxane Polymeric Insulator with Rice Husk Ash Filler

Fig. 8 shows the results of ESDD of EP-RHA insulator in each composition against natural aging. The experiment period is 52 weeks. It is calculated by using equation (3).

ESDD value of EP-RHA insulator material with various compositions is fluctuating during the aging process. This phenomenon happened due to variation of composition and local climate condition during the test. The highest the filler composition the lower the ESDD value is. The increase of filler material then makes methyl group (CH₃) on insulator surface also increases. This makes the insulator material more hydrophobicity[10]. When there is a rain, the EP-RHA insulator surface will be wiped up by the water. This hydrophobic property will decrease the ESDD and surface leakage current, so the power losses will be decrease as well[20].

Fig. 8 shows ESDD value from initial aging until week 12th which fluctuates and tends to increase (Nov 2010 to Jan 2011). It is because of the tropical climate with low rain intensity. From week 14th to 28th (Feb - May 2011), the ESDD value of EP-RHA insulator surface tends to decrease due to high rain intensity (rainy season). From week 30th to 44th (Jun - Sep 2011), the ESDD tends to increase due to entering summer season. From week 46th to the end of week 52nd (Sep-Nov 2011), the value of ESDD decreases due to beginning of rainy season.

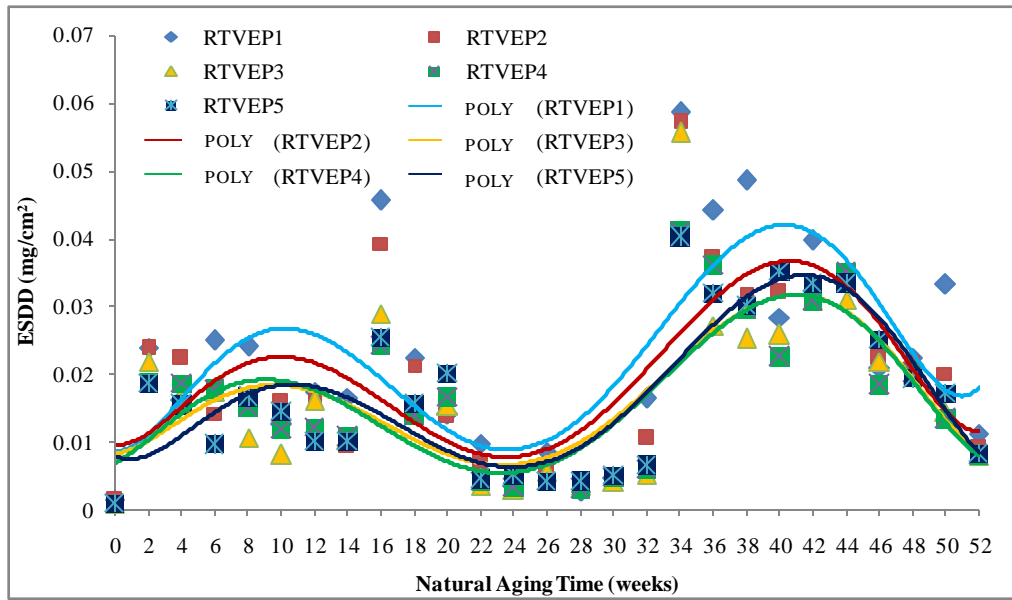


Figure 8. ESDD value against duration of aging for various filler composition in 52 weeks natural aging

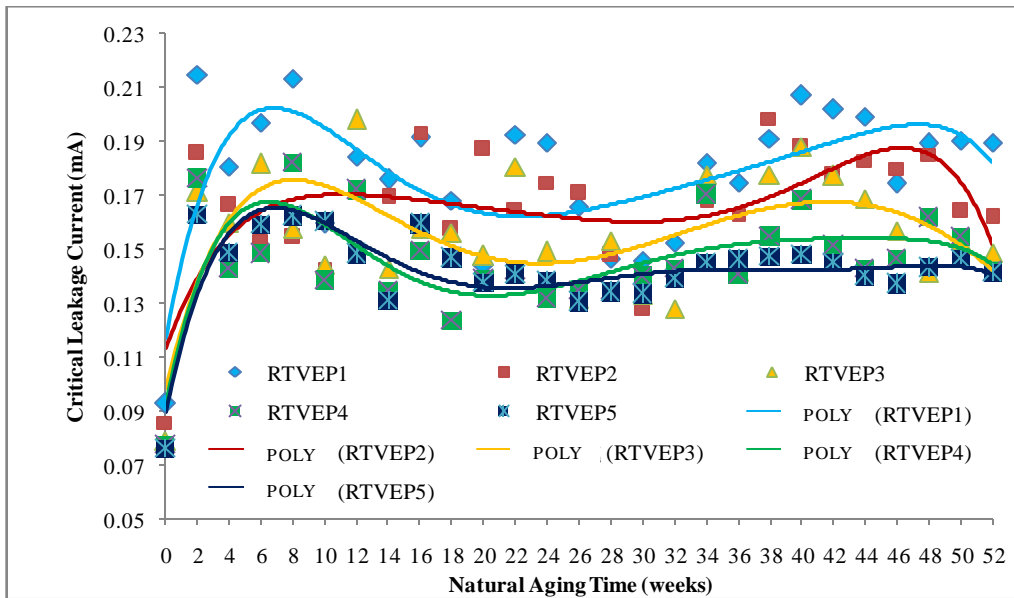


Figure 9. Critical leakage current on insulator surface for various filler composition in 52 weeks natural aging

The results of measured ESDD for every sample are shown in Table 2.

Table 2. ESDD performance of EP-RHA insulator

Test samples	ESDD (mg/cm ²)	
	(min – max)	average
RT V _{EP1}	0.0016-0.0586	0.0226
RT V _{EP2}	0.0015-0.0572	0.0195
RT V _{EP3}	0.0010-0.0557	0.0166
RT V _{EP4}	0.0010-0.0411	0.0164
RT V _{EP5}	0.0010-0.0403	0.0171

5.2. The Critical Leakage Current Performance of

Epoxy-polysiloxane Polymeric Insulator with Rice Husk Ash Filler

The Fig. 9 shows the two dimensional results of critical leakage current of EP-RHA insulator in each composition against natural aging. The experiment period is 52 weeks. The critical leakage current values of EP-RHA insulator material with various compositions are fluctuating during the aging process. These values have the same trend with fluctuating value of ESDD. The higher ESDD the higher critical leakage current is, as shown in Fig. 10.

The natural atmospheric condition covers those EP-RHA insulators with pollutants. The pollution layer increases the conductivity on the insulator surfaces. In wet atmospheric condition, the salt component in the pollution layer will dissolve in the water which is a form of electrolyte.

As the result, the EP-RHA insulator surfaces become conductive, and therefore the leakage current flows on its surface. The higher ESDD the higher the conductivity is on the EP-RHA insulator. The higher conductivity, the higher surface critical leakage current is.

The filler material is measured in percentage of overall composition. The higher filler composition the lower the ESDD is. For example in case of 10% composition (RTV_{EP1}) the average ESDD is 0.0226 mg/cm². In the other hand in case of 50% composition the average ESDD is 0.0171 mg/cm².

Table 3. Critical leakage current performance of EP-RHA insulator

Test samples	Critical leakage current (mA)	
	(min – max)	average
RTV _{EP1}	0.0927-0.2149	0.1782
RTV _{EP2}	0.0858-0.1984	0.1653
RTV _{EP3}	0.0788-0.1981	0.1556
RTV _{EP4}	0.0776-0.1822	0.1460
RTV _{EP5}	0.0758-0.1628	0.1425

Finally, a lower ESDD makes the critical leakage current lower of EP-RHA insulator surface. The results of critical leakage current on insulator surface for every sample are shown in Table 3.

5.3. The Flashover Voltage Performance of Epoxy-polysiloxane Polymeric Insulator with Rice Husk Ash Filler

The flashover voltages of EP-RHA insulator material with various compositions are fluctuating during the aging process (52 weeks) as shown in Fig. 11.

The standard flashover voltage for EP-RHA insulator with various compositions tends to decrease until week 52nd. The standard flashover voltage is affected by the ESDD value and surface leakage current. The ability of an insulator to withstand surface voltage is affected by pollution layer and surface wetting phenomenon[22]. In wet condition, a contaminant layer is formed on the surface, so that the insulator surface is conductive properties. The surface conductivity will increase if the surface pollution layer is thicker. This make the leakage current increase, so that the leakage current creates in non-uniform heating of the contamination layer that eventually causes dry bands.

The insulator surface between both electrodes is a form of dry band arcing that series connected with a conductive pollutant layer[19,20]. The dry band arcing can extend or shrink/vanish. When the electric field strength reaches certain value in dry band, then the surface electric discharge occurs, initiates a flashover voltage on the EP-RHA insulator surface.

The higher filler content in EP-RHA insulator, the lower the ESDD and the critical leakage current. If the ESDD and the critical leakage current are decreased, then the flashover voltage is increased.

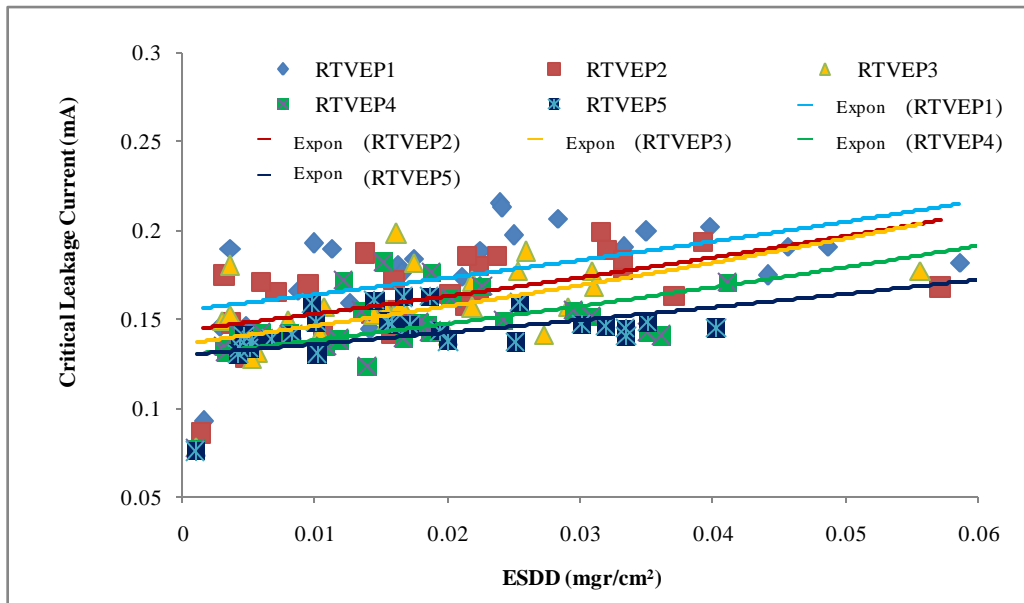


Figure 10. Critical surface leakage current against ESDD value for various filler composition

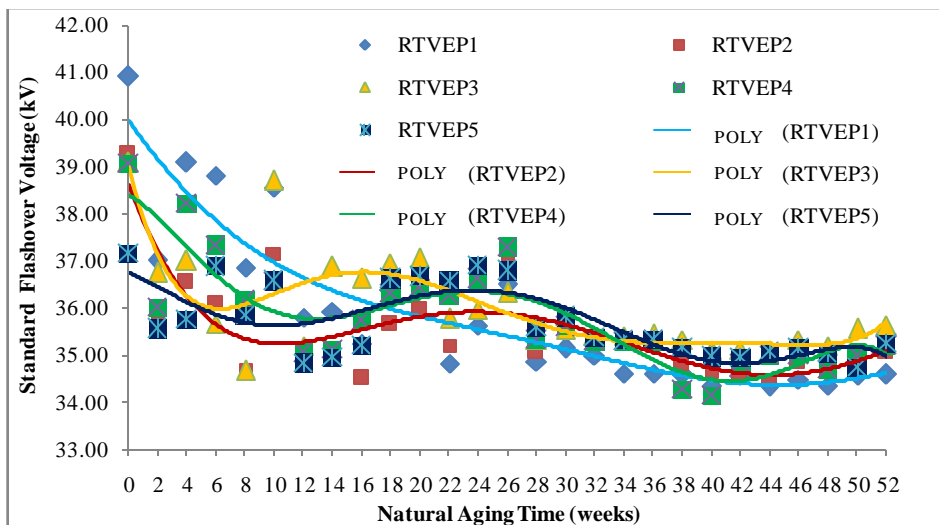


Figure 11. Standar flashover voltage against duration of aging for various filler composition in 52 weeks natural aging

The results of standard flashover voltages of EP-RHA insulator for every sample are shown in Table 4.

Table 4. Standard flashover voltage performance of EP-RHA insulator

Test samples	Standard flashover voltage (kV)	
	(min – max)	average
RTV _{EP1}	34.348-40.916	35.867
RTV _{EP2}	34.496-39.334	35.541
RTV _{EP3}	34.685-39.091	36.017
RTV _{EP4}	34.160-39.072	35.827
RTV _{EP5}	34.752-37.169	35.741

6. Conclusions

The performances of ESDD, critical leakage current and standard flashover of epoxy-polysiloxane polymeric insulator material with rice husk ash filler (EP-RHA) are fluctuating depend on local climate where the experiment is held.

During natural aging, the higher filler content in EP-RHA insulators results the lower value of ESDD and critical leakage current. If the ESDD and the critical leakage current are decreased, then standard flashover voltage is increased.

The performance measurements of EP-RHA insulator for each composition are (in average value), RTV_{EP1}: ESDD = 0.0226 mg/cm², I_{lc} = 0.1782 mA, V_{fo} = 35.867 kV; RTV_{EP2}: ESDD = 0.0195 mg/cm², I_{lc} = 0.01653 mA, V_{fo} = 35.541 kV; RTV_{EP3}: ESDD = 0.0166 mg/cm², I_{lc} = 0.1556 mA, V_{fo} = 36.017 kV; RTV_{EP4}: ESDD=0.0164 mg/cm², I_{lc} = 0.1460 mA, V_{fo} = 35.827 kV; and RTV_{EP5}: ESDD = 0.0171 mg/cm², I_{lc} = 0.1325 mA, V_{fo} = 35.741 kV.

ACKNOWLEDGEMENTS

The authors would like to say thank you to Mr. Daryadi

and Mr. Prasetyohadi as laboratory assistant of High Voltage laboratory, Electrical Engineering and Information Technology, Gadjah Mada University for their assist during this experiment completion.

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