

Accelerated Aging Effect on Epoxy-polysiloxane-Rice Husk Ash Polymeric Insulator Material

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Abstrak

Kinerja Isolator polimer di luar ruangan dipengaruhi oleh kondisi lingkungan. Penggunaan bahan polimer pada komposisi tertentu dapat dihasilkan isolator yang tahan terhadap pengaruh lingkungan. Makalah ini mempresentasikan pengaruh iklim tropis buatan terhadap sifat hidrofobik, rapat kandungan garam ekuivalen (ESDD), arus bocor permukaan, tegangan lewat denyar, dan degradasi permukaan pada bahan isolasi polimer epoksi-polisiloksan dan abu sekam padi (RHA). Sampel uji dibuat pada kondisi suhu ruang (RTV) dengan mencampur epoksi-polisiloksan dan bahan pengisi abu sekam padi pada variasi komposisi tertentu. Penuaan dilakukan dalam kotak pengujian pada kondisi suhu 50°C-62°C, kelembaban relatif 60%-80%, dan terdapat radiasi ultraviolet (UV) 21,28 w/cm² untuk kondisi simulasi siang hari selama 96 jam. Hasil eksperimen menunjukkan bahwa tegangan lewat denyar berfluktuasi dari 34,13 kV sampai 40,92 kV dan cenderung turun pada setiap variasi komposisi bahan. Arus bocor permukaan berfluktuasi dan cenderung naik. Sampel uji dengan komposisi bahan pengisi yang lebih tinggi menghasilkan nilai sudut kontak hidrofobik yang lebih besar, rapat endapan garam ekuivalen yang lebih kecil, dan arus bocor kritis lebih kecil, sehingga dapat meningkatkan tegangan lewat denyarnya. Bahan isolator (RTV_{EP3}) memiliki kinerja terbaik di daerah beriklim tropis. Terpaan iklim tropis buatan untuk waktu yang singkat kurang berpengaruh terhadap degradasi permukaan bahan isolator polimer epoksi-polisiloksan.

Kata kunci: abu sekam padi, epoksi-polisiloksan, penuaan dipercepat, tegangan lewat denyar

Abstract

The performances of outdoor polymeric insulators are influenced by environmental conditions. The use of polymeric materials in a particular composition can be produced insulators that are resistant to environmental influences. This paper presents the effect of artificial tropical climate on the hydrophobicity, equivalent salt deposit density (ESDD), surface leakage current, flashover voltage, and surface degradation on epoxy-polysiloxane polymeric insulator materials with rice husk ash (RHA). Test samples are made at room temperature vulcanized (RTV) of various composition of epoxy-polysiloxane with rice husk ash as filler. The aging was carried out in test chamber at temperature from 50°C to 62°C, relative humidity of 60% to 80%, and ultraviolet (UV) radiation 21.28 w/cm² in daylight conditions for 96 hours. The experiment results showed that the flashover voltage fluctuates from 34.13 kV up to 40.92 kV and tends to decrease on each variation of material composition. The surface leakage current fluctuates and tends to increase. Test samples with higher filler content result greater hydrophobicity, smaller equivalent salt deposit density, and smaller critical leakage current, which caused the increase of the flashover voltage. Insulator material (RTV_{EP3}) showed the best performance in tropical climate environment. Artificial tropical aging for short duration gives less effect to the surface degradation of epoxy-polysiloxane insulator material.

Keywords: accelerated aging, epoxy-polysiloxane, flashover voltage, rice husk ash

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1. Introduction

Power system insulator isolates the high voltage conductor from tower or pole and from another high voltage conductor. In order to achieve this insulating property, better understanding of specific insulator is important. An outdoor insulator must have dielectric

strength greater 10 kV/mm, low dissipation factor, and high resistance value in order to cancel the conductivity [1].

Nowadays, Indonesian electrical power system uses plenty of porcelain and glass insulators. The usage of porcelain and glass insulator on high voltage system is inappropriate due to high specific mass (2.3-3.9 gram/cm³) which caused higher transmission tower cost. Another consideration is excessive energy used during porcelain and glass insulator manufacturing (over 1000°C for vulcanization). Polymeric insulator is more economic due to lower specific mass (0.9-2.5 gram/cm³), lower energy used during manufacturing (low temperature process: 25-80°C, high temperature process: 100-300°C, lower dielectric constant 2.3-5.5 (compare to porcelain dielectric constant: 5.0-7.5, glass: 7.3) and lower dissipation factor (0.1-5.0)(10⁻³) compare to porcelain (20-40)(10⁻³) or glass (15-50)(10⁻³) [2]. The polymeric materials in various compositions for high voltage outdoor insulators have been discussed by several researchers. its performance decreases after aging [3-8].

To obtain a polymer insulator is resistant to the effects of aging, it is necessary to the selection of a polymer insulator material with a specific composition. In developed country, polymeric insulator is massively produced and used in high voltage level of transmission and distribution system. Problems related with ultraviolet radiation, temperature, humidity, air pressure, rain intensity and pollution caused surface degradation resulting the damage of polymeric insulator. Several researches related with polymeric insulator were held to analyze performance and aging effect of silicon rubber and Ethelvin Propylene Diene Monomer (EPDM) polymeric insulator outside Anneberg Bulk Station at west shore of Sweden. The relationship between the surface condition and polymeric insulator performance was studied by using six Silicon Rubbers (SiR) and three EPDM polymeric insulators which are analyzed with Electron Spectroscopy for Chemical Analysis (ESCA), Attenuated Total Reflection Fourier Transform Infrared (ATR-FTIR) dan Scanning Electron Microscopy (SEM). The results showed very strong relationship between polymeric insulator surface condition with hydrophobicity performance, leakage current and flashover voltage [3].

Application of bisphenol A resin polymeric insulator material which is formed by Phenol and Acetone reaction with silica sand as filler at normal air condition showed satisfactory performance, but then it is decreased during longterm used as outdoor due to surface tracking caused by ultraviolet radiation [4]. Application of cast epoxy-cycloaliphatic, which is formed by mixing Diglycidyl Ether of Bisphenol-A (DGEBA), anhydride acid hardener, and Aluminium Trihydrate (ATH) during normal air condition service showed satisfactory performance, but then it is decreased due to polluted condition [5]. The weakness of cast epoxy-cycloaliphatic comes from Aluminium Trihydrate as filler due its impurity which may contain sodium oxide (Na₂O) and potassium oxide (K₂O). These two alkali oxides will form alkali hydroxyl (OH and KOH), strong electrolyte, which can disturb dielectric property of cast epoxy-cycloaliphatic.

Application of filler on polymeric insulator gives mechanical enhancement, tracking and erosion resistance enhancement, thermal conductivity enhancement, reducing thermal expansion, reducing water absorption level and reducing manufacturing cost. The research of epoxy polymeric insulator material with fiber as filler showed different dielectric performance at different environmental conditions (such as: temperature, humidity, and ultraviolet radiation) [6]. The application of barium titanate as filler gives material relative permittivity enhancement, ZnO as filler gives material electric conductivity enhancement. Aluminium Trihydrate (ATH) and silica sand as fillers give material thermal conductivity enhancement which reduced erosion due to electric arc at conductive dry band on material surface [7]. Tropical climate natural and accelerated aging on DGEBA base material with MPDA hardener and 325 mesh silica sand filler with SiR coating showed better electrical performance, chemical reaction and mechanical strength [8].

Various filler application on polymeric insulator has its advantage and disadvantage factor, but generally filler is an nature anorganic material which consists of several chemical compounds such as SiO₂, Al₂O₃, MgO, CaO, TiO, Fe₂O₃, etc. Many researches related with silica as filler are taken frequently, one of them is using active amorphous silica from Rice Husk Ash (RHA). A consideration of using RHA is SiO₂ content 86.90 %-97.30% from total weight [9]. Compound property of RHA 200 mesh with type 1 cement (Tiga Roda brand) for various composition showed compound with cement: RHA ratio 1: 1¼ has required viscosity, strength and durability as building material [10].

Based on previous researches, this research will be focused on the effect of artificial tropical climate aging to the performance of epoxy-polysiloxane polymeric insulator materials with RHA filler. Silica (SiO_2) content from RHA becomes consideration in this research. Performance parameters which are observed in this research are: electrical performance (hydrophobicity property, equivalent salt deposit densities, surface leakage current, flashover voltage) and material surface degradation after 96 hours of laboratory accelerated aging. The purpose of this research was finding satisfactory composition of epoxy-polysiloxane polymeric insulator materials which are able to sustain tropical climate environment and replace glass/porcelain insulator in Indonesia.

2. Research Method

2.1 Research Material

A material used in this research is Epoxy. Epoxy is a thermosetting chemical compound which consists of oxygen and carbon chemical bond produced by epichlorohydrin and bisphenol A reaction. Complex structure of Epoxy has molecular epoxy-resin bond shown in Figure 1.

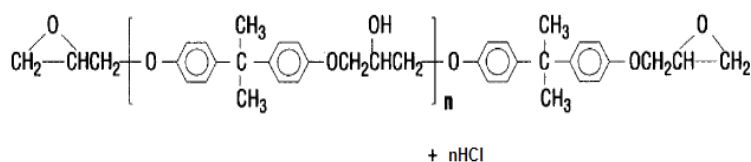


Figure 1. Epoxy resin structure

Epoxy-resin will be hardened when combined with hardener, catalyst and filler. The application is widely used, such as: insulator, household tools, machinery component, automotive, liquid tank/pipe, aeroplane body material, aerospace component, bridge structure, etc. Epoxy has fine electrical properties: volume resistance (ρ) 10^{13} - $10^{15}\Omega\text{m}$, dielectric constant (ϵ) 3.5-3.9 (at 50/60 Hz) and power dissipation factor ($\tan \delta$) $(35-90) \times 10^{-4}$, but weak against ultraviolet radiation.

Polysiloxane is a polymer with silicon and oxygen as its main chain. Polysiloxane main chain is more flexible compared to vinyl and polyolefin. The chemical structure of polysiloxane is shown in Figure 2.

Silicon rubber is a PDMS which has CH_3 as side group. Different chemical compound in every bond will give different property for each polymeric material [11]. Silicon rubber chemical structure has more flexible siloxane backbone compared to other polymeric materials. This flexibility advantage can be understood by chain structure image in Figure 3.

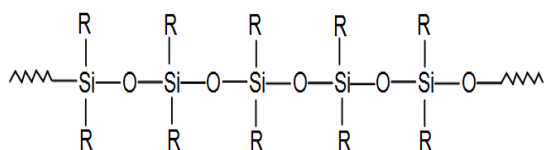


Figure 2. Polysiloxane chemical structure

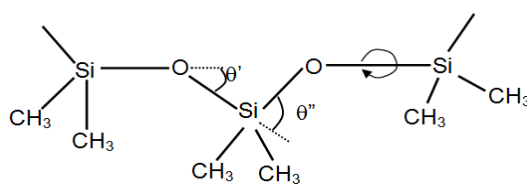


Figure 3 Silicon rubber chain structure

Silicon rubber chain structure doesn't have carbon at the backbone, but presents at side group. Those structures show semi-organic structure with high bond energy of Si-O which gives very high thermal stability. Bond energy of Si-O is 25% higher than C-C in ethylene backbone. The comparison of main bond energy of several polymeric compounds shown in Table 1.

Eventhough Si-O thermal stability is very good, the ionic property is relatively high which made it easier to be broken by high alkali or acid concentration. Strong Si-O bond gives higher durability for silicon rubber against destruction possibility caused by environment and corona. It also gives similar property as glass or quartz which doesn't cause conductive layer

when burned (for example: burned by electrical arc). In the other hand, silicon rubber also has stable elasticity within -50°C to $+230^{\circ}\text{C}$ range which is the most important property of electrical insulator material [12].

Hydrophobic property of Epoxy-polysiloxane is caused by low molecular weight (LMW) diffusion from silicon rubber (as filler) to the surface of the material which acts as coating [13]. An advantage of silicon rubber material is the water proof ability caused by hydrophobicity of methyl (CH_3) as main compound in silicon rubber chemical structure. The present of free methyl group and the polarity of Si-O bond causes polysiloxane chain to be straight resulting hydrophobic surface.

Rice husk is usually used as burning material or filler in brick manufacturing and plant seeding media while its ash is used as rubbing ash or wasted. Burned rice husk will produce RHA with high SiO_2 content (more than 80% from total weight). RHA used in this research contains several compounds as shown in Table 2.

Table 1. Polymeric material bond energy

Atomic Bond	Bond Energy (kJ/mol)
C-H	413
C-O	360
C-N	308
C-C	348
H-H	436
H-O	366
H-N	391
Si-O	445
Si-H	318
Si-C	318
Si-Si	222
O-O	195
O-H	366

Table 2. RHA composition

Compound	% weight
SiO_2	73.6835
Al_2O_3	12.4315
Fe_2O_3	4.8953
CaO	0.4388
MgO	0.8587
K_2O	3.4401
Na_2O	1.2063
H_2O	0.3715

Test samples are made in thin cylinder shape with 70 m diameter and 5 mm thickness at room temperature. Test sample compositions are shown in Table 3.

Table 3. Test sample composition

Type	Epoxy DGEBA (% pbw)	Hardener MPDA (% pbw)	Filler (% pbw)		
			RHA	Polysiloxane	Total
RTV_{EP1}	45	45	5	5	10
RTV_{EP2}	40	40	10	10	20
RTV_{EP3}	35	35	15	15	30
RTV_{EP4}	30	30	20	20	40
RTV_{EP5}	25	25	25	25	50

2.2 Flashover Voltage Performance against Hydrophobic Contact Angle, ESDD and Surface leakage Current

Hydrophobic property can be observed by measuring water droplet contact angle on the insulator surface. This property is not static, sometimes it can be vanished and restored depend on insulator material surface. Hydrophobic property will be restored after 10-12 hours after arc period [14]. This process can be explained by 6 following postulates: 1) Hydrophilic surface reorientation, 2) Polymeric chain migration, 3) loss of oxygen or other polar type to the atmosphere, 4) further reaction of polar or other active compounds which are blocking chain reorientation, 5) surface roughness change and 6) external insulator surface contamination [15].

Measuring polymeric insulator hydrophobicity property requires measurement of contact angle. Figure 4 shows contact angle illustration on wetted material surface. Several researchers concluded: a material called hydrophilic when liquid (water) contact angle at its surface is smaller than 30° , a material called partially wet when the contact angle between 30° - 89° and a material called hydrophobic when the contact angle is bigger than 90° [16].

Material surface wetted by liquid can be explained by DUPRE adhesion energy formula as shown in equation 1.

$$W_A = \gamma_S + \gamma_{LV} - \gamma_{SL} \quad (1)$$

γ_{LV} is liquid surface energy with air, γ_S is surface energy of solid material, γ_{SL} is interface free energy of solid and liquid. Physical condition of water droplet follows Young formula,

$$\gamma_{SV} = \gamma_{SL} + \gamma_{LV}\cos\theta_c \quad (2)$$

The relationship of contact angle and free energy surface of solid material, liquid, and air is shown in Figure 5.

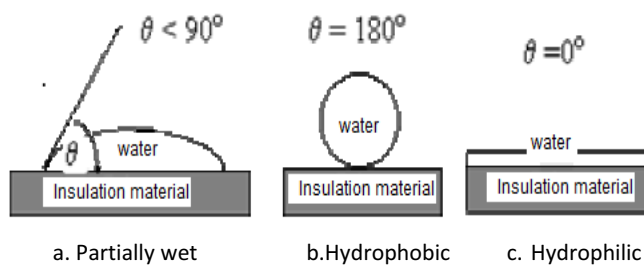


Figure 4. Wetting form on solid material surface

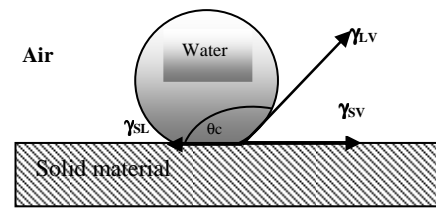


Figure 5. Water droplet contact angle on solid material surface

where: γ_{SV} is surface tension between solid material and air, γ_{SL} is surface tension between solid material and liquid, γ_{LV} is surface tension between liquid and air, θ_c is the equilibrium contact angle.

Contaminant level which is caused by a certain salt can be measured by ESDD method which is expressed in mg/cm^2 .

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

where: ESDD is equivalent salt deposit density (mg/cm^2), V_{ap} is water volume for washing (ml), D_1 is equivalent salt concentration of water and cotton before washing of insulator (%), D_2 is equivalent salt concentration of water and cotton after washing of insulator (%), S =washed insulator surface area (cm^2).

Environment contamination caused the outdoor insulator to be covered by pollutant or chemical compound in a very long time. This pollutant layer has less effect when the insulator is dry. Insulator surface in high impedance with very small leakage current is caused by surface discharge. In wet atmospheric condition, the contaminant particle on insulator surface will dissolved in water and create conductive path rapidly between high voltage electrode and ground.

The relationship between electric field strength (E) and leakage current (I_{lc}) is shown in equation 4 [17].

$$\bar{E} = N I_{lc}^{-n} \quad (4)$$

where: E =electric field (kV/cm); I_{lc} = surface leakage current (mA); N =a constant related with electric field; n =a constant related with leakage current.

Flashover voltage is external disturbance on the surface of insulator as arc which can be happened in solid surface or gas. This flashover voltage has small value compared with puncture voltage. Voltage at the surface of insulator is affected by material surface resistance, surface condition and electric field form between electrodes and insulator.

Flashover voltage on polluted insulator follows several steps [17][18]:

- (i) Insulator with dryband and conductive pollutant layer can be expressed as series relationship along x (air gap) and pollutant layer resistance per unit $R'=R'(l)$, as Figure 6.
- (ii) Insulator surface between 2 electrodes is expressed as electric arc which is series with conductive pollutant layer.
- (iii) Electric arc can expand or shut off. When electric field strength reaches certain value, electric discharge happened and accelerate flashover voltage phenomenon.
- (iv) Flashover voltage happens when electric arc covered whole drybands between two electrodes.

The relationship between surface conductivity and flashover voltage can be expressed in equation 5 [17].

$$V_{fo} = N^{\frac{1}{(n+1)}} \kappa^{\frac{-n}{(n+1)}} L \quad (5)$$

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

2.3 Measurement Method

Test samples are covered by artificial pollutant (by fogging in fog chamber). The test samples are placed into a special chamber that simulates a tropical climate at night (temperature of 50°C , humidity of 80%) and at daylight (temperature of 62°C , humidity of 60% and artificial UV radiation of $21.28 \text{ Watt}/\text{cm}^2$). Accelerated aging scheme was 24 hours as 1 cycle lasted during 96 hours [19][20].

Hydrophobic contact angle measurement is shown in Figure 7. Put $50 \mu\text{l}$ destilated water on the test sample surface (using assipette No 100), turn the 1000 watt special lamp on then take the picture of water droplet. Camera position must be adjusted to obtain flat point of view for better result. The contact angle is measured by using ImagePro software.

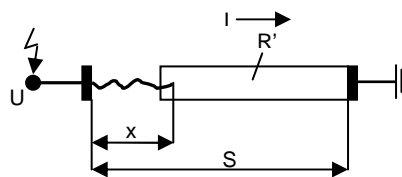


Figure 6. Insulator with drybands and pollutant layer model to determine I and U

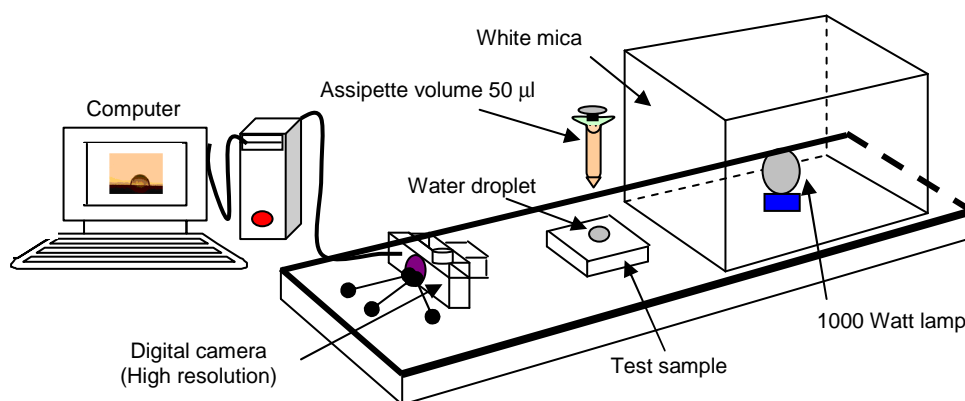


Figure 7 Test sample contact angle measurement method

ESDD measurement follows these steps: 1) preparing 200 ml of distilled water and 1 gram of cotton; 2) putting the cotton into the distilled water; 3) measuring the temperature and conductivity of water and cotton mixture by using conductivity meter; 4) separating pollutant from test sample surface by using distilled water and cotton; 4) storing the distilled water and

cotton after washing of test sample into glass jar and measure its conductivity and temperature; 5) converting conductivity measurement result into 20°C standard by using b factor correction (IEC 507,1991) resulting salt concentration in %, and ESDD can be calculated by using equation 3.

Flashover voltage measurement follows these steps: 1) preparing test chamber with 70% humidity (after fogging); 2) every test sample is tested by applying increase voltage with step of 1.5 kV/sec until flashover occurs; 3) recording temperature, humidity and air pressure as correction for standard flashover voltage [21]

Surface leakage current measurement follows these steps: 1) preparing chamber with 70% humidity (after fogging); 2) every test sample is tested by applying increasing voltage with step of 1.5 kV/sec, from 11.5 kV up to 50% flashover voltage; 3) recording measured voltage using CRO and converting it into surface leakage current value by multiplying it with 0.0273 ($I_{lc} = 0.0273.V_{cro}$). Flashover voltage and surface leakage measurement arrangement are shown in Figure 8.

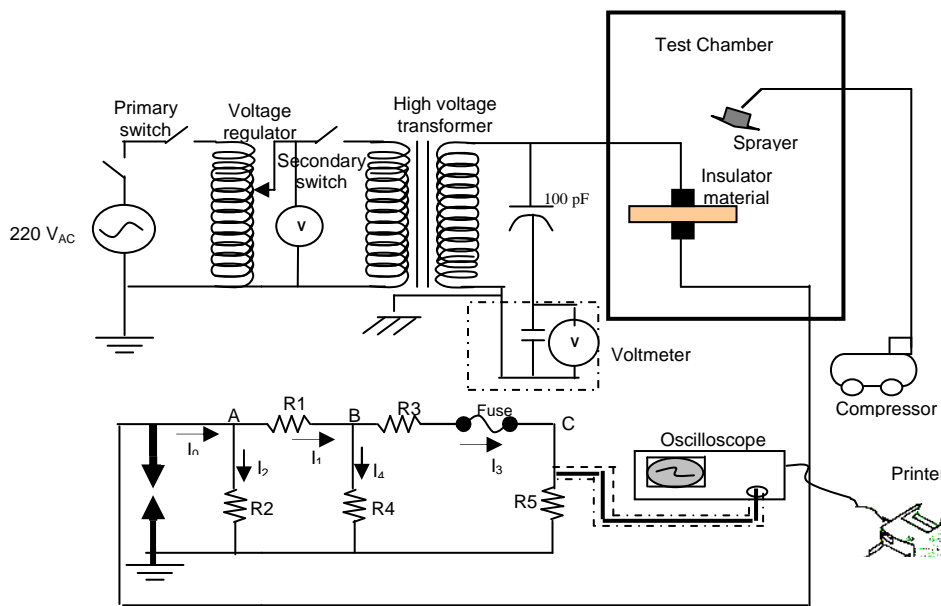


Figure 8. Flashover voltage and surface leakage current measurement arrangement

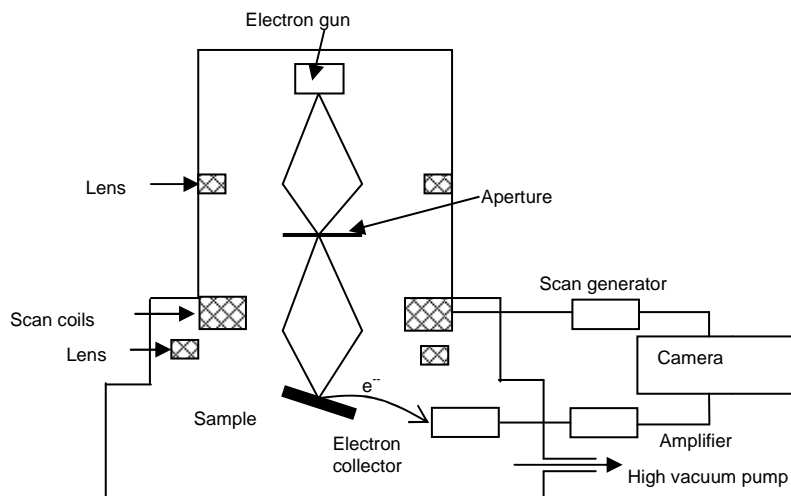


Figure 9. SEM Methode in the sample surface test

Test sample surface degradation test was applied to the new sample and accelerated aging sample (during 96 hours). The procedure follows these steps: 1) preparing/cutting test sample in 5x5x5 mm; 2) cleaning it with handspry; 3) putting the test sample into vacuum evaporator inside ion sputter JFC-1000 tools to cover test sample with conducting layer; 4) scanning test sample by using SEM, 5) recording the image of test sample for further analysis. Surface degradation test arrangement is shown in Figure 9.

3. Results and Analysis

3.1 Hydrophobic Contact Angle (θ_h) of epoxy-polysiloxane polymeric insulator materials with RHA

Measurement result of hydrophobic contact angle for every half cycle during artificial tropical climate accelerated aging for 96 hours on epoxy-polysiloxane polymeric insulator materials with RHA coded as RTV_{EP1} to RTV_{EP5} is shown in Figure 10.

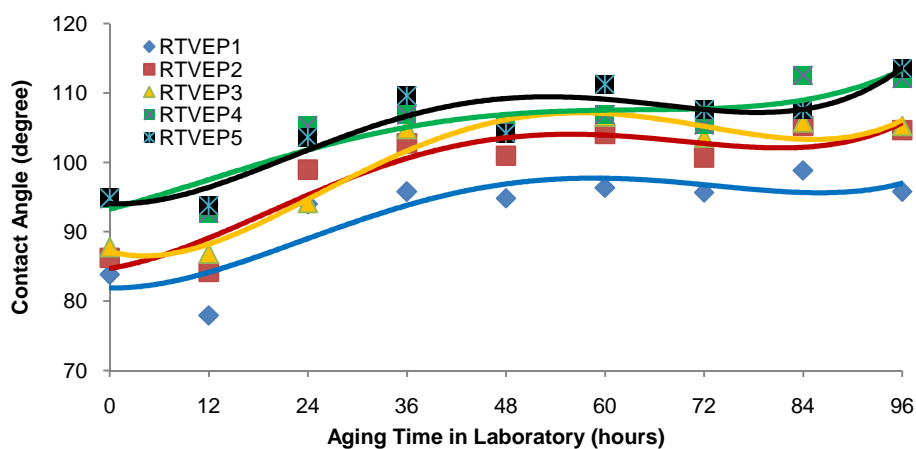


Figure 10. Hydrophobic contact angle during artificial accelerated aging for various filler composition

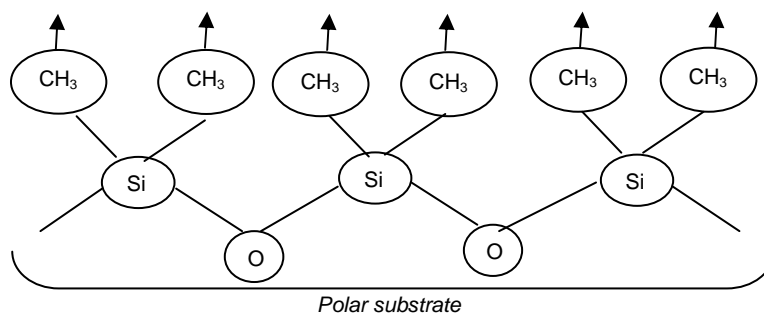


Figure 11. Water repellent property of free rotating methyl groups on insulator surface

Figure 10 shows increase fluctuation of hydrophobic contact angle for every test sample affected by artificial accelerated aging simulation (UV, temperature and humidity). The order of contact angle from the highest to the lower is 105.12° (RTV_{EP5}), 104.64° (RTV_{EP4}), 99.92° (RTV_{EP3}), 98.64° (RTV_{EP2}), and 92.55° (RTV_{EP1}). The property showed in this samples is water repellent due to the fact that average contact angle value is bigger than 90° [16]. This property presence because of water repellent nature from polysiloxane in RHA filler, chemical structure of polysiloxane which is dominated by methyl group reduced surface energy resulting lower adhesion pulling force between water molecule and other surface molecules. The presence of

free rotating methyl groups and polarability of Si-O bond causes polysiloxane chain to be straightened; resulting in surface hydrophobicity is shown in Figure 11. Measurement result shows the tendency of bigger contact angle for higher filler content compared to smaller filler content due to the difference of methyl group content.

Tropical climate simulation affects surface contact angle on insulator material. UV radiation causes micro crack on the surface of insulator material, as shown in SEM test results (Figures 15-17). This micro crack causes the surface to be rough. When the surface of insulator material is contacted with water, the micro crack pores does not get wet, because very small air bubble is trapped in the micro crack pores. This causes the rough surface of insulator material seems to be difficult to get wet, due to the trapped air bubble, hence the rough surface of insulator material has a higher contact angle. Other possibilities are that hydrophobicity can be caused by diffusion of silicon rubber as filler. Low molecular weight of silicon rubber diffuses through vulcanization matrix from bulk to the surface [15][16].

Compared to the results of measurements of the average value of contact angle of epoxy-silane-silica sand as a filler that has undergone accelerated aging for 96 hours [8]. The order of contact angle from the highest to the lower is 126.83° (RTV₂₅), 126.19° (RTV₂₄), 125.08° (RTV₂₂), 121.75° (RTV₂₁), 119.21° (RTV₂₃). The highest contact angle is obtained in the filler composition of 50%. Overall the contact angle is greater than the value of contact angle is obtained on the epoxy-polysiloxane-RHA filler. But in this research were obtained material which is hydrophobic at each composition, since the contact angle greater than 90° [16].

3.2 ESDD of epoxy-polysiloxane polymeric insulator materials with RHA

Measurement result of ESDD for every half cycle during artificial tropical climate accelerated aging for 96 hours on epoxy-polysiloxane polymeric insulator materials with RHA coded as RTV_{EP1} to RTV_{EP5} is shown in Figure 12.

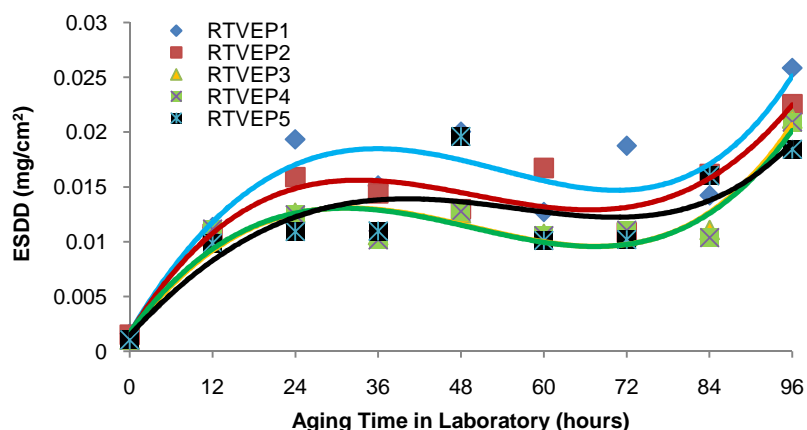


Figure 12. ESDD result during artificial accelerated aging for various filler composition

Figure 12 shows fluctuation result of ESDD with increasing tendency due to pollutant spraying and even more pollutant deposit during long aging duration. The tropical climate affects ESDD. The highest filler content sample shows lower ESDD value compared to other samples. RTV_{EP4} sample has the lowest ESDD with average value 0.01116 mg/cm^2 , followed by RTV_{EP3} sample with ESDD average value 0.01120 mg/cm^2 , RTV_{EP5} sample with ESDD average value 0.01191 mg/cm^2 , RTV_{EP2} sample with ESDD average value 0.01353 mg/cm^2 and RTV_{EP1} sample with ESDD average value 0.01543 mg/cm^2 .

Based on the measurement, ESDD RTV_{EP5} is slightly higher than RTV_{EP3} and RTV_{EP4} due to non-uniform pollutant spraying resulting more pollutant at RTV_{EP5}. Wetting and aging affect pollutant accumulation on the insulator surface. At humid condition, the pollutant at the surface has tendency to decrease [8][17].

Compared to the results of measurements of the average value of ESDD of epoxy-silane-silica sand as a filler that has undergone accelerated aging for 96 hours [8]. The order of ESDD from the highest to the lower is 0.00775 mg/cm^2 (RTV₂₅), 0.00748 mg/cm^2 (RTV₂₄),

0.00730 mg/cm² (RTV₂₁), 0.00677 mg/cm² (RTV₂₂), 0.00670 (RTV₂₃). The highest ESDD is obtained in the filler composition of 50%. Overall the ESDD is lower than the value of ESDD is obtained on the epoxy-polysiloxane-RHA filler. This possibility is due to the large contact angle values obtained in the material epoxy-silane-silica sand as a filler [8], so that when the surface is wetted produce low pollutant on the insulator surface.

3.3 Critical leakage current (I_c) of epoxy-polysiloxane polymeric insulator materials with RHA

Measurement result of critical leakage current for every half cycle during artificial tropical climate accelerated aging for 96 hours on epoxy-polysiloxane polymeric insulator materials with RHA coded as RTV_{EP1} to RTV_{EP5} is shown in Figure 13. Figure 13 shows fluctuation result of critical leakage current for various sample with increasing tendency due to increasing ESDD value. Artificial tropical climate affects ESDD on insulator surface. In wet or humid condition, pollutant contamination tends to decrease due to material surface hydrophobic property. Critical Leakage currents for every sample are: RTV_{EP5} with average value 0.1283 mA, RTV_{EP4} with average value 0.1290 mA, RTV_{EP3} with average value 0.1348 mA, RTV_{EP2} with average value 0.1353 mA, and RTV_{EP1} with average value 0.1456 mA.

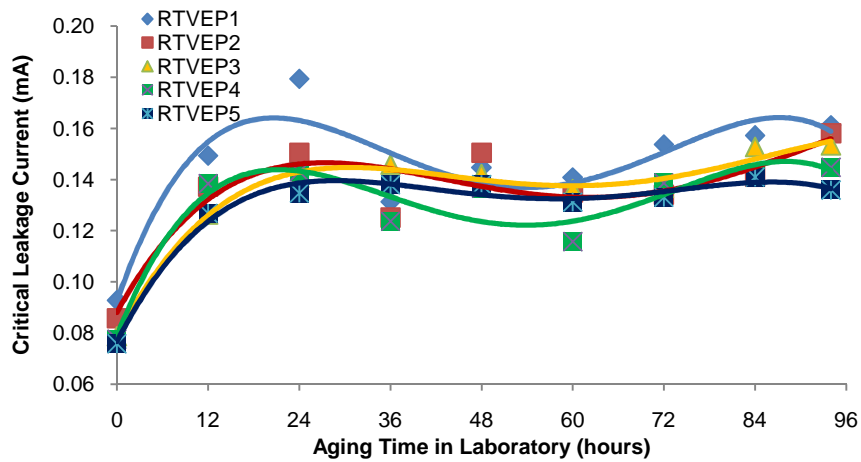


Figure 13. Surface leakage current during artificial accelerated aging for various filler composition

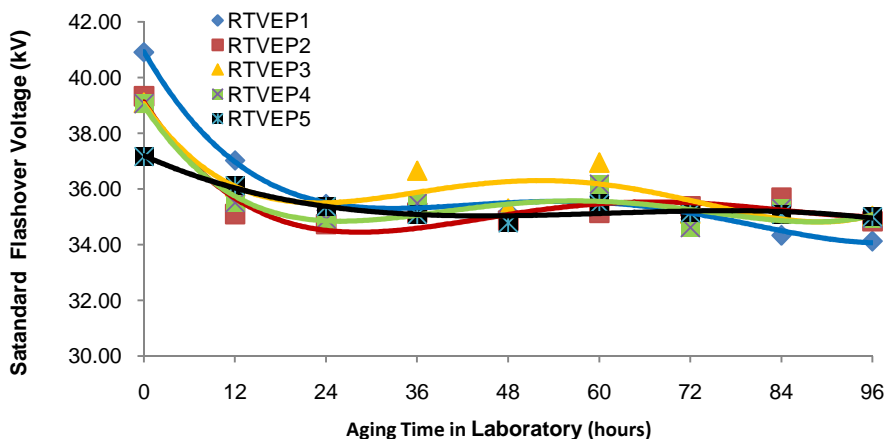


Figure 14 Standard V_{to} during artificial accelerated aging for various filler composition

Compared to the results of measurements of the average value of leakage current of epoxy-silane-silica sand as a filler that has undergone accelerated aging for 96 hours [8]. The

order of leakage current from the highest to the lower is 0.0633mA (RTV₂₃), 0.0600 mA (RTV₂₂), 0.0595 mA (RTV₂₄), 0.0592 mA (RTV₂₅), 0.0590 (RTV₂₁). The highest leakage current is obtained in the filler composition of 30%. Overall the leakage current is lower than the value of leakage current is obtained on the epoxy-polysiloxane-RHA filler. This is due to the large contact angle and low ESDD obtained in the material epoxy-silane-silica sand as a filler [8]. If ESDD on insulator surface is lower, then the surface leakage current is also lower.

3.4 Flashover voltage (V_{f_0}) of epoxy-polysiloxane polymeric insulator materials with RHA

Measurement result of standard flashover voltage for every half cycle during artificial tropical climate accelerated aging for 96 hours on epoxy-polysiloxane polymeric insulator materials with RHA coded as RTV_{EP1} to RTV_{EP5} shown in Figure 14. Figure 14 shows fluctuation result of flashover voltage for various samples with decreasing tendency due to pollutant effect and artificial tropical climate (UV radiation, temperature and humidity). Higher ESDD value causes higher surface conductivity. Wetting phenomenon during high humidity condition creates water droplets which form conductive layer at insulator surface. When Alternating Current (AC) voltage is applied to the insulator, leakage current will flow at conductive polluted surface resulting resistance heating. These resistance heating and leakage current cause the formation of dry bands on the surface of the test sample [18]. Wetting progress will increase water droplet density and reduce droplet distance which results the formation of filament. Increasing electric field will create discharge point between filaments which decrease hydrophobic property resulting longer filament and shorter distance between electrodes. Longer filament and conductive layer short circuit test sample through conductive electrolyte. Conductive surface gives a direct path for electric arc on electrolyte layer surface causing lower flashover voltage. During night simulation, standard flashover voltage tends to decrease due to high humidity which creates electrolyte layer. During daylight simulation the standard flashover voltage will increase due to dry insulator surface. Test sample with lower RHA filler results higher standard flashover voltage at the beginning of aging process but at the end of aging process it decreased rapidly compared to other test samples with higher filler. This phenomenon is caused by polysiloxane content on test sample. Higher filler composition causes higher methyl (CH₃) groups content which is hydrophobic causing lower pollutant concentration during wet condition. Lower pollutant reduces leakage current and increases flashover voltage. On the other hand, test sample with higher Si-O content is more durable against UV radiation (see Table 1) because of insufficient energy from UV to break chemical chain of epoxy-polysiloxane polymeric insulator materials with RHA. Standard flashover voltages for every test samples are: RTV_{EP5} with average value 35.48 kV, RTV_{EP4} with average value 35.65 kV, RTV_{EP3} with average value 36.07 kV, RTV_{EP2} with average value 35.58 kV, and RTV_{EP1} with average value 35.94 kV. From those results, insulator material code RTV_{EP3} has higher standard flashover voltage compared the others.

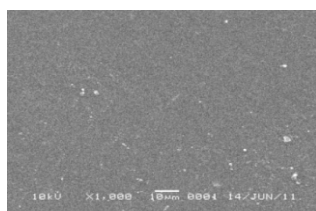
Compared to the results of measurements of the average value standard flashover voltage of epoxy-silane-silica sand as a filler that has undergone accelerated aging for 96 hours [8]. The order of standard flashover voltage from the highest to the lower is 37.23 kV (RTV₂₄), 37.07 kV (RTV₂₅), 35.85 kV (RTV₂₃), 34.27 kV (RTV₂₂), 32.02 kV (RTV₂₁). The highest standard flashover voltage is obtained in the filler composition of 40%. The standard flashover voltage is higher than the value of standard flashover voltage is obtained on the epoxy-polysiloxane-RHA filler. This is due to the large contact angle, low ESDD, and low leakage current obtained in the material epoxy-silane-silica sand as a filler [8]. so that the standard flashover voltage on the epoxy-silane-silica sand as a filler is greater than the epoxy-polysiloxane-RHA filler.

3.5 Surface degradation of epoxy-polysiloxane polymeric insulator materials with RHA

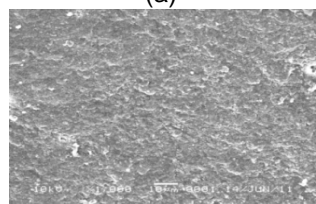
The surface degradation of epoxy-polysiloxane polymeric insulator materials with rice husk ash after artificial tropical climate accelerated aging for 96 hours can be observed by using Scanning Electron Microscopy (SEM). Analytical SEM results of insulator material surface by using type JSM-6360LA tools (1000 times zoom) are shown in Figure 15, Figure 16, and Figure 17.

There is slight difference on polymeric insulator surface after 96 hours tropical climate accelerated aging. Test sample RTV_{EP3} shows smaller change compare to other samples. This change is affected by UV radiation, humidity and temperature during aging process. Based on these facts, it concluded that artificial tropical climate aging for short time duration hasn't

affected insulator material surface degradation of epoxy-polysiloxane polymeric insulator materials with RHA significantly.

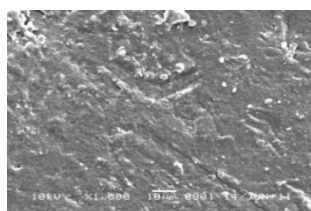


(a)

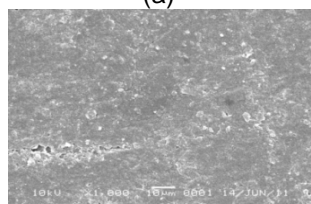


(b)

Figure 15. SEM Photograph (x1000) of test sample with 10% filler: (a) RTV_{EP1} new and (b) RTV_{EP1} after 96 hours aging

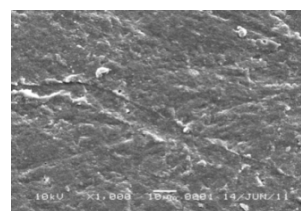


(a)

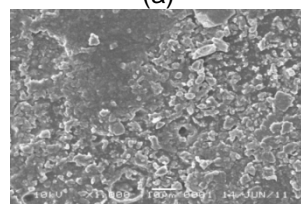


(b)

Figure 16. SEM Photograph (x1000) of test sample with 30% filler: (a) RTV_{EP3} new and (b) RTV_{EP3} after 96 hours aging



(a)



(b)

Figure 17. SEM Photograph (x1000) of test sample with 50% filler: (a) RTV_{EP5} new and (b) RTV_{EP5} after 96 hours aging

4. Conclusion

On this experiment, the performance of epoxy-polysiloxane polymeric insulator materials with RHA under artificial tropical climate aging has been observed. Material composition gives important effect to modify epoxy-polysiloxane polymeric insulator materials with RHA performance. The result shows higher percentage filler increasing hydrophobic property on the insulator material surface which decreases ESDD and leakage current resulting higher flashover voltage. The surface degradation of epoxy-polysiloxane polymeric insulator materials with RHA hasn't showed significant effect during short time artificial tropical climate aging. Polysiloxane addition in RHA filler gives better durability against ultraviolet radiation for epoxy polymeric insulator. Based upon experiment result, RTV_{EP3} (35% DGEBA, 35% MPDA, 15% polysiloxane and 15% RHA) has the best performance, because it has higher average flashover voltage (36.07kV) than others. The surface does not change significantly after exposed to UV radiation, so the RTV_{EP3} can be proposed as an alternative outdoor insulation material in tropical climate area.

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