

# Mathematical Analysis for the Electrical Performance Study of RTV Silane Epoxy Resins in Tropical Climate

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**Abstract:** Mathematical analysis for studying the electrical performance of polymeric insulation materials in tropical climate is a multiple regression model. It is derived from statistical science combined with statistics toolbox from matlab programme. For engineering point of view, it could be applied for silane epoxy resins, for some purpose, namely, 1) to prove ageing mathematical model by means of data obtained from the natural and acceleration ageing, 2) to determine optimal performance of sample placed in tropical climate area, and it was found that the best performance belonged to sample coded RTV<sub>24</sub>, 3) to predict service lifetime of samples, which depend on critical electrical field ( $V_{50}/L$ ) and design criteria of electrical insulator, 4) to determine the correlation between natural and acceleration ageing, which is represented by acceleration ageing factor, determined by ultraviolet radiation, temperature, and humidity, the value of which are 77, 2, and 2 respectively. By this method, natural aging test which takes long time and high cost is not necessary to be performed, since accelerated ageing performance could predict the performance of natural ageing. With the use of multiple regression model, it can be concluded that the silane treatment of the filler with the dose of 40 %, or specimen code of RTV<sub>24</sub> resulted in optimal performance in the tropical climate. Therefore, these materials can be proposed as insulator materials for high voltage transmission line in tropical area, and as an alternative substitution for porcelain and glasses.

**Keywords:** silane epoxy resins, mathematical analysis, ageing, and tropical climate.

## I. INTRODUCTION

Polymers play a significant role as insulating media because of their excellent physical and chemical properties. Polymeric insulators are increasingly being used in both distribution and transmission voltage ranges and are steadily capturing a wider share of the market [1-3]. Overhead lines are still the most economical means for bulk power delivery. To maintain high reliability of power delivery, it is necessary that the lines is provided with adequate insulation. The reason for choosing polymeric insulators has to be found in their lower weight, their resistance to vandalism, easy of

handling, reduced installation and maintenance costs, and improved contamination performance [4-8].

Presently, polymers, such as epoxy resins are a family of thermosetting polymers in which two components are mixed to eventually form a glassy product at room temperature, which has reasonable electrical insulation properties and is also highly impermeable to water [9-10]. Epoxy resins are extremely useful for high mechanical strength, good adhesion to material and metal, and are widely used as insulating material for electrical apparatus because of their excellent electrical characteristics. Apart from their several advantages, thermosetting polymeric material has some disadvantages. They are very sensitive if used in high temperature and in very humid areas where high intensity of ultraviolet radiation exist, which will cause decreases of epoxy resins performances. A contaminant layer practically always exists on the surface of insulators used for outdoor transmission or distribution lines. This especially true in regions of heavy industry or the sea coast. The nature and severity of the surface contamination can vary over a wide range. There is an increase in leakage current when fog, dew or drizzle wets the contaminated surface. The leakage current can initiate a heat conduction process occurring on the insulator surface. The formation of a dry-band zone, which may eventually cause a flashover of the insulator, can be viewed as the final result of such a heat conduction process. Local temperature elevation and dry-band associated surface discharges are two leading factors in those responsible for material degradation of polymer insulator [11]. Flashover voltage of a clean insulator depends not only on its shape and dimension but also on weather conditions such as pressure, temperature, humidity, rainfall and so on. Polymer insulator showed degradation due to climate stresses such ultraviolet in sunlight, moisture, temperature, etc, and the degradation may reduce the performance. This reduction is actually a result of chemical and physical changes taking place on the surface of the polymer. In tropical regions, like Indonesia, external polymer

insulator are subjected to extremely simultaneous severe climate condition such as the ultraviolet irradiation being always 12 hours a day, humidity approaching 100 % during the night and early morning, and temperature being always higher than 16° C [12]. The study towards improving the performance of the epoxy resin is conducted by adding silane treatment as filler, and a new performance obtained regarding with hydrophobicity is realized. Silane epoxy resins are the name of new thermosetting polymeric insulation materials that have been developed, with the materials composition being obtained from the experimental research. The above arguments made the increase in the motivation to undertake this study. In order to quantitatively clarify the effect of filler treatment on the electrical performance, natural and accelerated ageing tests were performed with rtv epoxy resins specimens insulation material mixed with silicon rubber treatment the filler.

## II. MATHEMATICAL ANALYSIS

### A. Regression Model

Mathematical analysis for studying the ageing performance of the polymeric insulation materials for high voltage insulator in tropical climate is a multiple regression model, which is derived from statistical science, combined with statistics toolbox from matlab programme [13-16]. In most research problem where regression analysis is applied, more than one independent variables needed in regression model as follows :

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k + \varepsilon \quad (1)$$

where :  $y$  is dependent variable,  $x_1, x_2, \dots, x_k$  are the independent variables,  $\beta_i$  determines the contribution of the independent variable  $x_i$ . The estimate response is obtained from the sample regression equation is,

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + \dots + b_k x_k \quad (2)$$

In using the concept of least squares to arrive at estimates  $b_0, b_1, \dots, b_k$  with minimize the expression. In fitting a multiple regression model, particularly when the number of variables exceeds two, a knowledge of matrix theory can facilitate the mathematical manipulations considerably. One criterion that is commonly used to illustrate the adequacy of a fitted regression model is the coefficient of multiple determination ( $R^2$ ). The square root of  $R^2$  is called the multiple correlation coefficient ( $r$ ) between  $Y$  and the set  $x_1, x_2, \dots, x_k$ . A better method is to conduct a test of hypothesis involving all the  $\beta$  parameters (except  $\beta_0$ ) in a model. In particular we would test,

$$H_0 : b_1 = b_2 = \dots = b_k, \quad H_1 : \text{At least one } b_i \neq 0$$

The test statistic used to test this hypothesis is an  $F$  statistic, and several equivalent versions of the formula can be used

$$\text{Test statistic : } F_{cal} = \frac{R^2 / k}{(1 - R^2) / [n - (k + 1)]} \quad (3)$$

where  $n$  is the sample size and  $k$  is the number of term in the model. If  $F_{cal} > F_{0.05}$ , rejection  $H_0$ , acceptance  $H_1$  and the independent variable has been contributed to the dependent variable. Test statistic  $F$  could be valid if data test ( $n$ ) > 30, and  $n$  < 30 test statistic is

$$\text{Test statistic : } t_{n-2} = r \sqrt{(n-2)} / \sqrt{(1-r^2)} \quad (4)$$

### B. Ageing Mathematical Model

The flashover mechanism of contaminated insulators and the influence of tropical climate are complex. An ageing mathematical model has been developed and is used in order to investigate the ageing phenomenon on polymeric insulation [17-19]. In model [17], the contamination flashover voltage ( $V_{fo}$ ) is given by

$$V_{fo} = N \left[ \frac{1}{(n+1)} \right]_{\kappa} \left[ \frac{-n}{(n+1)} \right]_L \quad (5)$$

Where  $\kappa$  is the surface conductivity and  $L$  is the leakage length of the insulator.  $N$  and  $n$  are constants related to the electric field  $E$  and leakage current  $I$  in the arc by

$$\bar{E} = N I^{-n} \quad (6)$$

Surface conductivity related with esdd [20] is given by

$$\text{ESDD} \propto \kappa \quad (7)$$

The contact angle of the hydrophobicity related with electric field [21-22] is given by

$$\bar{E} \propto \theta_h^c \quad (8)$$

From equation (5) through (8) the ageing mathematical model for polymeric insulation can be applied to silane epoxy resins is expressed as

$$V_{fo} = C \left[ I_{lc} \times \text{ESDD} \right] \left[ \frac{-n}{(n+1)} \right] \left[ \theta_h \right] \left[ \frac{c}{(n+1)} \right] L \quad (9)$$

## III. EXPERIMENTAL PROCEDURE

### A. Material

The amount of silane was varied and the vulcanization was conducted at room temperature. Variation of the filler were as follows: 10 %, 20 %, 30 %, 40 %, 50 %, and 60 %, with the same ratio of the 325-mesh silica and silane. The specimens used in this research are in square forms with the dimension of 70 mm x 70 mm x 5. So, there are six types of specimens

coded, as follows: RTV<sub>21</sub>, RTV<sub>22</sub>, RTV<sub>23</sub>, RTV<sub>24</sub>, RTV<sub>25</sub>, and RTV<sub>26</sub>.

### B. Equipment

Experimental method for 6 types of specimens was carried out through the following procedure, 1) the specimens was installed on the Parangtritis natural aging test, located  $\pm 30$  km in the South of Yogyakarta for 60 weeks, and the performance observation every two weeks. This site had heavy coastal pollution as well as high sunny levels, 2) acceleration aging test on laboratory using a fog chamber for 96 hours, with simulated tropical climate, and performance observation was conducted every 12 hours. The observed performances from the two experimental methods were as follows: flashover voltage ( $V_{fo}$ ), leakage current on surface ( $I_{lc}$ ), equivalent salt deposit density (esdd), and the contact angle of the hydrophobicity ( $\theta_h$ )

### C. Test Procedure

Leakage current of each surface of specimen, and the pollution flashover voltage were determined according to the IEC 507 salt fog method, and using the electrical circuit. The ac voltage was applied between two electrodes inserted into specimen surface with accelerated 1.5 kV/ second. The ESDD on the surface of the specimen was calculated by means of [20], while digital camera and computer were use for detecting the contact angle of the hydrophobicity

## IV. RESULTS AND DISCUSSION

The study towards improving the performance of the epoxy resins was conducted by adding silane treatment as filler, and a new performance in regard with hydrophobicity was obtained. The recovery of the hydrophobicity could be due to the diffusion of the low molecular weight (LWM), in this case silane chains moved to the surface from the bulk material [21-26]. Mathematical analysis for studying the ageing performance of the polymeric insulation materials for high voltage insulator in the tropical climate is the multiple regression model, it is derived from statistical science combined with statistics toolbox from matlab programme. It could be applied for silane epoxy resins, for some purpose, namely, 1) to prove aging mathematical model with the data from the natural and acceleration aging. The result for 6 types of specimens can be concluded that  $F_{cal.} > F_{0,05}$ , the rejection of  $H_0$ , the acceptance of  $H_1$ , and the independent variable ( $I_{lc}$ , ESDD, and  $\theta_h$ ) had been contributed to the dependent variable ( $V_{fo}$ ). Also the correlation coefficient for 6 types of specimens was high, there is a good relationship between independent with dependent variable, 2) to determine optimal performance the sample in tropical climate. The result for 6 types specimens can be concluded that  $F_{cal.} > F_{0,05}$ , the rejection of  $H_0$ , the acceptance of  $H_1$ , and the independent variable (time, temperature, humidity, pressure, velocity of wind, rainfall, and ultraviolet radiation) had been contributed to the dependent variable ( $V_{fo}$ ,  $I_{lc}$ , esdd, and  $\theta_h$ ). Also the correlation

coefficient for 6 types of specimens was high, there was a good relationship between independent with dependent variable. The final result of the optimal performance of the sample in tropical climate was the sample coded RTV<sub>24</sub>, 3) in predicting the service life time of samples, which depended on critical electrical field ( $V_{fo}/L$ ) and the design criteria of insulator, and 4) to determine the correlation between natural and acceleration aging test, represented by acceleration factor, with turned out for ultraviolet radiation, temperature, and humidity are 77, 2, and 2 respectively. With this method, natural ageing test which will take long time and high cost is not necessary to be performed, since the accelerated ageing performance could predict the performance of natural ageing test.

Based on the results of multiple regression model, it can be concluded that the silane treatment of the filler with the dose of 40 %, or specimen code of RTV<sub>24</sub> resulted in optimal performance in the tropical climate. Therefore, these materials can be proposed as insulator materials for high voltage transmission line in tropical area, and as an alternative substitution for porcelain and glasses.

## V. CONCLUSIONS

On the basis of the results which were obtained, it can be concluded that,

1. The silane epoxy resins are the name of new thermosetting polymeric insulation materials that have been developed, with the materials composition was obtained from the experimental research. These material has a good performance intense of hydrophobicity

2. Mathematical analysis to study the ageing performance of the polymeric insulation materials for high voltage insulator in the tropical climate is the multiple regression model, it is derived from statistical science combined with statistics toolbox from matlab programme. The applied methodology is proposed to be used for engineering purposes. It could be implemented for silane epoxy resins, for some purpose, namely, a) to prove ageing mathematical model with the data from the natural and acceleration aging, b) to determine optimal performance the sample in tropical climate, and the result is the sample coded RTV<sub>24</sub>, c) to predict the service lifetime of samples, depending on critical electrical field ( $V_{fo}/L$ ) and design criteria of insulator, and d) to determine the correlation between natural and acceleration ageing test, in the form of acceleration factor, with turned out for ultraviolet radiation, temperature, and humidity, which are 77, 2, and 2 respectively. By this method, natural ageing test which takes long time and high cost is not necessary to be performed, since the accelerated ageing performance could predict the performance of natural ageing test.

3. Based on the results of multiple regression models, it can be concluded that the silane treatment of the filler with the dose of 40 %, or specimen code of RTV<sub>24</sub> gives optimal performance in the tropical climate. Therefore, these materials can be proposed as insulator materials for high voltage transmission line in tropical

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