EFFECT OF DIFFERENT VOLUME RATIO ON RESISTIVITY, DIELECTRIC CONSTANT AND LOSS FACTOR OF PURE EPOXY RESIN

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Abstract- In this paper, epoxy resin based composites with different volume ratio were studied. The relationship between volume ratio change as well as resistivity, relative permittivity and loss factor were investigated. The results show that, the resistivity decrease when hardener (Part A) content are higher than material (Part B) itself after 500V voltage applied on it in 60 seconds. In addition, the permittivity of all sample decrease as the frequency reaches 10k Hz. Yet, loss factor is about to increase when the frequency is increased. Thus, resistivity, permittivity and loss factor of insulation are depending on volume ratio change.

Keywords: Epoxy resins; volume resistivity; relative permittivity; loss factor

I. INTRODUCTION

A good insulation has high resistivity but poor insulation, relatively low resistance. Epoxy resin which a material can be hardened into a usable plastic is defined as a molecule with more than one epoxy group. The epoxy group, which also known as glycidyl group, has through its characteristic appearance given the name to epoxy[1].

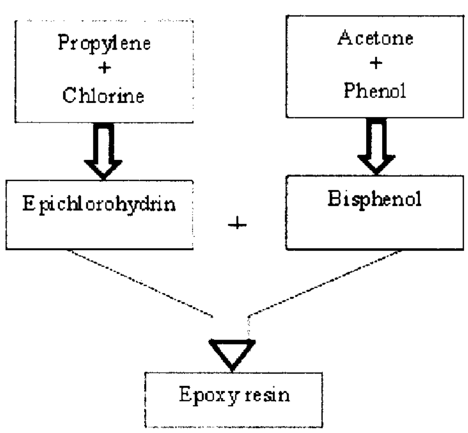

Fig 1 Epoxy resin is manufactured from simple basic chemical

Epoxy resins is the type of thermosetting polymers that widely used for high performance applications, but brittleness is a major drawback of it[2]. Epoxy resin is a material that has essential factors as good electrical insulation properties, mechanical and chemical properties[3, 4]. Those factors are low shrinkage and good adhesion properties. Furthermore, as an insulation material epoxy resin possess outstanding electrical properties such as high volume resistivity and surface resistance, low power factor and loss factor, and high dielectric strength. These factors make people interest to fit them into electrical trade[5]. These properties have been responsible in order to potting and encapsulating for wide use of epoxy resins in electrical laminates application such as printed circuit bases [5]. Epoxy resin classified as excellent electrical insulators because, it has normally $10^{15}\Omega.cm$ volume resistivity. Combination of high moisture resistance and chemical resistance makes the epoxy suitable for both manufacture of electronics components and the embedment of transformers[1].

For more than 60 years, epoxy resins have been successfully used in high voltage equipment for AC system. Nowadays, epoxy resin insulators are more often used in HVDC equipment due to the increasing demand on HVDC system worldwide. Humidity level related to water absorption behaviour is a factor that would cause the degradation of their volume resistivity is considered for a proper choice of suitable materials[6].

Insulating quality of solid insulating materials can be characterized by two parameters called surface and volume resistivity derived from d.c voltage and current measurement according to (American Society for Testing and Materials) ASTM [7]. However, this paper only stressed on volume resistivity parameter in order to characterized the insulating quality of different ratio of epoxy resins. Electrical resistance through a cube of insulation material defined as volume resistivity. The length of electrification time and applied voltage are the factors that resistivity depending on [8]. Other than that, environmental factor such as humidity, also affect the insulator's resistivity. Thus, to obtain the accurate comparison for a specific test, the applied voltage, electrification time and environmental condition should be kept constant for each test. Commonly used test condition is a voltage of 500V applied for 60 second based on ASTM standard [8].

Relative permittivity or known as dielectric constant is important parameter in characterizing capacitors. Capacitance exists when conductor and dielectrics which permits the storage of electrically separated charges when potential differences exist between the conductors [9]. Permittivity of insulating materials is used in general in two different ways. First, insulate and support components of an electrical network from one to another and from ground. Other purpose of permittivity is functioning as the dielectric of a capacitor. In this work, permittivity is likely to have the capacitance of the support as small as possible, consistent with acceptable mechanical, chemical and heat-resisting properties [9].

II. MEASUREMENT THEORY

a) Keithley Model 6517 Electrometer/High Resistance Meter and Jig

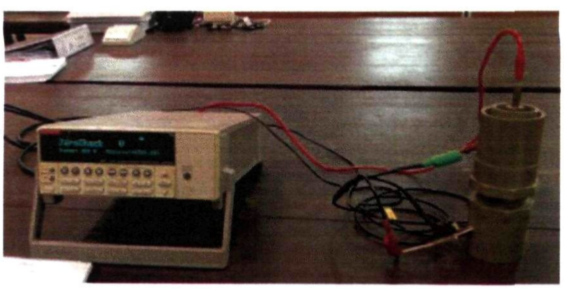

Fig 2 Connection between Keithley Model 6517 Electrometer/High Resistance Meter and Jig

Jig contain of electrodes connecting the terminals and the sample test. Volume resistivity is measured by applying a voltage potential across opposite site of the insulator sample as shown in Fig 2. The results displayed on the screen of Electrometer stored for 60 second electrification time with 500V voltage supply. Volume resistivity reading displayed by automatic calculation inside the Electrometer [8]:

$$\rho_v = \frac{K_v}{\tau} R \quad (1)$$

Where

ρ_v = Volume resistivity

K_v = The effective area of the guarded electrode for the particular electrode arrangement employed

τ = Average thickness of the sample (mm)

R = Measured resistance in ohms (V/I)

Based on the above equation, value of resistance that will be used in $tan\,\delta$ calculation is calculated.

For circular electrodes:

$$K_v = \pi \left(\frac{D_1}{2} + B\frac{g}{2}\right)^2 \quad (2)$$

Where

D_1 = Outside diameter of guarded electrode

g = Distance between the guarded electrode and the ring electrode

B = Effective area coefficient

However, an effective area of coefficient (B) of 0 is generally used for volume resistivity. Thus this is used in this work [8]:

$$K_v = \pi \left(\frac{D_1}{2}\right)^2 \quad (3)$$

b) Hioki LCR 3522-50 HiTester

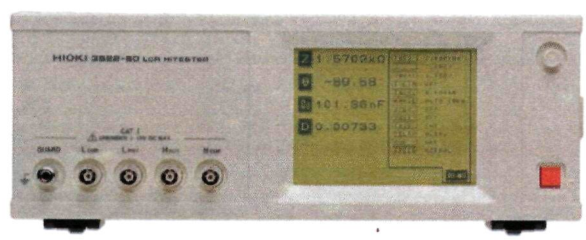

Fig 3 Hioki LCR 3522-50 HiTester equipment

This equipment has 5ms measurement capabilities and capable to provide DC or high frequency which is 1mHz to 100kHz for measurement [10] make it most suitable instrumentation in this work. Other feature for this LCR 3522-50 is high resolution and high accuracy. It provides a full five digits as well as basic measurement accuracy ±0.08% [10]. The equation of capacitance, C can be calculate using [11]:

$$C = \varepsilon_o \varepsilon_r \frac{A}{D} \quad (4)$$

Where

ε_o = Permittivity of free space (8.854×10^{-12}F/m)

ε_r = Relative permittivity

A = Area of a test cell

D = Distance of electrode

The equation (4) is used to calculate the permittivity since the capacitance values obtained from the LCR instrument.

The ratio of the loss current to the charging current declares the frequency response of the circuit. The tan delta or called as dielectric loss is determined by equation [12]:

$$\tan\delta = \frac{1}{\omega CR} \quad (5)$$

Where

ω = 2πf, f: frequency

C = Capacitance

R = Resistance

Which capacitance and resistance is obtained and calculated from the experiment handled.

III. EXPERIMENT/METHODOLOGY

a) Sample Preparation

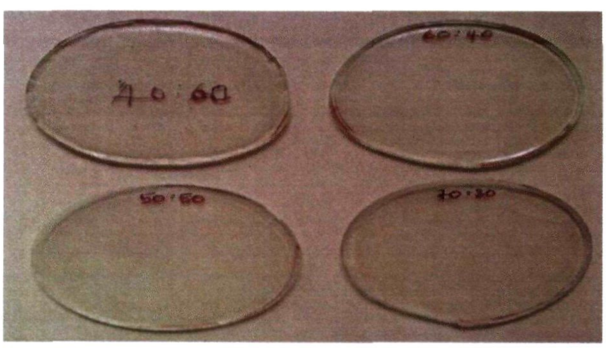

Fig 4 Ready samples for test

Surface area of the plates is determined by the samples diameter and spacing between the electrodes which based on the samples thickness are the most important factors in measuring resistivity and capacitance. In order to ensure the accuracy, 5cm diameter and 2mm thickness of the samples are maintained according to ASTM standard plus, top and bottom surfaces of the samples should be flat. Total of nine samples are prepared following the volume ratio of Part A (hardener) and Part B (material) in order to forming epoxy resins. The volume ratio is varies by 10% from 10:90 to 90:10 by weight. Out of nine samples, only four which based on 40:60, 50:50, 60:40 and 70:30 samples are forming solid condition insulation that can be tested in this work. All four solid samples require one to two weeks to form an epoxy resins. However, those samples can be affected by the ratio concentrations (Part A and Part B) and surrounding humidity. Inaccurate ratio of concentration would cause inaccurate composition in the samples and affecting the measurement. Another factor considered is a surface of the samples. Sample surface must be flat to ensure the electrodes and the sample surface to be contacted together to avoid existence of air holes between the electrodes and the dielectric which can affect the measurement.

b) Volume Resistivity Test

The Keithley Model 6517 Electrometer/High Resistance Meter was employed for measuring resistivity of the epoxy resin solid insulation. The connection between the measurement instrument and jig is presented in Fig 2. 500V supply was set as injection voltage on to the samples test in the jig for 60 second.

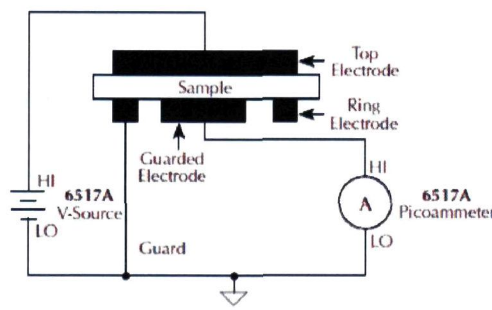

Fig 5 Volume resistivity measurement technique

Based on connection in Fig 5, voltage supply and picoammeter are using the same 6517A equipment. On the top electrode, positive side of voltage source is connected in order to applying voltage injection. On the other side, the HIGH picoammeter wire connected to guarded electrode for the purpose of resistivity measurement.

Solid dielectric test sample is placed between electrodes which together to forming a capacitor for permittivity and volume resistivity measurement. Thick massive electrodes do not properly adhere to stiff dielectrics and large measuring errors can occur. Contact between thick electrodes and the dielectric can be improved by coating the contact parts of electrodes with conductive rubber[13]. However, volume resistivity measurement is always enlarging when rubber electrodes are used. Conductive rubber electrodes also not allowed in permittivity measurement because it diametrically alters the measurement results. At present, extremely thin electrodes are applied to ensure resistivity and permittivity measurements with smallest errors in consequence of close contact with the dielectric[13].

c) Dielectric Frequency response Test

The Hioki LCR 3522-50 HiTester was used for measuring the capacitance of the solid insulation test. The same structure of jig was employed to placing the sample test and connected to the LCR meter. Measurement for frequency of 1 Hz, 10 Hz, 100 Hz to 1k Hz with steps of 100Hz; 1k Hz to 10k Hz with increment by 1k Hz were conducted.

d) Flowchart

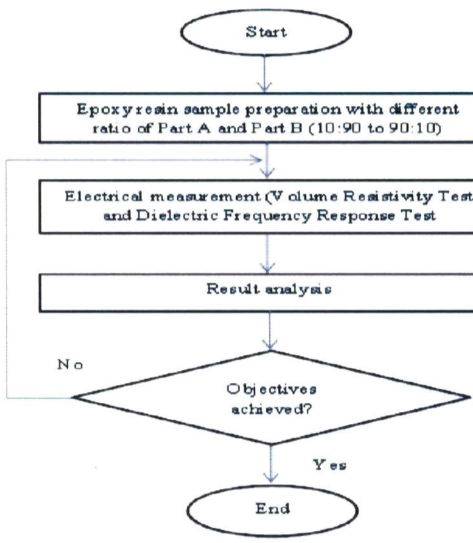

Fig 6 Overall processes on this experiment

IV. RESULTS AND DISCUSSION

a) Volume resistivity

Results for volume resistivity test are represented in Fig 7 and 8. Resistivity comparison between 40:60, 50:50, 60:40 and 70:30 is representing in Fig 7. Better insulation attain when it's contain with higher resistivity. According to Fig 7, 40:60 ratio of epoxy resin given the highest resistivity value within 60 second compared to other samples makes it a good insulator than three others roughly.

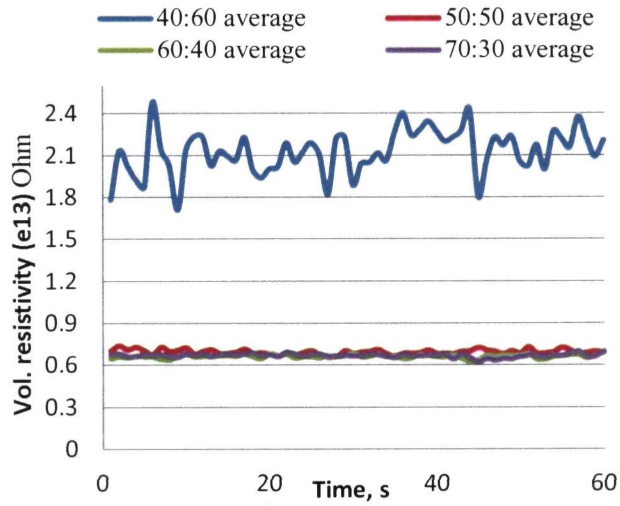

Fig 7 Resistivity of 40:60, 50:50, 60:40 and 70:30 epoxy resin samples for 60 seconds

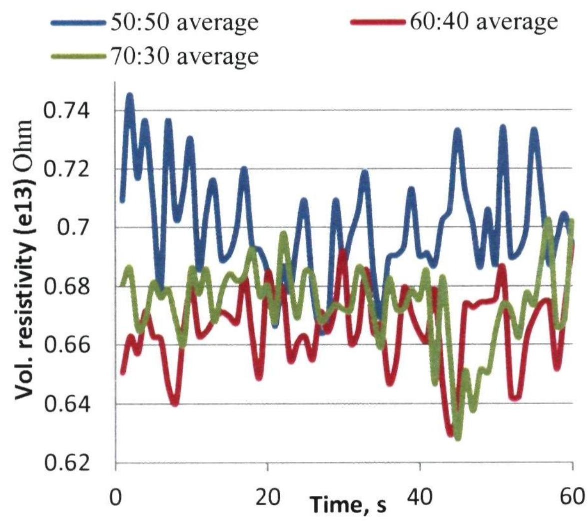

Fig 8 Magnifying resistivity of 50:50, 60:40 and 70:30 epoxy resin samples

However, as seen in Fig 8, resistivity of 70:30 and 60:40 were compared with 50:50 epoxy resin samples. The equivalent ratio gives greater resistivity, however, at certain time interval, the resistivity of 50:50 looks decreases. Factors related to tested object and metrological factors which are employed method plus measuring instrument are two main factors that affected the results obtained. The resistivity influenced by the material properties in the specimen volumes where the reaction of Part A (hardener) and Part B (material) with different volume causing a composition change in the samples. Therefore, the results proved that when the insulation material itself (Part B) has greater volume than the hardener, the resistivity obtained is larger.

b) Permittivity/Dielectric constant

According to resistivity and capacitance measurement, permittivity and tan delta computation were presented in the graph plotted in Fig 9 to Fig 14. Based on Fig 9, ratio of 40:60 gives the lowest value of permittivity while 70:30 ratio samples give the highest permittivity value from 1 Hz frequency to 100 Hz. However, the permittivity start to decrease as frequency goes up. Significant change of permittivity value occurs at 1 Hz up to 100 Hz and start to decrease slightly until 10 kHz.

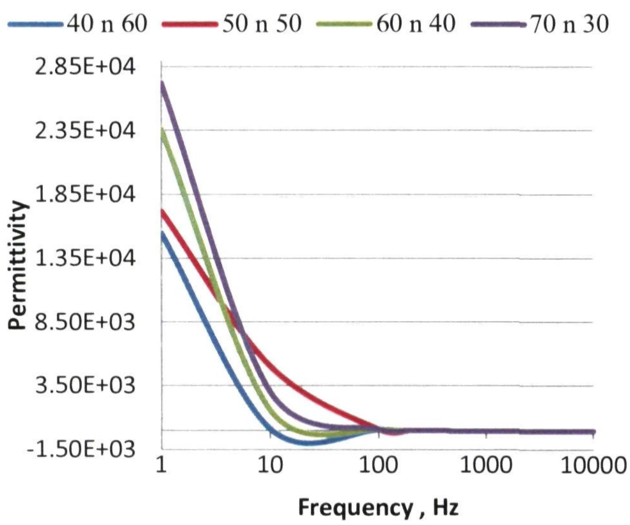

Fig 9 Permittivity of 40:60, 50:50, 60:40 and 70:30 epoxy resin samples against frequency in logarithmic scale

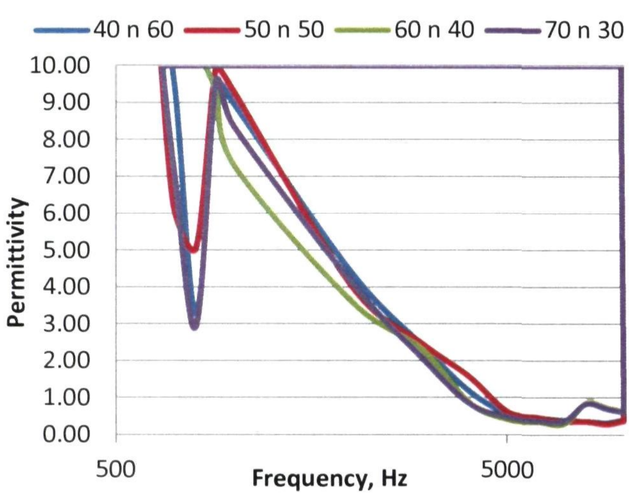

Fig 10 Permittivity magnifying within 500 Hz and 5 kHz

As seen in Fig 10, permittivity of 40:60, 50:50 and 70:30 decreased at frequency 800 Hz and at a very short time, the permittivity goes up before it goes down until frequency 5k Hz.

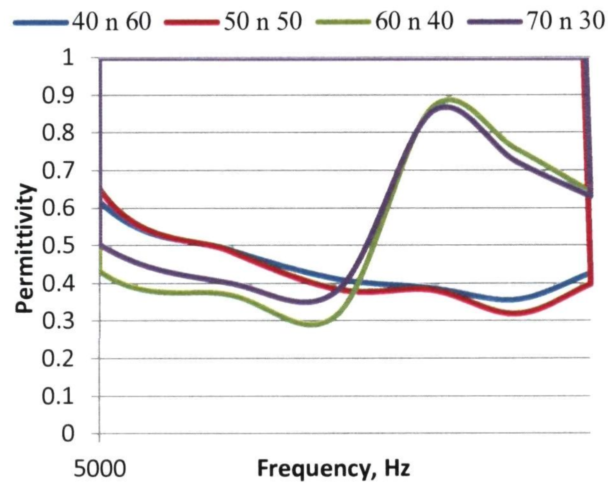

Fig 11 Permittivity magnifying within 5 kHz and 10 kHz

Furthermore, permittivity shows significant change for 60:40 and 70:30 ratio samples at 8k Hz to 10k Hz frequency as illustrated in Fig 11. Permittivity changes occur due to the change in value of capacitance obtained from frequency response test. Based on the capacitance calculation in equation (4), it shows that permittivity is directly proportional with capacitance value.

Good adhesion is one characteristic of pure epoxy resin causing it was easily doped by many modifiers. Thus, the modifiers can significantly change thermal and dielectric characteristic of resins in consequence of electrical characteristic own by each materials.

c) Dielectric loss/Tan Delta

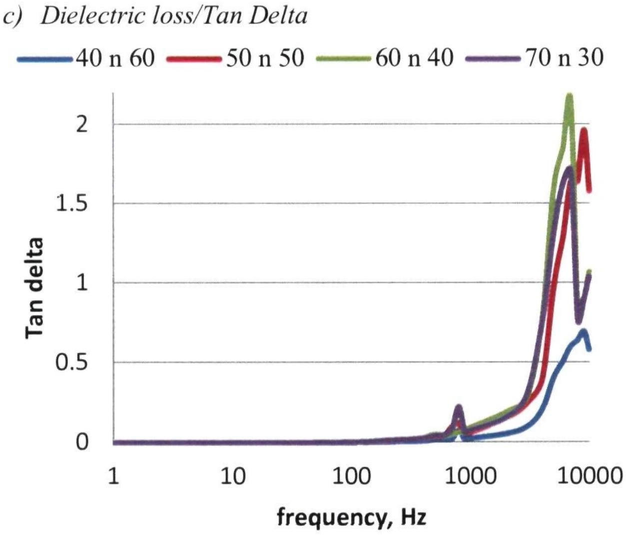

Fig 12 Tan delta against frequency in logarithmic scale

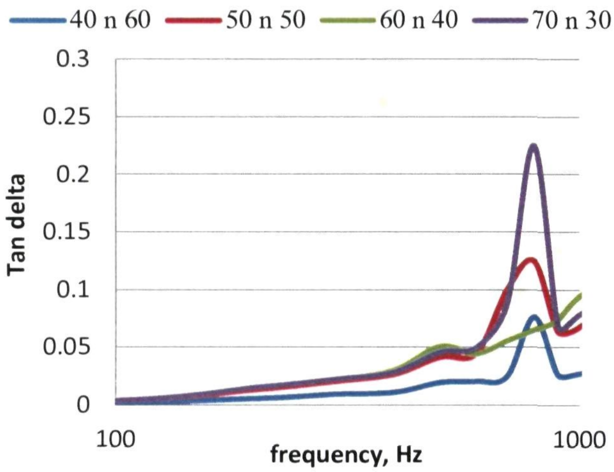

Fig 13 Tan delta magnifying within 100 Hz and 1 kHz

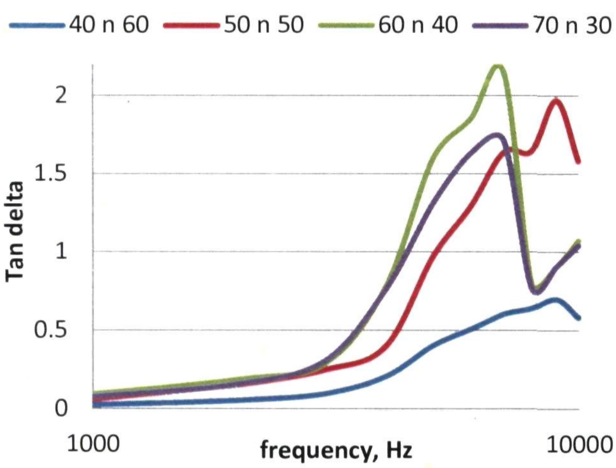

Fig 14 Tan delta magnifying within 1 kHz and 10 kHz

Tan delta obtained from the calculation by implementing equation (5) which the value of capacitance, C obtained from the experiment conducted while resistance, R calculated from the equation (1). According to graph formed for tan delta in Fig 12, 40:60 ratio samples gives the lowest tangent loss or also known as dissipation factor. However, referring to Fig 13 at frequency 800 Hz tan delta for 40:60, 50:50 and 70:30 shown an abrupt increase before it dropped significantly. Yet, at 7k Hz in Fig 14, all four samples had increased its tan delta value. Nevertheless, at point 9k Hz, 40:60 and 50:50 experienced increases value of tan delta while 60:40 and 70:30 had decrease loss factor value.

V. CONCLUSION

The results of resistivity (ρ_v), permittivity (ε_r) and loss factor ($\tan\delta$) determine the electrical properties and performance of epoxy resin with different volume ratio. Based on the analysis results, 40:60 ratio samples gives the best ratio in forming pure epoxy resins insulation with highest resistivity and lowest loss factor as frequency rising. The results show that two different substances forming epoxy resins with different volume ratio gives different resistivity, permittivity and loss factor measurement.

VI. REFERENCES

[1] C. Augustsson, *NM Epoxy Handbook*, 3rd ed.: Nils Malmgren AB, 2004.

[2] Y. G. Chen Yufei, Xiao Yiyue, Bai Mengyao, *Li* Shixia, Ahang Xu, *Li* Fangliang, "Preparation and Study on Properties of Epoxy Resin Modified by poly(ether sulfone)," 2011.

[3] A. S. A. Qi Wang and George Chen, "Influence of Nanofillers on Electrical Characteristic of Epoxy Resins Insulation," presented at the 2010 International Conference on Solid Dielectrics, Postdom, Germany, 2010.

[4] M. S. Marian Klampar, Pavel Skarvada, Dinara Dallaeva, Jozef Kobrtek, Karel Liederman, "Dielectric Properties of Epoxy Resins with Oxide Nnofillers and Their Accelerated Ageing," presented at the 2013 Electrical Conference, Ottawa, Ontario, Canada, 2013.

[5] B. P. B. A. B. E. G. C.F.PITT, "Electrical Properties of Epoxy Resins," present at Biennial Electronic Material Symposium Philadelphia, 1957.

[6] J. K. B.Lutz, "Influence of Absorbed Water on Volume Resistivity of Epoxy Resin Insulator " presented at the International Conference on Solid Dielectrics, Potsdam, Germany, 2010.

[7] "Standard Test Methods for

DC Resistance or Conductance of Insulating Materials," ed, 2007.

[8] Keithleys, "Model 6517A Electrometer User's Manual," in *Volume Resistivity*, ed, 1996, p. 343.

[9] "ASTM AC loss Characteritic and permittivity (Dielectric Constant) of Solid Electrical Insulation," ed, 2011.

[10] "HIOKI LCR HiTester 3522-50/3532-50," ed, p. 8.

[11] A. Sadiku, *Fundamentals of electric circuit*, Third Edition ed.: McGraw Hill, 2007.

[12] V. K. M S Naidu, *High Voltage Engineering*, 4 ed.: Tata Mc Graw Hill Education rivate Limited, 2008.

[13] M. L. a. A. Skopec, "Effective Area of Thin Guarded Electrode in Determining of Permittivity and Volume Resistivity," ed, 19 November 2008, p. 8.