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A Study on Evaluation of Activation Energy of EPR through Volume Electrical Resistivity

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1. Introduction

A cable is one of the major nuclear power plant components that are directly related to safety. Therefore, countries of advanced atomic energy have been studying for cable aging evaluation and to approximate remaining cable life through various condition monitoring methods from studying around government and regulatory agencies. Also, these studies have been studying around institutions and universities at the domestic. Typical condition monitoring such as physical, mechanical and chemical randomly defined end of cable life to diagnose remaining cable life from 100% point of elongation and weight change to elongation 50% or weight change 5% point, but electrical parameters such as volume electrical resistivity can be defined end life to breakdown time for electric components as cable in electric stress. Thus, for the remaining life expectancy is determined to be the optimal parameters. In this paper, it is researched to get the activation energy that need to estimate the cable life time for cable insulation materials using electrical parameters from condition monitoring method through volume electrical resistivity in current study.

2. Experimental Procedure

2.1 Cable Specimen and Volume Electrical Resistivity

Ethylene propylene rubber(EPR, TAIHAN Electric wire Co. LTD) were used as starting specimen (EPR 120-0). The starting sample is subjected to 120℃ heating for 6.51days(EPR 120-5). Resistances change according to the aspects such as the shape and size of insulating material of cable. However, volume electrical resistivity do not change, the value of the material is unique and do not be affected by the aspects such as the shape and size of insulating material of cable. Measurement of volume electrical resistivity uses 3-terminal guard-ring electrode. The layout of 3-terminal guard-ring electrode is designed as described in Fig 1, consisted of two parallel plate electrode to apply a voltage to a cable specimen and added with a guard ring electrode to absorb leakage current. Volume electrical resistivity ρ(Ω·cm) is expressed as follows:

$$\rho = R\frac{S}{t} = \frac{V}{I}\cdot\frac{S}{t} \quad \text{..........(1)}$$

Volume electrical resistivity ρ is computed from results of electrometer by equation 1. Where, V is voltage of digital voltmeter, I is current of electrometer, S is upper electrode area and t is thickness of cable specimen. The final volume electrical resistivity is obtained from measuring the electric current of specimen using the 3-terminal measurement circuit as shown in Fig.1

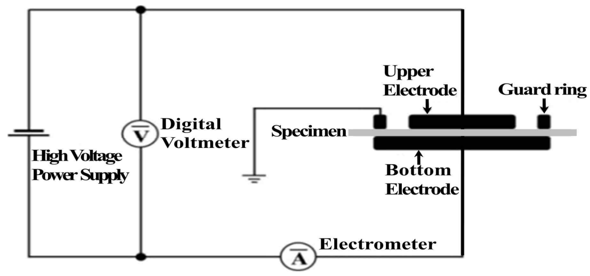


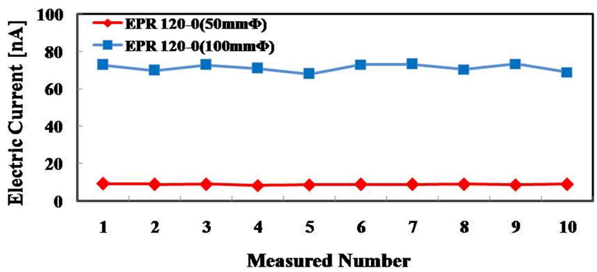
Fig. 1 3-Terminal Measurement Circuit

Upper electrode diameters are 50mmΦ and 100mmΦ, bottom electrode diameter is 130mmΦ. Guard ring width is 6mm.

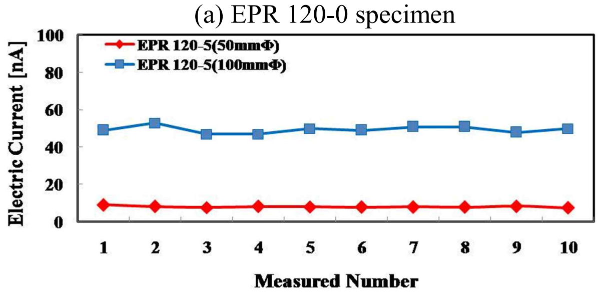
3. Experimental Results and Discussion

3.1 Electric Current

In case of 50mmΦ upper electrode, the electric currents of EPR 120-0 and EPR 120-5 specimen were 8.79 ~ 9.4nA and 7.55 ~ 9.13nA respectively as show in Fig. 2(a) and (b).



(a) EPR 120-0 specimen

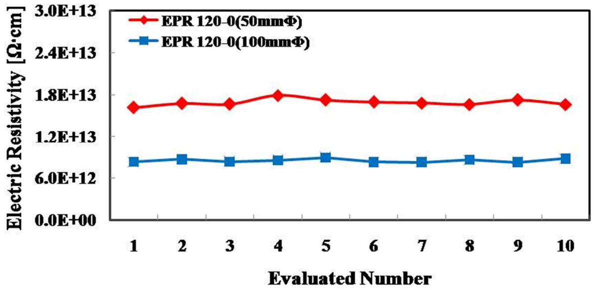


(b) EPR 120-5 specimen

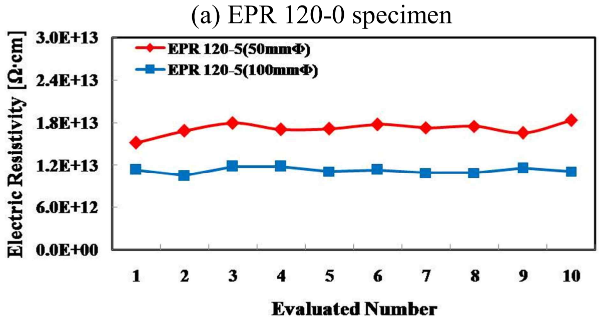
Fig. 2 Electric current versus measured number

3.2 Electrical Resistivity

In case of 50mmΦ upper electrode, the volume electrical resistivities of EPR 120-0 and EPR 120-5 specimen were 1.61×10^{13}~1.72×10^{13} Ω·cm and 1.52×10^{13} ~ 1.83×10^{13} Ω·cm respectively as show in Fig. 3(a) and (b).



(a) EPR 120-0 specimen



(b) EPR 120-5 specimen

Fig. 3 Volume electrical resistivity versus evaluated numbers

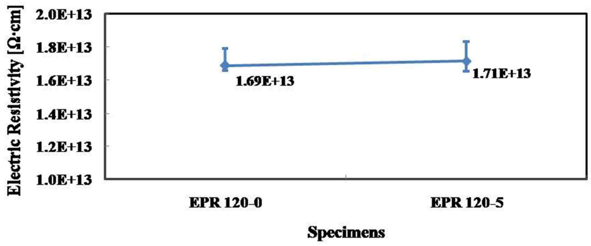


Fig. 4 Volume electrical resistivity of EPR 120-0 specimen and EPR 120-5 specimen

A dielectric or insulator is usually consisted of electrical components such as resistance(R) and capacitance(C). If the insulation material has the linear and isotropic characteristic, R and C show the following equation (2) and (3) respectively.

$$R = \frac{V}{I} = \frac{-\int_L E \cdot dl}{\oint_S J \cdot ds} = \frac{-\int_L E \cdot dl}{\oint_S \sigma E \cdot ds} \text{ ....(2)}$$

$$C = \frac{Q}{V} = \frac{\int_S D \cdot ds}{-\oint_L E \cdot dl} = \frac{\int_S \varepsilon E \cdot ds}{-\oint_L E \cdot dl} \text{ ....(3)}$$

Where, E(V/cm) is electric field, D(C/cm^2) is electric flux density, J(A/cm^2) is electric current density, σ (S/cm) is conductivity and ε (F/cm) is permittivity.

Comparision of equation (2) and (3) shows the following interesting relationship:

$$R \cdot C = \frac{\varepsilon}{\sigma} \text{ ....(4)}$$

In these cases, if the capacitance of an insulation material of cable is known, the resistance can be obtained directly from the ratio ε/σ without recomputation. The reciprocal of conductivity is called volume electrical resistivity ρ (Ω·cm).

The Arrhenius equation can explain a relationship of chemical reaction velocity and temperature. The Arrhenius is expressed as follows:

$$k = k_0 \cdot e^{-E_A/RT} \text{ ....(5)}$$

Where, k is reaction velocity on isothermal, k_0 is proportional constant of initial value, E_A is activation energy, T is absolute temperature(K) and R is gas constant(R=8.31 J/mol·°K= 1.987 cal/mol·°K = 8.62× 10^{-5}eV/atom). Activation energy is the energy necessary to the place where the chemical change occurs. If the characteristic of volume electrical resistivity ρ versus temperature is a straight line, it can be obeyed the Arrhenius law. Therefore, the modified Arrhenius is expressed as follows:

$$\rho = \rho_0 \cdot e^{-E_A/RT} \text{ ....(6)}$$

Where, ρ is volume electrical resistivity at change temperature and ρ_o is proportional constant of initial value. It can be obtained the activation energy of EPR.

4. Conclusions

If the characteristic of volume electrical resistivity ρ versus temperature is a straight line, it can be obtained the activation energy of EPR by the modified Arrhenius equation (6). It can be stated that the condition monitoring of cable through a volume electrical resistivity is more convenient than others, and is possible to verify cable insulating capability. In the future, apparent density, XRD(X-ray diffraction meter), FE-SEM(field-emission scanning electron microscopy), EDS(energy dispersive spectroscopy) and XRF(X-ray fluorescence analyzer) have to be conducted to evaluate physical properties of the thermal aging cable.

REFERENCES

[1] Weifang Jin, "Dielectric Physics," Beijing, China, Mechanical Industry Press, 1997

[2] Jidan Chen, Ziyu Liu, "Dielectric Physics," Beijing, China. Mechanical Industry Press, 1982

[3]] Erling Ildstad, Sajal R. Chalise, "AC Voltage Endurance of Polyimide Insulated Magnet Wire," In IEEE Conference on Electrical Insulation and Dielectric Phenomena, pp85-88 , Virginia Beach, VA, Oct. 18-21, 2009

[4] M. Nedjar, "Effect of Thermal Aging on the Electrical Properties of Crosslinked Polyethylene", Journal of Applied Polymer Science, Vol.111, 1985-1990, 2009

[5] Michal Lisowski, Ryszard Kacprzyk, "Changes Proposed for the IEC 60093 Standard Concerning Measurements of the Volume and Surface Resistivities of Electrical Insulation Materials", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 13, No. 1, 2006