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Calculating the Activation Energy of NPP Cable by using OIT and Isothermal Method

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1. Introduction

In nuclear power plant, it is very important to assess the life of the equipments. In this paper, we focused on cables only. To assess the life of the cables, we should calculate the activation energy of their materials, which is necessary for finding the condition of accelerated aging equivalent to natural aging. There are so many methods for calculating the activation energy of polymer such as cable materials. Of them, the methods by using elongation at break, modulus, mass change or oxidation induction time (OIT) are widely used. If using those methods, we should experiment repeatly after making materials accelerated thermal aging at more than three different temperatures. When we use isothermal method and OIT, we can save the experiment time, since isothermal method does not need accelerated aging.

2. Basis of Methodology

2.1 OIT Measurement

OIT is a technique that can be used to evaluate aging of organic materials. OIT testing can be used as a evaluation of the cable lifetime technique for electric cable used in electric power plants, control, instrumentation, and power cables. Polymers age by means of chemical reactions with oxygen. Antioxidants are chemicals added to polymers in order to inhibit oxidative reactions. As long as antioxidants remain in an insulation polymer, the properties of the cable insulation do not degrade significantly. The OIT is related to the amount of antioxidant remaining in a polymer, and thus to the age, or remaining life, of the polymer. In an OIT test, a small sample of material is placed in a differential scanning calorimeter (DSC) and subjected to a constant temperature of approximately 180℃ to 220℃ in an oxygen atmosphere until a strong exothermic reaction occurs in the material. The strong exothermic reaction begins when the antioxidant is consumed. The period from the start of the test until the strong exothermic reaction begins is the OIT. This time is indicative of the amount of remaining life of the insulation material. The shorter the OIT, the closer is the material to its end of life. Figure 3 shows a general DSC heat flow graph of OIT measurement.

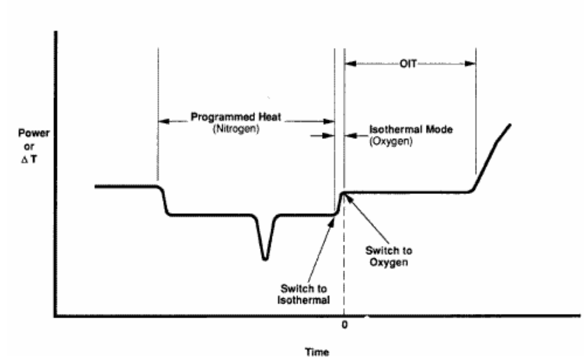

Figure 1. Evaluation of OIT from recorded-time-base thermogram

2.2 Isothermal Method

Isothermal method also determines the activation energy of a set of time-to-event and isothermal temperature data using differential scanning calorimeter from a series of isothermal experiments over a small temperature range. The time-to-event is exothermal reaction such as thermoset curing reaction, crystallization transformation and OIT. Therefore, this test method using OIT is applicable to determine the activation energy.

The relation between time-to-event and temperature is identified as an Arrhenius behavior. So following equation 1 is derived from Arrhenius equation and relation between the rate of heat evolution and the rate of reaction.

$$\ln(\Delta t) = \frac{E}{RT} + C \qquad (1)$$

Δt = lapsed time at isothermal temperature, T(min)
E = activation energy(J/mol)
R = gas constant = 8.314(J/mol·K)
T = temperature(K)
C = constant

We can draw a plot of the logarithm of the lapsed time under a series of differing isothermal conditions versus the reciprocal of absolute temperature (1/T). This plot maybe has the form of straight line and the slope is equal to E/R.

So, we can calculate activation energy(E) from the slope and gas constant(R) according to following equation 2.

$$E = m \bullet R \tag{2}$$

m = the slope of the LMS line

3. Experiment Results

The material tested for calculating of activation energy is XLPE (cross-linked polyethylene) and PVC which is most widely used as an insulation and jacket of cable. We experimented at four different isothermal temperatures. The each result of thermogram of XLPE material at different temperatures from DSC after OIT test is shown as followed figure 2.

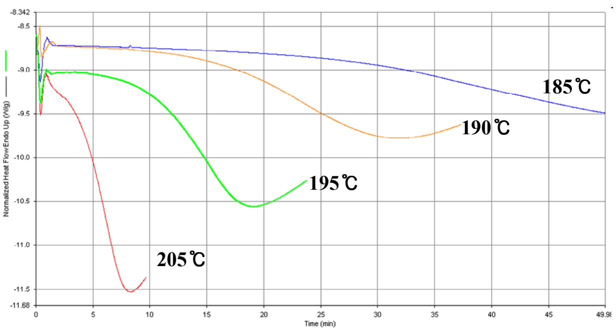

Figure 2. Thermogram of XLPE material at different temperatures

As shown in figure 2, higher the isothermal temperature, shorter the OIT and lower the peak. The OIT result of each material according to isothermal temperature is shown in table 1, 2.

Isothermal Temperature(T), K	OIT(Δt), min	1000/T, 1/K	ln(Δt), min
458	25.953	2.183	3.256
463	15.983	2.159	2.771
468	9.954	2.136	2.298
478	4.245	2.092	1.445

Table1. OIT result of XLPE material

Isothermal Temperature(T), K	OIT(Δt), min	1000/T, 1/K	ln(Δt), min
453	49.388	2.207	3.899
458	25.64	2.159	3.244
463	18.378	2.136	2.911
473	10.867	2.114	2.385

Table2. OIT result of PVC material

We can draw a plot of ln(Δt) versus 1000/T as shown in figure 3. The slope of the lines calculated by least mean square method is respectively 19.800 and 15.757. Then activation energy of this material is respectively 164.726 KJ/mol and 130.362KJ/mol.

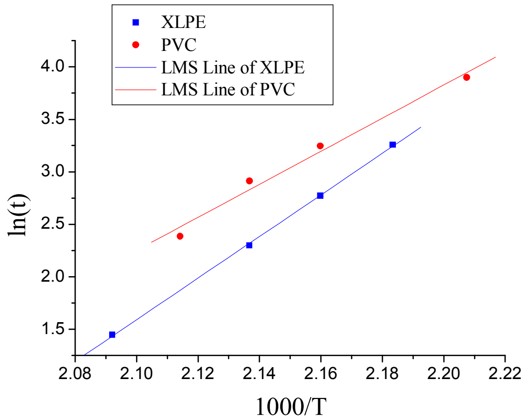

Figure 3. Plot of ln(Δt) versus 1000/T

3. Conclusion

We calculated the activation energy of polymer material by using OIT and isothermal method. In case of PVC material, the activation energy by using this method was 130.362KJ/mol, and the one by using TGA system was 127.3KJ/mol. The results of calculation by using two different methods show similar activation energy value. So, we can calculate the activation energy of the material that cannot use break-elongation, indenting or TGA method. Furthermore, we can save experiment time definitely by using this method.

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