Cable Lore

The Arrhenius Relationship

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ANACONDA

If a power cable is expected to have a useful life over an extended period, its two basic ratings—temperature and voltage—must be maintained. It's only logical that a cable rated at 5 kV and 90° C will have a relatively short life, if used in an application that calls for a 10 kV or 180° C rating.

Recognizing this, investigators routinely use high temperatures and voltages in laboratory testing to accelerate the breakdown of power cables. How are these data then used to extrapolate to the lower temperatures and voltages used in the field? The Arrhenius Plot is frequently used to determine proper cable operating temperatures on the basis of information gathered from cables exposed to very high temperatures. (Voltage extrapolation will be discussed in the next *Cable Lore*.)

In 1884, a Swedish chemist named Arrhenius developed an equation to correlate the rate of a chemical reaction with the absolute temperature of the reacting materials, and a constant for that reaction called its "Activation Energy". This constant may be visualized as an energy barrier which must be overcome before the reaction can proceed. The number of molecules active enough to overcome this barrier increases with temperature; at low temperatures, the number may be so few that for all practical purposes the reaction is not noticeable.

This reaction rate theory applies to the cross-linking of rubbers by chemicals in a CV tube or a laboratory press. The higher the temperature in the tube or press, the more rapid the reaction and the less time is needed for the reaction to be completed. In fact, the Arrhenius relation holds for any process which is thermally activated. Such processes include oxidation, diffusion, creep, and stress relaxation.

Oxidation of many rubbers (but not butyl) causes hardening or embrittlement. Historically, insulation on wires in a protected environment, such as the interior of a building has, over a long period of years, oxidized or degraded resulting in a loss of elongation and the development of brittleness and hardness.

If the Arrhenius relationship holds, it is reasonable to assume that accelerated aging at a high temperature to a measured end of useful life could be extrapolated to the end of useful life at a lower temperature. The procedure for using the Arrhenius technique includes the following steps.

1. Measure the initial physical properties of a compound for use as a reference point. Of particular interest for most rubbers is the initial unaged elongation, usually close to 300 percent.

2. Prepare a number of samples for aging in air ovens set for at least four temperatures; 150° C, 140° C, 130° C, and 120° C are frequently used.

3. Choose the elongation that would represent the end of useful life; some engineers use 50 percent while others prefer 100 percent elongation.

4. Remove samples from the air ovens at regular time intervals, measure their elongations, and then plot elongations against time. For most rubbers, elongation decreases with time, since oxidation increases the number of cross links.

5. From the elongation-time plots, interpolate the time required at each temperature to reach the selected end-of-life points.

6. Plot the four points on Arrhenius paper. The vertical axis will be a logarithmic scale of time and the horizontal scale will be calibrated for temperature on the Celsius scale in a non-linear fashion; it is linear for the reciprocal of the absolute temperature.

7. Determine if a straight line can be drawn through the points. If so, assume the same reaction is rate determining throughout the temperature range. (The slope of the line can be used to estimate the activation energy of the rate determining reaction.)

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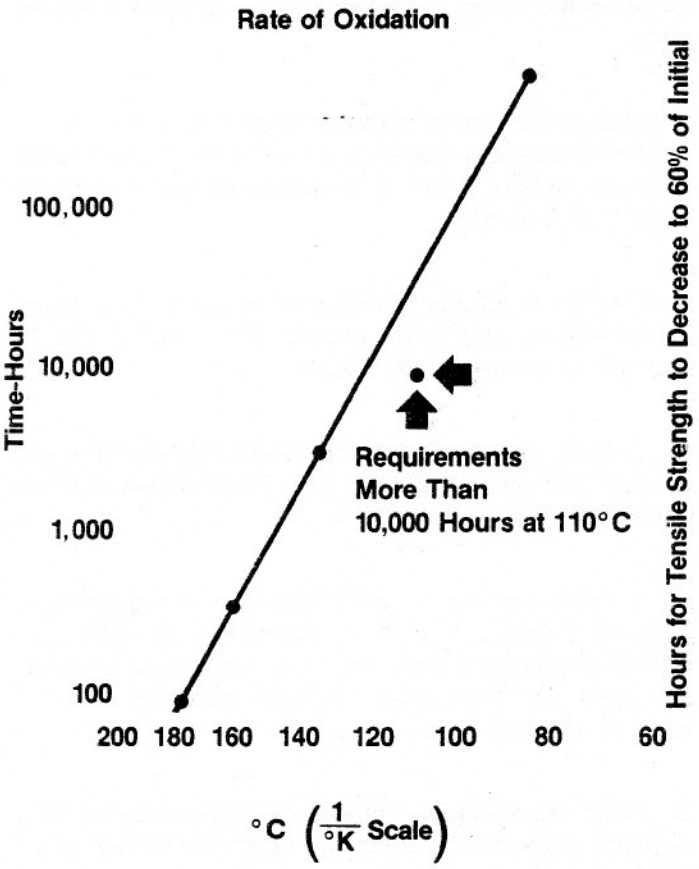
8. To extrapolate the time to end of life at a lower temperature (e.g. 50° C) than those used to obtain the four plotted points, pick the 50° C points on the horizontal scale and extend a perpendicular from that line to the extended line established by the four data points. From the intersection, draw a horizontal line to intersect the logarithmic time scale. This point of intersection will give the estimate of time to reach the end of useful life at that temperature.

An actual Arrhenius plot for an EP insulation is given below:



By such a procedure, data collected in a relatively short time at temperatures above the operating temperature can be used to estimate the very long time required to reach the same end point with natural oxidation at the lower temperatures of service.

This technique is limited to estimating the effect of temperature on the life of a cable; but demonstrating a basic resistance to oxidation (natural aging) is a prerequisite to the appropriate evaluation in other environments.

Perhaps the best perspective on the Arrhenius technique is given in the minutes of the November 1974 meeting of the IEEE Insulated Conductor Committee. The moderator of a lengthy discussion on *Testing of Cable Life* concluded:

"The perils and theoretical limitations of Arrhenius plotting of and extrapolation from test data have been well documented. Despite this, a number of investigators have presented evidence that, within limits, cables and cable materials does appear to plot linearly and that there are a variety of approaches to legitimately relate substantial test data to more or less extended lives."

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