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Revised sealed tube test procedure for thermal verification of liquid-immersed transformer insulation systems

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Abstract

Over the last few years, there have been numerous claims that the thermal performance of cellulose can be improved by the presence of ester liquids. However, solid verification of this phenomenon by a recognized, standardized test procedure is still missing. The article will present a summary of different historical studies that suggest some improvement of cellulose when immersed in ester liquids. Inaccuracies of these studies and a shortage of some important data will also be discussed. The recent industry discussion on the actual thermal performance of cellulose in natural or synthetic ester liquids resulted in a need for performing thorough studies on this subject. It was agreed within IEC Technical Committee 14 “Power Transformers”, that comprehensive studies shall be made. It is likely that the sealed tube test methodology discussed in this article could be used for developing more systematic conclusions on cellulose-ester thermal performance.

A number of standardized test procedures were proposed in the past for new insulation system thermal evaluation. They included the Lockie Test, sealed tube testing and other laboratory testing methods. The Lockie Test was one method used to verify the higher thermal capability claimed for this new insulation system. However, the method uses complete transformers in the procedure and as such is specific to the individual manufacturer’s design. More recently, the dual temperature test has been proposed and has been shown to be a useful procedure, although the equipment necessary is very specialized and complicated. However, this procedure only tests the wire insulation, although it is still the best procedure for testing a system with widely differing thermal capability between the liquid and the solid insulations.

The latest revision of IEEE Std C57.100 defines the Lockie Test procedure along with the dual temperature test and the sealed tube test. The sealed tube test was originally developed only as a means of determining equivalent

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material substitution and has been maligned in the past as an inadequate laboratory test. As with all simulated accelerated testing, this procedure certainly has its weaknesses. However, the 2011 revision of IEEE Std C57.100 now uses a relative thermal index technique rather than the original absolute method, mitigating one of the most problematic issues with the procedure. This new version also addresses many of the other weaknesses of the original method. The end of life criteria is based on either degree of polymerization (DP) or retained tensile as the determining factor. However, since DP is specific to cellulose products, tensile retention is suggested as the end of life criteria which works universally for almost all solid materials for both power and distribution transformers.

An example of a new insulation system based on aramid enhanced cellulose paper immersed in mineral oil will be presented in detail, in order to clarify the procedure of full thermal evaluation following the IEEE Std C57.100-2011 sealed tube test procedure.

Keywords: thermal evaluation; insulation system; liquid-immersed transformer; relative thermal index (RTI); sealed tube test

1. Introduction

Since the early1900's, researchers have searched for the best way to test the life of the insulation system for liquid-immersed transformers. IEEE Std C57.91-2011 [1] Annex I documents this effort with a very good historical perspective. Early testing was performed in what is described as "test tubes" using a broad range of equipment and varied procedures. A large body of data was accumulated. Although the resulting analysis varied significantly and some was questionable, selected portions exist even to modern times. For example, the annex states "Montsinger [2] published early aging data and made an observation about the aging rate that has been widely used. He noted that the rate of deterioration of mechanical properties doubled for each 5–10 °C increase in temperature. The doubling factor was not a constant, being about 6 °C in the temperature range from 100–110 °C and 8 °C for temperatures above 120 °C. However, people tend to remember the doubling factor as a constant and the present IEC Loading Guide uses 6 °C." He stated in 1944 [3] that "There is, of course, some question whether laboratory aging tests made on isolated strips of paper in sealed tubes can be applied directly in estimating the life of insulation in a transformer." So early on the question of laboratory testing of insulation systems was questioned, largely due to poor test procedures.

According to the annex, "In the mid-1950s, a task force of the AIEE Transformers Committee composed of the manufacturers and users of distribution and power transformers undertook the most comprehensive examination of transformer life to date. Sample distribution transformers of each manufacture were subjected to a series of carefully selected loading tests at a number of different manufacturing locations." This test program eventually failed since the transformers survived much longer than anticipated and it was impractical to attain three test temperatures due to the excessive time required for the lower temperature test.

"In 1948, Dakin [4] made a more significant advance in defining insulation aging rates by recognizing that aging of cellulose is the result of a chemical reaction, so the rate of change of a measured property can be expressed in the form of a reaction rate constant." This reaction is now commonly expressed in the form of the Arrhenius equation used to define the insulation life versus temperature. A key point made by this annex is that all too often, the word "insulation" is omitted from the term "loss-of-life" which has been the goal sought by these many years of investigation. "Loss-of-insulation-life" is not the same as loss-of-transformer-life as many transformers continue to operate satisfactorily well after the insulation would normally be considered past end of life. Yet these investigations serve a useful purpose by providing transformer users as an example, with guidance on the relative effects of overloading, especially when it occurs on a regular basis. This type of testing is also useful in comparing the thermal performance of different systems and can provide guidance on the suitability of operating at higher temperatures, which has become more important in recent years.