Dielectric Fluids

Discussion on Overloadability and Life Extension of Paper Insulation Systems using Envirotemp® FR3™ Fluid

Service Information
R900-20-14

INTRODUCTION

The **IEEE®** transformer loading guide defines transformer insulation life versus temperature for thermally upgraded kraft (TUK) paper in mineral oil insulation systems in terms of "A" and "B" factors in an exponential model. This bulletin explains how the A & B factors were determined for Envirotemp® FR3™ fluid and TUK paper insulation systems.

Sealed tube aging studies compared TUK paper in Envirotemp® FR3™ fluid to the same paper in mineral oil. The aging studies were done at 130, 150, 160, and 170°C. Tensile strength and degree of polymerization data were used to determine the time to insulation end-of-life of the paper/fluid systems at each temperature. "A" factors for paper/mineral oil and paper/Envirotemp FR3 fluid systems were calculated, giving insulation life versus temperature equations.

The **IEEE®** transformer insulation life as a function of temperature, shown in Fig. 1, is given as

$$\text{Life (T):} = A \bullet e^{\left(\frac{B}{T+273}\right)} \qquad \text{Where} \begin{bmatrix} A \\ B \end{bmatrix} := \begin{bmatrix} 9.80 \bullet 10^{-18} \\ 15000 \end{bmatrix}$$

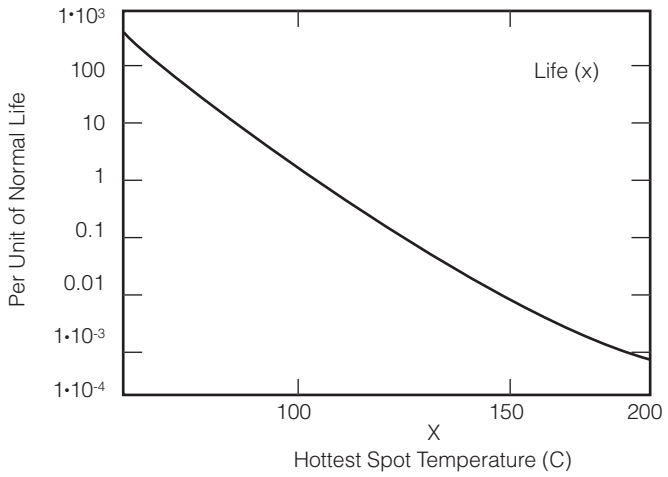

Figure 1.
Unit normal life versus hottest spot temperature from "IEEE® Guide for Loading Mineral-Oil-Immersed Transformers", IEEE Standard C57.91-1995™.

Benchmark insulation end-of-life points at 110°C from **IEEE Standard C57.91™**, as well as times to insulation end-of-life calculated for higher temperatures, are given in Table 1.

TABLE 1
Normal Insulation Life for 65°C Rise Insulation Systems

Temperature	(°C)			
End-of-Life Basis	110	150	160	170
50% retained tensile strength	65,000 (7.4 yrs)	1,602	706	323
25% retained tensile strength	135,000 (15.4 yrs)	3,327	1,467	671
Degree of polymerization lowered to 200	150,000 (17.1 yrs)	3,697	1,630	746
IEEE® composite "normal" life	180,000 (20.5 yrs)			

Normal insulation life of a well-dried, oxygen-free 65°C average winding temperature rise insulation system at the reference temperature of 110°C [times at 150, 160, 170°C calculated using t = life(T) x endpoint]. From "IEEE Guide for Loading Mineral-Oil-Immersed Transformers", **IEEE Standard C57.91-1995™**.

The "A" factor for TUK paper and Envirotemp FR3 fluid is estimated to be 7.82 X 10 E-17 based on sealed tube aging study data, significantly lower than that of comparable mineral systems. The "B" factor remains unchanged at 15000, since the same TUK paper is being used. The predicted insulation life in Envirotemp FR3 fluid can then be calculated using the following:

$$\text{Life (T):} = A \bullet e^{\left(\frac{B}{T+273}\right)} \qquad \text{Where} \begin{bmatrix} A \\ B \end{bmatrix} := \begin{bmatrix} 7.82 \bullet 10^{-17} \\ 15000 \end{bmatrix}$$

Life (in per unit) = 7.98

For equivalent aging rates the predicted hottest spot temperature rise for the insulation in Envirotemp FR3 fluid is 101°C vs. 80°C in mineral oil systems.

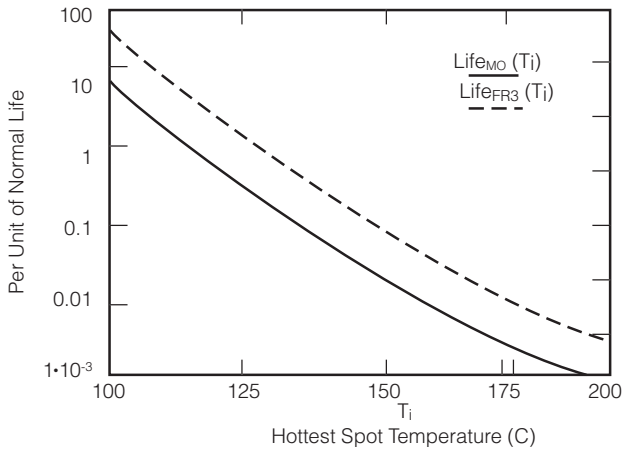

Figure 2.
Calculated transformer insulation life versus winding hottest-spot temperature of thermally upgraded kraft paper in Envirotemp FR3 fluid compared to the IEEE® curve for the same paper in mineral oil.

Since ambient is considered as 30°C, the calculations suggest that transformer insulation in Envirotemp FR3 fluid at a hottest-spot of 131°C should age no more rapidly than transformer insulation at a hottest spot of 110°C in conventional mineral oil. Therefore 1 per unit thermal life for the transformer insulation system in Envirotemp FR3 fluid is achieved at a hottest-spot rise of 101°C (hottest spot of 131°C for 30°C ambient).

It is therefore theoretically possible to design a transformer rated for a hottest-spot rise of 101°C. However, a practical limitation is the ability of other materials commonly used in transformer design*. Most materials currently in use have been designed for 65°C rise transformers and are designed to meet suggested limits of temperature and load stated in the **IEEE Standard C57.91™** Loading Guide.

The table below is Table 6 from the **IEEE Standard C57.91™** Loading Guide.

Suggested limits of temperature and load for loading above nameplate distribution transformers with 65°C rise	
Top-oil temperature	120°C
Hottest-spot conductor temperature	200°C
Short-time loading ($^1/_2$ h or less)	300%

The table above sets practical limits on maximum temperature and load for distribution transformers.

The table below is Table 7 from the **IEEE Standard C57.91™** Loading Guide.

Suggested limits of temperature and load for loading above nameplate power transformers with 65°C rise	
Top-oil temperature	110°C
Hottest-spot conductor temperature	180°C
Maximum loading	200%

The table above sets practical limits on maximum temperature and load for power transformers.

When Envirotemp FR3 fluid is used to retrofill transformers, materials used in the transformer will be limited to maximum temperatures and load as suggested in Tables 6 & 7 of the **IEEE®** Loading Guide.

When Envirotemp FR3 fluid is used in new transformers to take advantage of improved thermal properties, material compatibility at higher temperatures must be verified to determine new limits for loading above nameplate.

REFERENCES:

IEEE Standard C57.91-1995™ – **IEEE®** Guide for Loading Mineral Oil Immersed Transformers

IEEE Standard C57.100-1999™ – **IEEE®** Standard Test Procedure for Thermal Evaluation of Liquid-Immersed Distribution and Power Transformers.

*** Annex B, IEEE Standard C57.91-1995™ –** Effect of loading transformers above nameplate rating on bushings, tap changers, and auxiliary components.

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