Dielectric Fluids

Reference Information

R2080

Thin Film Oxidation

INTRODUCTION

Surfaces coated with thin films of Envirotemp™ FR3™ fluid are especially susceptible to oxidation from air exposure. Natural esters, preferred over mineral oil for their fire and environmental safety and other positive attributes, have less oxidation stability. Factors influencing the oxidation stability of Envirotemp FR3 fluid include elevated temperatures, film thickness, air exposure time, type of surface, and exposure to ultraviolet light. The length of time to reach a sticky or tacky phase is important to understand, as this should be the limit of replenishing air exposure during draining and un-tanking, core-coil repair, component repair, and unit maintenance.

TESTING AND FIELD EXPERIENCE OF THIN FILM EXPOSURE TO AIR

Numerous laboratory tests conducted over extended periods of time show that thin films of Envirotemp FR3 fluid oxidize at a faster rate than do larger volumes of fluid. However, even though the rate of oxidation is faster, the time required to oxidize thin films is typically long enough to allow normal maintenance procedures to be used during transformer repairs.

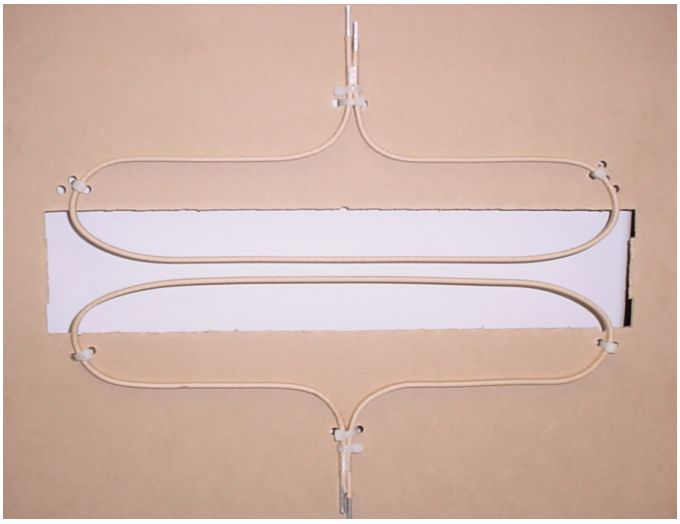


Figure 1.
Pressboard Sample Impregnated with Envirotemp FR3 Fluid, Exposed To Air

The above sample was one of many that consisted of two paper insulated aluminum secondary conductors mounted to a piece of high-density T-IV pressboard. The sample was fully impregnated in September of 2005, and then stored in an Envirotemp FR3 fluid tank until November of 2005. The samples were taken out of the Envirotemp FR3 fluid, dielectrically tested and stored indoors. After exposure to air for three months, the samples were examined for detectable stickiness or tackiness, which would confirm advanced oxidation. No indication of advanced oxidation (sticky/tacky) was noted.

A practical experiment was then designed to simulate typical maintenance settings. A 25kVA Envirotran Envirotemp FR3 fluid filled production transformer was used to evaluate thin films. The transformer, with high voltage bushings removed, was drained and the cover loosely placed back on the unit. A piece of copper metal strip was dipped in Envirotemp FR3 fluid and placed on top of the core clamp (See Figure 2). The transformer was then continuously exposed to warm air (40°C (104°F)) in an oven with a blower. The air was forced in on the back wall of the oven near the bottom and flowed upwards. The two bushing holes allowed open exposure to the air inside the oven. The transformer was inspected at various times for development of a sticky or tacky feel on the various surfaces.

Table 1 summarizes the observations over the course of the testing.

TABLE 1
Transformer Inspections for Envirotemp FR3 Fluid Stickiness at 40°C (104°F)

Days	Observations
0	No sticky or tacky areas
4	No sticky or tacky areas
7	No sticky or tacky areas
11	No sticky or tacky areas
17	No sticky or tacky areas
23	One small sticky film on Envirotemp FR3 fluid puddle on LV conductor
25	Dime size sticky area on A1 LV conductor, quarter size sticky area on top of core clamp
49	Sticky areas on copper strip, two on core clamp, one on LV A1 strip, o-ring seal area under cover. Paper, pressboard, and polymer standoff surfaces were not sticky or tacky.

These results show that a small dime size puddle of Envirotemp FR3 fluid on a horizontal aluminum surface oxidized to form a sticky/tacky film near its edges after about 23 days at 40°C (104°F). At 25 days, only two small puddles of Envirotemp FR3 fluid formed a sticky area. Within 49 days, most metal surfaces, especially horizontal surfaces, formed a sticky coating, but paper and pressboard surfaces were still free of any sticky coating.

In a separate experiment using steel paint panels containing a horizontal coating of Envirotemp FR3 fluid, a polymerized sticky coating formed within seven days in a forced air

fume hood environment at room temperature. Prolonged exposure to direct sunlight will accelerate oxidation, as will increased temperature. These tests were developed to address indoor service shop environments, where sunlight is typically not a factor.

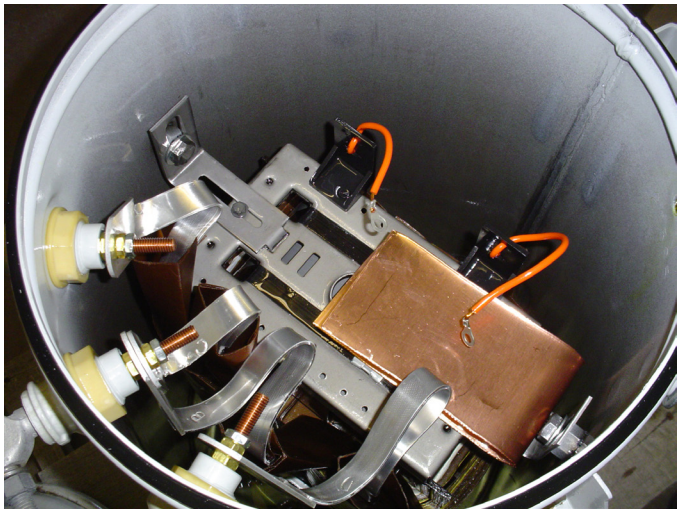
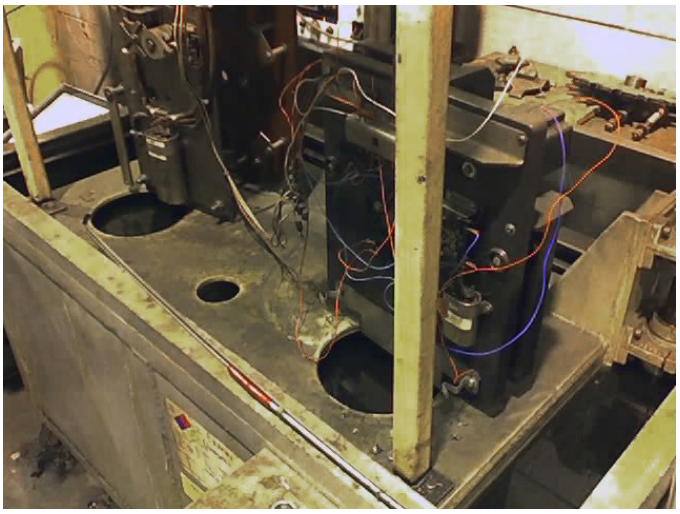


Figure 2.
25 kVA Envirotemp FR3 Fluid-Filled Transformer

OPEN TANKS OF ENVIROTEMP FR3 FLUID:

A 200 gallon test tank of Envirotemp FR3 fluid has been left uncovered in ambient air for approximately five years without any processing. Samples were taken and analyzed with results summarized in Table 2.



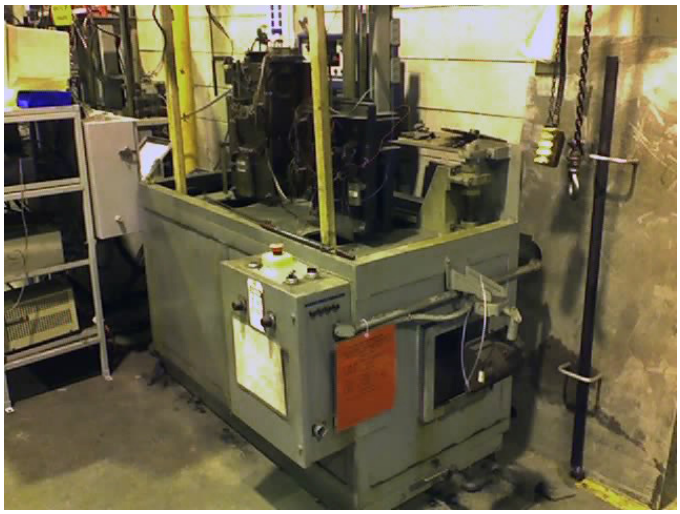


Figure 3.
200 Gallon Tank Filled with Envirotemp FR3 fluid

TABLE 2
Summary of Envirotemp™ FR3™ Fluid Test Results

Test Performed	ASTM Test Method	Envirotemp FR3 Fluid sampled from 5 yr old uncovered tank (1/29/07)	IEEE C57.147 Acceptance Limits for New Envirotemp FR3 Fluid
Color and Condition	D 1500/1524	Clear, light green	Clear, light green
Dielectric Strength (kV)	D 1816 (2mm)	32	≥ 35
Dissipation Factor 25 °C (%)	D 924	1.39	≤ 0.20
Dissipation Factor 100 °C (%)	D 924	21.0	≤ 4.0
Moisture Content (ppm)	D 1533	322	≤ 100
Acid Number (mg KOH/g)	D 974	0.06	≤ 0.06
Pour Point (°C)	D 97	-19	-10
Flash Point (°C)	D 92	323	≥ 275
Fire Point (°C)	D 92	357	≥ 300
Viscosity at 40 °C (cSt)	D 445	35.2	≤ 50.0
Viscosity at 100 °C (cSt)	D 445	8.3	≤ 15.0
Vol. Resistivity (ohm-cm)	D 1169	8.2×10^{11}	-
Inhibitor Content (%)	D 4768	0.22	-

The results indicate that while the inhibitor content decreased (having been consumed in reactions with oxygen), the viscosity did not significantly increase. This proves that volume of fluid relative to the surface exposed to ambient air significantly impacts the rate and degree of polymerization that occurs. Additionally, most other key fluid property values measured tested within the acceptable limits for new fluid.

Cargill recommends retrofilling transformers filled with Envirotemp FR3 fluid when viscosity increases more than 10% (approximately 38 cSt). This is well within the acceptance criteria for viscosity of new natural ester fluids, < 50cST measured at 40 °C, per both ASTM D6971-03 and IEEE C57.147.

CAUTION: Unlike transformer assemblies impregnated with mineral oil, hot air drying is an unacceptable process for drying out and or reducing power factor of assemblies already impregnated with a natural ester fluid. For additional drying of natural ester impregnated assemblies, it is required to use methods of drying that do not expose the impregnated insulation to air to avoid polymerization of the dielectric fluid. Consult Cargill Storage and Handling Guide (S10) for suggestions on drying various Envirotemp FR3 fluid impregnated insulation systems deemed to have too much moisture.

CONCLUSIONS:

Cargill has conducted many tests relative to oxidative stability. Results show that the rate of oxidation of thin films is slow indoors at room temperatures, but can be accelerated by exposure to sunlight (UV light), elevated temperature, and increased air flow. Also, the surface type (porous vs. non-porous) affects rate of oxidation as well. A larger concern is the rate of moisture absorption since moisture directly impacts dielectric strength.

Additionally, it is clear that the ratio of volume to surface area of Envirotemp FR3 fluid exposed to air impacts rate of oxidation. Two hundred gallons of Envirotemp FR3 fluid in an open tank stored indoors was exposed to ambient air for five years. Test results showed that half of the oxidation inhibitor was consumed, but viscosity did not significantly change. Large quantities of Envirotemp FR3 fluid stored in uncovered tanks or pools are significantly less affected by oxidation as compared to thin films.

When performing indoor maintenance on Envirotemp FR3 fluid filled transformers, expect little if any impact of thin film oxidation for repairs requiring seven days or less exposure to air. For those few occasions where the repair requires more than seven days, Cargill recommends the components or assemblies be immersed in an Envirotemp FR3 fluid bath while not being directly serviced, particularly important in ambients with high humidity.

For long term storage of reclaimed components after being immersed in Envirotemp FR3 fluid, Cargill recommends these components be thoroughly cleaned, and rinsed in a seed oil solvent (or mineral oil) bath to remove any remaining thin films of Envirotemp FR3 fluid.

9350 Excelsior Crossing Blvd
Hopkins, MN 55343 USA
www.cargill.com/fr3fluid