Envirotemp™ FR3™ Fluid

Reference Data

R2020

Envirotemp™ FR3™ Fluid Behavior in Cold Temperature Environments

INTRODUCTION

Dielectric fluids perform two important tasks in the operation of transformers: acting as an electrical insulator, and transferring heat from the core and coils to the tank walls and radiators. Transformers require a dielectric fluid that will perform these functions even in very cold conditions. Envirotemp™ FR3™ fluid at temperatures well below its pour point still removes the heat from the core and coils and maintains adequate dielectric strength.

POUR POINT

Pour point is defined as the lowest temperature at which a fluid is observed to flow under specified conditions (ASTM D97 is a commonly used test method). Conventional transformer mineral oils have pour points below -40 °C (-40 °F), lower than pour points of natural ester dielectric fluids.

The pour point of Envirotemp FR3 fluid is approximately -21 °C (-6 °F). However, this pour point temperature should not be considered a limiting factor when choosing a dielectric fluid for use in cold environments. For natural esters like Envirotemp FR3 fluid, cold temperature performance is not strictly related to flow, but is also a function of its ability to transfer heat from the coils to the fluid via thermal conduction and then initiate convection.

HEAT TRANSFER

Unlike water, most dielectric fluids do not have a well-defined solid/liquid phase transition temperature. During extended exposure to very cold temperatures, dielectric fluids do not change immediately from liquid to solid, but instead begin to thicken, and with time, gel (See Figure 1).

When increasing viscosity inhibits the ability of dielectric fluids to flow, the fluids lose their ability to convectively transfer heat. Fluids in such a state are perceived as an inadequate heat transfer means, possibly resulting in transformer overheating.

However, Cargill knows of no published case histories proving that transformers suffer thermal runaway due to cold fluid.

Furthermore, a paper presented at the October 1999 IEEE CEIDP conference summarizes a series of full load cold start tests performed to determine the temperatures of transformer coils when Envirotemp FR3 fluid is below its pour point temperature. Distribution transformers instrumented to measure core, coil, and oil temperatures were energized at full rated load at -30 °C (-22 °F). The units showed no abnormal temperature excursions and remained well below the temperature limits given in IEEE standards.[1]

These tests confirm that Envirotemp FR3 fluid transferred heat from the energized coils to the core and colder fluid, absorbing and conducting the heat away from the coils. As the fluid warmed, convective cooling was established in the area immediately around the core-coil assembly, heating the surrounding fluid. Temperatures stayed well below the normal hottest spot temperature limit for 65 K rise transformers. This was true even though radiators were necessary to meet the winding temperature limits given in the IEEE loading guide[2] at normal heat run ambient temperatures.

Based on these and other test results, Cargill recommends cold starting Envirotemp FR3 fluid-filled transformers at any temperature, provided that physical operation of liquid immersed components is not required below their published low temperature limits (in Envirotemp FR3 fluid).

MOVEMENT OF LIQUID IMMERSED COMPONENTS

Dielectric coolants increase in viscosity as their temperatures decrease. When exposed to prolonged

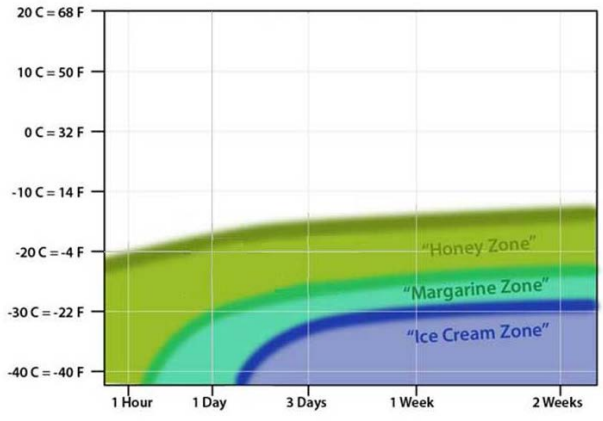

Figure 1.
Envirotemp™ FR3™ fluid consistency at low temperature

[1] K.J. Rapp, G.A. Gauger, J. Luksich, "Behavior of Ester Dielectric Fluids Near the Pour Point", IEEE Conference on Electrical Insulation and Dielectric Phenomena, October 17-20, 1999, Austin, TX

[2] IEEE Standard C57.91 "IEEE Guide for Loading Mineral Oil Immersed Transformers", Institute of Electrical and Electronics Engineers Inc, New York

temperatures below their pour point, the higher viscosity can potentially restrict the operation of transformer accessories. For example, high viscosity fluids might hamper mechanical movement of liquid immersed components (switches, etc.), and may extinguish arcs more slowly. These are two of the factors that led the ANSI/IEEE Transformer Standards Committee to state in C57.12.00 that top oil temperatures below -20 °C are not considered as usual service conditions.

In order to determine the temperature at which Envirotemp FR3 fluid impacts moveable components, one transformer manufacturer exposed a small transformer, a 10KVA single phase pole mount transformer containing approximately 15 gallons of fluid, to -25 °C temperature continuously for eleven days. The viscosity of Envirotemp FR3 fluid did not interfere with the operation of mechanical devices, and no voids were formed, indicating flow still occurred.

TEMPERATURE ANALYSIS

Transformers, due to their large mass and thermal time constant, require several hours or days to reach equilibrium with ambient temperatures. This is the case even when de-energized. As a result, daily low temperatures (those reported during the evening news) do not reflect the true transformer temperature. Daily average temperature (hourly temperatures averaged over 24 hours) is a more realistic measure of operating conditions.

The US National Oceanic and Atmospheric Administration has many years of temperature data (readings taken at the nation's weather stations on an hourly basis, and used to report daily weather conditions). Two noteworthy conclusions can be drawn from the data:

1. Daily average temperatures are not as extreme as daily low temperatures reported by local weather people, due to daily cyclical heating.
2. Less than 1% of the contiguous US, and less than 0.1% of installed transformers experience average daily temperatures of -25 °C for prolonged periods of time (longer than 3 days)

It is important to recognize that, for in-service distribution transformers, the temperature of fluid is significantly higher than the ambient temperature. Even no-load losses are typically enough to keep the fluid flowing in transformers exposed to continuous temperature of -30 °C.

As reported in the 1999 IEEE CEIDP paper, cold exposure tests confirm that Envirotemp FR3 fluid in transformers can require exposure times of days to reach equilibrium with its ambient. Consult your transformer or component equipment suppliers to obtain their low temperature component verifications and recommended transformer starting procedures for fluid temperatures below -20 °C.

More than one million transformers filled with Envirotemp FR3 fluid are in service. There have been no cold ambient transformer start-up or energized operation problems reported to Cargill.

FLUID DIELECTRIC STRENGTH

A transformer fluid must also perform as an electrical insulation medium. Tests confirm that Envirotemp FR3 fluid maintains its dielectric strength to at least –50 °C (-58 °F).

Various factors impact a fluid's dielectric strength, but typically the most common and important contaminant is water. For all dielectric fluids, the dielectric strength decreases as water content increases.

Water moves between solid insulation and dielectric fluid trying to reach relative humidity equilibrium. In transformers, the paper insulation holds much more water than the dielectric fluid.

Figure 2 shows how temperature affects the fluid's saturation point (the point where the fluid cannot hold any more water). The hotter a transformer operates, the more moisture migrates from paper into fluid. The fluid can absorb more moisture driven off the paper due to significant increase in its saturation point as temperature increases. Additionally the hotter a transformer operates, the faster the insulation paper ages, producing more moisture. This water migration continues until both the paper and fluid are at relative saturation equilibrium at the current temperature.

Water in excess of the saturation point is 'free' water. At 25 °C mineral oil saturates at about 70 mg/kg and Envirotemp FR3 fluid at about 1000 mg/kg. However,

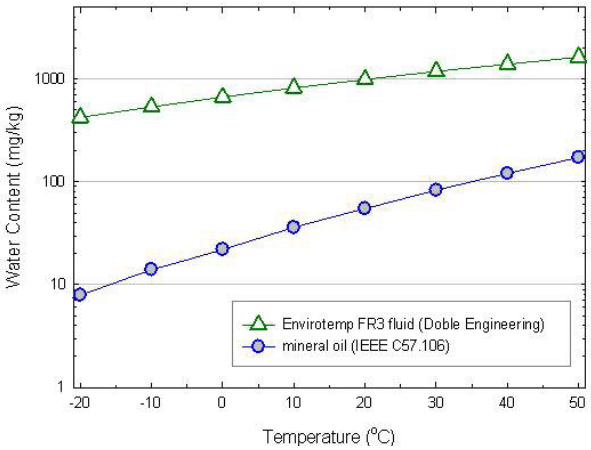

Figure 2.
Saturation points at low temperature

at -20 °C, mineral oil saturates at about 8 mg/kg, while Envirotemp FR3 fluid saturates at about 425 mg/kg. Therefore, Envirotemp FR3 fluid is not likely to reach saturation in cold ambient conditions. This helps prevent the formation of free water, significantly reducing the risk of transformer failure due to low dielectric strength during cold start up.

SPECIAL CONSIDERATIONS

Sampling the Fluid

In colder climates, it is normal for a small volume of Envirotemp FR3 fluid in the drainpipe and valve to be at ambient temperature, even though the transformer may have been in service during or just prior to sampling. Because the sampling valve (typically located at the lowest point of the transformer temperature gradient) contains a small volume of isolated fluid, and the valve metal "transmits" the cold, the probability of gelled fluid in the valve is much higher than in the main tank. In these cases, the service pipe and drain valve should be warmed until the fluid flows. Cargill recommends following the procedures given in ASTM D923 Standard Practices for Sampling Electrical Insulating Liquids.

On-Load-Tap-Changers (OLTC) & Voltage Regulators

For new applications contact the OLTC or regulator manufacturer to verify compatibility and operational limits. Where design and climate data warrant it, Voltage regulators filled with Envirotemp FR3 fluid are equipped with a low temperature relay to lock out the automatic control when the fluid temperature is below -10 °C.

Forced Fluid Flow (Pumps)

Contact the pump manufacturer to verify the pump's operational limits with Envirotemp FR3 fluid. Care should be exercised when energizing pumps when the fluid temperature is below the pump manufacturer's low temperature limit for Envirotemp FR3 fluid. Figure 3 shows viscosity versus temperature for Envirotemp FR3 fluid.

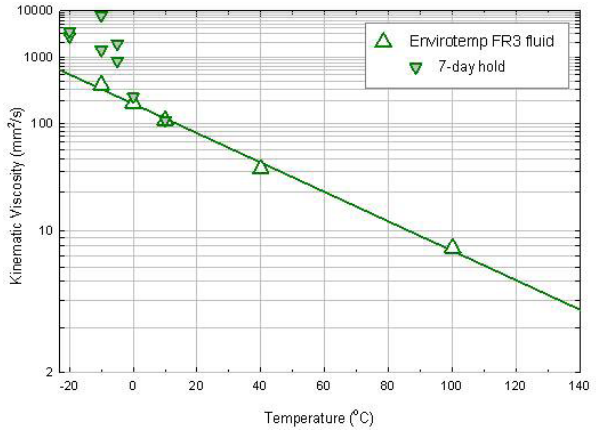

Figure 3.
Viscosity versus temperature

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