

CERTIFIED TEST REPORT

COOPER POWER SYSTEMS FIELD ANALYSIS OF ENVIROTEMP[®] FR3[™] FLUID FILLED TRANSFORMERS FOR MICROBIOLOGICAL GROWTH

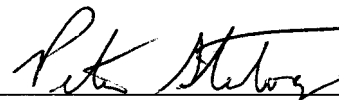
CERTIFICATION

Statements made and data shown are, to the best of our knowledge and belief, correct and within the usual limits of commercial testing practice.

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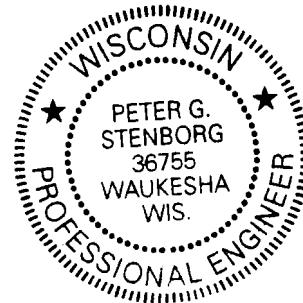


Table of Contents

1. Scope	4
2. Experimental	4
3. Results & Discussion	5
3.1. Microbiological Tests	5
Table 1: Microbiological Test Results	6
3.2. Water Content	6
3.3. Antioxidant Additive	7
4. Conclusions.....	7

1. Scope

The natural ester, Envirotemp® FR3™ fluid, in a transformer is required for cooling and electrical insulation. Transformers of sealed design protect internal components from exposure to the elements. Occasionally, a transformer does develop a leak above the fluid level, exposing the internal components to water and oxygen. These substances are required in sufficient quantities to support most types of microbiological growth in the environment. There is a need for information about whether Envirotemp FR3 fluid in a transformer will attain the necessary levels of water and oxygen to support microbiological activity.

It is speculated by some that natural ester insulating fluids, like Envirotemp FR3 fluid, may support microbiological growth in transformers. In this case, the natural seed oil would be the nutrient, one of the requirements affecting microbial growth. During FR3 fluid development, sealed transformers were intentionally seeded with microorganisms and operated at 40°C. Microbial testing of the fluid was done at various intervals. In addition, two different field trial FR3 fluid units, currently operating for eight years, were tested for microorganisms in the fluid. One of the field units was a pole top that was opened and inspected for signs of microbial growth. An on-going eight-year aging study of intentionally free-breathing-design FR3 fluid units failed to show microbiological growth. It is likely that, if microbial growth is possible in a FR3 fluid transformer, one of the above transformer units or a fluid sample from a unit would indicate it as such.

This report documents the results of microbiological testing of Envirotemp FR3 fluid sampled from several sealed transformers. Open cover inspections of both sealed and free-breathing FR3 fluid transformers over the past eight years showed no evidence of microbiological growth. Some discussion of the activities of antioxidants and water is included that supports the overall findings. The results show that FR3 fluid does not support microbiological growth in either a sealed or a free-breathing transformer design.

2. Experimental

The concern of microbiological growth was addressed in the development of FR3 fluid during the Locke transformer test phase III.¹ A temperature of 40°C was chosen to provide a condition favorable for the growth of microorganisms. The FR3 fluid in each of two 37.5 KVA transformers was brought into contact with human skin for 10 seconds. The units were sealed, evacuated of air and pressurized to 1 psig with dry nitrogen gas. The transformers were cycled per Locke conditions between a top oil temperature of 40°C and ambient. The units were sampled for microbiological testing after 0, 600, 3000 and 4200 hours of aging. Silliker Laboratories of Illinois, Inc., 1304 Halsted St., Chicago, IL 60411, performed the following tests.

- 1) Aerobic plate count
- 2) Anaerobic plate count
- 3) Coliforms
- 4) Yeasts
- 5) Molds

FR3 fluid samples were obtained from two different field trial units after about one year of operation. A 225 KVA 3-phase 4160/240 volt pad and a 15 KVA, 4800 volt pole sealed-design FR3 fluid transformer were sampled and tested for microorganisms.² The pad transformer is continuously loaded at about 90% of nameplate rating. The pole unit is loaded at 96% of rating for 11 hours per day with no load for the remainder. The pole transformer was uncovered and the internal components were inspected after microbial sampling. Recently, the 15 KVA pole unit was uncovered and the internal components were inspected after 8 years of operation. After each inspection, the transformer was sealed with a cover and allowed to maintain an air headspace.

Two intentionally free-breathing 25 KVA single-phase 7200/240 volt pole transformers have been opened and inspected regularly over the past eight years as well. Each transformer had a 1.65 mm vent hole that allowed the unit to free-breathe. Pressure transducers verified free-breathing operation. The transformers are part of a test project that consisted of four different aging test periods, each with different aging and loading cycles as follows.

The first test period was 4800 hours of indoor operation at 65°C top oil temperature for FR3 fluid unit B-9 and 4800 hours at 65°C + ambient for the other FR3 fluid unit C-9. Each transformer contained a thermocouple in the top oil that measured the temperature, which was controlled by varying the primary current. A data logger was used to monitor the primary current and excitation voltage. The first test period began January 22, 1997 and ended on February 16, 1999. Internal inspections were done periodically. Fluid sampled from the sealed and vented transformers was tested for water content every 600 hours using ASTM D1533.

The second test period was measured in cycles and was designed to approximate the thermal cycling conditions of actual transformers in operation, but in this case, under vented indoor operation. The vented units were tested for a total of 87 cycles. Each cycle combined 8 hours of load necessary to reach 65°C or 65°C + ambient top oil temperatures with 16 hours at 25% of the load. The test commenced on May 7, 1999 and ended on August 27, 1999. Transformer electrical tests, fluid moisture analyses and internal inspections were performed during the second test period.

In December 1999, the free-breathing units were relocated to an outdoor installation where they are located at this time. During the third test period, the transformers were energized at 7200 volts continuously on the primary, with the secondary floating (no loading). As a result of the energizing voltage and solar radiation, the top oil temperatures fluctuated from 2 to 15°C above ambient. The units were placed outdoors and energized on December 15, 1999 until the completion of the third test period on October 29, 2002. Fluid analysis for water content and internal inspections were performed during the third test period.

The fourth test period began November 5, 2002 with the transformers energized with 7200 volts continuously and loaded at 100 % for 8 hours per day and no load for 16 hours. The transformers continue to operate under the fourth test period conditions. Transformer electrical tests, moisture analyses and internal inspections were done during the current fourth test period.

The time in years of operation was tabulated from the total number of hours that the transformers were energized with voltage in a vented condition. Downtime during end point testing and fluid sampling was not logged, but it would add significantly to the total amount of test time that microbes could grow and multiply.

3. Results & Discussion

No microbiological activity has been detected in any Envirotemp FR3 fluid samples taken from transformers operating for about one year. The operating top oil temperature of between 40°C and 65°C plus ambient provides a favorable condition for microbiological growth. However, all living things require water and water availability. Most microorganisms cannot grow at reduced water activity.⁴ Water molecules are bound loosely in pure liquid water, have high activity and can easily rearrange. When water is added to other substances (solutes), in this case FR3 fluid, the water molecules are attracted to the FR3 fluid, dissolve and become bound through hydrogen bonding. This significantly reduces the activity of the water molecules in the FR3 fluid, which results in a fluid environment that will not support microbial growth.

Some microorganisms can grow under very dry conditions, usually molds and yeasts. Both of these were included in the testing protocol and were found to be undetectable.

3.1. Microbiological Tests

No biological activity was detected in any of the FR3 fluid samples taken from four different transformers over a one year period. The results are summarized in Table 1 below.

Table 1: Microbiological Test Results

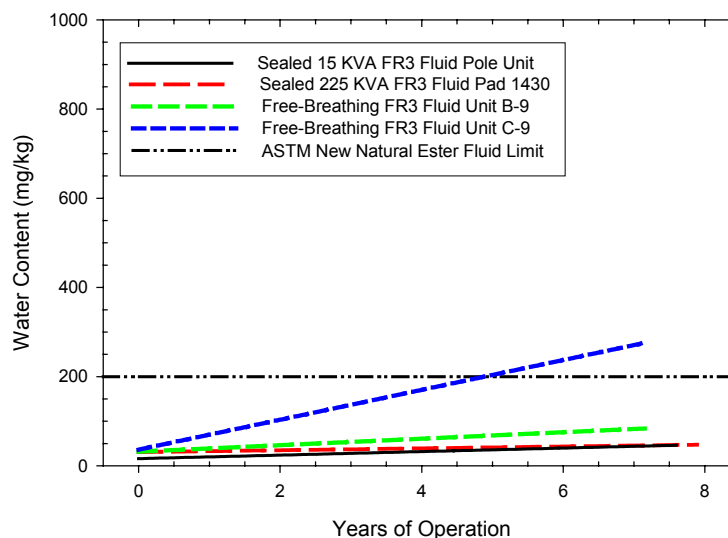
FR3 Fluid Sample Description	Time on Test (hrs)	Aerobic plate count/g	Anaerobic plate count/g	Coliforms MPN/g	Yeasts/g	Molds/g
A-7 Sealed BioUnit Phase III Locke 37.5 KVA Transformer S/N CP961079401 (40°C Top Oil)	0	ND	ND	ND	ND	ND
	600	ND	ND	ND	ND	ND
	3000	ND	ND	ND	ND	ND
	4200	ND	ND	ND	ND	ND
B-7 Sealed BioUnit Phase III Locke 37.5 KVA Transformer S/N CP961079402 (40°C Top Oil)	0	ND	ND	ND	ND	ND
	600	ND	ND	ND	ND	ND
	4200	ND	ND	ND	ND	ND
15 KVA Sealed Pole S/N 961060992	8000	ND	ND	ND	ND	ND
225 KVA Sealed Pad S/N 966001430	8000	ND	ND	ND	ND	ND

ND: non-detectable is defined as <0.3 MPN/g Coliforms and <10/g for all others, which are the minimum detectable amounts per Silliker Laboratory methods.

3.2. Water Content

The following plot of water content shows the relatively low levels of dissolved water detected in FR3 fluid sampled from free-breathing and sealed transformers. The free-breathing units B-9 and C-9 have free access to air and humidity. FR3 fluid in unit C-9 became about 20% saturated (267 ppm water) after 7 years of operation. Both Free-breathing transformers were opened and inspected many times. The sealed 15 KVA pole unit was opened and inspected after one year and eight years. There has been no observed growth of microorganisms on the FR3 fluid surface, on materials below the fluid surface and on materials in the headspace above the fluid.

Water Content



3.3. Antioxidant Additive

FR3 fluid contains an antioxidant additive as part of its composition, which protects the ester molecules from oxidation. This additive serves another purpose as an antimicrobial agent. The dual functionality of the chemical is utilized in the food industry where packaging technology cannot eliminate oxygen and water activity is high. The main factors affecting microbial growth are water activity, pH, available oxygen, temperature and nutrients. The results from our testing show that the protective function of the antioxidant additive and the low water activity in FR3 fluid provides an environment that will not support microbiological growth in transformers.

4. Conclusions

Analysis of FR3 fluid and internal inspection of sealed and free-breathing transformers after eight years of field operation shows no indications of microbiological growth. Units seeded with microbes and maintained at a temperature favorable to microorganisms showed non-detectable levels of aerobic, anaerobic, coliforms, yeasts and mold microbes.

The low water activity in FR3 fluid, even after eight years in free-breathing transformers, in combination with the effectiveness of the antioxidant/antimicrobial additive does not provide an environment that supports microbiological growth. The internal components of the transformers appeared to be in new condition.

Thus, we conclude that FR3 fluid, used as an insulating dielectric fluid in electrical devices, is not subject to microbiological growth or decay and will function for its intended purpose for at least eight years. Beyond this, theory suggests that growth of microorganisms in FR3 fluid filled equipment is unlikely during the expected life time of the equipment.

¹ Test Report ML 294-95-010, "Evaluation of Envirotemp FR3 Fluids after Locke Phase III Completion," Released 10/19/1999, Thomas A. Edison Technical Center, Franksville, WI 53126.

² Test Report ML 286-97, "Analysis of Envirotemp FR3 Fluid from a 15 KVA Unit S/N 961060992," Released 7/2/97, Thomas A. Edison Technical Center, Franksville, WI 53126.

³ Test Report ML 402-2000, "Interim Report on Locke Phase IV (Vented) Transformer Operation with Envirotemp FR3 Fluid," Released 7/29/2003, Thomas A. Edison Technical Center, Franksville, WI 53126.

⁴ <http://www.bact.wisc.edu/Bact303/Controlofmicrobialgrowth>