

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM



ETV JOINT VERIFICATION STATEMENT

TECHNOLOGY TYPE:	VEGETABLE OIL-BASED INSULATING DIELECTRIC FLUID		
APPLICATION:	VEGETABLE OIL-BASED INSULATING DIELECTRIC FLUID FOR USE IN ELECTRICAL APPARATUS REQUIRING A LIQUID DIELECTRIC COOLANT		
TECHNOLOGY NAME:	ENVIROTEMP®FR3™ INSULATING DIELECTRIC FLUID		
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The U.S. Environmental Protection Agency has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and information dissemination. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of innovative, improved, and more cost-effective technologies. The ETV Program is intended to assist and inform those individuals in need of credible data for the design, distribution, permitting, and purchase of environmental technologies.

ETV works in partnership with recognized testing organizations to objectively and systematically document the performance of commercial ready environmental technologies. Together, with the full participation of the technology developer, they develop plans, conduct tests, collect and analyze data, and report findings. Verifications are conducted according to an established workplan with protocols for quality assurance. Where existing data are used, the data must have been collected by independent sources using similar quality assurance protocols.

EPA's ETV Program, through the National Risk Management Research Laboratory (NRMRL), has partnered with the California Department of Toxic Substances Control (DTSC) under an ETV Pilot

Project to verify pollution prevention, recycling, and waste treatment technologies. This verification statement provides a summary of performance results for the Cooper Power Systems **Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid**.

TECHNOLOGY DESCRIPTION

Cooper Power Systems (Cooper) has developed a vegetable oil-based dielectric fluid comprised of >98.5% vegetable oil and <1.5% additives. Envirotemp®FR3™ fluid is used in liquid-filled electrical apparatus such as transformers to act as an electrical insulating medium. Envirotemp®FR3™ fluid is currently used in pole, padmount, network, and small and medium power transformers with a voltage rating of 35 kV and a maximum rating of 10 MVA. Other electrical apparatus include loadbreak switches, cables, electromagnets, klystron modulators, power supplies, and bushings. To date, approximately 475 transformers currently use Envirotemp®FR3™ fluid.

EVALUATION DESCRIPTION

The evaluation consisted of:

- Developing a Technology Evaluation Workplan by DTSC to independently evaluate the technology with respect to the identified performance objectives for general performance, aquatic biodegradability, flammability, acute toxicity, chemical composition, and protection of worker health and safety;
- Implementing the Technology Evaluation Workplan by DTSC and Cooper at their manufacturing facility in Waukesha, Wisconsin. Field sampling has also been performed at transformers located at San Mateo High School in San Mateo, California, and Texas Instruments in Santa Cruz, California. The field sampling included collection of 12 samples from three different unused (virgin) product lots at Cooper's facility, and four samples from four different in-service transformers (one sample per in-service transformer).
- Analyzing virgin product samples for general performance parameters (fire and flash point, dielectric breakdown, dissipation factor, neutralization number, interfacial tension, viscosity, pour point, and water content), aquatic biodegradation, aquatic toxicity using the California sample preparation method, fatty acid content, phenolic antioxidants, SVOCs, and metals. In-service transformer sample analyses included general performance parameters (fire and flash point, dissipation factor, water content, conductivity, neutralization number, and interfacial tension,), fatty acid content, phenolic antioxidants, SVOCs, and metals;
- Reviewing supporting documentation on Envirotemp®FR3™ fluid including ASTM data, an acute toxicity report, aquatic biodegradability data, and material safety data sheets (MSDSs).

VERIFICATION OF PERFORMANCE

Performance results of Cooper Power Systems' Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid are as follows:

- **General Performance.** Envirotemp®FR3™ fluid met Cooper's performance specifications for dielectric breakdown (minimum and gap), pour point, viscosity at 40°C and 100°C, water content, interfacial tension, and neutralization number. Envirotemp®FR3™ fluid also met the ASTM, IEEE, and IEC specifications for dielectric breakdown (minimum, gap, and impulse) and met the ASTM D3487, IEEE, and IEC specifications for the neutralization number. However, all samples had higher dissipation factors at 100°C than past samples tested by Cooper. Envirotemp®FR3™ fluid also had an average dissipation factor at 25°C that did not meet the Cooper specification listed in Table 1. The high dissipation factors may be due to contaminants introduced during product storage, sample collection, sample preparation, or sample testing.

Table 1. Summary of Virgin Product Sampling Results

Performance Parameters	Specification Standards ¹					Sampling Results				
	Cooper	ASTM D3487	ASTM D5222	IEEE C57.121	IEC 1099	Lot 01D1	Lot 01C6		Lot 01P2	Average*
						VFR3-01	VFR3-05	VFR3-07	VFR3-10	
Dielectric Properties										
Dielectric Breakdown (kV)										
minimum	≥ 30	≥ 30	≥ 42	≥ 25-30	--	45	45	45	46	45 ± 1
gap	≥ 20	≥ 28	≥ 30	≥ 20-30	≥ 23	36	37	34	39	37 ± 3
impulse	--	≥ 145	NA	--	--	170	168	164	168	168 ± 4
Dissipation Factor (%)										
@ 25°C	≤ 0.15	N/A	N/A	N/A	--	<i>0.127</i>	0.159	0.157	<i>0.127</i>	<i>0.143 ± 0.029</i>
@ 100°C**	--	N/A	N/A	N/A	N/A	2.70	3.17	3.23	2.46	2.89 ± 0.59
Chemical Properties										
Interfacial Tension (dyne/cm)	≥ 18	N/A	N/A	N/A	--	28	27	28	28	28 ± 1
Neutralization Number (mgKOH/g)	≤ 0.07	≤ 0.03	≤ 0.01	≤ 0.03	≤ 0.03	<u>0.03</u>	<u>0.03</u>	<u>0.02</u>	<u>0.03</u>	<u>0.03 ± 0.01</u>
Water Content (ppm)	≤ 75	N/A	N/A	N/A	≤ 200	53	59	57	52	55 ± 5
Physical Properties										
Pour Point (°C)	≤ -18	N/A	N/A	N/A	N/A	-18	-18	-18	-18	-18
Viscosity (cSt) @ 100°C	≤ 8.5	N/A	N/A	N/A	--	8	7.88	7.9	7.95	7.93 ± 0.09
@ 40°C	≤ 35	N/A	N/A	N/A	N/A	32.63	32.67	32.79	32.74	32.71 ± 0.11
@ 0°C	--	N/A	N/A	N/A	--	188.01	187.14	187.53	187	187.42 ± 0.72

Note: Sampling results values in bold indicate these values met all the specification values listed for a given performance parameter. Italicized values met only the Cooper specification value. Underlined values meet all but one specification value.

*Data variability was calculated at 95% confidence using a two-tailed T-test assuming normal distribution.

**Cooper does not have specification value for the dissipation factor at 100°C. Cooper does not routinely test for the dissipation factor at 100°C but reported three past samples had values ranging 1.4% to 1.9%.

Acronyms and Abbreviations:

-- = No specification value available

ASTM D3487 = American Society for Testing and Materials (ASTM) standard specification for mineral insulating oil used in electrical apparatus

ASTM D5222 = ASTM standard specification for high fire-point electrical insulating oil (high molecular weight hydrocarbon specification)

cm = centimeter

Cooper = Virgin product specification for Envirotemp[®]FR3[™] fluid developed by Cooper Power Systems

cSt = centistoke

IEC 1099 = International Electrochemical Commission (IEC) Specifications for Unused Synthetic Organic Esters for Electrical Purposes

IEEE C57.121 = Institute of Electrical and Electronic Engineers (IEEE) 1998 IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers (silicone oil specification)

kV = kilovolt

mgKOH/g = milligrams of potassium hydroxide per gram

N/A = Not applicable since these specification values were developed for fluids with different physical and chemical characteristics than Envirotemp[®]FR3[™] fluid.

ppm = parts per million

For in-service transformer samples, the dissipation factor, neutralization number, interfacial tension, conductivity and water content met the Cooper and IEC 1203 specifications for in-service fluid (see Table 2). Based on the historical data for the oldest in-service transformers, Envirotemp[®]FR3[™] fluid appears to have degraded little over the service life of the unit.

Table 2. Summary of In-service Transformer Sampling Results

Performance Parameters	Specification Standards		Sampling Results			
	Cooper	IEC 1203	ISFR3-01	ISFR3-02	ISFR3-03	ISFR3-06
Dissipation Factor (%) @ 25°C	≤ 1.0	≤ 0.8	0.139	0.196	0.120	0.146
Water Content (ppm)	≤ 400	≤ 400	98	56	33	41
Interfacial Tension (dyne/cm)	≥ 18	---	26	26	24	23
Neutralization Number (mgKOH/g)	≤ 2.5	≤ 2.0	0.03	0.02	0.01	0.08
Conductivity @ 25°C (pS/m)	--	≥ 1.1	10.6	17	12.75	13.6

Note: Sample results in bold indicate these values met the both specifications listed in this table.

Envirotemp®FR3™ was compared to the IEC 1203 specification since its in-use performance is similar to synthetic oil.

1. ISFR3-01 and ISFR3-02 were collected from two separate transformers owned by Cooper Power.
2. ISFR3-03 was collected from one transformer owned by Texas Instrument.
3. ISFR3-06 was collected from one transformer owned by San Mateo High School.

Acronyms and Abbreviations:

-- = No specification value available
 cm = centimeter
 Cooper = In-service fluid specification for Envirotemp®FR3™ developed by Cooper Power Systems
 IEC 1203 = International Electrochemical Commission (IEC) Synthetic Organic Esters for Electrical Purposes - Guide for Maintenance of Transformer Esters in Equipment
 mgKOH/g = milligrams of potassium hydroxide per gram
 ppm = parts per million
 pS/m = picosiemen per meter

- **Aquatic Biodegradability.** The average biodegradability of Envirotemp®FR3™ fluid was 120% ± 33% after 28 days using OPPTS Method 835.3110. The higher than expected biodegradability is due to possible CO₂ leaks from the control samples. The average biodegradation rates for Envirotemp®FR3™ fluid and mineral oil based on literature data are presented in Table 3.

Table 3. Aquatic Biodegradation Rates

Compound	Biodegradation Rates				
	Cooper ETV ¹	Universite de Liege ²	CONCAWE ³	USACE ^{4,5}	TERC ^{6,7}
Envirotemp®FR3™	120% ± 33% after 28 days	---	---	---	98% after 28 days
Mineral oil	---	70% after 40 days	28% after 28 days	42-49% after 28 days	30.5% after 28 days
HMWH	---	---	---	---	21.3% after 28 days

¹U.S. EPA, *Environmental Technology Verification Report ABB Inc. BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid*, 2001.
²Cloesen, C. & Kabuya, A, *Research RW N° 2174 Physical and chemical properties of environment friendly lubricants*, no date.
³Conservation of Clean Air and Water-Europe (CONCAWE), *Lubricating Oil Basestocks*, pp. 20-22, June 1997.
⁴U.S. Army Corps of Engineers (USACE), *Engineering and Design Environmentally Acceptable Lubricating Oils, Greases, and Hydraulic Fluids*, April 1997.
⁵USACE, *Engineering and Design Environmentally Acceptable Lubricating Oils, Greases, and Hydraulic Fluids*, February 1999.
⁶Thomas Edison Research Center, *The Biodegradation of Envirotemp®FR3™, Univolt 60, and R-Temp Transformer Fluids*, April 1999.
⁷The mineral oil used in the TERC study was Univolt 60 while the high molecular weight hydrocarbon (HMWH) oil was R-Temp.

Based on the information above, the virgin Envirotemp®FR3™ fluid appears to biodegrade more readily than mineral oil. Although Envirotemp®FR3™ readily biodegrades per this test, releases to water should be prevented. The product's ability to degrade in the environment is dependent on site-specific factors such as climate, geology, moisture, pH, temperature, oxygen concentration, dispersal of oil, the presence of other chemicals, soil characteristics, nutrient quantities, and populations of various microorganisms at the location.

- **Flammability.** The flash and fire point for the virgin and in-service fluid were consistently above the minimum values listed in the ASTM D3487, D5222, and Cooper performance specifications presented in Table 4. The fire point results obtained also agreed with values reported by Underwriters Laboratories.

Table 4. Flash and Fire Point Results for Virgin and In-Service Samples

Product Lot No./ Transformer SN	Flash Point (°C)			Fire Point (°C)		
	Specification Criteria		ETV Result	Specification Criteria		ETV Result
	Cooper	ASTM D3487		Cooper	ASTM D5222	
Virgin Product						
01D1	≥ 320	>145	328	≥ 350	304-310	362
01C6	≥ 320	>145	333	≥ 350	304-310	363
01P2	≥ 320	>145	318	≥ 350	304-310	362
Average	≥ 320	>145	328 ± 11	≥ 350	304-310	363 ± 2
In-service Transformer Fluid						
ISFR3-01	≥ 320	>145	338	≥ 350	304-310	362
ISFR3-02	≥ 320	>145	328	≥ 350	304-310	364
ISFR3-03	≥ 320	>145	330	≥ 350	304-310	364
ISFR3-06	≥ 320	>145	340	≥ 350	304-310	364
Note: Data variability was calculated at 95% confidence using a two-tailed T-test assuming a normal distribution.						
SN = Sample Number						

- **Acute Toxicity.** The average LC₅₀ for virgin Envirotemp®FR3™ fluid was less than 250 mg/L. This low LC₅₀ value is thought to reflect the physical impacts on fish due to oil coating the gills and preventing oxygen exchange. The average LC₅₀ indicates the spent (or waste) Envirotemp®FR3™ fluid may exhibit a hazardous characteristic under California regulations (California Code of Regulations, Title 22, Section 66261.24(a)(6)). This determination is based on a limited set of data for the virgin product and may not apply in states other than California where hazardous waste criteria and test methods may differ. End-users should characterize their spent Envirotemp®FR3™ fluid at the time of disposal since changes to the oil may occur due to use, storage, or age. End-users should also consult their appropriate local, state, or federal regulatory authority on applicable waste characteristic definitions and available disposal options.
- **Chemical Composition.** The AOAC results for the virgin Envirotemp®FR3™ samples showed the virgin and in-service fluid agreed closely with Cooper's formulation. The virgin product consisted of 23.8% ± 0.1% monounsaturated fatty acids, 59.9% ± 0.1% polyunsaturated fatty acids, and 15.7% ± 0.1% saturated fatty acids. The in-service transformer fluid consisted of 22.0% to 23.8% monounsaturated fatty acids, 59.8% to 62.4% polyunsaturated fatty acids, and 15.2% to 16.3% saturated fatty acids.

Antioxidant concentrations in the virgin Envirotemp®FR3™ samples ranged from 2,787 ppm ± 834 ppm. Antioxidant concentrations in the in-service transformer samples ranged from 3,550 ppm to 4,595 ppm. The antioxidants detected agreed with the ingredients list provided by Cooper.

For the 65 standard SVOC compounds analyzed by the DTSC Hazardous Material Laboratory, none were detected in the virgin product samples. Bis- (2-ethylhexyl) phthalate, butyl benzyl phthalate,

and di-n-butyl phthalate were detected in the in-service transformer samples. These compounds were suspected to be contaminants introduced from the sampling equipment and deionized water used. Other tentatively identified compounds were various sterols normally found in vegetable oils.

All the virgin product samples and two in-service samples contained barium and zinc between 25 mg/kg and 36 mg/kg, and between 11 mg/kg and 24 mg/kg, respectively. Cadmium and molybdenum were also detected in one in-service transformer sample at 0.42 mg/kg and 2.6 mg/kg, respectively. The barium and zinc might have been introduced during the processing of the basestock oil, degassing of the oil, or storage in the finishing tank.

- Worker Health and Safety. Based on the MSDS information, Envirotemp®FR3™ fluid appears to have similar PPE requirements compared to select mineral oil-based transformer fluids. Envirotemp®FR3™ fluid had less stringent PPE requirements when compared to select silicone oil-based transformer fluids. Envirotemp®FR3™ fluid has a slightly higher nuisance particulate OSHA PEL than mineral oil. Envirotemp®FR3™ fluid does not contain listed IARC confirmed carcinogens or teratogens. The select mineral oil-based transformer fluids listed a hydrotreated light naphthenic petroleum distillate, which is an IARC confirmed carcinogen. The silicone based transformer oils listed dimethyl polysiloxane as the primary ingredient, which is a teratogen in animals. Although the product appears to contain ingredients with less serious health effects, the end-user must comply with all applicable worker health and safety regulations when using this product.
- Estimated Cost of Using Envirotemp®FR3™ fluid versus Mineral Oil. The initial purchase cost of a new transformer unit containing Envirotemp®FR3™ fluid is approximately 1.2 to 1.3 times more than that of a comparable mineral oil transformer. When comparing the price per gallon of Envirotemp®FR3™ fluid to mineral oil, the difference may be between \$5 to \$8 more per gallon depending on the volume purchased. Based on historical accelerated aging test results, the estimated life expectancy of an Envirotemp®FR3™ transformer is estimated to be 20 years, which is comparable to mineral oil-based transformers.

Results of the verification/certification show that the Cooper Power Systems Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid is a readily biodegradable, vegetable oil-based dielectric fluid with a flash and fire point above 300°C. The product has dielectric breakdown voltages comparable to mineral oils, silicone oils, synthetic esters, and high molecular weight hydrocarbons.

Envirotemp®FR3™ samples from in-service transformers had flash and fire points above 300°C, and showed no signs of oil degradation due to use for the oldest transformers, which were in-service for 4.8 years. The LC₅₀ results for virgin Envirotemp®FR3™ fluid indicate the spent Envirotemp®FR3™ fluid may exhibit a hazardous characteristic per California's hazardous waste characteristic definition. This interpretation is based on a limited set of test data. The end-user should characterize the spent Envirotemp®FR3™ fluid at the time of disposal since changes may occur to the oil due to use, storage, or age.

Although Envirotemp®FR3™ fluid is a vegetable oil-based product, end-users are still subject to the federal oil pollution prevention regulations under 40CFR112. End-users should contact their appropriate local, state, or federal regulatory authority regarding the management of Envirotemp®FR3™ fluid and Envirotemp®FR3™ spills.

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NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and Cal/EPA make no expressed or implied warranties as to the performance of the technology. The end-user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of commercial product names does not imply endorsement.

Availability of Verification Statement and Report

Copies of the public Verification Statement and Verification Report are available from the following:

1. **U.S. EPA**

Web site: <http://www.epa.gov/etv/library.htm> (*electronic copy*)

2. **Department of Toxic Substances Control**

Office of Pollution Prevention and Technology Development
P.O. Box 806
Sacramento, California 95812-0806

Web site: <http://www.dtsc.ca.gov/sciencetechnology/etvpilot.html>
http://www.dtsc.ca.gov/sciencetechnology/techcert_index.html
or <http://www.epa.gov/etv> (*click on partners*)

(Note: Appendices are not included in the Verification Report and are available from DTSC upon request.)