

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 3-PHASE TRANSFORMERS, UP TO 20MVA		
TECHNOLOGY NAME:	BIOTEMP[®] 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 ABB Inc. **BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid**.

TECHNOLOGY DESCRIPTION

ABB Inc. (ABB) has developed a dielectric insulating fluid called BIOTEMP® which is comprised of >98.5% vegetable oil and <1.5% antioxidants. BIOTEMP® is used in liquid-filled electrical transformers to act as an electrical insulating medium, and to transport heat generated in the transformer around the windings, core and connected circuits to cooling surfaces. BIOTEMP® is currently used in pole-mounted, distribution, network, and small power transformers with a voltage rating ≤ 69 kV and a maximum kVA rating of 20 MVA. Approximately 250 transformers supplied with BIOTEMP® fluid are presently in-service.

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 worker health and safety;
- Implementing the Technology Evaluation Workplan by DTSC and ABB at their manufacturing facility in South Boston, Virginia and at Pacific Gas and Electric's (PG&E) in-service transformers in San Francisco, California. The field sampling included collection of 12 samples from three different unused (virgin) product lots, 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, oxidation stability, viscosity, pour point, 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), fatty acid content, phenolic antioxidants, SVOCs, and metals;
- Reviewing supporting documentation on BIOTEMP® including ASTM data, an acute toxicity report, aquatic biodegradability data, and material safety data sheets (MSDSs).

VERIFICATION OF PERFORMANCE

Performance results of ABB Inc. BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid are as follows:

- General Performance. The average sample results for the each virgin product lot and the overall average for all three lots are presented in Table 1. BIOTEMP® met the ASTM and ABB performance specifications for dielectric breakdown (minimum and gap), oxidation stability at 72 hours (sludge generation and neutralization number), and oxidation stability for 164 hours (sludge generation only) for all three lots. Only two lots had values that met the ASTM D3487 and ABB performance specifications for dissipation factor at 25°C. All three BIOTEMP® lots met the ABB performance specifications for dielectric breakdown (impulse), pour point, water content and viscosity at 0°C, 40°C, and 100°C while only two lots met the ABB specification for dissipation factor at 100°C. However, the data consistently exceeded the neutralization number listed for all

three specifications for the oxidation stability at 164 hours. The data also did not meet the oxidation stability criteria for the rotating bomb method for ABB and ASTM D3487 specifications.

Table 1. Summary of Virgin Product Sampling Results

Performance Parameters	Specification Standards			Average Sample Results			
	ABB	ASTM D3487	ASTM D5222	Lot 2000-216	Lot 2000-224	Composite Lot*	Average
Dielectric properties							
Dielectric breakdown (kV)							
Minimum	≥ 30	≥ 30	≥ 42	46 ± 4	51 ± 6	55	50 ± 3
gap	≥ 28	≥ 28	≥ 30	37 ± 3	37 ± 5	39	37 ± 2
Impulse**	≥ 100	≥ 145	--	<i>177 ± 83</i>	<i>200 ± 68</i>	<i>173</i>	<i>185 ± 32</i>
Dissipation Factor (%)							
@ 25°C	≤ 0.05	≤ 0.05	≤ 0.01	0.160 ± 0.184	<u>0.022 ± 0.011</u>	<u>0.028</u>	0.075 ± 0.054
@ 100°C	≤ 2.0	≤ 0.3	≤ 0.3	2.95 ± 1.15	<u>0.837 ± 0.307</u>	<u>0.931</u>	1.665 ± 0.762
Chemical Properties							
Oxidation Stability							
Percent Sludge (%)							
<i>after 72 hours</i>	≤ 0.2	≤ 0.1	--	<u>0.02 ± 0.01</u>	<u>0.02 ± 0.015</u>	<u>0.02</u>	<u>0.02 ± 0.00</u>
<i>after 164 hours</i>	≤ 0.2	≤ 0.2	--	<u>0.03 ± 0.04</u>	<u>0.02 ± 0.02</u>	<u>0.02</u>	<u>0.02 ± 0.01</u>
Neutralization No. (mgKOH/g)							
<i>after 72 hours</i>	≤ 0.2	≤ 0.3	--	<u>0.19 ± 0.04</u>	<u>0.16 ± 0.02</u>	<u>0.16</u>	<u>0.17 ± 0.02</u>
<i>after 164 hours</i>	≤ 0.5	≤ 0.4	--	21.13 ± 1.31	18.41 ± 3.66	16.02	19.02 ± 1.85
Rotary Bomb (minutes)	≤ 200	≤ 195	800-1,000	118 ± 4	116 ± 5	116	117 ± 2
Water Content (ppm)	≤ 150	N/A	N/A	75 ± 21	72 ± 37	102	79 ± 14
Physical Properties							
Pour Point (°C)	-15 to -25	N/A	N/A	-18 ± 6	-17 ± 5	-18	-17 ± 2
Viscosity (cSt)							
@ 100°C***	≤ 10	N/A	N/A	8.61	8.57	8.55	8.59 ± 0.05
@ 40°C	≤ 45	N/A	N/A	40.73 ± 0.51	40.75 ± 0.38	40.45	40.68 ± 0.19
@ 0°C***	≤ 300	N/A	N/A	276.27	274.7	275.84	275.77 ± 1.19

Note: Bold values met the ABB, ASTM D3487, and ASTM D5222 specification values. Underlined values met the ABB and ASTM D3487 specification values. Italicized values met the ABB specification values. Data variability was calculated at 95% confidence using a two-tailed T-test and assuming a normal distribution.

*The values listed are based on the results for two samples except for the viscosity at 100°C and 0°C where only one sample was analyzed.

**Due to large variations between sample results analyzed at different points in time for the same lot, the lower impulse voltages (averaging around 133 kV) were assumed to be correct as a conservative assumption.

***These values are based on the results for two samples except for the composite lot values where only one sample was analyzed.

Acronyms and Abbreviations:

-- = No value provided in the specification for this parameter

ABB = Virgin product specification for BIOTEMP® developed by ABB, Inc.

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.

cSt = centistoke

kV = kilovolt

mgKOH/g = milligrams of potassium hydroxide per gram

N/A = Not applicable due to the differences in physical and chemical characteristics between BIOTEMP® and mineral oil and high temperature hydrocarbon oil.

ppm = parts per million

Although the oxidation stability test method states there is no correlation between the fluid's performance in the test and its performance in service, the test is used to evaluate oxidation inhibitors and to check the consistency of oxidation stability for a particular fluid.

The in-service transformer sample results are presented in Table 2. All four in-service transformer samples had dissipation factors and water contents below the maximum value listed for the IEC 1203 specification. All four in-service transformer samples had conductivity values higher than the minimum ABB specified value. The higher results listed for sample INS-07 relative to the other samples may be due to the extreme operating conditions (e.g., overloads) the transformer was subjected to as part of ABB's ongoing research project.

Table 2. Summary of In-service Transformer Sampling Results

Performance Parameters	Specification Standards		Sampling Results			
	ABB	IEC 1203	INS-01	INS-02	INS-03	INS-07
Dissipation Factor @ 25°C (%)	≤ 0.05	≤ 0.8	<i>0.13</i>	<i>0.088</i>	<i>0.082</i>	<i>0.252</i>
Water Content (ppm)	≤ 150	≤ 400	<u>15</u>	<u>19</u>	<u>16</u>	<u>78</u>
Conductivity @ 25°C (pS/m)	≤ 2.0	--	<i>16.17</i>	<i>11.5</i>	<i>8.51</i>	<i>24.65</i>

Note: Underlined values met both ABB and IEC 1203 specification values. Italicized values met either IEC 1203 or ABB specifications.

1. Samples INS-01, INS-02, and INS-03 collected from transformers owned by PG&E.
2. Sample INS-07 collected from a transformer owned by ABB which is used for testing BIOTEMP[®] under extreme operating conditions.

Acronyms and Abbreviations:

ABB = Virgin product specification for BIOTEMP[®] developed by ABB, Inc.
 IEC 1203 = International Electrochemical Commission (IEC) specification for Synthetic Organic Esters for Electrical Purposes - Guide for Maintenance of Transformer Esters in Equipment.
 ppm = parts per million
 pS/m = picosiemens per meter

- **Aquatic Biodegradability.** The average biodegradability of BIOTEMP[®] was 99% ± 3% after 21 days. The average biodegradation rates for BIOTEMP[®] and mineral oil (based on literature data) are presented in Table 3.

Table 3. Aquatic Biodegradation Results

Compound	Biodegradation Rates			
	ABB ETV ¹	Universite de Liege ²	CONCAWE ³	USACE ^{4,5}
BIOTEMP [®]	99% ± 3% after 21 days	---	---	---
Mineral oil	---	70% after 40 days	28% after 28 days	42-49% 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.

Based on the information above, the virgin BIOTEMP[®] fluid appears to biodegrade more readily than mineral oil. Although BIOTEMP[®] 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, 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 ABB performance specification presented in Table 4. The fire point results obtained also agreed with values reported by the Factory Mutual Research Center (FMRC) and Underwriters Laboratories (UL). The flash point results agreed with the values reported by FMRC but were higher than the values reported by the UL due to the different ASTM method used.

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
	ABB	ASTM D3487		ABB	ASTM D5222	
Virgin Product						
2000-216	>300	>145	329 ± 4	>300	304-310	361 ± 3
2000-224	>300	>145	331 ± 5	>300	304-310	360 ± 3
composite	>300	>145	337	>300	304-310	360
Average	>300	>145	331 ± 3	>300	304-310	360 ± 1
In-service Transformer Fluid						
ISFR3-01	>300	>145	330	>300	304-310	362
ISFR3-02	>300	>145	334	>300	304-310	364
ISFR3-03	>300	>145	334	>300	304-310	362
ISFR3-06	>300	>145	328	>300	304-310	362
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 BIOTEMP[®] 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) BIOTEMP[®] fluid may exhibit a hazardous characteristic when tested 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 BIOTEMP[®] 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.** Virgin BIOTEMP[®] samples contained 80.1% ± 0.3% oleic acid, 10.5% ± 0.1% diunsaturated fatty acids, 0.3% ± 0.0% triunsaturated fatty acids, and 9.2% ± 0.2% saturated fatty acids which agree closely with the formulation. The in-service transformer samples contained 79.5% to 84.4% oleic acid, 5.3% to 10.7% diunsaturated fatty acids, 0.2% to 0.3 % triunsaturated fatty acids, and 9.5% to 10.0% saturated fatty acids. Other tentatively identified compounds were TBHQ, 2-isopropyl-1,4-benzenediol, 2,3-dihydro-2-methyl-5-phenyl-benzofuran,

2-isopropyl-1,4-benzoquinone, p,p'-dioctyldiphenylamine, beta-sitosterol, squalene, and vitamin E. Metals were not detected in the in-service transformer samples except for one sample, which had a zinc concentration of 2.3 mg/kg. For the virgin samples, copper ranged from non-detect to 4.13 mg/kg, barium ranged from non-detect to 0.32 mg/kg and zinc ranged from non-detect to 2.02 mg/kg.

The phenolic antioxidant content was between 3,207 mg/kg \pm 103 mg/kg for the virgin BIOTEMP[®] fluid and between 2,990 and 3,600 mg/kg for the in-service transformer samples. Variations observed in the antioxidant content may be due to the varying quantities of antioxidant added by ABB's off-site blender.

- Worker Health and Safety. Based on the MSDS information from the Vermont Safety Information Resources, Inc. (SIRI) MSDS archive, BIOTEMP[®] appears to have personal protective equipment (PPE) requirements similar to select mineral oil-based transformer fluids but less stringent when compared to select silicone oil-based transformer fluids. BIOTEMP[®] has a slightly higher nuisance particulate permissible exposure level (PEL) than mineral oil based on the OSHA PEL for an 8-hour TWA exposure. In California, the nuisance particulate PEL is 10 mg/m³. BIOTEMP[®] also contains no IARC confirmed carcinogens. Some mineral oil-based transformer fluids contain a light naphthenic petroleum distillate that has been identified by the IARC as a confirmed carcinogen. Although BIOTEMP[®] appears to contain ingredients that cause less serious health effects, the end-user must comply with all applicable worker health and safety regulations for use of this product.
- Cost Comparison. The initial purchase cost of a new transformer unit containing BIOTEMP[®] costs approximately 1.25-1.30 times more than that of a comparable mineral oil transformer. When comparing the price per gallon of BIOTEMP[®] to mineral oil, the difference may be between \$4 to \$9 depending on the volume purchased. Based on historical accelerated aging test results, the estimated life expectancy of a BIOTEMP[®] transformer is estimated to be 20 years, which is a comparable to mineral oil-based transformers.

Results for this verification/certification show that the ABB Inc. BIOTEMP[®] Vegetable Oil-Based Dielectric Fluid is a biodegradable, vegetable oil-based dielectric fluid with a flash and fire point above 300°C. The product has dielectric breakdown voltages comparable to mineral oil and high temperature hydrocarbon oil. The product may have varying amounts of antioxidants based on past and current oxidation stability results. BIOTEMP[®] samples from in-service transformers had flash and fire points above 300°C, and only one sample showed signs of oil degradation due to extreme operating conditions. LC₅₀ results indicate the spent BIOTEMP[®] may exhibit a hazardous characteristic per California's hazardous characteristic definition but this is based on limited data for the virgin product. The end-user should characterize the spent BIOTEMP[®] at the time of disposal since changes may occur to the oil due to use, storage, or age.

Although BIOTEMP[®] 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 BIOTEMP[®] (virgin and spent), and BIOTEMP[®] spills.

Original signed by:
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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.)