**June 2002**
**DTSC R-02-03**
**EPA 600/R-02/043**

# Environmental Technology Verification Report

## ABB Inc. BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid

**Prepared by**

Cal/EPA
California Environmental Protection Agency

**Department of Toxic Substances Control**

**Under a cooperative agreement with**

EPA **U.S. Environmental Protection Agency**

ETV ETV ETV

June 2002

# Environmental Technology Verification Report

## ABB Inc.

# BIOTEMP®
# Vegetable Oil-Based Insulating Dielectric Fluid

**By**

**California Environmental Protection Agency**
**Department of Toxic Substances Control**
**Office of Pollution Prevention and Technology Development**
**Sacramento, California 95812-0806**

# Notice

The information in this document has been funded in part by the U.S. Environmental Protection Agency (EPA) under a Cooperative Agreement number CR 824433-01-0 with the California Environmental Protection Agency (CalEPA), Department of Toxic Substances Control (DTSC). The Pollution Prevention and Waste Treatment Technology Center under the U.S. EPA Environmental Technology Verification (ETV) Program supported this verification effort. This document has been peer reviewed by the EPA and recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA or the Department of Toxic Substances Control (DTSC) for use.

This verification is limited to the use of the ABB BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid for use in pole-mounted, small distribution and small power transformer units as an alternative to mineral oil-based dielectric fluids or those containing PCBs. EPA and DTSC make no express or implied warranties as to the performance of the ABB BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid technology. Nor does EPA and DTSC warrant that the ABB BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid is free from any defects in workmanship or materials caused by negligence, misuse, accident or other causes.

# Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's air, water, and land resources. Under a mandate of national environmental laws, the EPA strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development (ORD) provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The Environmental Technology Verification (ETV) Program has been established by the EPA, to verify the performance characteristics of innovative environmental technologies across all media and to report this objective information to the permitters, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification Organizations oversee and report verification activities based on testing and Quality Assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. There are now six ETV technology centers, which include the original twelve ETV technology areas. Information about each of the environmental technology centers covered by ETV can be found on the Internet at http://www.epa.gov/etv.htm

Effective verifications of pollution prevention and treatment technologies for hazardous waste are needed to improve environmental quality and to supply cost and performance data to select the most appropriate technology. Through a competitive cooperative agreement, the California Department of Toxic Substances Control (DTSC) was awarded EPA funding and support to plan, coordinate, and conduct such verification tests, for "Pollution Prevention and Waste Treatment Technologies" and report the results to the community at large. Information concerning this specific environmental technology area can be found on the Internet at http:\|www.epa.gov/etv/03/03_main.htm.

The following report reviews the performance of the ABB BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid. BIOTEMP® is used as an insulating dielectric fluid for pole-mounted, small distribution, and small power units as an alternative to mineral oil-based dielectric fluids or those containing PCBs.

## Acknowledgment

DTSC wishes to acknowledge the support of all those who helped plan and implement the verification activities, and prepare this report. In particular, a special thanks to Ms. Norma Lewis, Project Manager, and Ms. Lauren Drees, Quality Assurance Manager, of EPA's National Risk Management Research Laboratory in Cincinnati, Ohio.

DTSC would also like to thank Mr. Ron West of Pacific Gas and Electric for their support and for providing the facility and necessary resources to conduct the verification field test. Additionally DTSC would like to thank Mr. Jim Baker, Mr. Phillip Collins, and Mr. Gerry Schepers of ABB Inc. for their participation in this Environmental Technology Verification Pilot Project.

# THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

California Environmental Protection Agency

# 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** | | |
| COMPANY: | **ABB INC.** | | |
| ADDRESS: | **2135 PHILPOTT ROAD** | PHONE: | **(540) 688-4929** |
| | **SOUTH BOSTON, VIRGINIA 24592** | FAX: | **(540) 688-3844** |
| WEB SITE | **http://www.abb.com/us/** | | |
| EMAIL: | **don.cherry@us.abb.com** | | |

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:

▪ <u>General Performance.</u> 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 | -- | *177 ± 83* | *200 ± 68* | *173* | *185 ± 32* |
| **Dissipation Factor (%)** | | | | | | | |
| @ 25°C | ≤ 0.05 | ≤ 0.05 | ≤ 0.01 | 0.160 ± 0.184 | 0.022 ± 0.011 | 0.028 | 0.075 ± 0.054 |
| @ 100°C | ≤ 2.0 | ≤ 0.3 | ≤ 0.3 | 2.95 ± 1.15 | *0.837 ± 0.307* | *0.931* | *1.665 ± 0.762* |
| **Chemical Properties** | | | | | | | |
| **Oxidation Stability** | | | | | | | |
| Percent Sludge (%) | | | | | | | |
| *after 72 hours* | ≤ 0.2 | ≤ 0.1 | -- | 0.02 ± 0.01 | 0.02 ± 0.015 | 0.02 | 0.02 ± 0.00 |
| *after 164 hours* | ≤ 0.2 | ≤ 0.2 | -- | 0.03 ± 0.04 | 0.02 ± 0.02 | 0.02 | 0.02 ± 0.01 |
| Neutralization No. (mgKOH/g) | | | | | | | |
| *after 72 hours* | ≤ 0.2 | ≤ 0.3 | -- | 0.19 ± 0.04 | 0.16 ± 0.02 | 0.16 | 0.17 ± 0.02 |
| *after 164 hours* | ≤ 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 = centistokes

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 | *0.13* | *0.088* | *0.082* | *0.252* |
| Water Content (ppm) | ≤ 150 | ≤ 400 | <u>15</u> | <u>19</u> | <u>16</u> | <u>78</u> |
| Conductivity @ 25°C (pS/m) | ≤ 2.0 | -- | *16.17* | *11.5* | *8.51* | *24.65* |

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

- <u>Aquatic Biodegradability</u>. 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 |

[1]U.S. EPA, *Environmental Technology Verification Report ABB Inc. BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid*, 2001.
[2]Cloesen,C. & Kabuya, A, *Research RW N° 2174 Physical and chemical properties of environment friendly lubricants*, no date.
[3]Conservation of Clean Air and Water-Europe (CONCAWE), *Lubricating Oil Basestocks*, pp. 20-22, June 1997.
[4]U.S. Army Corps of Engineers (USACE), *Engineering and Design Environmentally Acceptable Lubricating Oils, Greases, and Hydraulic Fluids*, April 1997.
[5]USACE, *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 $LC_{50}$ for virgin BIOTEMP® was less than 250 mg/L. This low $LC_{50}$ value is thought to reflect the physical impacts on fish due to oil coating the gills and preventing oxygen exchange. The average $LC_{50}$ 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 ± 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 $mg/m^3$. 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. $LC_{50}$ 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:
E. Timothy Oppelt 6/10/02

E. Timothy Oppelt Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental
Protection Agency

Original signed by:
Kim F. Wilhelm 6/5/02

Kim F. Wilhelm, Acting Chief Date
Office of Pollution Prevention
and Technology Development
Department of Toxic Substances Control
California Environmental Protection Agency

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.)

# TABLE OF CONTENTS

## TABLES



## FIGURES

APPENDICES

**Appendix A: ABB Field Test Results**

*Appendix A-1*: Select ASTM Test Methods: Objective 1
*Appendix A-2:* Aquatic Biodegradability Test Method: Objective 2
*Appendix A-3:* Flammability ASTM Test Method: Objective 3
*Appendix A-4:* Acute Toxicity Test Method: Objective 4
*Appendix A-5:* Worker Health and Safety Assessment: Other Verification/Certification Objectives
*Appendix A-6:* AOAC Test Methods, EPA Test Method 8270 (SVOCs), and EPA Test

**Appendix B: ABB Field Test Plan**

Technology Evaluation WorkPlan (ABB), April 2, 2001; Department of Toxic Substances Control, Office of Pollution Prevention and Technology Development.

**Note:** Appendices are not included in the Verification Report and are available upon written request to DTSC at the following address:

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

## List of Abbreviations and Acronyms

| | |
|---|---|
| Ωcm | ohm-centimeter |
| ABB | ABB,Inc. |
| ANSI | American National Standards Institute |
| AOAC | Association of Analytical Chemists |
| ASTM | American Society of Testing and Materials |
| BHA | butylated hydroxy anisole |
| BHT | 3,5-di-tert-butyl-4-hydroxytoluene |
| EC | degrees Celsius |
| C-H | carbon-hydrogen bond |
| CAA | Clean Air Act |
| CAS | Chemical Abstracts Service |
| CCR | California Code of Regulations |
| CEC | Coordinating European Council |
| CFR | Code of Federal Regulations |
| $CH_2$ | ethyl |
| $CH_3$ | methyl |
| $CO_2$ | carbon dioxide |
| CONCAWE | Conservation of Clean Air and Water-Europe |
| cSt | centistokes (millimeter squared per second or $mm^2/s$) |
| CWA | Clean Water Act |
| DI | deionized |
| DL | detection limit |
| DTSC | California Department of Toxic Substances Control |
| EPA | United States Environmental Protection Agency |
| EPCRA | Emergency Planning and Community Right-to-Know Act |
| ETV | Environmental Technology Verification |
| FDA | Food and Drug Administration |
| FMRC | Factory Mutual Research Center |
| FRP | facility response plan |
| g | gram |
| HML | Hazardous Materials Laboratory |
| HSC | Health and Safety Code |
| HTH | high temperature hydrocarbons |
| IARC | International Agency for Research on Cancer |
| IEC | International Electrochemical Commission |
| IEEE | Institute of Electric and Electronic Engineers |
| IR | infrared spectroscopy |
| KOH | potassium hydroxide |
| kPa | kilopascals |
| KV or kV | kilovolts |
| kVA | kilovolt amperes |
| $LC_{50}$ | lethal concentration for 50% of the test population |
| $LD_{50}$ | lethal dose for 50% of the test population |

| | |
|---|---|
| mg/kg | milligrams per kilogram |
| mg KOH/g | milligrams of potassium hydroxide per gram |
| mg/L | milligrams per liter |
| ml | milliliter |
| mmHg | millimeters of mercury |
| MSDS | material safety data sheet |
| MVA | megavolt amperes |
| NIOSH | National Institute for Occupational Safety and Health |
| NRMRL | National Risk Management Research Laboratory |
| OPPTD | Office of Pollution Prevention and Technology Development |
| ORD | U.S. EPA Office of Research and Development |
| OSHA | Occupational Safety and Health Administration |
| PCBs | polychlorinated biphenyls |
| PEL | permissible exposure limit |
| PG&E | Pacific Gas and Electric |
| PPE | personal protective equipment |
| ppm | parts per million |
| psi | pounds per square inch |
| pS/m | picosiemens per meter |
| RCRA | Resource Conservation and Recovery Act |
| SIRI | Safety Information Resources, Inc. |
| SOP | standard operating procedure |
| SPCC | Spill Prevention, Control, and Countermeasures |
| SVOCs | semivolatile organic compounds |
| TBHQ | mono-di-tert-butyl hydroquinone |
| TCLP | toxicity characteristic leaching procedure |
| TSCA | Toxic Substances Control Act |
| TWA | time weighted average |
| UL | Underwriter Laboratories |
| USACE | U.S. Army Corps of Engineers |
| U.S. EPA | United States Environmental Protection Agency |
| WET | waste extraction test |

## Glossary of Terms

| | |
|---|---|
| Dielectric breakdown (gap) | The dielectric breakdown voltage indicates the fluid's ability to resist electrical breakdown at a power frequency of 60 Hz and is measured as the minimum voltage required to cause arcing between two submerged electrodes in the fluid spaced 1.0 mm or 2.0 mm apart. This method is considered more sensitive to the adverse effects of moisture in the oil in insulating systems. |
| Dielectric breakdown (impulse) | The impulse dielectric breakdown voltage indicates the fluid's ability to resist electrical breakdown under transient voltage stresses such as lightning and power surges and is measured as the voltage required to cause arcing between a submerged point and sphere electrode. |
| Dielectric breakdown (minimum) | The dielectric breakdown voltage at a 60 Hz test voltage indicates the fluid's ability to resist electrical breakdown and is measured as the minimum voltage required to cause arcing between two submerged electrodes in the fluid. This test is recommended for acceptance tests on virgin product. |
| Dissipation Factor (maximum) | The fluid's dissipation factor is a measure of the dielectric losses in the fluid. A low dissipation factor indicates low dielectric losses and a low concentration of soluble, polar contaminants. |
| Diunsaturated fatty acids | Fatty acids consisting of several carbons with 2 double carbon bonds (e.g., C18:2). |
| Flash point | The lowest temperature corrected to a barometric pressure of 101.3 kPa (760 mmHg) at which application of a test flame causes the vapor of a specimen to ignite. |
| Fire point | The lowest temperature at which the fluid will sustain burning for 5 seconds. |
| Kinematic viscosity | The measure of the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer. |
| Linoleic acid | A diunsaturated acid found as a triglyceride in high oleic oils. It has 18 carbons and 2 carbon-carbon double bonds (C18:2). |

| | |
|---|---|
| Linolenic acid | A triunsaturated acid found as a triglyceride in high oleic oils. It has 18 carbons and 3 carbon-carbon double bonds (C18:3). |
| Monounsaturated fatty acids | Fatty acids consisting of several carbons with 1 carbon-carbon double bond (e.g., C18:1). |
| Neutralization number | This number is a measure of the acidic or basic substances in the oil and is used as a quality control indicator. An increase in the value of the neutralization number may indicate degradation of the oil due to increased water content. This value is measured by dissolving the oil sample in a mixture of toluene, isopropyl alcohol, and a little water. A color indicator, *p*-naphtholbenzein, is added to this mixture and then titrated with potassium hydroxide until an orange (acid) or green-brown (base) color change occurs. |
| Oleic acid | A monounsaturated acid found as a triglyceride in many natural oils such as sunflower, olive, and safflower oil. This compound has 18 carbons with one carbon-carbon double bond (C18:1). |
| Oxidation stability | This value measures the amount of sludge and acid products formed by the oil under accelerated aging conditions. The oil sample is oxidized in a 110°C bath containing a copper catalyst coil. Oxygen is bubbled through duplicate specimens for 72 and 164 hours, respectively. At the end of each period, the amount of sludge and acid formed are measured. The sludge results are expressed as a percentage, which is calculated by dividing the weight of sludge formed by the weight of the oil sample. The acid content is determined by titrating the filtered solution containing *p*-naphtholbenzein (a color indicator) with potassium hydroxide (KOH). The acid content is expressed in the units of milligrams of KOH per grams of oil (mg KOH/g). |
| Polar contaminant | A polar contaminant in a dielectric fluid ionizes and imparts electrical conductivity to the solution. Examples of polar contaminants in dielectric fluids include water, dirt, and metals. |

| | |
|---|---|
| Polyunsaturated fatty acids | Fatty acids consisting of diunsaturated and triunsaturated fatty acids (i.e., several carbons with 2 or more carbon-carbon double bonds, respectively such as C18:2, C18:3)). |
| Pour Point | The lowest temperature at which the movement of the oil is observed. An average electrical power distribution application will require a dielectric fluid to have a pour point below -20°C. |
| Rotary Bomb Oxidation Stability | The time measured for the oil to react with a given volume of oxygen. The oil is placed in a copper vessel (bomb) with a glass sample container and exposed to oxygen at an initial pressure of 90 psi. The bomb is placed in a 140°C bath and agitated until a specific pressure drop occurs in the bomb. The time that elapses between the start of the experiment and the pressure drop is measured and recorded. This method is designed to evaluate the oxidation stability of new mineral oil containing 2,6-tertiary-butyl-para-cresol or 2,6-ditertiary-butyl phenol from shipment to shipment. According to the method, the method's applicability for inhibited insulating oils with a viscosity greater than 12 centistokes (cSt) at 40°C has not been determined. |
| Stearic acid | A saturated acid found as a triglyceride in high oleic oils. It has 18 carbons and no double carbon bonds (C18:0). |
| Triunsaturated fatty acids | A triunsaturated acid found as a triglyceride in high oleic oils consisting of several carbons with 3 carbon-carbon double bonds (i.e., C18:3). |
| Water content | The measure of the presence of water in oil expressed as a concentration (ppm). Water in the insulating oil will increase the breakdown rate of fatty acid esters in the vegetable oil base and leads to the formation of polar contaminants. This breakdown rate is proportional to the amount of water available for the reaction. An indicator of such reactions is a significant increase in the value of the neutralization number due to the increased acidity of the fluid. Compared to conventional mineral oils, vegetable oils have a much higher water content saturation point, typically well over 500 ppm at room temperature. Five to 10% of the saturation level (25 to 50 ppm) is the recommended range for vegetable oil after processing. |

# Section 1. Introduction

## Background

Electric power utilities use electrical transformers for a variety of applications, including power distribution. The transformers generate significant amounts of heat, and must contain cooling/insulating (dielectric) media to prevent gas formation, electrical shorts, fire or explosion, and transformer damage. Most transformers currently use some type of mineral oil as the cooling fluid; however high temperature hydrocarbons (HTHs) and synthetics (less-flammable fluids) are used in transformers that must operate in safety-related applications (near or inside buildings). Recently, transformer fluid vendors have developed vegetable seed oil-based dielectric fluids. These fluids have been certified as meeting “less-flammable” safety-related requirements by organizations such as Underwriters Laboratories or Factory Mutual Research Corporation.

Typically, liquid-containing distribution class transformers store from 30 to 1,000 gallons of oil. Spills from transformers are potentially an environmental concern because even small amounts of oil can contaminate bodies of water, possibly deplete oxygen, coat plant and animal life, be toxic or form toxic products, affect breeding, produce rancid odors, or foul shorelines or other habitats. Effects on soils are not as well characterized.

Polychlorinated Biphenyls (PCBs) are still in use but no longer produced because of their high toxicity - they are regulated under the federal Toxic Substances Control Act (TSCA). According to Title 40 Code of Federal Regulations Section 261.8 (40CFR 261.8), dielectric fluids and electric equipment with dielectric fluids regulated under TSCA are not regulated under the federal Resource Conservation and Recovery Act (RCRA). Non-PCB transformer fluids do not meet the requirements for regulation as hazardous waste under RCRA; however, mineral oils that have been in service for approximately 10 years have exceeded California’s acute toxicity levels for copper due to leaching from the transformer coils.

Facility owners and operators that handle, store, or transport oils (e.g., petroleum oils, vegetable oils, animal fats, etc.) are required to report an oil spill, which “may be harmful to the public health or welfare, or environment”. A reportable oil spill is defined as one that either (1) violates water quality standards, (2) causes a sheen or discoloration on the surface of a body of water, or (3) causes a sludge or emulsion to be deposited beneath the surface of the water or on adjoining shorelines. The oil spill must be contained, cleaned up, and reported to the National Response Center, the federal point of contact for all chemical and oil spills.

Table 1 illustrates the types and amounts of waste oil change-outs, spills, and associated clean-up costs that a small to medium-sized electrical utility transmission system monitoring and maintenance facility experienced in 1992. This facility, which is only one of several operated by the electrical utility, generated 155 tons of spilled oil and contaminated soil, most of which was caused by accidents involving utility poles and transformers.

**Table 1. Summary of 1992 PCB Waste Generation - Electric Utility**

| Waste Generated | Annual Quantity Generated (tons) | Annual Costs ($) |
|---|---|---|
| Oil Spill and Leak Residue | 155 | 46,000 |
| Source of Waste: Primarily damage to transformers | | |
| Waste Oil from Electrical Transformers | 126 | 100,000 |
| Source of Waste: Draining of oil prior to reconditioning or decommissioning transformers | | |
| Wastes Containing PCB | 28 | 50,000 |
| Source of Waste: Primarily damage to transformers and PCB recovery | | |

Source: U.S. EPA, Risk Reduction Engineering Laboratory, EPA/600/S-92/063 - October 1992

## BIOTEMP® Dielectric Insulating Fluid

ABB Inc. (ABB) has developed a dielectric insulating fluid called BIOTEMP® which is comprised of >98.5% vegetable oil and <1.5% antioxidants and optional color additives. 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 in-service. Customers that use this product include Pacific Gas & Electric, Boston Edison, Seattle City Light, Montana Power, American Electric Power, Empire District Electric, Southern Company Services, Carolina Power & Light, Arco Alaska, Hawaiian Electric, Cone Mills and US Gypsum.

## Evaluation Approach

The BIOTEMP® evaluation was designed to provide the data necessary to draw conclusions on the fluid's performance, chemical composition, toxicity, and safety. The evaluation included a review of supporting documents, information, and laboratory data submitted by ABB, and field sampling to provide independent data on the technology's performance, chemical composition, and toxicity.

The field sampling was conducted at ABB's manufacturing facility in South Boston, Virginia and at Pacific Gas and Electric's (PG&E) in-service transformers in San Francisco, California. PG&E is an ABB customer and agreed to provide staff and access to three in-service transformers as part of the field sampling activities. Prior to the field sampling, the Department of Toxic Substances Control staff (DTSC) prepared a Technology Evaluation Workplan (Workplan) to identify specific field objectives, data quality objectives, testing procedures, and roles and responsibilities. ABB assumed overall responsibility for obtaining access to all locations where field sampling was conducted. DTSC staff provided independent oversight and was present to observe all field sampling activities. The agreed-upon Workplan specified that DTSC would maintain a record of all samples collected, and record all measurements and observations made during sampling.

The oldest transformer in-service using BIOTEMP® as the dielectric insulating fluid is 2.5 years old. Since the technology is still new, no data was available to assess the long-term transformer performance and waste characteristics of BIOTEMP® fluid at the end of its service life. According to ABB, the service life is expected to be in the range of 20 years.

## Section 2. Description of Technology

BIOTEMP®, developed by ABB Inc., is a vegetable oil-based dielectric fluid comprised of greater than (>) 98.5% vegetable oil and less than (<) 1.5% antioxidants. The product may use up to three different antioxidants to prevent unsaturated bonds in the oil from polymerizing with oxygen. The vegetable oil used in BIOTEMP® is manufactured off-site in a four-step process: crushing and refining, bleaching, deodorizing, and winterizing. The oil is extracted from crushed seeds using a solvent such as hexane. As part of the bleaching process, the oil is subject to a clay treatment to remove polar contaminants. Next, the oil is deodorized using steam distillation to remove unwanted volatile compounds. The last step, winterizing, involves chilling the oil to remove excessive saturates. In the past, the vegetable oil and antioxidants were blended at a contract blending facility per ABB's product specifications. ABB is currently using blending equipment at ABB's South Boston, Virginia facility to oversee and control this portion of the process.

BIOTEMP® is used in liquid-filled electrical transformers as an electrical insulating medium. An example of a 3-phase transformer is presented in Figure 1. The main parts of a transformer are the core, the windings, the tank containing the core and windings, and the cooling system. The core is made of thin steel sheet laminates, which are coated, with an oxide film to insulate the sheets from each other. Two distinct sets of coils called windings are placed upon the core at a suitable distance from each other. These windings consist of wire insulated with a paper covering. An example of a three-phase transformer core is presented in Figure 2. When the transformer is in-service, the oil and core expands and contracts as the heat generated by the transformer windings varies with the load. As the oil becomes heated, the hot oil rises to the top of the transformer where heat is dissipated to the outside, and then moves along the case to the bottom. Fins are sometimes attached to deflect moving air against the case and to increase the cooling area. Overheating the core can lead to damage and overheating the windings can cause the insulation to deteriorate, which reduces the life of the transformer.

**Figure 1. Transformer Cross Section**

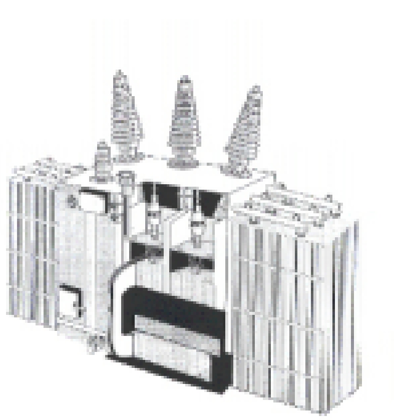
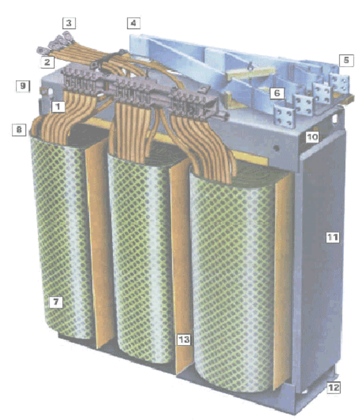


**Figure 2. Transformer Core**



For large power transformers, the tops of the tanks are designed to have a nitrogen gas seal to prevent the oil from oxidizing with the air. The expansion of the oil reduces the volume of the nitrogen gas causing the gas pressure to be greater during power load periods. Large transformers may also use radiators, fans, circulating pumps or cooling water to increase heat exchange.

## Section 3. Verification Objectives

The verification/certification objectives were to verify the applicant's technology performance claims listed below.

**Verification/Certification Claim #1 - General Performance**

- In the following composition ratio (98.5% vegetable oil, 1.5% additives), BIOTEMP® meets criteria for oxidative, thermal, and chemical stability, as measured by Oil Qualification Tests - ASTM D3487 (Mineral Oil) and ASTM D5222 (High Temperature Hydrocarbons).

**Verification/Certification Claim #2 - Aquatic Biodegradability**

- BIOTEMP® biodegrades 97% in 21 days, based on the average of several performance tests as measured by the Coordinating European Council (CEC) Test Method CEC-L-33-A-93.

**Verification/Certification Claim #3 - Flammability**

- BIOTEMP® has a Flash Point of at least 300°C, and a minimum Fire Point of 300°C, based on the average of several performance tests as measured by ASTM D92 (Cleveland Open Cup).

**Verification/Certification Claim #4 - Acute Toxicity**

- The virgin BIOTEMP® product passes the aquatic toxicity characteristic criterion specified in the Code of California Regulations, Title 22, Section 66261.24(a)(6) based on U.S. EPA/600/4-90/027F Test for Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms.

**Other Verification/Certification Tests:**

- Verify that BIOTEMP® consists of >98.5 % vegetable oil and <1.5% antioxidant and color additives, and that the formulator is meeting selected ABB purchase specifications.

- Establish a baseline for measuring potential metals leaching and oil degradation of BIOTEMP® under electrical loading over time.

- Evaluate the worker health and safety aspects of BIOTEMP®.

- Estimate expected lifetime costs of BIOTEMP® as compared to mineral oil.

# Section 4. Verification Activities and Results

## 4.1 Verification Activities

### 4.1.1 Field Sampling

Prior to sampling, DTSC developed a technology evaluation workplan, which described the sample collection procedures and analyses to be performed. A copy of the technology evaluation plan is included in Appendix B. To ensure independent and representative samples were collected, DTSC personnel oversaw sample collection in the field of virgin product and in-service transformers. Samples were assigned a field sample identification number, which was determined prior to sampling. Table 2 lists the samples collected and the analysis performed as part of this verification/certification. Proper chain of custody and storage procedures were followed.

Virgin Product

Samples of virgin fluid were collected at ABB's manufacturing facility in South Boston, Virginia. Three different lots were sampled by an ABB representative with DTSC oversight. A total of 12 samples (four samples per lot) were collected. Initially, three samples from each lot were analyzed for SVOCs, metals, acute toxicity, aquatic biodegradation, and select AOAC and ASTM methods. One duplicate was analyzed for SVOCs, metals, and select AOAC and ASTM methods. Two matrix spikes and an equipment blank were analyzed for SVOCs and metals. A field blank was analyzed for metals only. Six additional samples, consisting of two samples from Lot 2000-216, three samples from Lot 2000-224, and one sample from the composite lot, were analyzed by the ASTM methods listed in Table 2 to verify performance results reported by Doble Engineering**.**

Samples from Lots 2000-216 and 2000-224 were collected from 55-gallon drums. Samples were also collected from a 250-gallon holding tank used to store residual unused fluid from several different lots (the composite lot). Barrel samples were collected using a glass Coliwasa. A new glass Coliwasa was used at each new barrel sampled to reduce the potential of cross contamination. The tank samples were collected at a sampling spigot located at the bottom of the tank. The tank contents were not mixed prior to sampling. Approximately one pint of oil was drained from the tank via the spigot prior to sampling. Sampling activities are presented in Figures 3 and 4**.**

Virgin product samples collected as part of this verification/certification were from lots produced by ABB's off-site blender. Since BIOTEMP® was blended off-site, ABB was not able to continuously monitor the blending of antioxidants into the oil and make adjustments based on atmospheric conditions such as humidity. Lots blended at ABB's South Boston facility were not available for this sampling event since ABB was completing installation and testing of their on-site blending equipment.

# Table 2. BIOTEMP® Samples and Analyses

| Sample ID | Lot No. | SVOCs | Metals | Acute Toxicity | Aquatic Biodegradation | AOAC Methods | ASTM Methods | Comments |
|---|---|---|---|---|---|---|---|---|
| BIO-01 | 2000-216 | a | b | e | d | f | g,h,i,k,l,m, n,p,q,r | |
| BIO-02 | 2000-216 | | | | | | g,h,j,k,l,m, n,p,q,r | Duplicate sample. Analyzed for ASTM methods. Collected from same barrel as BIO-01. |
| BIO-03 | 2000-216 | a | b | | | f | g,h,i,k,l,m, n,p,q,r | Duplicate sample analyzed for methods marked. |
| BIO-04 | 2000-216 | | | | | | g,h,j,k,l,m, n,p,q,r | Duplicate sample. Analyzed for ASTM methods. Collected from same barrel as BIO-03. |
| BIO-05 | 2000-224 | a | b | | | | g,h,j,k,l,m, n,p,q,r | Matrix spike for metals and SVOC. Analyzed for ASTM methods. |
| BIO-06 | 2000-224 | | | | | | g,h,j,k,l,m, n,p,q,r | Duplicate sample. Analyzed for ASTM methods. Collected from same barrel as BIO-05. |
| BIO-07 | 2000-224 | a | b | e | d | f | g,h,i,k,l,m, n,p,q,r | |
| BIO-08 | 2000-224 | | | | | | g,h,j,k,l,m, n,p,q,r | Duplicate sample. Analyzed for ASTM methods. Collected from same barrel as BIO-07. |
| BIO-09 | composite | a | b | | | | g,h,j,k,l,m, n,p,q,r | Matrix spike for metals and SVOC. Analyzed for ASTM methods. |
| BIO-10 | composite | a | b | e | d | f | g,h,i,k,l,m, n,p,q,r | |
| BIO-11 | composite | | | | | | | Duplicate sample not analyzed |
| BIO-12 | composite | | | | | | | Duplicate sample not analyzed |
| BIO-13 | N/A | c | | | | | | Field blank |
| BIO-14 | N/A | c | b | | | | | Equipment blank |
| INS-1 | N/A | a | b | | | f | g,o,r,s | |
| INS-2 | N/A | a | b | | | f | g,o,r,s | |
| INS-3 | N/A | a | b | | | f | g,o,r,s | |
| INS-4 | N/A | c | | | | | | Field blank |
| INS-5 | N/A | c | b | | | | | Equipment blank |
| INS-6 | N/A | c | b | | | | | Equipment blank |
| INS-7 | N/A | a | b | | | f | g,o,r,s | |

The letter assigned to each sample corresponds to the analysis performed:

a - U.S. EPA Method, 8270 (SVOC screening) and prepared per U.S. EPA Method 3580

b - U.S. EPA Method 6010 (metals screening) and prepared per U.S. EPA Method 5030

c - U.S. EPA Method, 8270 (SVOC screening) and prepared per U.S. EPA Method 3051

d - CEC-L-33-A-93, *Biodegradability of Two-Stroke Cycle Outboard Engine Oils in Water*

e - U.S. EPA Method 600/4-90/027F, *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms* and prepared per the requirements in California Regulations, Title 22, Section 66261.24(a)(6), *Static Acute Bioassay Procedures for Hazardous Waste Samples*.

f - AOAC Method 981.11, *Oils and Fats*, AOAC Method 972.28, *Total Fatty Acids in Oils and Fats,* AOAC Method 963.22, *Methyl Esters of Fatty Acids in Oils and Fats*, AOAC Method 983.15, *Phenolic Antioxidants in Oils, Fats, and Butter*, and AOAC Method 977.17, *Polymers and Oxidation Products of Vegetable Oil.*

g - ASTM Method D92, *flash and fire point*

h - ASTM Method D97, *pour point*

i - ASTM Method D445, *kinematic viscosity (0, 40, & 100°C)*

j - ASTM Method D445, *kinematic viscosity (40°C)*

k - ASTM Method D877, *dielectric breakdown (minimum)*

l - ASTM Method D1816, *dielectric breakdown (gap)*

m - ASTM Method D3300, *dielectric breakdown (impulse)*

n - ASTM Method D924, *dissipation factor (25°C & 100°C)*

o - ASTM Method D924, *dissipation factor (25°C)*

p - ASTM Method D2440, *oxidation stability*

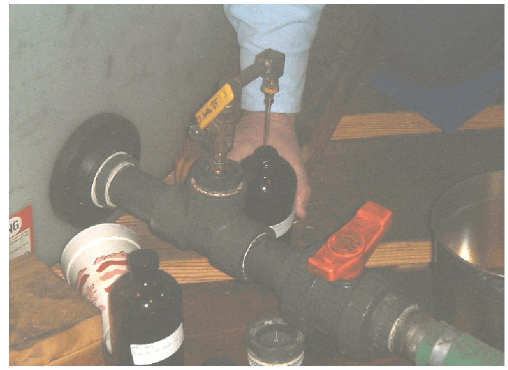
q - ASTM Method D2112, *oxidation stability (rotary bomb)*

r - ASTM Method D1533, *water content*

s - ASTM Method D4308, *conductivity*

**Figure 3. Drum Sampling**

**Figure 4. Tank Sampling**



<u>In-Service Transformer</u>

Samples of in-service fluid were taken from transformers that have been in use for **at least one year** and part of a regular sampling/testing environment. Samples from the PG&E transformers were collected by PG&E and ABB representatives under DTSC oversight and in conjunction with PG&E's on-going sampling program. The sample from the ABB transformer was collected by an ABB representative under DTSC oversight. Only one sample per transformer was collected to minimize the amount of fluid removed from each transformer and the impact to the ongoing test program. New Tygon tubing connectors were used at each transformer fluid sampling port to reduce the potential of cross contamination.

The transformer pressure valve is checked to confirm the unit is under positive pressure prior to sampling. A sampling syringe with Tygon tubing and a T-shaped sampling valve are attached to the sampling port. The T-shaped sampling valve is set to allow oil to flow through a purge line, which bypasses the sampling syringe. The sampling port valve is cracked open and oil is purged through the Tygon tubing, sampling valve, and purge line. The sample bottles are filled after a pint of oil has been purged through the line.

Four transformers were sampled; three owned by PG&E in San Francisco, California and one owned by ABB in South Boston, Virginia. Two of the PG&E transformers were located in underground vaults on Mission Street between First and Second Street. The other PG&E transformer was located in an underground vault on Howard Street between Fremont Street and Beale Street. The three PG&E transformers were in normal service. The ABB transformer was used for testing BIOTEMP® under extreme operating conditions. Table 3 lists information on the transformer type, size, and condition at the time of sampling. Transformer sampling activities are presented in Figures 5 and 6.

**Table 3. Equipment Information on Sampled Transformers**

| Owner | Transformer Information | | | | | | |
|---|---|---|---|---|---|---|---|
| | Type | Serial Number | kVA Rating (kVA) | Primary Voltage (kV) | Secondary Voltage (kV) | Temp. Rise (°C) | Initial In-Service Date |
| PG&E | 3-phase vault network transformer | NAB4424-003T | 1,000 | 12,000 | 480 | 65 | March 2000 |
| PG&E | 3-phase vault network transformer | NAB4424-004T | 1,000 | 12,000 | 480 | 65 | March 2000 |
| PG&E | 3-phase vault network transformer | NAB4424-005T | 1,000 | 12,000 | 480 | 65 | March 2000 |
| ABB | 3-phase RSL insulated unit substation | PAO7914-001 | 1,000 | --- | --- | 65 | June 2000 |

**Figure 5. Flushing Sampling Port**

**Figure 6. Transformer Sampling**

### 4.1.2 Historical Data

DTSC staff also reviewed internal product development testing data provided by ABB. These data were collected as part of ongoing testing for internal use by ABB prior to entry into the verification/certification agreement. Historical data collected by independent testing facilities under contract with ABB were also reviewed. These data provided background information on the technology performance for past virgin lots and indicated trends on the fluid's performance in tested transformers for select ASTM parameters.

## 4.2 Results: Objective 1, General Performance

For this verification/certification, BIOTEMP® was tested for select physical (e.g., pour point, viscosity), chemical (e.g., water content, oxidation stability), thermal (e.g., flash and fire point) and dielectric (e.g., dielectric breakdown, dissipation factor) properties to verify general performance claims listed in ABB's product specifications. Since no standard suite of general performance tests exist for vegetable oil-based dielectric fluids, two ASTM specifications developed for mineral oils (ASTM D3487) and high temperature hydrocarbons (HTH) (ASTM D5222) were used. These ASTM standards were selected because ABB claimed the dielectric and oxidation properties for BIOTEMP® were similar to those for mineral oil and HTH fluid. For the in-service transformer samples, results were compared to the International Electrochemical Commission (IEC) 1203 specification for in-service synthetic organic esters since BIOTEMP® has similar fluid characteristics to synthetic esters when in use. Doble Engineering (Doble), an independent testing laboratory, tested virgin and in-service samples for physical, chemical, thermal, and dielectric properties using the ASTM methods listed in Table 2. The results for the thermal properties are discussed in Section 4.4. Results for the other properties are discussed below.

### 4.2.1 Virgin Product Performance Results

*Dielectric Properties (or Dielectric Strength)*

Dielectric breakdown is the basic property used to evaluate a dielectric fluid's performance. The dissipation factor is also used to evaluate a dielectric fluid's performance but this property may vary between various dielectric fluids due to the chemical properties. Table 4 lists the test results, and dielectric breakdown and dissipation factor specification standards for ASTM D3487, D5222, and ABB that were used to evaluate BIOTEMP®'s electrical performance.

<u>Dielectric Breakdown</u>

> Both the minimum and gap dielectric breakdown tests measure the minimum voltage required to cause arcing between two submerged electrodes in a dielectric fluid. A low dielectric breakdown value may indicate the presence of water, dirt, or other electrically conductive particles in the oil, which may cause damage to the transformer core or windings due to arcing. The dielectric breakdown values for the virgin BIOTEMP® samples were higher than the lowest value specified for the minimum and 1.0 mm gap dielectric breakdown voltages for all three specifications. Precision criteria are not specified in ASTM Method D877 (minimum breakdown voltage) and ASTM Method D1816 (gap breakdown voltage). Since BIOTEMP®'s dielectric breakdown values were higher than the ABB and ASTM specifications, the fluid met these performance criteria and would not likely cause damage to the transformer core or windings due to arcing.

## Table 4. Performance Results for Virgin BIOTEMP®

| Performance Parameters | Specification Standards | | | Sampling Results | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lot 2000-216 | | | | | Lot 2000-224 | | | | | Composite Lot | | |
| | ABB | ASTM D3487 | ASTM D5222 | BIO-01 | BIO-02 | BIO-03 | BIO-04 | Average* | BIO-05 | BIO-06 | BIO-07 | BIO-08 | Average* | BIO-09 | BIO-10 | Average |
| **Dielectric Properties** | | | | | | | | | | | | | | | | |
| **Dielectric breakdown (kV)** | | | | | | | | | | | | | | | | |
| minimum | ≥ 30 | ≥ 30 | ≥ 42 | 48 | 45 | 48 | 43 | **46 ± 4** | 49 | 52 | 56 | 48 | **51 ± 6** | 55 | 54 | **55** |
| gap | ≥ 28 | ≥ 28 | ≥ 30 | 34 | 39 | 37 | 38 | **37 ± 3** | 34 | 40 | 34 | 38 | **37 ± 5** | 36 | 41 | **39** |
| impulse | ≥ 100 | ≥ 145 | NA | 134 | 220 | 130 | 224 | **177 ± 83** | 226 | 220 | 136 | 216 | **200 ± 68** | 214 | 132 | **173** |
| **Dissipation Factor (%)** | | | | | | | | | | | | | | | | |
| @ 25°C | ≤ 0.05 | ≤ 0.05 | ≤ 0.01 | 0.128 | 0.242 | 0.098 | 0.141 | **0.160 ± 0.184** | 0.015 | 0.017 | 0.029 | 0.025 | **0.022 ± 0.011** | 0.031 | 0.025 | **0.028** |
| @ 100°C | ≤ 2.0 | ≤ 0.3 | ≤ 0.3 | 2.6 | 3.3 | 2.42 | 3.12 | **2.95 ± 1.15** | 0.74 | 1.08 | 0.636 | 0.89 | **0.837 ± 0.307** | 1.06 | 0.801 | **0.931** |
| **Chemical Properties** | | | | | | | | | | | | | | | | |
| **Oxidation Stability** | | | | | | | | | | | | | | | | |
| Percent Sludge (%) | | | | | | | | | | | | | | | | |
| *after 72 hours* | ≤ 0.2 | ≤ 0.1 | NA | 0.02 | 0.01 | 0.02 | 0.01 | **0.02 ± 0.01** | 0.02 | 0.01 | 0.03 | 0.01 | **0.02 ± 0.015** | 0.02 | 0.01 | **0.02** |
| *after 164 hours* | ≤ 0.2 | ≤ 0.2 | NA | 0.06 | 0.01 | 0.04 | 0.01 | **0.03 ± 0.04** | 0.01 | <0.01 | 0.04 | 0.02 | **0.02 ± 0.02** | 0.01 | 0.03 | **0.02** |
| Neutralization No. (mgKOH/g) | | | | | | | | | | | | | | | | |
| *after 72 hours* | ≤ 0.2 | ≤ 0.3 | NA | 0.17 | 0.23 | 0.19 | 0.18 | **0.19 ± 0.04** | 0.17 | 0.16 | 0.14 | 0.17 | **0.16 ± 0.02** | 0.16 | 0.16 | **0.16** |
| *after 164 hours* | ≤ 0.5 | ≤ 0.4 | NA | 21.68 | 20.51 | 21.98 | 20.34 | **21.13 ± 1.31** | 18.99 | 21.43 | 16.61 | 16.63 | **18.41 ± 3.66** | 17.61 | 14.44 | **16.02** |
| Rotary Bomb (minutes) | ≥ 200 | ≥ 195 | 800-1,000 | 120 | 117 | 120 | 115 | **118 ± 4** | 117 | 120 | 115 | 112 | **116 ± 5** | 117 | 115 | **116** |
| **Water Content (ppm)** | ≤ 150 | ≤ 35 | ≤ 25 | 93 | 62 | 76 | 70 | **75 ± 21** | 55 | 51 | 80 | 101 | **72 ± 37** | 98 | 106 | **102** |
| **Physical Properties** | | | | | | | | | | | | | | | | |
| **Pour Point (°C)** | -15 to -25 | -40 | -24 | -21 | -15 | -21 | -15 | **-18 ± 6** | -15 | -15 | -21 | -15 | **-17 ± 5** | -15 | -21 | **-18** |
| **Viscosity (cSt)** | | | | | | | | | | | | | | | | |
| @100°C | ≤ 10 | ≤ 3 | 11.5-14.5 | -- | -- | 8.61 | -- | **8.61** | -- | -- | 8.57 | -- | **8.57** | -- | 8.55 | **8.55** |
| @ 40°C | ≤ 45 | ≤ 12 | 100-140 | 40.55 | 41.04 | 40.38 | 40.96 | **40.73 ± 0.51** | 41.08 | 40.71 | 40.5 | 40.71 | **40.75 ± 0.38** | 40.50 | 40.39 | **40.45** |
| @ 0°C | ≤ 300 | ≤ 76 | 1,800-2,200 | 276.42 | -- | 276.1 | -- | **276.27** | -- | -- | 274.7 | -- | **274.7** | -- | 275.8 | **275.84** |

Note: Due to the differences in the physical and chemical properties (e.g., water content) of BIOTEMP® versus mineral oil and high fire-point hydrocarbon insulating oils, the values listed under these headings are compared the ABB specification values only. The ASTM specification values are provided as a reference to the reader.

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

Acronyms and Abbreviations:

-= Sample not tested for this parameter

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

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

STM D5222 = ASTM standard specification for high fire-point electrical insulating oil.

t = centistokes

V = kilovolt

gKOH/g = milligrams of potassium hydroxide per gram

/A = Not available

= parts per million

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The impulse dielectric breakdown test is designed to determine the minimum voltage to cause arcing in the fluid under lightning or power surge conditions. The minimum breakdown voltages the oil must exceed for use are listed for each specification in Table 4. Of the ten samples analyzed, six samples had voltages higher than the minimum voltage listed under ASTM D3487. All ten samples exceeded the ABB minimum voltage specification.

The ten samples listed in Table 4 were analyzed at two different points in time. Initially, Doble analyzed samples BIO-01, BIO-03, BIO-07, and BIO-10. ABB later requested Doble to analyze samples BIO-02, BIO-04, BIO-05, BIO-06, BIO-08, and BIO-09 to verify results for certain parameters. The confidence interval for data obtained for the two sets of samples were calculated separately. The two sets of data met the repeatability criteria in ASTM Method D3300 of ± 13KV with a 95% confidence at ± 4.1KV and ± 4.8KV, respectively. When the data were combined into one data set, the 50% confidence interval was ±10.0KV, which did not meet the method criteria of 5KV at 50% confidence for any two series of samples tested.

The percent difference between sample results collected from the same barrel and the same lot but analyzed at different points in time was between 48% and 54% (i.e., BIO-01 and BIO-02, BIO-03 and BIO-04, BIO-07 and BIO-08). The percent difference for samples BIO-05 and BIO-06, which were from the same barrel, the same lot and analyzed at the same point in time, was 3%. ASTM D3300 does not require the test instrument to be calibrated before and after testing using a calibration solution. Instead, the instrument calibration is based on the five successive voltage readings obtained for the test fluid. These large variations in the sample results from the same drum and lot suggest inherent inaccuracies within the method and possible quality issues associated with Doble's analyses.

A low impulse voltage might be due to a high contaminant or water content in the oil. A high contaminant or water content might also cause a higher dissipation factor or lower gap voltage. A direct correlation between these three values was not apparent from the data in Table 4. Since the impulse voltages varied greatly for samples taken from the same barrel and the same lot, it wasn't clear which results for BIOTEMP® were correct. Assuming conservatively that the lower impulse voltages were correct, BIOTEMP® met ABB's performance specification for the impulse dielectric breakdown voltage, but not the ASTM D3487 specification.

Dissipation Factor

The dissipation factor is used to measure the dielectric losses to an insulating dielectric fluid (such as oil) when it is exposed to an alternating electric field. For ASTM Method D924, the dissipation factor is determined by passing an alternating electric current through a test cell filled with dielectric fluid and measuring the capacitance with an electronic bridge circuit. This value is used to control the product quality, and to determine changes in the fluid due to contamination or degradation during use. A low dissipation factor indicates a low dielectric loss and a low contaminant concentration (e.g., dirt, water, or metals).

The dissipation factor for the four samples from Lot 2000-216 were much higher than the six samples taken from Lot 2000-224 and the composite lot. Results indicate the four samples from Lot 2000-216 did not meet any specification values at 25°C and 100°C. None of the ten samples were found to meet the ASTM D5222 specification values. BIOTEMP® met the ABB specification for the dissipation factor at 25°C and 100°C for two out of three lots sampled. The same two lots also met the ASTM D3487 specification for the dissipation factor at 25°C. The high dissipation factors for Lot 2000-216 indicate a higher contaminant concentration in this lot compared to the other lots. This may be due to contaminants introduced while storing empty barrels or during the barrel filling process. The higher dissipation factors at 100°C may also be due to the higher water content of BIOTEMP® versus mineral oil and HTH.

*Chemical Properties*

<u>Oxidation Stability</u>

Oxidation stability was originally designed to assess the amount of sludge and acid products formed in mineral transformer oils under specific test conditions. Good oxidation stability minimizes the formation of sludge and acid in order to maximize the service life of the oil. Oils that met the requirements specified for ASTM Method D2440 tend to minimize electrical conduction, ensure acceptable heat transfer, and preserve system life. According to ASTM Method 2440, there is no proven correlation between performance in this test and performance in service, since the test does not model the whole insulation system (oil, paper, enamel, and wire). However, the test can be used as a control to evaluate oxidation inhibitors and to check the consistency of the oxidation stability of production oils.

The first oxidation stability tests on BIOTEMP® were performed per ASTM Method D2440 over a 72-hour period (the 72 hour test). The percentages of sludge generated and the neutralization numbers after 72 hours met both ABB and ASTM D3487 specifications. Data were within the precision criteria listed in ASTM Method D2440. The difference between results at the 95% confidence level did not exceed 0.017% for the generated sludge and 0.093 mg KOH/g for the neutralization number.

Oxidation stability tests were also performed on BIOTEMP® per ASTM Method D2440 over a 164-hour period (the 164 hour test). The percentage of sludge generated after 164 hours met the ABB and ASTM D3487 specifications for all samples. Sludge results were within the precision criteria listed in ASTM Method D2440 and did not exceed 0.026% at 95% confidence. However, the neutralization number after 164 hours exceeded the maximum value for the ABB and ASTM D3487 specifications for all samples. Doble's chemist verified the results were correct and no unusual material formation was observed. The confidence interval for the neutralization numbers at 95% confidence were ± 1.85 mg KOH/g that did not meet the precision criteria of ± 1.027 mg KOH/g.

Past oxidation stability tests performed by Doble Engineering reported the neutralization number after 164 hours at 0.25 mg KOH/g. A yellow deposit formed at the top of the test tube, which had a pH of 4.6 when dissolved in water. ABB had observed these deposits during product testing but noted that they did not form on a consistent basis. The yellow deposit was thought to be composed of acid crystals produced when the fluid degraded due to heat and oxidation. ABB believed the deposit might be volatile acids associated with the antioxidants used in BIOTEMP® (Lewand, 2001). The high neutralization numbers reported for the samples listed in Table 4 may be due to the formation of these acids in solution.

The oxidation stability of BIOTEMP® was also tested using ASTM Method 2112, oxidation stability by rotating bomb (the rotary bomb test). The rotary bomb test was developed as a rapid method for evaluating the consistency of the oxidation stability for a new mineral oil between shipments. Results ranged between 112 and 120 minutes, which were below the minimum ABB, ASTM D3487 and D5222 specification values. The confidence limit at 95% for the data was ± 2.0 minutes, which met the precision criteria in ASTM D2112 of ± 23 minutes at 95% confidence. Past testing performed by Doble reported a rotary bomb test results of 162 minutes, which was less than ABB's specification (Lewand, 2001) and D3487's specification.

BIOTEMP® met ABB's specifications and was comparable to mineral oil for the 72-hour oxidation stability test, and for the percent of sludge generated using the 164-hour oxidation stability test. The fluid did not meet ABB's oxidation stability specification for the neutralization number using the 164-hour test or the rotary bomb test. BIOTEMP® was not comparable to the HTH fluids per the rotary bomb test. As stated earlier, there is no proven correlation between performance in this test and performance in service, since the test does not model the whole insulation system. However, these tests indicate possible inconsistencies in the addition and/or blending of antioxidants used in BIOTEMP® due to the low results for the rotary bomb tests and the high neutralization number for the 164-hour test.

Water Content

Water content is used by industry to monitor a dielectric fluid's quality and as an indicator of possible oil deterioration, which could adversely affect the oil's electrical properties such as dielectric breakdown. This value is based on the relative saturation of the water in the dielectric fluid. The relative saturation is based on the amount of water dissolved in the oil divided by the total amount of water the oil could hold at that temperature. The dielectric strength of oil starts to fall when saturation reaches about 50%. For petroleum based dielectric oils, 50% saturation at room temperature is 30-35 mg/kg. Synthetic esters and vegetable oil contain about 500-600 mg/kg of water at room temperature and 50% saturation. A water content at or near 50% saturation may indicate the oil has deteriorated and may cause a lower dielectric breakdown voltage, which can damage the transformer core and windings.

Water content was tested by Doble using ASTM Method D1533, water in insulating liquids. The water contents for all samples were below the maximum value listed for the ABB specification of 150 ppm. No precision criteria were available for results greater than 50 ppm. The water content varied between barrels from the same lot by approximately 20% to 40% in Lot 2000-216, 23% to 66% for Lot 2000-224, and 7% for the composite tank. For Lot 2000-216 and 2000-224, two samples each were collected from two separate barrels for each lot. When sample results for the same barrel and same lot were compared, the water content varied 40% for samples BIO-01 and BIO-02, 8% for BIO-03 and BIO-04, 8% for BIO-05 and BIO-06, and 23% for samples BIO-07 and BIO-08. This may be due to variability in the analytical method, atmospheric conditions at the time of testing, or sample storage conditions. Although BIOTEMP®'s water content is higher compared to mineral oil and HTH, the water content did not adversely affect the dielectric strength since BIOTEMP® met the dielectric breakdown specifications for ABB, ASTM D3487, and ASTM D5222. Presently, ABB is using their own blending equipment at their South Boston, Virginia facility to ensure future consistency of their product.

*Physical Properties*

Pour Point

The pour point indicates the lowest temperature an oil can be used. Initially, BIO-01, BIO-03, BIO-07, and BIO-10 were analyzed and the pour point was measured at -21°C for all four samples. The other six samples were analyzed at a later date with pour points all measured at -15°C. These combined data exceeded the repeatability criteria of 3°C between readings per ASTM Method D97. This may be due to a different operator conducting the tests. The pour points for all samples were within the ABB specification range. BIOTEMP® did not meet the values listed for the ASTM D3487 and D5222 specifications and was not expected to meet these values since they were based on the physical properties of mineral oils and HTH.

Viscosity

The dielectric fluid's viscosity is used by transformer designers to confirm that the fluid is appropriate for the unit under certain operating conditions. The viscosity of BIOTEMP® was determined at 0°C, 40°C, and 100°C. The viscosities at 0°C, 40°C, and 100°C varied slightly between samples and were below the ABB maximum specification values at these temperatures. The fluctuations in the measured viscosity at 40°C and 100°C were not within the precision criteria listed in ASTM Method D445 of $< 0.35\%$ of the sample mean. This may be due to different operators testing the material at two different points in time. No precision criteria were listed for viscosities measured at 0°C. BIOTEMP® was not expected to meet and did not meet ASTM D3487 and D5222 specifications for viscosity. These ASTM specifications were developed for mineral oils and HTH that have different physical properties and were provided as a reference only.

### 4.2.2 In-service Transformer Fluid Results

For in-service transformer samples, monitoring results for the past year are presented in Figure 7. The sample results generated as part of this verification/certification are presented in Table 5. These samples were tested for flash and fire point, dissipation factor, water content, and conductivity. Flash and fire point results are presented in Section 4.4. In-service transformer results are compared to the IEC 1203 performance specification, which was developed to evaluate the quality of in-service synthetic esters (IEC 1203). The performance of BIOTEMP® in service is similar to that of synthetic esters. The performance specifications for the dissipation factor, water content, and conductivity listed under ASTM D3487, D5222, and ABB are for virgin product and are used to determine if the oil has degraded.

**Table 5. Performance Results for In-Service BIOTEMP® Samples**

| Performance Parameters | Specification Standards | | | | Sampling Results | | | |
|---|---|---|---|---|---|---|---|---|
| | ABB | ASTM D3487 | ASTM D5222 | IEC 1203 | INS-01 | INS-02 | INS-03 | INS-07 |
| Dissipation Factor @ 25°C (%) | ≤ 0.05 | ≤ 0.05 | ≤ 0.01 | 0.8 | 0.13 | 0.088 | 0.082 | 0.252 |
| Water Content (ppm) | ≤ 150 | ≤ 35 | ≤ 25 | 400 | 15 | 19 | 16 | 78 |
| Conductivity @ 25°C (pS/m) | ≥ 2.0 | -- | -- | -- | 16.17 | 11.5 | 8.51 | 24.65 |

Note:

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.
3. Sample results for the dissipation factor are compared only to IEC 1203. The values listed for ABB, ASTM D3487, and D5222 are for virgin product.
4. Water content values are compared to the ABB and IEC 1203 specification values.

Acronyms and Abbreviations:

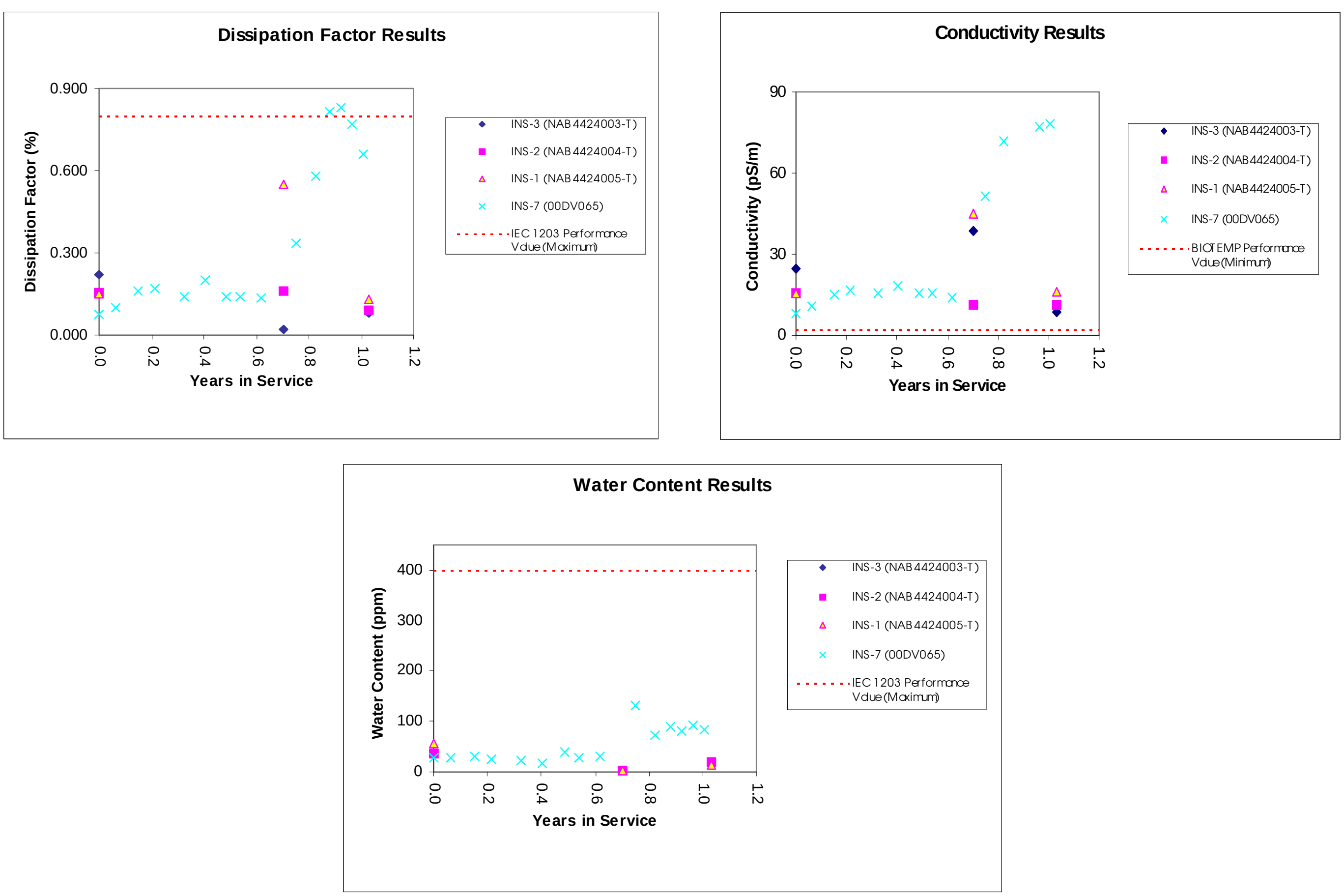
-- = Specification did not list a value for this parameter
ABB = Virgin product specification for BIOTEMP® developed by ABB, Inc.
IEC 1203 = International Electrochemical Commission (IEC) specification for Synthetic Organic Esters for Electrical Purposes - Guide for Maintenance of Transformer Esters in Equipment.
ppm = parts per million
pS/m = picosiemens per meter

The dissipation factor for all four transformer samples were below the IEC 1203 maximum value. All but two historical data points associated with the ABB transformer monitoring program were below the IEC 1203 maximum values. The ABB transformer sample (INS-07) had a higher value than the PG&E transformer samples and was noted to have an amber-orange color. The PG&E samples were described as light yellow. According to ABB, the ABB transformer was used to test BIOTEMP® under extreme operating conditions such as overload scenarios. Historical results for the ABB transformer showed a steady rise in the dissipation factor, which corresponded to the overload scenarios. When the in-service sample results were compared to the ABB virgin product specification, the in-service sample results ranged from 64% to 404%, indicating the oil may have a higher contaminant content due to use. The color and higher dissipation factor for the ABB transformer might indicate thermal decomposition of the fluid or possible oxidation.

The water content for the in-service transformer samples were all below the maximum value listed for IEC 1203 and ABB. Most of the historical water content data for the ABB transformer (INS-07) were below the ABB maximum value. When compared to the other transformer sample results, the ABB transformer sample (INS-07) had the highest water content. The higher water content observed in INS-07 corresponds to the overload tests conducted by ABB.

The conductivity values for all four samples are greater than the minimum value specified by ABB specifications. IEC 1203 did not specify a conductivity value but does specify a minimum volume resistivity value of 6.00 x $10^{11}$ Ωcm. The conductivity values are the inverse of resistivity and can be converted. The calculated volume resistivity values for samples INS-01, INS-02, INS-03, and INS-07 are 6.2 x$10^{12}$ Ωcm, 8.7 x $10^{12}$ Ωcm, 1.2 x$10^{13}$ Ωcm, and 4.0 x $10^{12}$ Ωcm, respectively. These values were greater than the minimum volume resistivity specified in IEC1203. It should be noted that the ABB transformer sample had the higher conductivity value compared to PG&E transformer samples. Again, the higher conductivity value for INS-07 corresponds to overload tests and was probably the result of extreme operating conditions.

**Figure 7. Trends for In-Service Transformer Parameters**



## 4.3 Results: Objective 2, Aquatic Biodegradability

Three virgin BIOTEMP® samples were analyzed by the Coordinating European Council (CEC) test method CEC-L-33-A-93. This method was originally intended to measure the biodegradability of hydrocarbons, specifically two-stroke motor oils, in water. This method compares the biodegradation potential of BIOTEMP® against the standard oil specified in the test method. BIOTEMP® and the standard oil are placed in separate flasks containing an inoculum/mineral substrate mixture. Two separate poisoned flasks containing BIOTEMP® and the standard oil are also prepared with 1 ml of mercuric chloride and no inoculum. The extract solutions from these flasks are collected on the zero-day and after the 21-day incubation period. The extract solution is analyzed by infrared spectroscopy (IR) measuring the maximum absorption of the stretch between carbon and hydrogen (C-H) at the ethyl-methyl ($CH_2$-$CH_3$) bond. This is conducted at a wavelength of 2930 $cm^{-1}$ ±10$cm^{-1}$. The biodegradability is expressed as a percent difference in the residual oil contents between the poisoned flasks and the respective test flasks. Powertech, an independent testing laboratory, performed these tests.

Table 6 presents the results for the three virgin product samples sent to Powertech. Also presented are historical results for virgin product analyzed by another independent laboratory, Parametrix, using the same test method. The average biodegradability of BIOTEMP® was 99% after 21 days. An earlier study by ABB showed 90% biodegradation after 21 days. The results from Powertech met the method's repeatability criteria of less than 14.8% at 95% confidence. The biodegradability result for the method reference oil, RL130, at 88% was compared to an interlaboratory program value of 89.6% and met the reproducibility criteria of less than 25.2% at 95% confidence. Biodegradability results reported by Powertech and Parametrix also met the reproducibility criteria.

**Table 6. Aquatic Biodegradability Results**

| Sample ID | Biodegradability (%) |
|---|---|
| BIO-01 | 100 |
| BIO-07 | 98 |
| BIO-10 | 100 |
| Average | 99 ± 3 |
| Historical Data[1] | 89 ± 8 |

Note: Data variability is calculated at 95% confidence.
[1]This value is the average of six test results reported in an internal ABB document dated March 1997.

While mineral oil was not tested as part of this study, literature data were available on biodegradability using the same CEC method, a U.S. EPA method, and an Organization of Economic Cooperation and Development (OECD) method. The Universite de Liege study reported the biodegradability of mineral oil over 70% after 40 days using test method CEC-L-33-T-82 (Cloesen, C. & Kabuya, A., no date). This method has been replaced by method CEC-L-33-A-93.

Biodegradation rates for conventional mineral oil ranged from 42-49% after 28 days using U.S. EPA Method 560/6/-82-003, Aerobic Aquatic Biodegradability (USACE, 1997, 1999). Another study by CONCAWE reported a ready biodegradation rate for a light naphthenic distillate mineral oil of 28% after 28 days when analyzed by OECD 301B, Sturm Test (CONCAWE, 1997). Both methods estimated the degree of biodegradability by the amount of carbon dioxide ($CO_2$) produced and expressed this result as a percentage of the theoretical $CO_2$, which can be produced. These methods are not considered equivalent to CEC-L-A-33-93 but the data does indicate that mineral oil is not readily biodegraded.

Based on a comparison to the reported biodegradation rates for mineral oil, the BIOTEMP® fluid appears to biodegrade more readily. Although BIOTEMP® readily biodegrades per this test, 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 (U.S.EPA 1997).

## 4.4 Results: Objective 3, Flammability

The flash point and fire point for virgin and in-service BIOTEMP® fluid were determined using ASTM Method D92, Cleveland Open Cup test. The flash point was measured to assess the overall flammability of the fluid and determine the presence of volatile or flammable material at elevated temperatures. The fire point was measured to determine the temperature at which the fluid would support combustion. These values were compared to ABB's specifications for BIOTEMP®. They were also compared to ASTM D3487 for flash point and ASTM D5222 for fire point, which are designed for virgin mineral oil and HTH oil, respectively. Both ASTM D3487 and ASTM D5222 specify ASTM D92 (Cleveland Open Cup) to determine flash and/or fire point. Results are presented in Tables 7 and 8. The individual and average flash and fire point values for both the virgin and in-service fluid met the ABB and ASTM specifications. The deviation in the flash and fire point values for the virgin product were within the precision margin of ± 8°C at 95% confidence specified in ASTM Method D92. Since the in-service fluid samples were collected from different transformers and a duplicate was not collected, the results were not compared to the precision criteria. After being in operation for over one year, the flash and fire points for the in-service transformer fluids were well above the minimum ABB, ASTM Method D3487, and ASTM D5222 specifications.

**Table 7. Flash Points for Virgin and In-service BIOTEMP® Samples**

| Sample Numbers | Virgin Lot No./ Transformer SN | Specification criteria (°C) | | | Flash Point (°C) |
|---|---|---|---|---|---|
| | | BIOTEMP® | ASTM D3487 | ASTM D5222 | |
| **Virgin Product** | | | | | |
| **BIO-01** | **2000-216** | >300 | >145 | NA | 328 |
| **BIO-02** | | >300 | >145 | NA | 328 |
| **BIO-03** | | >300 | >145 | NA | 332 |
| **BIO-04** | | >300 | >145 | NA | 326 |
| **Average*** | | >300 | >145 | NA | 329 ± 4 |
| **BIO-05** | **2000-224** | >300 | >145 | NA | 328 |
| **BIO-06** | | >300 | >145 | NA | 328 |
| **BIO-07** | | >300 | >145 | NA | 332 |
| **BIO-08** | | >300 | >145 | NA | 334 |
| **Average*** | | >300 | >145 | NA | 331 ± 5 |
| **BIO-09** | **composite** | >300 | >145 | NA | 334 |
| **BIO-10** | | >300 | >145 | NA | 340 |
| **Average** | | >300 | >145 | NA | 337 |
| **Overall Average*** | **NA** | >300 | >145 | NA | 331 ± 3 |
| **In-service Transformer Fluid** | | | | | |
| **INS-01** | **NAB4424-005T** | >300 | >145 | NA | 330 |
| **INS-02** | **NAB4424-004T** | >300 | >145 | NA | 334 |
| **INS-03** | **NAB4424-003T** | >300 | >145 | NA | 334 |
| **INS-07** | **PAO7914-001** | >300 | >145 | NA | 328 |
| **Average** | **NA** | >300 | >300 | NA | 332 ± 5 |
| NA = Not Applicable | *Calculated at a 95% confidence interval | | | | |

## Table 8. Fire Points for Virgin and In-service BIOTEMP® Samples

| Sample Numbers | Virgin Lot No./ Transformer SN | Specification criteria (°C) | | | Fire Point (°C) |
|---|---|---|---|---|---|
| | | BIOTEMP® | ASTM D3487 | ASTM D5222 | |
| **Virgin Product** | | | | | |
| **BIO-01** | **2000-216** | >300 | NA | 304-310 | 362 |
| **BIO-02** | | >300 | NA | 304-310 | 360 |
| **BIO-03** | | >300 | NA | 304-310 | 362 |
| **BIO-04** | | >300 | NA | 304-310 | 358 |
| **Average*** | | >300 | NA | 304-310 | 361 ± 3 |
| **BIO-05** | **2000-224** | >300 | NA | 304-310 | 360 |
| **BIO-06** | | >300 | NA | 304-310 | 360 |
| **BIO-07** | | >300 | NA | 304-310 | 362 |
| **BIO-08** | | >300 | NA | 304-310 | 358 |
| **Average*** | | >300 | NA | 304-310 | 360 ± 3 |
| **BIO-09** | **composite** | >300 | NA | 304-310 | 360 |
| **BIO-10** | | >300 | NA | 304-310 | 360 |
| **Average** | | >300 | NA | 304-310 | 360 |
| **Overall Average*** | **NA** | >300 | NA | 304-310 | 360 ± 1 |
| **In-service Transformer Fluid** | | | | | |
| **INS-01** | **NAB4424-005T** | >300 | NA | 304-310 | 362 |
| **INS-02** | **NAB4424-004T** | >300 | NA | 304-310 | 364 |
| **INS-03** | **NAB4424-003T** | >300 | NA | 304-310 | 362 |
| **INS-07** | **PAO7914-001** | >300 | NA | 304-310 | 362 |
| **Average*** | **NA** | >300 | NA | 304-310 | 363 ± 2 |
| NA = Not Applicable | *Calculated at a 95% confidence interval | | | | |

The fire point results agreed with those obtained by Underwriters Laboratory (UL) and the Factory Mutual Research Center (FMRC). UL and FMRC evaluated this product using ASTM Method D92 (Cleveland Open Cup) and reported fire points of 354°C and 360°C, respectively. UL determined the flash point of 243°C using ASTM Method D93 (Pensky-Martens closed-cup) while FMRC determined a flash point of 330°C using ASTM Method D92. The lower flash point reported by UL was due to their use of a different test method.

BIOTEMP® is one of five products that UL has classified as a dielectric medium with a fire hazard rating of 4 to 5, and is less of a fire hazard than paraffin oil (UL, 2001). The UL fire rating system uses the flash point determined by Pensky-Martens closed-cup to rate the material's flammability. The material's flammability is rated and classified using the following scale arranged from flammable to nonflammable: ether rated at 100, gasoline from 90 to 100, ethyl alcohol from 60 to 70, kerosene from 30 to 40, paraffin oil from 10 to 20, and water at 0.

FMRC classified this product as a less flammable transformer fluid. FMRC also identified BIOTEMP® as an alternative to high fire point hydrocarbons, silicone fluids, and synthetic esters or hydrocarbons where fire resistance, improved high temperature operation, and improved cooling are desired (FMRC, 1999).

## 4.5 Results: Objective 4, Acute Toxicity

Three virgin BIOTEMP® samples, one from each lot, were analyzed by U.S. EPA method, *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms*, EPA/600/4-90/027F, August 1993. Tests were performed by Associated Laboratories, a California certified laboratory, which performed the work under contract with DTSC. Based on the fish bioassay results provided by the client per this method, the screening test was not conducted and instead three test chambers were prepared containing 750 mg/l, 500 mg/l, and 250 mg/l of BIOTEMP®. Duplicate testing was performed in parallel with the test samples. The tests used juvenile pimephales promelas (fathead minnow) instead of juvenile oncorhynchus mykiss (rainbow trout) as stated in the test plan. Samples were prepared in accordance with the "Static Acute Bioassay Procedures for Hazardous Waste Samples" developed by the California Department of Fish and Game, Water Pollution Control Laboratory and specified in the Code of California Regulations, Title 22, Section 66261.24(a)(6). This procedure requires shaking the sample for six hours using a wrist-action or similar type of shaker to dissolve the oil in 200 ml of water before the sample is added to the aquatic bioassay fish tank. Dissolved oxygen (DO) content, pH, and temperature were monitored and maintained at 6.0-7.0 mg/l, 7.0-7.5, and 20°C, respectively as required by the method.

Earlier tests performed by Parametrix, an independent laboratory under contract with ABB, were conducted per U.S. EPA method, *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms*, EPA/600/4-90/027F, August 1993. The test species used was juvenile rainbow trout. DO content, pH, and temperature were monitored and maintained at 9.0-11.0 mg/l, 7.5 - 8.0, and 12°C, respectively as required by the method.

Results are presented in Table 9 and compared to the hazardous waste toxicity characteristic criterion listed in the Code of California Regulations, Title 22, Section 66261.24(a)(6). A waste is considered to exhibit a toxic characteristic if the $LC_{50}$ is less than 500 milligrams per liter when measured in soft water (total hardness 40 to 48 milligrams per liter of calcium carbonate).

**Table 9. Fish Bioassay Results for Virgin BIOTEMP® Samples**

| Sample Numbers | California Toxicity Criteria[1] (mg/l) | Sample Results (mg/l) |
|---|---|---|
| **BIO-01** | <500 | <250 |
| **BIO-07** | <500 | <250 |
| **BIO-10** | <500 | <250 |
| **Average** | <500 | <250 |
| **Historic Data[2]** | <500 | 776 |

[1]The virgin oil is considered to exhibit a toxic characteristic if the $LC_{50}$ is less than 500 mg/l when measured in soft water.
[2]The result is for a single sample collected by ABB in November 1998. The 95% confidence interval was 668 mg/L to 901mg/L.

A DTSC toxicologist reviewed the reports prepared by Associated Laboratories and Parametrix to identify the differences, which could lead to such conflicting results. As part of the review, the toxicologist also reviewed the test methods, and material safety data sheets for BIOTEMP® and its additives. The tank water was not analyzed for breakdown products associated with degraded vegetable oil. The main difference between the two sets of tests was the sample preparation method used. Associated Laboratories used a wrist-action shaker per the method specified. Parametrix prepared their samples using a carrier solvent, which is listed in U.S. EPA method, *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms*, to make the oil miscible in water. Oil samples prepared using the wrist action method are thought to stratify, with the oil at the top of the tank. Fish swimming through this upper layer of the tank will become coated with the product and gill exchange will be impaired. Oil samples prepared using the wrist shaker method are thought to provide more realistic results for conditions, which may occur during an environmental release. Samples prepared using the carrier solvent provided results that reflect systemic (chemical) impacts on fish.

In California, insoluble, viscous waste samples are prepared using the wrist-shaker method and ultrasonic method, and sometimes the solvent carrier method as part of the fish bioassay screening tests for hazardous waste characterization. The preparation method yielding the most conservative $LC_{50}$ result is then used to perform the definitive tests. This methodology is required by DTSC Waste Evaluation Unit and overseen by the Department of Health Services Environmental Laboratory Accreditation Program's Aquatic Toxicity Bioassay Section who certifies laboratories performing aquatic toxicity tests for DTSC. ABB disagrees with DTSC's methodology (see vendor's comment section for ABB's opinion). The reader should note that this methodology is used to characterize the hazardous characteristics for **waste**. Any statement concerning the hazardous characteristic of the BIOTEMP® fluid applies to the **spent (waste)** fluid only and is not intended to classify the virgin product.

The lower $LC_{50}$ results and physical effects described above are similar to those presented by the U.S. EPA in their responses to comments on the rule for Oil Pollution Prevention at Non-Transportation Related Onshore Facilities (40 CFR Part 112). The physical effects observed in the toxicity tests performed by Associated Laboratories have been observed in vegetable oils, and oils in general, and were therefore expected. These results, which are based on virgin product and a relatively small number of samples, suggest that spent BIOTEMP® may be classified as hazardous waste and need to be managed accordingly. The end-user should characterize the spent BIOTEMP® at the time of disposal since changes may occur to the oil due to use. The end-user should also consult their appropriate regulatory authority on the appropriate waste characterization and disposal method for their state.

## 4.6 Results: Other Verification/Certification Objectives

Chemical Composition

The chemical composition of the virgin and in-service fluids was analyzed for semivolatile organics (SVOCs) and metals to verify chemical composition. In addition, the samples were analyzed by various Association of Analytical Chemist (AOAC) methods to create a chemical "fingerprint" Krueger Food Laboratories analyzed samples per the AOAC methods while the Hazardous Materials Laboratory (HML) analyzed the SVOC and metals samples. Appendix B contains a list of the AOAC methods used.

According to ABB, BIOTEMP® is composed >98.5% vegetable oil and <1.5% additives (e.g., antioxidants and color). The vegetable oil is comprised of at least 75% oleic acid, less than 10% diunsaturated fatty acids, less than 3% triunsaturated fatty acids, and less than 8% saturated fatty acids. According to the manufacturer, the antioxidants may consist of combination of antioxidants, which include butylated hydroxyl anisole (BHA), mono-tertiary butyl hydroquinone (TBHQ), 3,5-di-tert-butyl-4-hydroxytoluene (BHT or DBPC), or Vitamin E.

Tables 10 and 11 present the sample results for virgin and in-service BIOTEMP® fluid. Analytes detected at percentages greater than 5% in virgin sample results meet the repeatability criteria listed in AOAC Method 963.22 with a relative percent difference between results of < 3% and an absolute percent difference of < 1%. Results for the in-service samples were not compared to the precision criteria. The in-service samples were collected from different transformers and a duplicate sample was not collected to minimize impacts on the transformer and the on-going sampling program.

**Table 10. AOAC Results for Virgin BIOTEMP® Samples**

| Analyte | | Sample Number | | | | |
|---|---|---|---|---|---|---|
| | | BIO-01 | BIO-03 | BIO-07 | BIO-10 | Average |
| *Total Fatty Acids* | | | | | | |
| Hexadecanoic (Palmitic) | 16:0 | 3.67% | 3.64% | 3.63% | 3.69% | 3.66% ± 0.04% |
| Octadecanoic (Stearic) | 18:0 | 3.54% | 3.40% | 3.38% | 3.50% | 3.46% ± 0.12% |
| Octadecenoic (Oleic) | 18:1 | 79.92% | 80.17% | 80.23% | 79.91% | 80.06% ± 0.26% |
| Octadecadienoic (Linoleic) | 18:2 | 10.52% | 10.41% | 10.41% | 10.47% | 10.45% ± 0.08% |
| Octadecatrienoic (Linolenic) | 18:3 | 0.27% | 0.26% | 0.24% | 0.26% | 0.26% ± 0.02% |
| Eicosanoic (Arachidic) | 20:0 | 0.30% | 0.30% | 0.29% | 0.30% | 0.30% ± 0.01% |
| Docosanoic (Behenic) | 22:0 | 1.46% | 1.51% | 1.50% | 1.56% | 1.51% ± 0.07% |
| Tetracosanoic (Lignoceric) | 24:0 | 0.31% | 0.30% | 0.31% | 0.30% | 0.31% ± 0.01% |
| *Phenolic Antioxidants (mg/kg)* | | 3,139 | 3,187 | 3,206 | 3,294 | 3,207 ± 103 |
| *Polymers and Oxidation Products (g/100g)* | | 2.80 | 2.29 | 1.81 | 2.00 | 2.23 ± 0.69 |
| Note: Data variability calculated at 95% confidence using a two-tailed T-test assuming normal distribution. | | | | | | |

Results are presented for the individual fatty acids along with their number of carbons and the number of double bonds (i.e., 18:1 represents 18 carbons and one double carbon bond). The percentage of monounsaturated, diunsaturated, and triunsaturated fatty acids are determined by adding the fatty acids with one, two or three double carbon bonds together, respectively. For example, the percentage of diunsaturated fatty acids would consist of fatty acids with two double carbon bonds or octadecadienoic acid (18:2). The percentage of saturated fatty acids is determined by summing the results for fatty acids with no double carbon bonds such as hexadecanoic (16:0), octadecanoic (18:0), eicosanoic (20:0), docosanoic (22:0), and tetracosanoic (24:0). The virgin BIOTEMP® samples had oleic acid ranging from 80.1% ± 0.3%, diunsaturated fatty acids ranging from 10.5% ± 0.1%, triunsaturated fatty acids ranging from 0.2% ± 0.0%, and saturated fatty acids ranging from 9.2% ± 0.2%, which agree closely with the formulation listed above. The in-service BIOTEMP® samples had oleic acid ranging from 79.5% to 84.4%, diunsaturated fatty acids ranging from 5.3% to 10.7%, triunsaturated fatty acids ranging from 0.2% to 0.3%, and saturated fatty acids ranging from 9.5% to 10.0%. The in-service samples are similar to the formulation above except that three samples had a low diunsaturated content compared with the virgin BIOTEMP® samples. This may be due to variations in formulation associated with the basestock oil.

**Table 11. AOAC Results for In-service BIOTEMP® Samples**

| **Analyte** | | **Sample Number** | | | |
|---|---|---|---|---|---|
| | | **INS-01** | **INS-02** | **INS-03** | **INS-07** |
| *Total Fatty Acids* | | | | | |
| Hexadecanoic (Palmitic) | 16:0 | 3.85% | 3.84% | 3.83% | 3.97% |
| Octadecanoic (Stearic) | 18:0 | 3.79% | 3.85% | 3.77% | 3.38% |
| Octadecenoic (Oleic) | 18:1 | 84.41% | 84.39% | 84.41% | 79.55% |
| Octadecadienoic (Linoleic) | 18:2 | 5.38% | 5.41% | 5.40% | 10.68% |
| Octadecatrienoic (Linolenic) | 18:3 | 0.22% | 0.25% | 0.21% | 0.27% |
| Eicosanoic (Arachidic) | 20:0 | 0.42% | 0.46% | 0.46% | 0.31% |
| Docosanoic (Behenic) | 22:0 | 1.62% | 1.46% | 1.54% | 1.53% |
| Tetracosanoic (Lignoceric) | 24:0 | 0.30% | 0.33% | 0.39% | 0.31% |
| *Phenolic Antioxidants (mg/kg)* | | 3,586 | 3,022 | 3,196 | 2,993 |
| *Polymers and Oxidation Products (g/100g)* | | 1.78 | 1.84 | 1.39 | 2.40 |

AOAC Method 983.15, *Phenolic Antioxidants in Oils, Fats, and Butter Oil*, was used to determine the concentrations of 7 commonly used antioxidants in food grade oils and fats. The results for the virgin and in-service transformer samples are presented in Tables 10 and 11. Phenolic antioxidants were detected in the virgin product between 3,207 mg/kg ± 103 mg/kg. The in-service transformer samples had antioxidant concentrations between 2,990 and 3,600 mg/kg.

The polymers and oxidation products listed in Tables 10 and 11 above are simple indicators used in the food industry to assess the quality of vegetable oil after exposure to heat. If lower values are reported for an oil as it is reheated, the difference is assumed to show an increase in non-elution material (compounds not dissolved using a solvent) that indicates the polar compounds in the oil such as unsaturated fatty acids are degrading. This method does not list a precision criteria for the data. Compared to the average virgin product value of 2.2% ± 0.7%, the in-service fluid samples appear to have degraded slightly due to use.

Virgin and in-service samples were screened for 65 standard SVOC compounds using U.S. EPA Method 8270/3580. Virgin samples and one in-service sample (INS-07) were extracted outside the 7 day extraction period, which deviated from the holding time requirements listed in the test evaluation plan. HML noted the recovery of pyrene in the matrix spikes could not be reliably calculated due to matrix interference, and the recovery of two surrogate compounds (2,4,6-tribromophenol and terphenyl-d14) may have also been affected due to difficulty in separating the oil samples using U.S. EPA Method 8270. Due to this difficulty and extraction times exceeding those listed in the test plan, the reported SVOC results should be regarded as approximations and not be used in lieu of actual waste characterization data.

For the 65 standard SVOC compounds analyzed by the HML lab, only n-nitrodiphenylamine was detected around the detection limit of 20 mg/L for the virgin and in-service transformer samples. This may be a component of one of the antioxidants used in the fluid. For the in-service fluid, bis-(2-ethylhexyl)phthalate was also detected. This compound, a widely used plasticizer, was also detected in the equipment and field blanks collected. 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. Due to the deviations discussed above, the SVOC data should be considered a qualitative measurement but does not change the assessment that BIOTEMP® consists primarily of vegetable oil with a small percentage of antioxidants.

Virgin and in-service samples were analyzed by U.S. EPA Method 6010/5030. Other than the sample preparation method used, the laboratory noted no other deviations to the final test evaluation plan. Metals were not detected in the in-service transformer samples except for INS-2, which had a zinc concentration of 2.3 mg/kg. For the virgin samples, copper was detected at 4.13 mg/kg in sample BIO-01. Barium was detected at 0.31 mg/kg in samples BIO-05, 0.32 mg/kg in BIO-07, and 0.32 mg/kg in BIO-10. Zinc was detected at 2.02 mg/kg in sample BIO-10. The detection limit was 2.50 mg/kg for copper, 0.25 mg/kg for barium, and 2.00 mg/kg for zinc. No metals were detected in the equipment blank.

Worker Health and Safety Aspects

This section presents some of the potential hazards associated with BIOTEMP® and compares them to those for select mineral oil-based and silicone oil-based transformer fluids. This is not considered a comprehensive review where all potential hazards associated with BIOTEMP® have been identified. End-users should review all applicable worker health and safety regulations for this product.

BIOTEMP® is a dielectric insulating fluid used to cool the core and coils within a transformer. The fluid is held in a tank inside the transformer where the tank headspace is filled with nitrogen to prevent the oil from oxidizing with the ambient air. A pressure relief valve installed on the tank releases gases in the headspace to the ambient air. Transformers that use mineral oil or other types of insulating fluid are also equipped with pressure relief valves. BIOTEMP® is designed for use in transformers where higher fire protection is required such as in or adjacent to buildings, or in underground vaults.

The BIOTEMP® material safety data sheets (MSDS) lists the components as >98.5% vegetable oil and <1.5% additives (e.g., antioxidants and color). The antioxidants used in this product are not listed as hazardous materials (see Section 5.1 for reference). Two of the antioxidants have been cleared by the Food and Drug Administration (FDA) for use as an indirect food additive in food packaging (Ciba-Geigy, 1996) while the third antioxidant is identified as a food grade antioxidant (Eastman, 1996). Although the BIOTEMP® components may be food grade, this product should not be used as a food product.

According to the BIOTEMP® MSDS, this product is also not considered a hazardous substance as defined under Title 8, California Code of Regulations, Section 5194, Hazard Communications. However, this does not relieve the end-user who uses this product from providing workers with information and training necessary to handle BIOTEMP® safely. Workers should review the MSDS and be familiar with the information concerning first aid procedures, physical properties, personal protective equipment (PPE), respiratory protection, and slip hazards. Workers should wash skin that has contacted the product with soap and water. For eye contact, the eyes should be flushed with water. The primary physical property workers should be aware of is the product's flash point of greater than 300°C. In the case of a BIOTEMP® spills, employees should be aware of the increased slip hazard in the affected area due to the product.

Before working with BIOTEMP®, employees should ensure the work area has adequate ventilation, and the appropriate respiratory protection and protective clothing are selected. When working with hot BIOTEMP®, workers should don neoprene gloves, rubber boots and aprons. Respiratory protection should only be worn if oil mists or dusts contaminated with oil are detected at concentrations equal to or exceeding the permissible exposure limit (PEL). The Occupational Safety and Health Administration (OSHA) has set the permissible exposure limit (PEL) for vegetable oil mist as a nuisance particulate at 15 mg/m$^3$ and 5 mg/m$^3$ for respiratory protection for an 8-hour time-weighted average (TWA) exposure. In California, the nuisance particulate PEL is 10 mg/m$^3$. The end-user should consult the appropriate regulatory authority about applicable nuisance particulate PELs used in their area.

If the transformer is located in a poorly ventilated area, then workers should use appropriate engineering controls to ventilate the area. Based on the MSDS information on BIOTEMP®'s antioxidants, BIOTEMP® may produce carbon monoxide, carbon dioxide, nitrogen oxides, and other toxic compounds when the antioxidants thermally decompose. Mineral oil-based and silicone oil-based transformer fluids may also thermally decompose and produce fumes, smoke, carbon monoxide, aldehydes and other products. For some mineral oil-based transformer fluids, sulfur oxides are also listed as a possible decomposition product while silicon dioxide is listed for some silicone oil-based fluids. No data are available on the composition of emissions from transformers in general.

When comparing the PPE requirements for handling BIOTEMP® to select mineral oil-based transformer fluids, the requirements were found to be similar. This comparison is based on MSDS information for select mineral-oil-based transformer fluids obtained from the Vermont Safety Information Resources, Inc. (SIRI) MSDS archive. However, respiratory protection for the mineral oil-based transformer fluids is required when the mineral oil mist concentration equals or exceeds the OSHA PEL set at 5 mg/m$^3$ for an 8-hour TWA exposure. For select silicone oil-based transformer fluids found in the Vermont SIRI MSDS archive, workers are advised to don impervious gloves and chemical goggles when handling the fluid.

Occupational exposure to transformer fluid is limited and associated to infrequent activities such as filling, draining, or sampling of transformers. These activities are not likely to generate a mist or aerosol at concentrations approaching the PEL. Potential hazards associated with filling or draining the transformer include slipping on work surfaces where the product was spilled, or splashing of the material into the eyes or onto the skin. Potential hazards associated with sampling the transformer include coming in contact with extremely hot oil, potential electrical arcing from the transformer, or slipping hazards due to spilled BIOTEMP® on the floor.

MSDS information for three silicone transformer fluids identified as less-flammable transformer oils by UL and FMRC were reviewed along with several mineral oil-based transformer fluids listed in the Vermont SIRI MSDS Archive. Health and safety information on the components listed on the MSDSs was compared to information listed in Sax's Dangerous Properties of Industrial Materials. The primary component of the mineral oil-based transformer fluid was a hydrotreated light naphthenic petroleum distillate (CAS No 64742-53-6) ranging from 30-100% which was identified as an International Agency for Research on Cancer (IARC) confirmed carcinogen based on experimental data for animals (Lewis, 2000). The primary ingredient of the silicone oil-based transformer fluids was dimethyl polysiloxane (CAS No. 63148-62-9) listed at 100% and identified as a combustible liquid, a teratogen, and the cause of reproductive effects based on experimental data on animals (Lewis, 2000).

Estimated Cost of Using BIOTEMP® versus Mineral Oil

An average transformer life of 20 years was used to compare the costs of BIOTEMP® versus mineral oil based on historical life testing results performed by ABB per ANSI/IEEE C57.100-1986, the accelerated life test. The ANSI/IEEE accelerated life tests performed on transformers using BIOTEMP® passed with an operational equivalence of 100 years, which is five times the normal transformer. If the initial purchase cost of a new transformer unit containing BIOTEMP® is compared to a mineral oil transformer, the BIOTEMP® transformer unit costs approximately 1.25-1.30 times more. The price of the BIOTEMP® fluid ranges from \$7 to \$11 per gallon depending on the volume purchased and is based on estimates provided by ABB. The fluid is available in 5 gallon containers, 55 gallon drums, 200 gallon totes, 6,000 gallon tanker trucks, or by the rail car. Prices for mineral oil typically range from \$2 to \$3 per gallon (Cooper, 2001). Monitoring costs will vary depending on the maintenance program the purchaser has in place. The waste characterization cost for a transformer using BIOTEMP® or mineral oil are anticipated to be approximately the same except for mineral oil suspected to contain PCBs where the costs will be higher. The disposal cost for mineral oil and BIOTEMP® are assumed to comparable since data are not available on the waste characteristics of BIOTEMP® after 20 years of use.

For a retrofilled transformer, no additional costs due to modifications of the transformer unit are incurred for using BIOTEMP®. The costs associated with draining and disposing of the used oil are expected to be the same for both mineral oil and BIOTEMP®. Costs associated with flushing and filling a retrofilled transformer with BIOTEMP® versus mineral oil are also anticipated to be higher since BIOTEMP® costs between $4 to $9 per gallon more than mineral oil depending on the volume purchased.

## Section 5. Regulatory Considerations

A review of Federal and California regulations was conducted to identify applicable regulations for virgin and spent (used) BIOTEMP®. The regulations listed below are based on the limited data available on this product. This review is not considered to be a comprehensive review of existing regulations. The reader should consult their local environmental regulatory agency concerning other applicable local and State regulations and the status of the regulations cited below. The regulations cited below may have been updated or superceded since this review was conducted.

Virgin (or unused) BIOTEMP® fluid is a vegetable oil-based dielectric fluid consisting of >98.5% food-grade vegetable oil and < 1.5% additives such as antioxidants and color. The product has a flash point of 243°C by ASTM Method D93 and an average fire point of 331°C by ASTM Method D92. The product has a neutral pH (pH = 7.0) and is not reactive with other chemicals at room temperature but is incompatible with strong oxidizers. The virgin BIOTEMP® fluid has a reported aquatic $LC_{50}$ value of less than 250 mg/L based on test results reported in **Section 4.5** of this report and 776 mg/L based on historical results provided by ABB. The difference between the results was thought to be due to the sample preparation method used. The lower $LC_{50}$ value was thought to reflect the physical impacts and the higher $LC_{50}$ the systemic (chemical) impacts of an oil spill to fish.

### 5.1 Regulation of Virgin BIOTEMP® Dielectric Fluid

Information on new product and materials introduced for commercial use are submitted to the U.S. EPA for review under the Toxic Substances Control Act unless the new product is a mixture of listed materials. The components of BIOTEMP® are listed under the Toxic Substances Control Act (TSCA) as Chemicals in Commerce. None of the components are listed as an imminently hazardous chemical substance or mixture which the EPA Administrator has "taken action under" Section 7. BIOTEMP® and its components are not listed as hazardous substances under Section 3001 of Resource Conservation and Recovery Act (RCRA), and Section 112 of the Clean Air Act (CAA). The product is included under Section 311 of the Clean Water Act, which addresses oil and hazardous substance releases to water. The product is shipped as a non-hazardous material per Department of Transportation regulations.

The components of BIOTEMP® are not listed in the Consolidated List of Chemicals Subject to Emergency Planning and Community Right-To-Know Act (EPCRA) and Section 112(r) of the CAA and therefore, are not reportable under Section 313. However, a material safety data sheet (MSDS) is required as part of the EPCRA under Section 311. California facilities should consult Health and Safety Code (HSC) Chapter 6.8 and determine if business plans need to be modified in the areas of emergency preparedness and response, and water quality if BIOTEMP® is used at their facilities.

## 5.2 Waste Characterization/Disposal Requirements

### 5.2.1 Waste Characterization and Disposal of Virgin BIOTEMP®

Under the RCRA definition of a hazardous waste, a waste is considered hazardous if it is a listed waste under Section 261.2 or exhibits a hazardous characteristic as defined in 40CFR261.20 through 40CFR261.24. A hazardous characteristic is defined as either having a flash point less than 60°C (ignitability), has a pH < 2.5 or pH > 12.5 (corrosivity), is reactive, or contains a contaminant equal to or greater than the regulatory value listed in 40CFR 261.24 (toxicity) per the Toxicity Characteristic Leaching Procedure (TCLP). The virgin BIOTEMP® is not a listed RCRA waste nor does it meet the definition of a hazardous waste per 40CFR261.20. Virgin BIOTEMP® fluid which is off-specification or has exceeded its shelf life is not listed as a hazardous waste per 40CFR 261.33 and may be returned to the manufacturer or disposed of as a non-hazardous material.

In California, a waste is considered hazardous if it is a RCRA listed waste or exhibits a hazardous characteristic per California Code of Regulations (CCR), Title 22, Division 4.5, Chapter 11, Article 3, Section 66261.20 (22CCR66261.20). The ignitability, corrosivity, and reactivity criteria listed under 22CCR66261.20 are the same as those listed for 40CFR261.20 above. The toxicity characteristic defined under 22CCR261.24 lists several criteria which are as follows: (1) the waste meets the criteria per 40CFR261.24, (2) the waste contains a substance listed in 22CCR66261.24 as determined by the Waste Extraction Test (WET), (3) the waste has an acute oral lethal dose ($LD_{50}$) of less than 5,000 mg/kg, (4) the waste has an acute dermal $LD_{50}$ of 4,300 mg/kg, (5) the waste has an acute inhalation lethal concentration ($LC_{50}$) of less than 10,000 ppm as a gas or vapor, (6) the waste has a acute aquatic 96-hour $LC_{50}$ of less than 500 mg/L, or the waste contains any of the substances listed in 22CCR66261.24(a)(7). Since $LC_{50}$ results reported under **Section 4.5** of this report indicate that spent BIOTEMP® may exhibit a hazardous characteristic, off-specification material may be subject to hazardous waste management regulation. Off-specification material may be considered a retrograde material if it meets the criteria per HSC 25121.5 and may be returned to the manufacturer without a manifest.

### 5.2.2 Waste Characterization of Spent BIOTEMP®

Spent BIOTEMP® fluid should be characterized by the end-user per 40CFR261.20 or per the applicable State regulation prior to disposal. To date, the longest continuous use of BIOTEMP® in a transformer has been approximately 2.5 years. The average service life of a transformer is approximately 20 years. Since changes to the oil may occur due to use, the spent BIOTEMP® must be characterized by the end-user prior to disposal. As part of the waste characterization for transformers that exclusively used BIOTEMP®, the end-user should determine the metals concentration per EPA Method 1311 and the TCLP. For retrofilled transformers, the spent BIOTEMP® must also be tested for PCBs per EPA Method 8082 if the transformer was known or suspected to have contained PCBs prior to using BIOTEMP®. If the spent BIOTEMP® fluid is characterized as hazardous per 40CFR261.20, then the fluid must be managed as a hazardous waste.
For spent BIOTEMP® generated in California, the Waste Extraction Test (WET) should also be performed as defined in 22CCR66261.24 (a)(1) and 66261.24 (a)(2), respectively, in addition to

EPA Method 1311. The spent oil should also be characterized for acute aquatic toxicity per 22CFR66261.24(a)(6) in addition to the TCLP. If the spent BIOTEMP® fluid is characterized as hazardous per 40CFR261.20, then the fluid must be managed as a hazardous waste. If the spent BIOTEMP® fluid is characterized as hazardous per 22CCR66261.20 but not by 40CFR261.20, then the fluid must be managed as a used oil per 22CCR66279.1.

Characterization results for BIOTEMP® for a specific transformer model may be used for others if the transformer has only used BIOTEMP® and has not been retrofilled with a different dielectric fluid during its service life. Depending on the results of the waste characterization, the spent BIOTEMP® fluid may be sent to a waste oil recycler or fat renderer for end-users located outside California. End-users outside of California should consult their appropriate regulatory authority about certified waste oil recyclers or fat renderers in their area and the recyclers' acceptance criteria for used vegetable oil. In California, the spent BIOTEMP® may only be sent to a licensed waste oil recycler if the waste characterization results show the fluid to exhibit a hazardous characteristic per 22CCR66261.20 and not by 40CFR261.20.

### 5.2.3 Disposal of Spent BIOTEMP®

Under the federal Used Oil Management Program, spent BIOTEMP® is not included under the definition of used oil. The U.S. EPA defines used oil as being "refined from crude oil or any synthetic oil, that has been used and as a result of such use is contaminated by physical or chemical impurities" (40CFR279.1). The U.S. EPA has stated that animal and vegetable oils are excluded from the federal used oil definition even when used as a lubricant (U.S. EPA, 1996). However, spent BIOTEMP® may be subject to hazardous waste management under RCRA if the spent oil meets the federal hazardous waste characteristics listed in 40CFR261.20 or contains a listed RCRA hazardous waste. End-users outside California should contact their appropriate regulatory authority about applicable used oil management regulations for their area.

In California, spent BIOTEMP® may be included in the Used Oil Program under the definition of a synthetic oil per 22CCR66279.1(d). As part of the synthetic oil definition, "vegetable or animal oil used as a lubricant, hydraulic fluid, heat transfer fluid or for other similar industrial purposes shall be managed as used oil if it is identified as a non-RCRA hazardous waste. Used vegetable or animal oil identified as RCRA hazardous waste is not used oil"(22CCR66279.1(d)) and must be managed as a hazardous waste. A non-RCRA hazardous waste is one that does not contain a RCRA listed waste, does not exhibit a federal hazardous waste characteristic per 40CFR261.20 through 40CFR261.24 but does exhibit a hazardous waste characteristic per 22CCR66261.20. If the spent BIOTEMP® meets the synthetic oil definition but contains more than 5 ppm of PCBs or has a total halogen content of greater than 1,000 ppm, then it cannot be included in the Used Oil Program and must be managed as a hazardous waste.

Used oil (e.g., mineral oils, synthetic oils) managed under the California program must be managed as a hazardous waste unless it is shown to meet one of the specifications for recycled oil in Health and Safety Code (HSC) Section 25250.1(b) or qualifies for a recycling exclusion under HSC 25143.2. Used oil generators are required to meet all used oil generator requirements except householders who perform their own oil changes. DTSC issues an EPA Identification Number for each site where used oil is stored except for generators of 100 kilograms or less of hazardous waste per month (including used oil) who ship used oil under a modified manifest. Above-ground storage tanks and containers accumulating used oil, and fill pipes used to transfer used oil to underground storage tanks must be labeled with the words "USED OIL _ HAZARDOUS WASTE" and the initial date of accumulation. Used oil must be sent to an authorized used oil storage or treatment facility by a registered hazardous waste transporter.

However, spent BIOTEMP® fluid may be exempt from the California used oil regulations if the oil is removed from a transformer, filtered, and then reused on-site in electrical equipment as a dielectric fluid (HSC 25250.4(b)). This exemption does not apply to transformer fluid that has been removed, filtered, and then sent off-site for reuse. Facilities should contact their local environmental agency on applicable recycling regulations.

### 5.2.4 Disposal of Waste the Clean-up of Virgin and Spent BIOTEMP® Spills

In the event of a spill, responders should consult the MSDS and their spill prevention, control, and countermeasures (SPCC) plan or facility response plan (FRP), if applicable, for the appropriate clean-up measures. Facilities should consult with their local environmental regulatory agency on clean-up levels and disposal options for waste generated from these spills. Since virgin BIOTEMP® may exhibit a hazardous characteristic per California's hazardous waste definition, the waste generated from spill clean-ups in California should be presumed hazardous until the waste has been characterized.

## 5.3 Spill Management

The spill management regulations listed in this section apply to both virgin and spent BIOTEMP®. Facilities should contact their appropriate regulatory authority on other local or State regulations pertaining to oil spill management.

Oil Discharge

Under 40CFR 110, Discharge of Oil Regulation, facility owners and operators that handle, store, or transport oils are required to report an oil discharge which "may be harmful to the public health or welfare, or the environment". A reportable spill is defined as one that either; (1) violates water quality standards, (2) causes a sheen or discoloration on the surface of a body of water, or (3) causes a sludge or emulsion to be deposited beneath the surface of the water or on adjoining shorelines. The term "oil" applies to petroleum based oil products and non-petroleum based oil products, which include animal fats, vegetable seed-based oils, and synthetic oils. Adding dispersants or emulsifiers to the oil prior to discharge is prohibited under Section 40CFR 110.4.

Oil discharged into or upon the navigable waters of the United States must be reported to the National Response Center, contained, and cleaned up. Depending on the discharge volume, extent and proximity to sensitive areas (e.g., wildlife areas), coordination and involvement of local emergency response agencies and the National Response Center may be required for the clean up effort. These reporting requirements apply to mineral oils and synthetic oils, as well as vegetable oils.

Oil Pollution Prevention

Under 40 CFR Part 112.1 through 112.7 of the Oil Pollution Prevention; Non-Transportation Related Onshore Facilities, facilities "that could be expected to discharge oil into or upon the navigable waters of the United States or adjoining shorelines, and that have (1) a total underground buried storage capacity of $\geq$ 42,000 gallons, (2) a total aboveground oil storage capacity of $\geq$ 1,320 gallons, or (3) an aboveground oil storage capacity in a single container of $\geq$ 660 gallons" are required to prepare and submit a SPCC plan. Some facilities may not be regulated if, due to their location, they could not reasonably be expected to discharge oil into navigable waters of the U.S. or adjoining shorelines.

Under the 40 CFR Part 112, facilities are required to prepare and submit a facility response plan (FRP) if they transfer $\geq$ 42,000 gallons of oil over water to a vessel or have a storage capacity $\geq$ 1,000,000 gallons and meet at least one of these four criteria; inadequate secondary containment, proximity to environmentally sensitive areas, proximity to public drinking water intakes, or occurrence of a 10,000 gallon or more oil spill in the last 5 years. The FRP includes response for worst-case discharges, estimates of planned resources, emergency response plans, and training drills/exercises. Under this regulation, the requirements for animal fats and vegetable oils are similar to those for petroleum oils, but involve new specific methodology for planning response actions for vegetable oils and animal fats.

The U.S. EPA's analysis of the impacts of the SPCC program indicated that a majority of electric utility substations and transformer installations would meet the aboveground storage capacity thresholds. Facilities such as schools and small business complexes are not anticipated to meet the SPCC or FRP program requirements. Typically, these facilities have several pad-mounted transformers with an average oil tank capacity of 40 gallons. For compliance, the facility owner is required to determine if oil storage capacity at a given site meets the criteria listed in the SPCC and FRP.

## Section 6. Conclusions

### 6.1 Objective 1, General Performance

The general performance specifications are useful for end users to determine whether the product will meet their specific needs. Verification testing confirmed that BIOTEMP® meets or exceeds the manufacturer's product specifications for dielectric breakdown (minimum, gap, and impulse), pour point, viscosity, water content, and oxidation stability at 72 hours. Two of the three lots tested met the manufacturer's specifications for dissipation factor (25°C and 100°C). BIOTEMP® did not meet the manufacturer's product specifications for oxidation stability at 164 hours or using the rotary bomb method. This may be due to possible inconsistencies in the addition and/or blending of antioxidants used in BIOTEMP®. When compared to the ASTM specifications, BIOTEMP® met some but not all of the specifications listed. It met ASTM D3487 and D5222 specifications for dielectric breakdown (minimum and gap). It met ASTM D3487 specifications for oxidation stability at 72 hours, while two of the three lots met the dissipation factor at 25°C. It did not meet the oxidation stability at 164 hours or by the rotating bomb method, nor did it meet the dissipation factor at 100°C for ASTM D3487 and D5222. BIOTEMP® also did not meet the pour point, water content, and viscosity standards per ASTM D3487 and D5222, but was not expected to meet these standards since the physical properties of mineral oils and HTH are different.

For in-service transformer fluid samples, the dissipation factor and water content values were below the maximum allowable value listed for in-service synthetic esters per IEC 1203. The conductivity values were all above the minimum performance value specified by ABB. The higher dissipation factor, water content, and conductivity values for INS-07 relative to the other transformers is likely due to the extreme operating conditions (e.g., overloads) the transformer was subjected to as part of ABB's ongoing research project.

### 6.2 Objective 2, Aquatic Biodegradability

The average biodegradability of BIOTEMP® was 99% ± 3% after 21 days as measured by CEC-L-33-T-82. Based on these results, 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 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 (U.S.EPA 1997).

### 6.3 Objective 3, Flammability

The flash and fire point for the virgin and in-service fluids were consistently above the minimum values listed in the ASTM D3487, D5222, and ABB performance specifications. The fire point results obtained also agreed with values reported by the FMRC and UL. The flash point results agreed with the values reported by FMRC.

## 6.4 Objective 4, Acute Toxicity

The average $LC_{50}$ for virgin BIOTEMP® was less than 250 mg/L, which indicates that spent BIOTEMP® may exhibit a hazardous characteristic per 22CCR 66261.24(a)(6) based on limited data for virgin product. The end-user should characterize their spent BIOTEMP® 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 regulatory authority about the applicable waste characterization definitions and available disposal options for their State.

## 6.5 Other Verification/Certification Objectives

Chemical Composition

Verification test results for the virgin BIOTEMP® samples showed the fluid consisted of oleic acid ranging from 80.1% ± 0.3%, diunsaturated fatty acids ranging from 10.5% ±0.1%, triunsaturated fatty acids ranging from 0.3% ± 0.0%, and saturated fatty acids ranging from 9.2% ± 0.2%. The in-service transformer fluid had oleic acid ranging from 79.5% to 84.4%, diunsaturated fatty acids ranging from 5.3% to 10.7%, triunsaturated fatty acids ranging from 0.2% to 0.3%, and saturated fatty acids ranging from 9.5% to 10.0%. These results are consistent with the formulation provided by ABB.

The virgin BIOTEMP® fluid contained phenolic antioxidants ranging from 3,207 mg/kg ± 103 mg/kg while the in-service transformer samples had concentrations between 2,990 mg/kg and 3,600 mg/kg. These concentrations were similar to the formulation provided by ABB.

For the 65 standard SVOC compounds analyzed by the HML lab, only n-nitrodiphenylamine was detected around the detection limit of 20 mg/L for the virgin and in-service transformer samples. 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 INS-2, which had a zinc concentration of 2.3 mg/kg. For the virgin samples, copper was detected at 4.13 mg/kg in sample BIO-01. Barium was detected at 0.31 mg/kg in samples BIO-05, 0.32 mg/kg in BIO-07, and 0.32 mg/kg in BIO-10. Zinc was detected at 2.02 mg/kg in sample BIO-10.

Worker Health and Safety

Based on the MSDS information, BIOTEMP® and mineral oil-based transformer fluids appear to have similar PPE requirements for material handling. When the PPE requirements for silicone oil-based transformer fluids are compared to BIOTEMP®, BIOTEMP® has less stringent PPE requirements. BIOTEMP® also has a slightly higher nuisance particulate OSHA PEL than mineral oil. The end-user must comply with all applicable worker health and safety regulations concerning this product.

The ingredients for BIOTEMP® appear to pose less of a health risk than those listed for the select mineral oil-based and silicone oil-based transformer fluids reviewed as part of this verification/certification. These select mineral oil-based transformer fluids listed a hydrotreated light naphthenic petroleum distillate, which is an IARC confirmed carcinogen, ranging from 30-100%. The silicone oil-based transformer fluids listed dimethyl polysiloxane as the primary ingredient at 100%, which is a teratogen in animals.

Estimated Cost of Using BIOTEMP® versus a Mineral Oil

The initial purchase cost of a new transformer unit containing BIOTEMP® costs approximately 1.25 to1.30 times more than a comparable mineral oil-based transformer. When comparing the price per gallon of BIOTEMP® to mineral oil, the difference may be between $4 to $9 more 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 similar to a comparable mineral oil-based transformer.

## Section 7. Vendor's Comment Section

*The following information was provided by ABB Inc. The purpose is to provide the vendor with the opportunity to share their comments regarding their environmental technology verification report. This information does not reflect agreement or approval by U.S. EPA and Cal/EPA.*

Vendor's Comment:

ABB is concerned that the aquatic toxicity of BIOTEMP® as determined by the California Environmental Protection Agency, Department of Toxic Substances Control, may be misrepresented by the method of evaluation chosen as the preferred one. ABB had previously determined the $LC_{50}$ for fathead minnows was 776 mg/L wherein the US EPA method, *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms*, was used. California EPA using a different method has determined that the $LC_{50}$ values were less than 250 mg/L. By California EPA definition, a waste is considered to exhibit a toxic characteristic if the $LC_{50}$ is less than 500 mg/L.

The US EPA method utilizes samples prepared with a carrier solvent to make the oil miscible in water. The California EPA used a system of sample preparation referred to as the wrist-action shaker method. The wrist-action shaker method can reasonably be expected to involve both a systemic effect (toxic to the minnows' system) as well as a physical effect (mixing the oil with the water in a fashion such that the gills and the skin of the minnows can be coated). The US EPA method used by ABB in their evaluation uses a carrier solvent which is chosen to be less toxic that the material being investigated. This causes a shift to a matrix that is more directly restrictive to the systemic effect on the minnow.

California EPA maintains that the wrist-action shaker method may be more applicable to real world spill incidents, but there is no real evidence to suggest that this is the case. The wrist-action shaker method can be more appropriate when materials such as powders or other difficult to dissolve substances are being tested. It is likely that any vegetable oil subjected to this method will suffer from enhanced toxicity by including the physical (mixing) as well as systemic (actual toxicity) effects together.

ABB does not wish to minimize either the hazards or the toxicity of their fluid. The physical hazards are well known and are stated in the Materials Safety Data Sheet. We are principally concerned that the aquatic toxicity is at best exaggerated by the wrist-action shaker method and that an enhanced level of alarm may be construed from this.

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