

# Transformer Insulation Options

## Advantages and Disadvantages

Type	Advantages	Disadvantages
I. Mineral Oil	<ul style="list-style-type: none"><li>• Low Transformer Cost</li><li>• Lower Viscosity at Low Temperatures</li><li>• Liquid Dielectric Performance</li><li>• Low Maintenance Cost</li><li>• Biodegradable/Low Toxicity Fluid</li><li>• Preventive Maintenance (DGA) per IEEE and IEC</li><li>• Load Break Operations</li><li>• Long Service Life Expectancy</li><li>• Typically Self-Healing Under Temporary Dielectric &amp; Thermal Overstress</li><li>• Easy to Reprocess/Dispose</li><li>• Pour Point &lt; -35°C</li><li>• A Century of Application History</li></ul>	<ul style="list-style-type: none"><li>• Requires Vault per NEC® Article 450-C (Indoor)</li><li>• Higher Installation Cost</li><li>• Relatively Low Fire Point</li><li>• Not Favored by Insurance Companies</li><li>• Containment with Absorption Bed may be Required</li><li>• Deluge Extinguishing System may be Required</li><li>• Longest Clearance Distances</li><li>• Excessive Min. Clearance Distance &amp; Fire Barriers may be Required (Outdoor)</li><li>• Extensive Soil Spill Cleanup Likely</li><li>• Not Classified as Edible Oil</li><li>• Non-Renewable Resource</li><li>• Growing Corrosive Sulfur Concerns</li></ul>

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<b>II. Less-Flammable Liquids</b>		
<b>A. Natural Ester (Envirotemp® FR3® Fluid)</b>	<ul style="list-style-type: none"> <li>• Flawless Safety Record Since Introduction (1997)</li> <li>• Time to Kraft Paper End-of-Life Improvement 5-8 Times</li> <li>• Excellent Dielectric Properties</li> <li>• Excellent Clarity</li> <li>• Rapidly and Completely Biodegrades</li> <li>• Field Experience to 242 kV, 200 MVA</li> <li>• Low Viscosity</li> <li>• Excellent Lubricity</li> <li>• Non-Toxic per Standard Test Methods</li> <li>• Good Compatibility</li> <li>• Not Listed as Hazardous Waste</li> <li>• Non-Sludging per Doble PFVO/ SFL</li> <li>• Low Maintenance Cost</li> <li>• Preventive Maintenance (DGA)</li> <li>• Food Grade Ingredients</li> <li>• Renewable Resource</li> <li>• Low UL Fire Hazard Value (4-5)</li> <li>• Easy to Reprocess/Dispose</li> <li>• US EPA Environmental Technology Verification</li> <li>• FM Approved</li> <li>• UL Classification: Fire Hazard Rating</li> <li>• UL Classification: Less-Flammable per NEC</li> <li>• Exclusive UL Classification for use with Internal Expulsion Fusing when used with CL Fusing in Series.</li> <li>• NEC &amp; NESC Safeguard Recognition</li> </ul>	<ul style="list-style-type: none"> <li>• Higher Cost than Mineral Oil</li> <li>• Liquid Containment Required Per NEC 450-23 (Indoor)</li> <li>• Pour Point -21°C</li> <li>• Appropriate only for Sealed or Positive Pressure Dry Nitrogen Equipped Tanks</li> </ul>

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Natural Ester (cont'd)	<ul style="list-style-type: none"> <li>Listed Transformer Option Available</li> <li>Long Service Life Expected</li> <li>Typically Self-Healing under Temporary Thermal and Dielectric Stress</li> <li>Complies with Edible Oil Act</li> <li>Fully Miscible with Mineral Oil, HMWH &amp; Most PCB Substitutes</li> <li>Eligible for Federal Biobased Purchase Program FB4P</li> <li>Provides Best Stability of Fluid-Immersed Stationary Contacts</li> <li>Maintains &gt; 300°C Fire Point up to 7% Mineral Oil Content.</li> </ul>	
B. Synthetic Ester (Envirotemp® 200 Fluid)	<ul style="list-style-type: none"> <li>Flawless Safety Record Since Introduction (1984)</li> <li>Excellent Dielectric Properties</li> <li>Essentially Non-Toxic</li> <li>Excellent Load Break Performance</li> <li>Rapidly Biodegrades</li> <li>Lowest Viscosity of Less-Flammable Fluids</li> <li>Best Lubricity</li> <li>Good Compatibility</li> <li>Not Listed Hazardous Waste</li> <li>Essentially Non-Sludging</li> <li>Low Maintenance Cost</li> <li>Preventive Maintenance (DGA)</li> <li>Long Service Life Expectancy</li> <li>Typically Self-Healing Under Temporary Dielectric &amp; Thermal Overstress</li> <li>Very Low Pour Point (-55°C)</li> </ul>	<ul style="list-style-type: none"> <li>High Cost</li> <li>Some Material Incompatibilities (PVCs)</li> <li>Liquid Containment Means Required per NEC 450-23 (Indoor)</li> <li>Not Listed by UL or FM</li> <li>Not Eligible for Edible Oil or Listed in Federal Biobased Purchase Program FB4P</li> </ul>

Type	Advantages	Disadvantages
<b>C. Fire-Resistant Hydrocarbons (R-Temp® Fluid – Limited Availability)</b>	<ul style="list-style-type: none"> <li>• Flawless Safety Since 1975 Introduction</li> <li>• Excellent Load Break Performance</li> <li>• Excellent Dielectric Properties</li> <li>• Easy to Reprocess/Dispose</li> <li>• Biodegradable/ Low Toxicity Fluid</li> <li>• FM Approved/UL Classified</li> <li>• Low UL Fire Hazard Value (4-5)</li> <li>• Good Stability/Essentially Non-Sludging</li> <li>• Low Maintenance Cost</li> <li>• Typically Self-Healing Under Temporary Dielectric &amp; Thermal Overstress</li> <li>• Preventive Maintenance (DGA) per IEEE and IEC</li> <li>• Miscible with Mineral Oil, Natural &amp; Synthetic Esters, &amp; Most PCB Substitutes</li> </ul>	<ul style="list-style-type: none"> <li>• Higher Viscosity at Low Temperature</li> <li>• Liquid Containment Means Required per NEC 450-23 (Indoor)</li> <li>• Higher Cost than Conventional Mineral Oil</li> <li>• Not Classified as an Edible Oil</li> <li>• Extensive Soil Spill Clean Up Likely</li> <li>• 3% Mineral Oil Contamination Reduces Fire Point &lt; 300°C</li> <li>• Pour Point -21°C</li> </ul>
<b>D. Silicone (Dimethylsiloxane)</b>	<ul style="list-style-type: none"> <li>• Good Fire Safety Record</li> <li>• Lowest Viscosity at Low Temperatures</li> <li>• Very Low Pour Point</li> <li>• Excellent Stability (&lt;150°C)</li> <li>• Excellent Clarity</li> <li>• NEC Recognition Since 1977</li> <li>• NESC Safeguard Recognition Since 1993</li> <li>• Low UL Fire Hazard Value (4-5)</li> </ul>	<ul style="list-style-type: none"> <li>• Non-Biodegradable</li> <li>• Persistence Potential in Environment</li> <li>• Produces Hazardous By-Product Particulates when Combusted (Oxides of Silicon, 80% of Liquid Weight)</li> <li>• Higher Viscosity at Nominal Operating Temperatures</li> <li>• Poor Lubricity</li> <li>• Material Non-Compatible (Silicone &amp; Standard Gaskets, Petrolatum, etc)</li> <li>• Not Compatible with Most Load Break Operations</li> <li>• Silicone Contamination (ppm) Can Cause Conventional Oil Foaming Under Vacuum</li> </ul>

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<b>Silicone (cont'd)</b>	<ul style="list-style-type: none"> <li>• FM Approved</li> <li>• UL Classified</li> </ul>	<ul style="list-style-type: none"> <li>• Special Concern for Paint Line Contamination</li> <li>• Very High Cost</li> <li>• Disposal Difficulties &amp; High Cost</li> <li>• UL Classification Doesn't Allow Bayonet Fuses in Silicone</li> <li>• Containment Means Required Indoor</li> <li>• Adjudicated Liability on Adverse Health Effects of Silicone Implants</li> <li>• Non-Self Healing Under Temporary Dielectric &amp; Heat Overstress (Can Form Semi-Conductive Bridging)</li> <li>• DGA Per IEEE C57.104 Not Applicable</li> <li>• Not Miscible with Other Types of Dielectric Coolants</li> </ul>
<b>E. Synthetic Hydrocarbons\ (Polyalphaolefins)</b>	<ul style="list-style-type: none"> <li>• Excellent Dielectric Properties</li> <li>• Good Low Temperature Viscosity</li> <li>• Excellent Lubricity</li> <li>• Essentially Non-Toxic</li> <li>• Biodegradable</li> <li>• Typically Self-Healing Under Temporary Dielectric &amp; Thermal Overstress</li> </ul>	<ul style="list-style-type: none"> <li>• High Cost</li> <li>• Limited OEM and End-Users</li> </ul>
<b>III. Dry</b>		
<b>A. Open Dry</b>	<ul style="list-style-type: none"> <li>• Low First Cost</li> <li>• Many Manufacturers</li> <li>• Ease of Code Compliance</li> <li>• No Liquid Containment Needed</li> </ul>	<ul style="list-style-type: none"> <li>• Subject to Contamination</li> <li>• Higher Standard Energy Losses</li> <li>• Require Periodic Cleaning</li> <li>• Reported Fires</li> <li>• Higher Noise Level</li> <li>• Lower Standard BIL Levels</li> <li>• High Enclosure Temperature</li> <li>• Standard Enclosure Does Not Pass Wire Probe &amp; Pry Test (ANSI/IEEE C57.12.28)</li> </ul>

Type	Advantages	Disadvantages
Open Dry (cont'd)		<ul style="list-style-type: none"> <li>• Special Outdoor Enclosure Affects Load Capacity &amp; Increases Cost</li> <li>• Greater Susceptibility to Harmonic Overheating</li> <li>• Lower Standard Overload Capability</li> <li>• BIL Subject to Degradation Due to Contaminants (Dust, Lint, Etc.)</li> <li>• Larger Footprint</li> <li>• DGA Preventive Maintenance Not Available</li> <li>• Heat Output Stresses HVAC (Indoor)</li> <li>• Non-Self Healing Insulation</li> </ul>
B. Cast Resin	<ul style="list-style-type: none"> <li>• Better Resistance to Contamination than Open Dry-Type</li> <li>• Ease of Code Compliance</li> <li>• No Liquid Containment Needed</li> <li>• Better Short Circuit Withstand than Open Dry</li> </ul>	<ul style="list-style-type: none"> <li>• Long Term Reliability Not Proven</li> <li>• Higher Standard Energy Losses</li> <li>• High Cost</li> <li>• Difficult to Repair Coil (Cost/Lead-Time/Limited Sources)</li> <li>• Low Standard BIL Levels</li> <li>• DGA Preventative Maintenance Not Available</li> <li>• Greater Susceptibility to Harmonic Overheating</li> <li>• Reported Explosions and Fires</li> <li>• Heat Output Stresses HVAC</li> <li>• Epoxy Cracking Concerns (Thermal Cycling)</li> <li>• Non-Recyclable Coils - Landfill Disposal</li> <li>• Larger Footprint - Heavier</li> <li>• Requires Periodic Bus Bar Cleaning</li> <li>• Relatively Few Manufacturers &amp; Repair Facilities</li> </ul>