Transformer Insulation Options

Advantages and Disadvantages

Type	Advantages	Disadvantages
I. Mineral Oil	• Low Transformer Cost	• Requires Vault per NEC® Article 450-C (Indoor)
	• Lower Viscosity at Low Temperatures	• Higher Installation Cost
	• Liquid Dielectric Performance	• Relatively Low Fire Point
	• Low Maintenance Cost	• Not Favored by Insurance Companies
	• Biodegradable/Low Toxicity Fluid	• Containment with Absorption Bed may be Required
	• Preventive Maintenance (DGA) per IEEE and IEC	• Deluge Extinguishing System may be Required
	• Load Break Operations	• Longest Clearance Distances
	• Long Service Life Expectancy	• Excessive Min. Clearance Distance & Fire Barriers may be Required (Outdoor)
	• Typically Self-Healing Under Temporary Dielectric & Thermal Overstress	• Extensive Soil Spill Cleanup Likely
	• Easy to Reprocess/Dispose	• Not Classified as Edible Oil
	• Pour Point < -35°C	• Non-Renewable Resource
	• A Century of Application History	• Growing Corrosive Sulfur Concerns

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Type	Advantages	Disadvantages
II. Less-Flammable Liquids		
A. Natural Ester (Envirotemp® FR3® Fluid)	• Flawless Safety Record Since Introduction (1997) • Time to Kraft Paper End-of-Life Improvement 5-8 Times • Excellent Dielectric Properties • Excellent Clarity • Rapidly and Completely Biodegrades • Field Experience to 242 kV, 200 MVA • Low Viscosity • Excellent Lubricity • Non-Toxic per Standard Test Methods • Good Compatibility • Not Listed as Hazardous Waste • Non-Sludging per Doble PFVO/SFL • Low Maintenance Cost • Preventive Maintenance (DGA) • Food Grade Ingredients • Renewable Resource • Low UL Fire Hazard Value (4-5) • Easy to Reprocess/Dispose • US EPA Environmental Technology Verification • FM Approved • UL Classification: Fire Hazard Rating • UL Classification: Less-Flammable per NEC • Exclusive UL Classification for use with Internal Expulsion Fusing when used with CL Fusing in Series. • NEC & NESC Safeguard Recognition	• Higher Cost than Mineral Oil • Liquid Containment Required Per NEC 450-23 (Indoor) • Pour Point -21°C • Appropriate only for Sealed or Positive Pressure Dry Nitrogen Equipped Tanks

Type	Advantages	Disadvantages
Natural Ester (cont'd)	• Listed Transformer Option Available • Long Service Life Expected • Typically Self-Healing under Temporary Thermal and Dielectric Stress • Complies with Edible Oil Act • Fully Miscible with Mineral Oil, HMWH & Most PCB Substitutes • Eligible for Federal Biobased Purchase Program FB4P • Provides Best Stability of Fluid-Immersed Stationary Contacts • Maintains > 300°C Fire Point up to 7% Mineral Oil Content.	
B. Synthetic Ester (Envirotemp® 200 Fluid)	• Flawless Safety Record Since Introduction (1984) • Excellent Dielectric Properties • Essentially Non-Toxic • Excellent Load Break Performance • Rapidly Biodegrades • Lowest Viscosity of Less-Flammable Fluids • Best Lubricity • Good Compatibility • Not Listed Hazardous Waste • Essentially Non-Sludging • Low Maintenance Cost • Preventive Maintenance (DGA) • Long Service Life Expectancy • Typically Self-Healing Under Temporary Dielectric & Thermal Overstress • Very Low Pour Point (-55°C)	• High Cost • Some Material Incompatibilities (PVCs) • Liquid Containment Means Required per NEC 450-23 (Indoor) • Not Listed by UL or FM • Not Eligible for Edible Oil or Listed in Federal Biobased Purchase Program FB4P

Type	Advantages	Disadvantages
C. Fire-Resistant Hydrocarbons (R-Temp® Fluid – Limited Availability)	• Flawless Safety Since 1975 Introduction • Excellent Load Break Performance • Excellent Dielectric Properties • Easy to Reprocess/Dispose • Biodegradable/ Low Toxicity Fluid • FM Approved/UL Classified • Low UL Fire Hazard Value (4-5) • Good Stability/Essentially Non-Sludging • Low Maintenance Cost • Typically Self-Healing Under Temporary Dielectric & Thermal Overstress • Preventive Maintenance (DGA) per IEEE and IEC • Miscible with Mineral Oil, Natural & Synthetic Esters, & Most PCB Substitutes	• Higher Viscosity at Low Temperature • Liquid Containment Means Required per NEC 450-23 (Indoor) • Higher Cost than Conventional Mineral Oil • Not Classified as an Edible Oil • Extensive Soil Spill Clean Up Likely • 3% Mineral Oil Contamination Reduces Fire Point < 300°C • Pour Point -21°C
D. Silicone (Dimethylsiloxane)	• Good Fire Safety Record • Lowest Viscosity at Low Temperatures • Very Low Pour Point • Excellent Stability (<150°C) • Excellent Clarity • NEC Recognition Since 1977 • NESC Safeguard Recognition Since 1993 • Low UL Fire Hazard Value (4-5)	• Non-Biodegradable • Persistence Potential in Environment • Produces Hazardous By-Product Particulates when Combusted (Oxides of Silicon, 80% of Liquid Weight) • Higher Viscosity at Nominal Operating Temperatures • Poor Lubricity • Material Non-Compatible (Silicone & Standard Gaskets, Petrolatum, etc) • Not Compatible with Most Load Break Operations • Silicone Contamination (ppm) Can Cause Conventional Oil Foaming Under Vacuum

Type	Advantages	Disadvantages
Silicone (cont'd)	• FM Approved • UL Classified	• Special Concern for Paint Line Contamination • Very High Cost • Disposal Difficulties & High Cost • UL Classification Doesn't Allow Bayonet Fuses in Silicone • Containment Means Required Indoor • Adjudicated Liability on Adverse Health Effects of Silicone Implants • Non-Self Healing Under Temporary Dielectric & Heat Overstress (Can Form Semi-Conductive Bridging) • DGA Per IEEE C57.104 Not Applicable • Not Miscible with Other Types of Dielectric Coolants
E. Synthetic Hydrocarbons\ (Polyalphaolefins)	• Excellent Dielectric Properties • Good Low Temperature Viscosity • Excellent Lubricity • Essentially Non-Toxic • Biodegradable • Typically Self-Healing Under Temporary Dielectric & Thermal Overstress	• High Cost • Limited OEM and End-Users
III. Dry		
A. Open Dry	• Low First Cost • Many Manufacturers • Ease of Code Compliance • No Liquid Containment Needed	• Subject to Contamination • Higher Standard Energy Losses • Require Periodic Cleaning • Reported Fires • Higher Noise Level • Lower Standard BIL Levels • High Enclosure Temperature • Standard Enclosure Does Not Pass Wire Probe & Pry Test (ANSI/IEEE C57.12.28)

Type	Advantages	Disadvantages
Open Dry (cont'd)		• Special Outdoor Enclosure Affects Load Capacity & Increases Cost • Greater Susceptibility to Harmonic Overheating • Lower Standard Overload Capability • BIL Subject to Degradation Due to Contaminants (Dust, Lint, Etc.) • Larger Footprint • DGA Preventive Maintenance Not Available • Heat Output Stresses HVAC (Indoor) • Non-Self Healing Insulation
B. Cast Resin	• Better Resistance to Contamination than Open Dry-Type • Ease of Code Compliance • No Liquid Containment Needed • Better Short Circuit Withstand than Open Dry	• Long Term Reliability Not Proven • Higher Standard Energy Losses • High Cost • Difficult to Repair Coil (Cost/ Lead-Time/Limited Sources) • Low Standard BIL Levels • DGA Preventative Maintenance Not Available • Greater Susceptibility to Harmonic Overheating • Reported Explosions and Fires • Heat Output Stresses HVAC • Epoxy Cracking Concerns (Thermal Cycling) • Non-Recyclable Coils - Landfill Disposal • Larger Footprint - Heavier • Requires Periodic Bus Bar Cleaning • Relatively Few Manufacturers & Repair Facilities