



A Practical Approach to Designing More Cost Efficient Transformers

*A Total Cost of Ownership Perspective Between
Mineral Oil And Envirotemp™ FR3™ Fluid Filled Transformers*

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As electric utilities seek for ways to add value to their shareholder base and increase efficiencies internally, taking a total cost of ownership perspective versus an initial cost only could create potential to gain more cost and resource savings across the organization.

One such opportunity is looking at existing transformer fleets - everything from how they are initially designed to extending asset life as well as resources needed to operate and maintain the existing fleet.

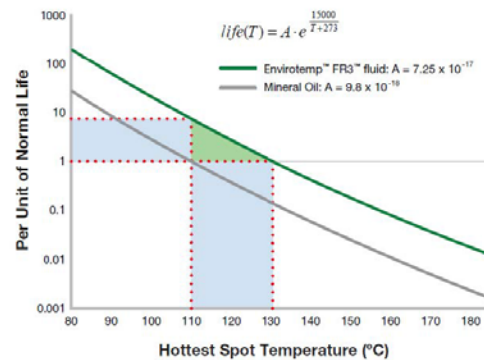
For electric utilities potentially dissatisfied with the current mineral oil filled transformers, better transformer solutions are available today. High temperature transformer insulation systems comprised of solid cellulose and liquid FR3 fluid insulations offer increased loading capability, extended insulation life, improved fire safety and reduced maintenance cycles.

Optimizing transformer design, increasing fire safety, extending asset life and reducing maintenance costs are all key considerations in a total cost of ownership perspective.

High Temperature Standards Create Design Opportunities for Cost Efficiencies

Transformer designs are constrained by the thermal class of the solid insulation system. The thermal class of kraft paper impregnated with mineral oil is 105, while the thermal class of thermally upgraded kraft paper impregnated with mineral oil is 120. International standards guiding the design of mineral oil filled transformers throughout industry have subsequently been written to accommodate a 95°C or 110°C hot spot, with 55°C or 65°C average winding rise (AWR), for cellulose and TUK, respectively, to achieve transformer unit life expectancy (defined as 20.55 years by the IEEE loading guide(IEEE C57.91)).

High temperature capability of FR3™ fluid compared to Mineral Oil



Since thermal class of insulation systems is directly linked to design constraints and operating conditions, the recent advancements in high temperature insulation systems, along with the publishing of IEEE standard C57.154 (and the equivalent IEC standard 60076-14) are helping global transformer designers and users alike understand how to design new transformers and implement solutions that are more cost efficient with higher performance capabilities. Kraft and TUK paper when impregnated with FR3 fluid are now thermal class 120 and 140 respectively. This new capability enables the design of transformers requiring “less cooling”. These designs use less fluid and construction materials while delivering the same or increased load capacity and it works for both power and distribution transformers.

An Example: Gaining design cost efficiencies with high temperature insulation system

Designing a transformer is a balancing act between optimizing the design constraints such as short circuit strength, total losses, temperature rise, and noise level with the ability to minimize the overall transformer cost.

A study, conducted by Cargill, Incorporated, which compared a 100MVA, 230kV-69kV transformer designed with mineral oil against the same transformer designed with high temperature insulation found the following:

- The study shows that moving incrementally from 110°C hottest spot to 120°C hottest spot resulted in **near cost parity** when comparing the Envirotemp™ FR3™ fluid filled transformer to the traditional mineral oil filled transformer, *while providing increased overloading capability, extended asset life.*
- Furthermore, when comparing an FR3 fluid filled transformer *optimized for 130°C hottest spot temperature* compared to the mineral oil transformer designed for 110°C hottest spot temperature, **the mineral oil transformer was more costly to produce than an FR3 fluid filled transformer**, *while still maintaining similar losses and life expectancy*
- The mineral oil transformer weighed 8.5% more than the FR3 fluid transformer
- The mineral oil transformer contained 9% more liquid than the FR3 fluid transformer
- The mineral oil transformer contained 13.5% more copper by weight than the FR3 fluid transformer

Beyond the initial transformer design, OEMs and customers should consider all construction costs associated with a new substation. With more efficient designs taking advantage of the high temperature capability, there could be a quicker construction cycle and less costly freight to site.

Improved fire safety reduces organizational risk

Because of its 360°C fire point (compared to the 160°C fire point of mineral oil), the risk of a transformer fire is significantly reduced, making it a safer solution. Since its introduction, there has never been a reported fire in an FR3 fluid-filled transformer.

If a fire were to occur, FR3 fluid is self-extinguishing reducing the risk of pool fires and limiting damage to the transformer and surrounding property.

FR3 fluid is rated as a K-Class fluid by UL and FM Global potentially enabling utilities to eliminate fire walls and place transformers closer to buildings which are critical in space constrained environments.

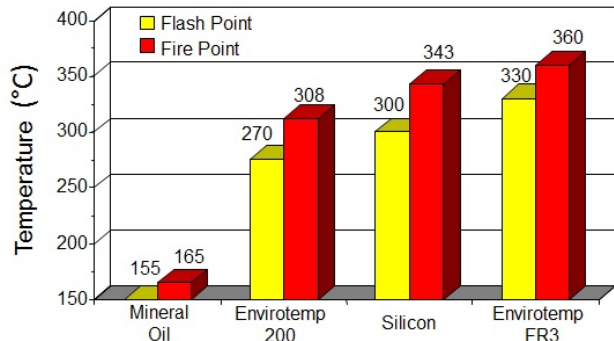


Figure 1: Comparison of fire and flash point of dielectric fluids

With the less-flammable fluid rating, the need for expensive deluge systems may be significantly reduced.

Protecting insulation system extends asset life and reduces replacement cycles

Commonly regarded as the 'weak link' in the expected life of the transformer, the aging of the insulating paper (predominantly made of cellulose – kraft paper – and, in some cases, incorporating additional chemical treatment to become thermally upgraded) is directly impacted by its interaction with the insulating liquid and the operating temperature of the transformer.

Cargill aging studies of cellulose and FR3 fluid provided interesting observations compared to the same studies in mineral oil. Cellulose was observed to last from five to eight times longer when impregnated with FR3 fluid than when impregnated with petroleum based mineral oil.

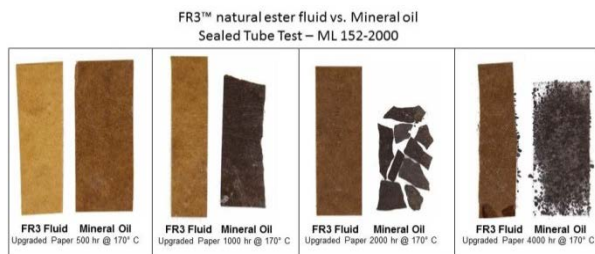


Figure 2: Thermally upgraded papers aged in FR3™ fluid and mineral oil for varying times at 170°C

Cargill research cellulose aged more slowly with FR3™ fluid whereas cellulose in mineral oil ages rapidly, particularly at higher temperatures.

Aging of the insulation paper is the number one factor that determines the life of a transformer. By using FR3-fluid filled transformers, the aging of the insulation system is slowed thus potentially reducing replacement cycles.

Reduce maintenance costs, simplify spill remediation

Condition based maintenance is becoming the norm for the transformer industry. Reprocessing, dehydrating, and reclaiming mineral oil are normally occurring events during the life of a transformer. FR3 fluid is self-drying (due to chemical process of hydrolysis) so therefore the expense and time of dehydrating the fluid could be less. And, since (as noted earlier) expensive fire mitigation deluge systems may be significantly reduced, the costs of maintaining those reduced systems would be reduced as well.

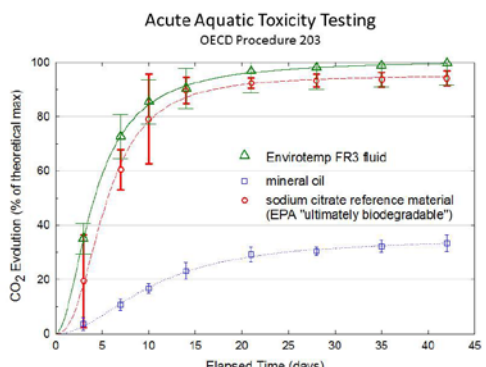


Figure 4 – Acute Aquatic Toxicity Testing comparing FR3 fluid and mineral oil, OECD Procedure 203

Finally, FR3 fluid has inherent environmental benefits that can also impact spill containment and spill remediation costs. FR3 fluid is made from renewable vegetable oil and is non-toxic and non-hazardous in soil and water. Furthermore, it is ultimately biodegradable (equivalent to greater than 99% biodegradable) meaning it will biodegrade in less than 28 days.

There are two important characteristics of FR3 fluid as it relates to spill containment. First, because of the physical properties of FR3 fluid (more viscous), it doesn't reach ground water as quickly as mineral oil, if at all and won't leave a sheen on the water. Second, because of its environmental characteristics, simplified containment may be possible.

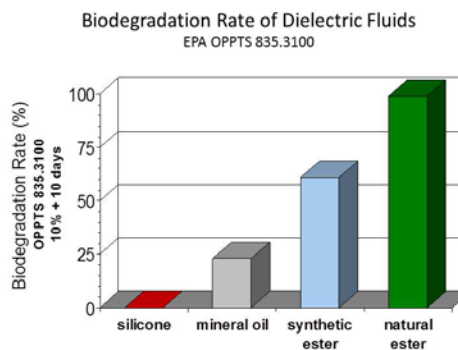


Figure 3 – Aerobic Aquatic Biodegradation EPA Test OPTS 835.3100

Remediation, the process used to repair the environment to pre-event condition, often requires excavating and disposing of contaminated soil, replacing it with 'clean soil' and then replanting indigenous plants. Mineral oil spills often require full remediation as it is not biodegradable and is toxic to the environment. In the case of FR3 fluid spills, an equally effective remediation plan may permit the use of bioremediation in lieu of the more common (and expensive) mineral oil process.

Consistent with EPA recommendations, Cargill recommends using bioremediation to remediate ground spills of FR3 fluid. To accelerate the process, Cargill advocates adding biomass consuming micro-organisms to the site by spreading active yeast over a spill site and adding water to activate the yeast. The yeast will consume the FR3 fluid, thereby effectively removing it from the environment, achieving the same result as the traditional mineral oil remediation process, but at substantially less

cost. Please refer to local state spill remediation regulations as well as the US EPA's Spill Prevention, Control, and Countermeasure (SPCC) regulations for specific requirements for ground spill situation.

Achieve operational and cost efficiencies with a total cost of ownership perspective

Utilities are seeking ways to improve grid reliability, optimize transformer performance to handle loads appropriately and realize real cost savings.

Cargill's cost comparison study highlights specific cost reductions that could be achieved with FR3™ fluid and high temperature insulation system. This technology provides substantial opportunity to all electrical equipment customers to use these enhanced capabilities to their advantage.

With the additional fire safety and environmental benefits of FR3 fluid, electric utilities could achieve broader organizational savings beyond the initial cost of the transformer.

For more information about Cargill's cost comparison study, email us at fr3fluid@cargill.com.

NOTE: The views expressed in this document are based on Cargill's extensive testing of FR3 fluid and third party validation as of the publication date. We can not guarantee that test results and/or third party standards will not change.

Transformer design parameters are dependent on individual specifications, utility practices, conditions in which a transformer will be used and applicable laws, regulations and codes. The study described herein outlines potential cost savings identified by Cargill that users of FR3 fluid could realize. However, results will vary and Cargill makes no representations or warranties whether express or implied, with respect to use of the information included herein or any cost savings users may or may not realize.

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