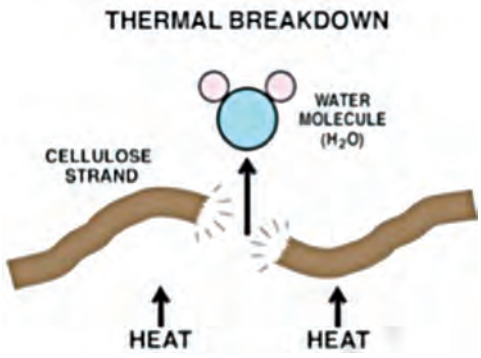
OPTIMIZING TRANSFORMER DESIGNS WITH NATURAL ESTERS

Transformers utilizing the standardized high temperature capability can increase reliability and loading capability by up to 20% while reducing the amount of materials and fluid required to create smaller, more effective transformer designs.

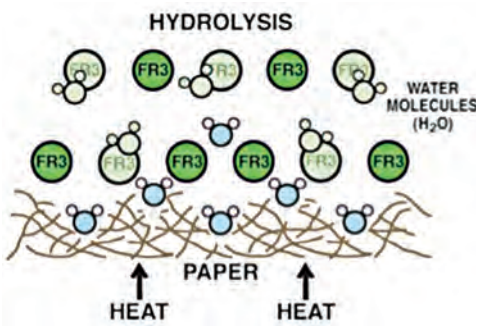
Cellulose paper, pressboard, and dielectric fluid typically comprise a transformer's insulation system. A common failure mode of an electrical transformer is caused by the degradation of the solid insulating system (cellulose paper). Subsequently, the (temperature) operating limits of a transformer are constrained by the thermal capabilities of the insulating materials within each design. However, that changed with the validation of enhanced insulation system life and high temperature capability enabled by natural ester dielectric fluids.

PROTECTING THE TRANSFORMER INSULATION SYSTEM

One of most significant factors contributing to the insulation system aging rate is moisture. In the insulation system, the relative water saturation level of each component will move towards equilibrium. Typically, in new transformers, this means water should leave the solid insulation and be absorbed by the fluid. One of the byproducts of paper aging due to thermal breakdown is the emission of H_2O (water) molecules, which makes the system 'wetter'. Thermal breakdown (and aging) subsequently accelerates more rapidly in a wet system, and the cycle continues; this autocatalytic reaction creates an exponential aging rate.



Mineral oil is very limited by its chemical structure to absorb this moisture, At 20ºC, mineral oil is fully saturated with 65 parts per million (ppm) of water in solution. This limitation forces most of the water to stay in the cellulose. This trapped water destroys the cellulose bonds, thus weakening the insulation system.

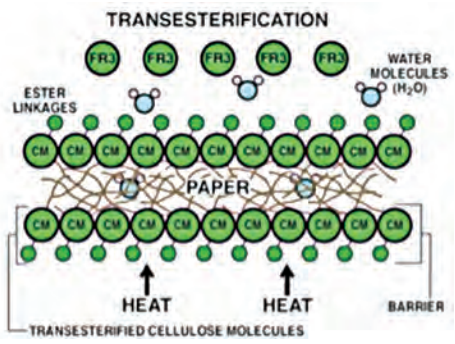


SOLID INSULATION IS MUCH 'DRIER'

Thermal aging cannot be avoided or stopped, but it can be slowed. Natural esters, like Envirotemp™ FR3™ dielectric fluid, perform very differently in the same scenario. First, the chemistry of FR3 fluid enables it to absorb a much greater level of water before reaching saturation (approximately 1000 ppm of water), therefore the solid insulation is much 'drier' than a comparative mineral oil system. Second, operating transformers reach temperatures that enable hydrolysis to occur: H_2O molecules are 'consumed' by FR3 fluid, yielding long-chain fatty acids. The result is a reduction in the water content of the fluid, maintaining its relative dryness.

Those long chain fatty acids then react (bond) with vulnerable sites on the cellulose in a process is called transesterification (taking up space where water would normally reside and cause damage to the cellulose).

The comparative results of aging studies are striking. As a mineral oil system ages and generates more water, it causes the system to age more quickly in a degenerative process. An FR3 fluid system is relatively 'drier' as the water it generates is consumed; the result is a much slower aging process when operated at the same temperature as systems containing mineral oil. Evaluated using industry standard accelerated aging test methods, an FR3 fluid system operating at conventional temperature limits lasts five to eight times longer than the equivalent mineral oil system.

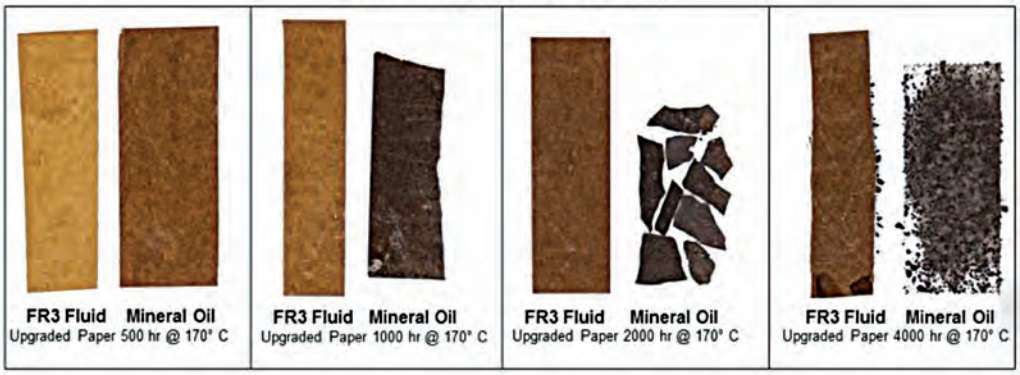


HIGH-TEMPERATURE INSULATION SYSTEMS

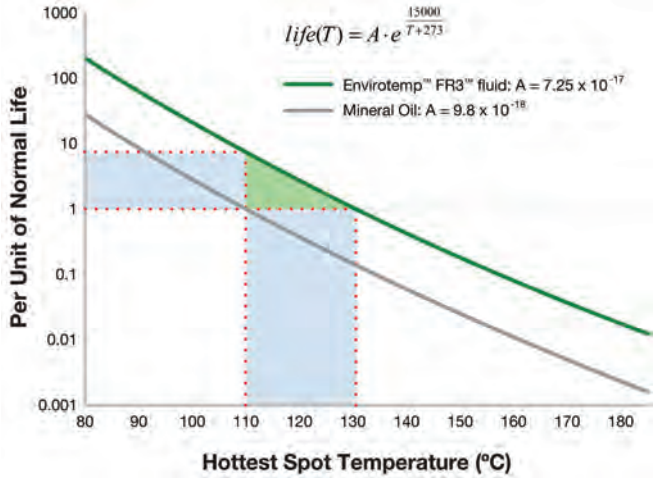
By setting maximum hot spot temperatures, the transformer industry seeks to standardize the aging rate of transformers. Traditionally, transformer hot spot temperatures were difficult and expensive to measure. As a result, the industry adopted as its typical reference point the AWR (average winding rise) of the transformer as a temperature limit.

Today conventional transformers are limited to 55ºC and 65ºC AWR for mineral oil designs using standard and thermally upgraded Kraft (cellulose) paper, respectively. Establishing similar life expectancy, using FR3 fluid in a high-temperature insulating system enables the operation of transformers at 65ºC and 85ºC AWR, respectively, yielding a hot spot temperature 15ºC and 20ºC warmer, respectively, than the equivalent mineral oil system. This capability is referenced in international standards and specifications.*

FR3™ natural ester fluid vs. Mineral oil
Sealed Tube Test – ML 152-2000



The high temperature capability utilized within a transformer can achieve one of three very desirable outcomes: (1) the insulation system ages at a very slow rate, minimising the potential that it will be the failure mode of the transformer, achieving improved system reliability, (2) the transformer designed to operate at the conventional temperature limits can be 'run 20°C warmer' – enabling increased loading capability – beyond nameplate value – without accelerating unit aging, or (3) enabled by the latest standards, a new transformer can be designed to run 20°C warmer – meaning it requires "20°C less cooling", typically achieved by utilizing less materials in a transformer of smaller dimensions. Depending upon the type and design, an optimised transformer designed with a high-temperature insulation system may include one or all of the following modifications – as compared to its mineral oil counterpart: smaller (steel) tank, less insulating paper, less dielectric fluid, less copper, and less or no external cooling (radiators). The specific details and options for less copper, and less heating dissipation elements (radiators or heat exchangers) for each transformer are dependent upon the application requirements, the manufacturer, and standard transformer design criteria.



CONCLUSION

Compared to mineral oil, FR3 fluid enables transformers to last longer, better manage temperature during peak energy demand periods, and can be built in a more compact design. With the improved fire safety (twice the flash and fire point as mineral oil) and inherent environmental benefits (ultimately biodegradable, carbon neutral, non-toxic and non-hazardous in soil and water) of FR3 fluid, designing with high temperature insulation systems provides smaller, safer, cost-competitive units with the ability to improve the reliability of the electrical grid.

See further at www.envirotempfluids.com

*See IEC/TS 60076-14 and IEEE C57.154™ Standard for the Design, Testing and Application of Liquid-Immersed Distribution, Power and Regulating Transformers Using High-Temperature Insulation Systems and Operating at Elevated Temperature.