CERTIFIED TEST REPORT

COOPER POWER SYSTEMS
OXIDATION STABILITY OF ENVIROTEMP® FR3™ FLUID AS MEASURED BY POWER FACTOR VALUED OXIDATION

CERTIFICATION

Statements made and data shown are, to the best of our knowledge and belief, correct and within the usual limits of commercial testing practice.

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1. Scope

An electrical insulating fluid in a transformer must have adequate oxidation stability to efficiently cool and maintain desirable electrical characteristics for the life of the transformer. The by-products of mineral oil oxidation can precipitate as sludge, can coat surfaces and eventually reduce a transformer's cooling capacity and electrical characteristic. Oxidation inhibitor additives help postpone the degrading effects of mineral oil oxidation. Sludge formed in the oil during accelerated thermal aging is an indicator of poor stability, while the oil power factor has been established as one reliable measure of a fluid's electrical characteristic.

Doble Engineering (Boston, USA) developed the Power Factor Valued Oxidation (PFVO) and Sludge Free Life (SFL) tests as indicators of the oxidation stability of transformer oil during accelerated life testing [1]. The PFVO test measures the presence and behavior of contaminants that are both inherent in a fluid and are produced during oxidation. The SFL test detects sludge that can be formed as by-products of oxidation. Both tests are part of the Doble Transformer Oil Purchase Specification (TOPS). The PFVO and SFL test results provide useful information that can be applied to natural esters in a more realistic operating environment than many of the ASTM methods[1]. The PFVO and SFL tests were performed on Envirotemp® FR3™ fluid and other natural and synthetic ester fluids that are composed of different base fluids and additives to determine comparative oxidation stability.

2. Experimental

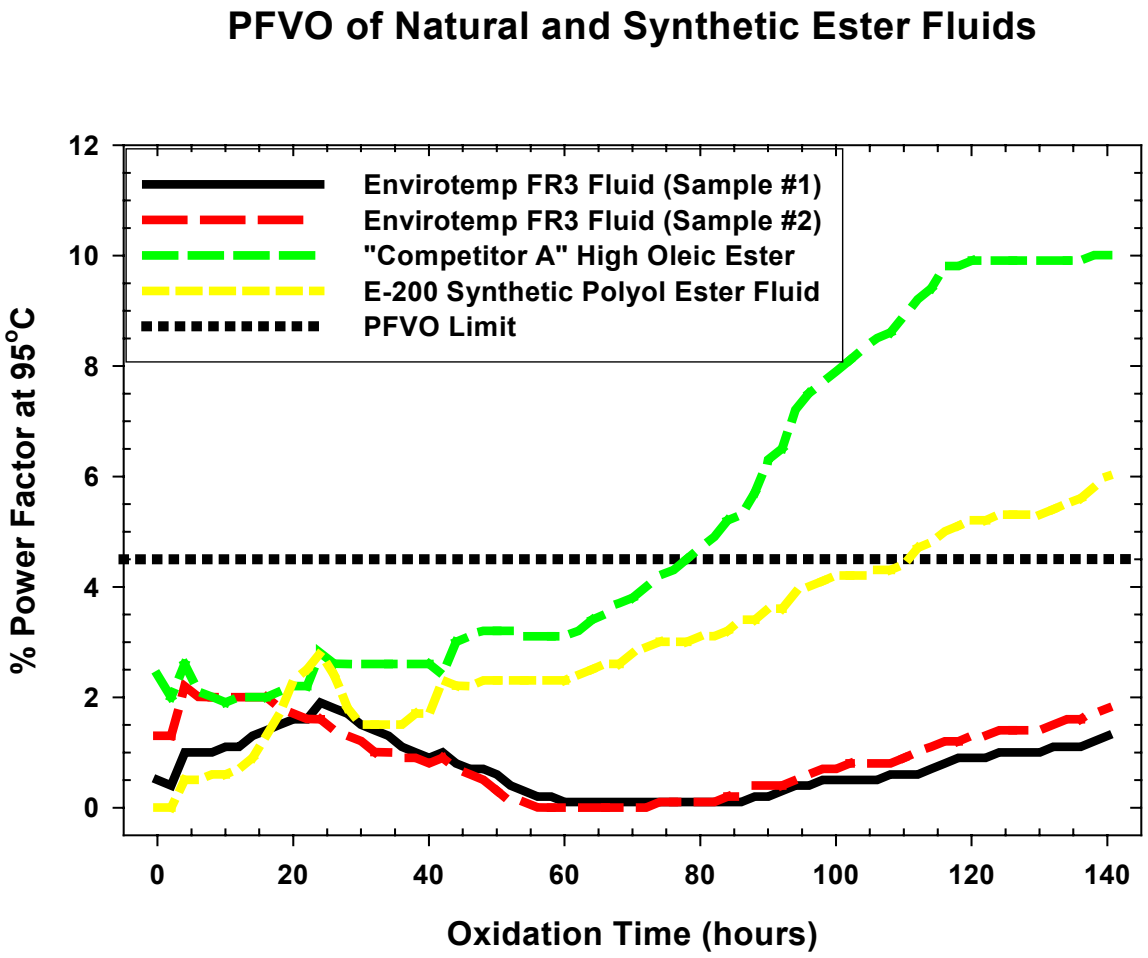
The SFL and PFVO testing was performed by the Doble Engineering Company per the referenced Doble methods [2]. The sludge free life is determined by withdrawing periodic samples that are monitored for evidence of sludge formation. The PFVO test consists of power factor measurements of a fluid during a required 140 hours of fluid oxidation at 95°C with a copper catalyst and an air atmosphere. Two different samples of the natural ester Envirotemp FR3 fluid, another high oleic natural ester identified as "Competitor A" and a synthetic polyol ester identified as Envirotemp 200 fluid were tested.

[1] See Appendix A

3. Results & Discussion

Sludge Free Life Test: The results of SFL testing showed that all four ester samples maintained sludge free life throughout the required 88 hours test duration.

Power Factor Valued Oxidation: The results of the PFVO testing are shown below in the comparative plot of fluid power factors at 95°C versus oxidation time in hours. Both Envirotemp FR3 fluid samples were well within the TOPS limit of 4.5% power factor. Envirotemp 200 fluid and "Competitor A" samples exceeded the TOPS limit prior to the 140 hour test duration.



4. Conclusions

The SFL test results show that several types of ester fluids meet the 88 hour sludge-free life requirement of the Doble TOPS, which was developed for conventional mineral oils.

The PFVO results showed different results for the three types of ester fluids tested:

- The “Competitor A” high oleic natural ester fluid, reported to be able to pass the ASTM D2440 oxidation stability test, actually had the least favorable outcome. It exceeded the Doble limit of 4.5% power factor before 80 hours.
- The synthetic ester, Envirotemp 200 fluid, exceeds the 4.5% Doble limit at 110 hours.
- The natural ester, Envirotemp FR3 fluid, performed the best. The power factor of both samples stayed below 2% over the required 140 hour time period.

The results of the SFL and PFVO tests, together with full scale accelerated aging per IEEE C57.100 [3], analysis of free-breathing transformers and data from in-service transformers of sealed design demonstrates that the natural ester, Envirotemp FR3 fluid, maintains excellent stability for application in transformers of sealed design and limited concern for transformers that may occasionally become free-breathing [4].

The changes seen in Envirotemp FR3 fluid in free-breathing transformers over the course of eight years confirm that while Envirotemp FR3 fluid may not be suitable for application in free-breathing designed transformers: 1) the dissipation factor and neutralization number will provide ample forewarning of atmospheric leaks, and 2) air leaks occurring over extended periods of time, measured in years, will not cause fluid degradation sufficient to adversely affect transformer operation.

Appendix A:

The ASTM test methods D2440 and D2112 [5,6] developed to evaluate, in a short period of test time, the relative effectiveness of anti-oxidation additives in conventional mineral oil. An all too common misapplication of the ASTM tests is to predict, based on the results, a given fluid's stability in actual transformer service. Another growing error is the application of the ASTM methods to fluid types other than mineral oil, including natural vegetable oil based ester dielectric fluids, such as Envirotemp® FR3™ fluid. The methods accomplish this by prescribing the use of ample pure oxygen and copper catalyst at temperatures up to 140°C. These ASTM accelerating test conditions are too severe for ester fluids and lead to polymerization with no useful information derived during the process, because they do not relate to any actual situation within a transformer in service.

Envirotemp FR3 fluid oxidizes differently than mineral oil and does not form sludge precipitates. Instead, the fluid will slowly become more viscous, but will maintain the important functional properties. The ASTM tests used to assess mineral oil lot-to-lot variability and effectiveness of oxidation inhibitor content are not applicable to ester-based fluids. The ASTM D2440 and D2112 test methods are intended only to evaluate antioxidant additives in mineral oil. The tests use conditions unrelated to transformer operation.

Transformers of sealed design protect internal components from exposure to oxygen and atmospheric moisture. In the event that a transformer does develop a leak above the fluid level, insulating fluid of any type is subject to some gradual oxidation from air at the headspace interface. An on-going study being conducted on free-breathing FR3 fluid filled transformers showed that the fluid viscosity increased a modest 8.6% after seven years of operation [4]. Significant antioxidant additive depletion is evident, as is the expected oxidation of the natural ester. However, the transformers are still operating normally and pass IEEE C57.100 electrical stress tests at regular intervals.

References

[1] Oliver, F.S., "Doble Power-Factor Valued Oxidation Tests," Doble Conference Minutes 1960, Insulating Fluids/ 10-401, pgs 1-9
[2] Instructions for Doble Oil Comparator 12E-I-871, Doble Engineering Company, pgs 1-23
[3] C.P. McShane, G.A. Gauger, J. Luksich, "Fire Resistant Natural Ester Dielectric Fluid and Novel Insulation System for Its Use", IEEE/PES T&T Conference, Apr. 12-16, 1999, IEEE 0-7803-7287-5/01/ IEEE T&D, © 2001
[4] Cooper Power Systems Dielectric Fluids Products Engineering Report DFR2004-1213, 'Field Analysis of Envirotemp FR3 Fluid in Sealed versus Free-Breathing Transformers, December 13, 2004
[5] "Standard Test Method for Oxidation Stability of Inhibited Mineral Oil by Pressure Vessel," ASTM D2112-01a, ASTM International, West Conshohocken, PA
[6] "Standard Test Method for Oxidation Stability of Mineral Insulating Oil," ASTM D2440-99, ASTM International, West Conshohocken, PA