Envirotemp® FR3® Fluid

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Cooper Power Systems
McGraw-Edison Development Corporation
19, Mykinon Street
GR-166 74 Glyfada, Athens
GREECE
telephone: +30 210 964 6332
email: cps-athens@cooperpower.com

Cooper Power Systems
1900 East North Street
Waukesha, Wisconsin 53188-3899
USA

telephone: +01 262 524 3300

Contents

1. Dielectric properties

1.1 Partial discharge behavior

Envirotemp FR3 fluid appears to have a higher partial discharge inception voltage compared to mineral oil.

Figure 1 shows results obtained by the University of New South Wales using needle to spherical section geometry [1]. Water was added to the fluids for the 4 mm gap tests, resulting in a much smaller inception voltage for both fluids.

The breakdown voltages of the two fluids are quite different, however. Envirotemp FR3 fluid has a much higher breakdown voltage compared to mineral oil. This may be attributed to its higher tolerance of water.

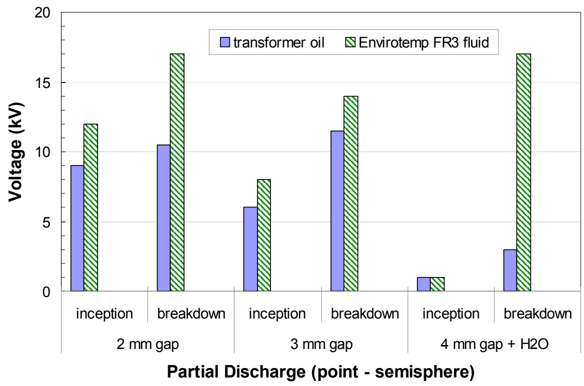


Figure 1. Partial discharge inception voltage for mineral oil and Envirotemp FR3 fluid. [1]

Figures 2-4 show results from the University of Hannover [2] using the IEC 61294 method and a 50mm gap. The variations of partial discharge inception with regard to temperature and relative water content were explored. At low relative saturations, mineral oil and Envirotemp FR3 fluid have similar inception voltages. As the relative water contents increase, Envirotemp FR3 fluid appears to have higher inception voltages compared to mineral oil.

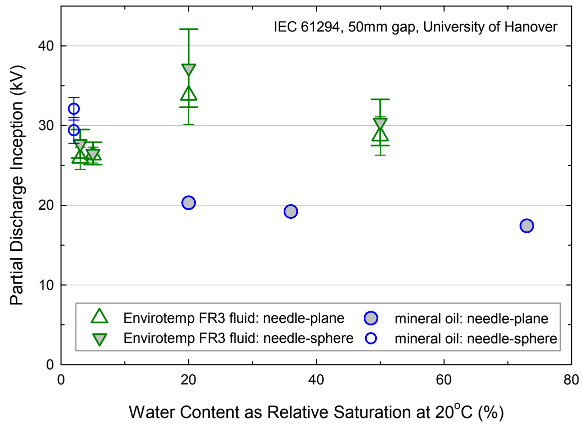


Figure 2. Partial discharge inception voltage *versus* water content of mineral oil and Envirotemp FR3 fluid at 20°C. [2]

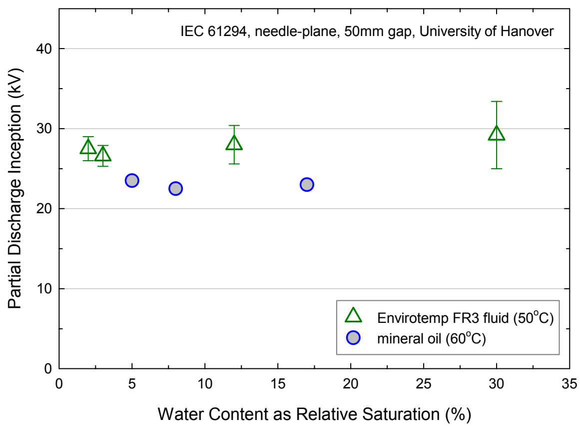


Figure 3. Partial discharge inception voltage *versus* water content of mineral oil at 60°C and Envirotemp FR3 fluid at 50°C. [2]

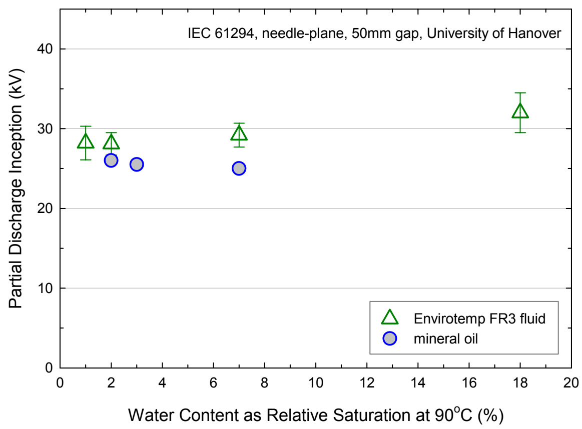


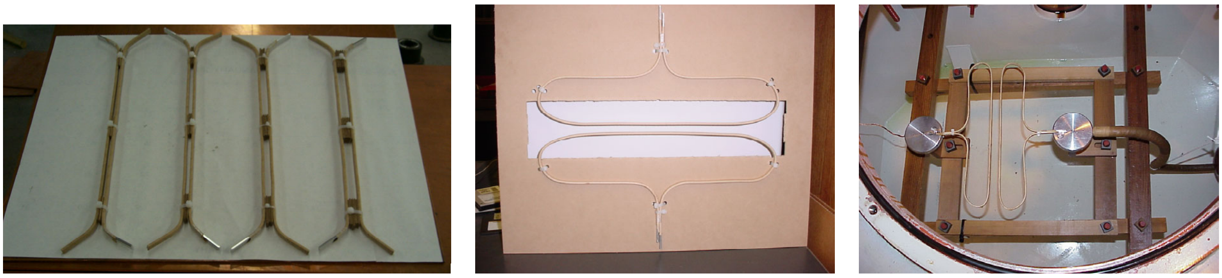
Figure 4. Partial discharge inception voltage *versus* water content of mineral oil and Envirotemp FR3 fluid at 90°C. [2]

1.2 Withstand capability curves

Oil gap withstand tests were conducted at three laboratories according to their voltage capabilities: Cooper Power Systems, Doble Engineering, and Waukesha Electric Systems. Figure 5 shows the electrode configurations. Withstand capabilities for 60 Hz (Figure 6), full wave negative and positive impulse (Figure 7), chopped wave negative and positive impulse (Figure 8), and switching surge negative and positive impulse (Figure 9) are shown.

Sphere-to-sphere full wave negative impulse withstand is shown in Figure 10. The University of Manchester used the ASTM D3300 test method with a 12.7mm gap.

All of the results demonstrate that the oil gap withstand capabilities of mineral oil and Envirotemp FR3 fluid are, for all practical purposes, equivalent.



(a) (b) (c)

Figure 5. Electrode configurations for oil gap tests performed at the Thomas A. Edison Technical Center (a), Doble Engineering (b), and Waukesha Electric Systems (c).

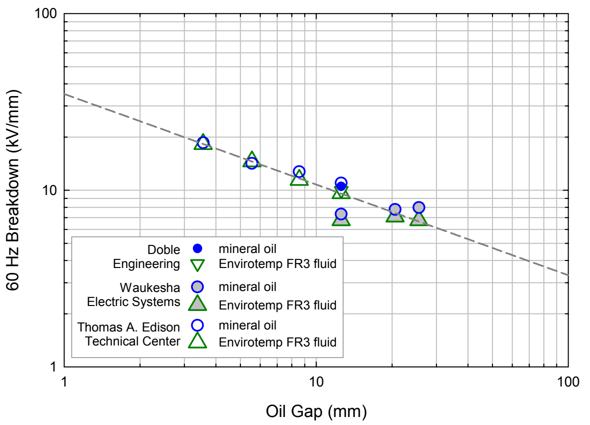


Figure 6. AC withstand for mineral oil and Envirotemp FR3 fluid.

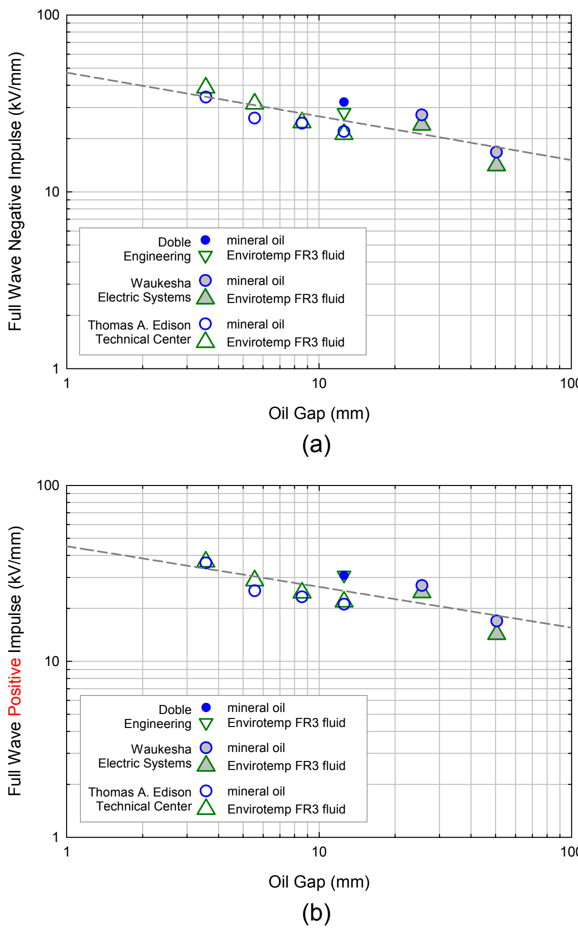


Figure 7. Negative (a) and positive (b) full wave impulse withstand for mineral oil and Envirotemp FR3 fluid.

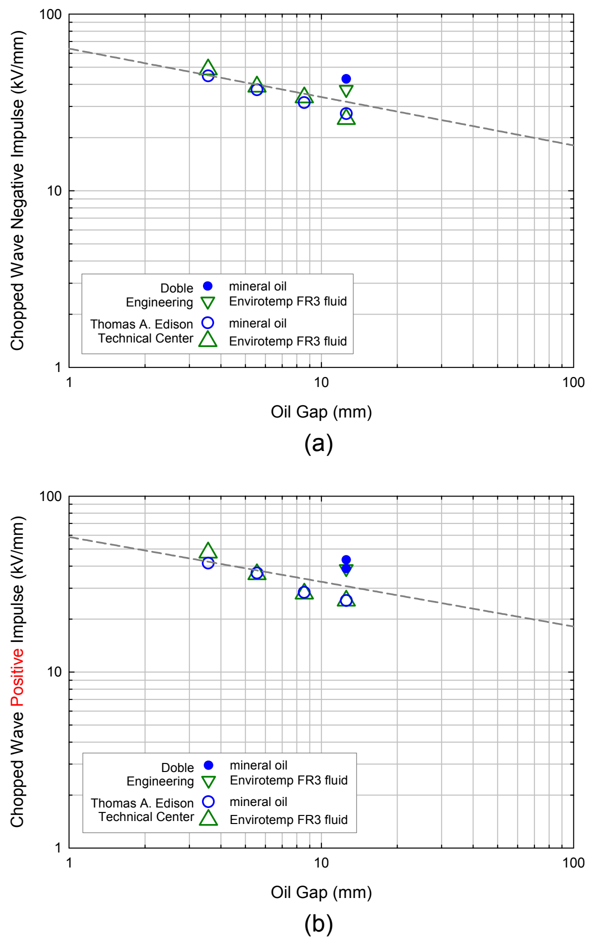


Figure 8. Chopped wave negative (a) and positive (b) impulse withstand for mineral oil and Envirotemp FR3 fluid.

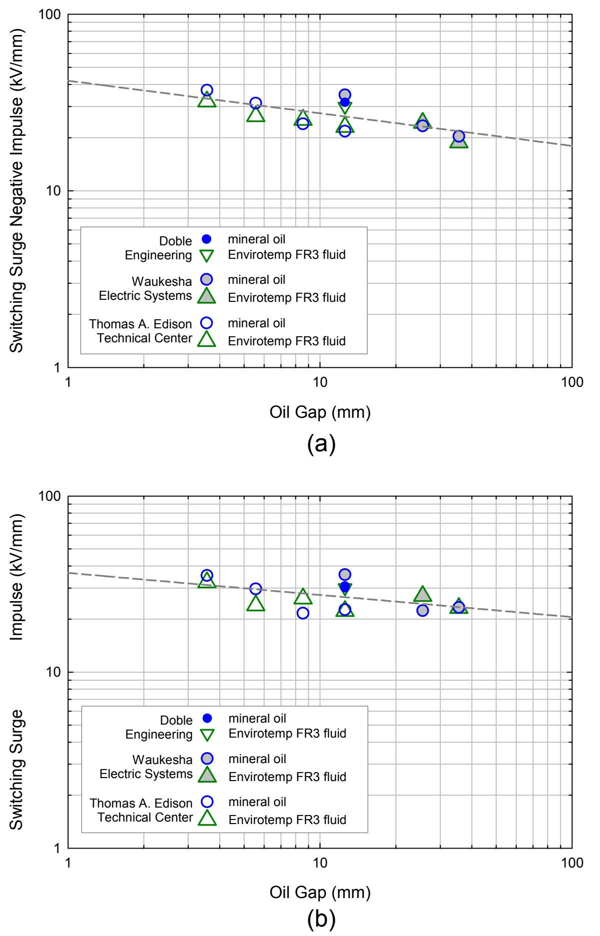


Figure 9. Switching surge negative (a) and positive (b) impulse withstand for mineral oil and Envirotemp FR3 fluid.

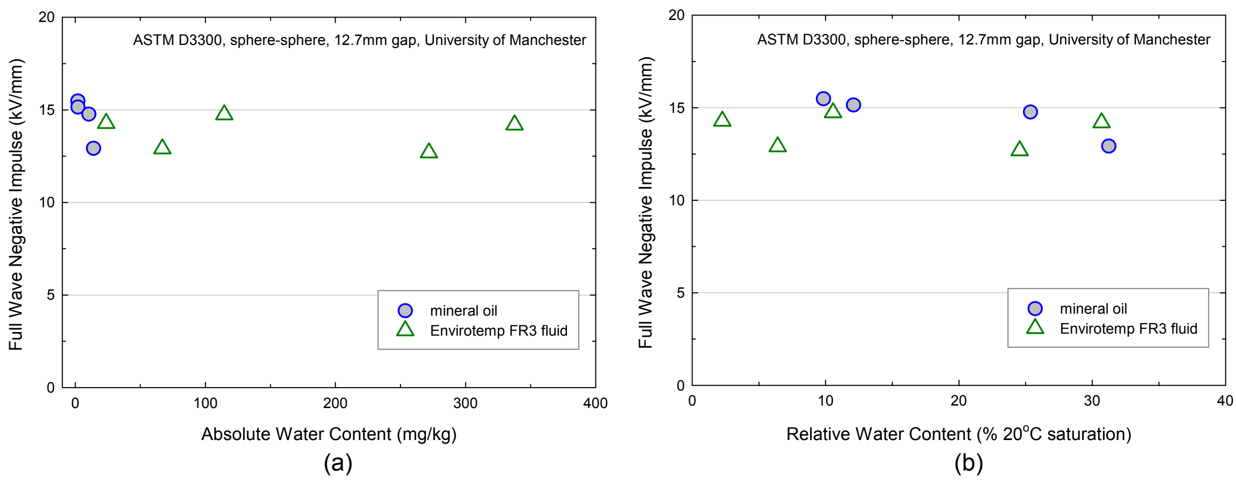
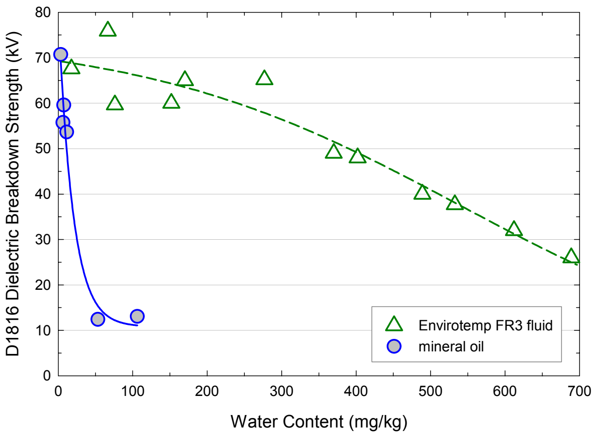


Figure 10. Full wave negative impulse strength *versus* absolute water content (a) and relative water content (b) of mineral oil and Envirotemp FR3 fluid. [2]

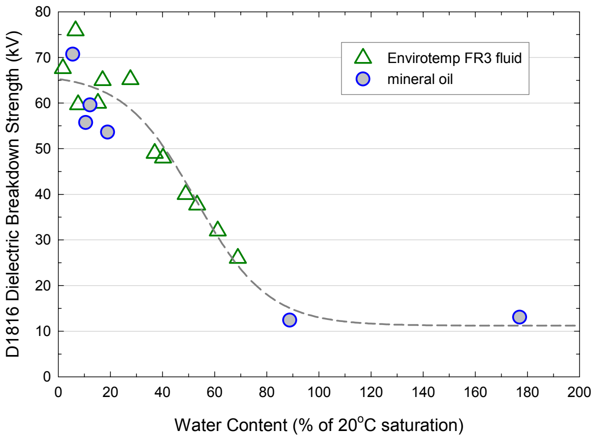
1.3 Effect of dissolved water and temperature on dielectric strength

The dependence of dielectric breakdown strength on water content is shown in Figures 11-13. Variation of ASTM D1816 (VDE electrodes) dielectric breakdown strength in term of both absolute and relative water contents are shown for 2mm gap (Figure 11) and 1mm gap (Figure 12). The ASTM D877 (disk electrodes) dependence on absolute water content is shown in Figure 13.

Dielectric breakdown strength variation with temperature is given in Figure 14.

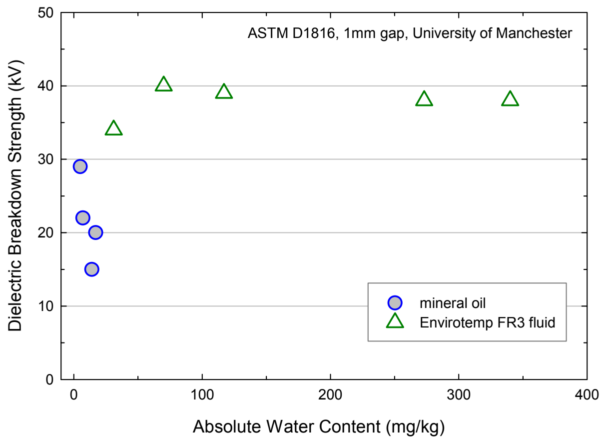


(a)

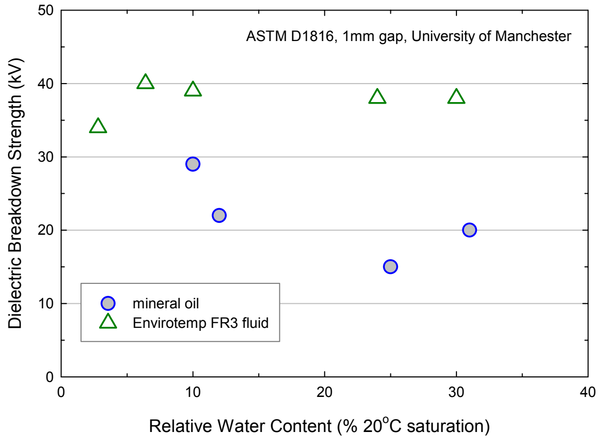


(b)

Figure 11. Dielectric breakdown strength *versus* water content for mineral oil and Envirotemp FR3 fluid.



(a)



(b)

Figure 12. Dielectric breakdown strength versus water content for mineral oil and Envirotemp FR3 fluid. [3]

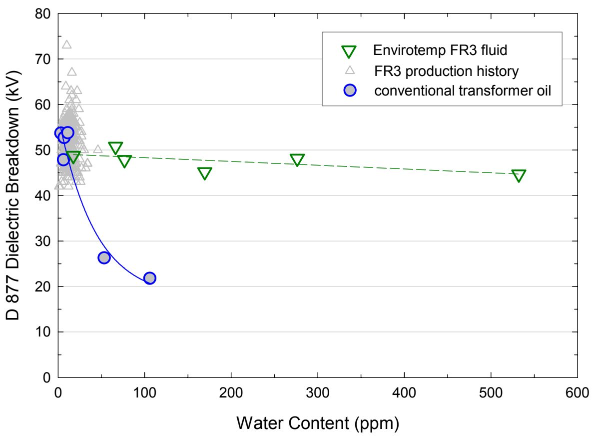


Figure 13. Dielectric breakdown strength *versus* water content for mineral oil and Envirotemp FR3 fluid.

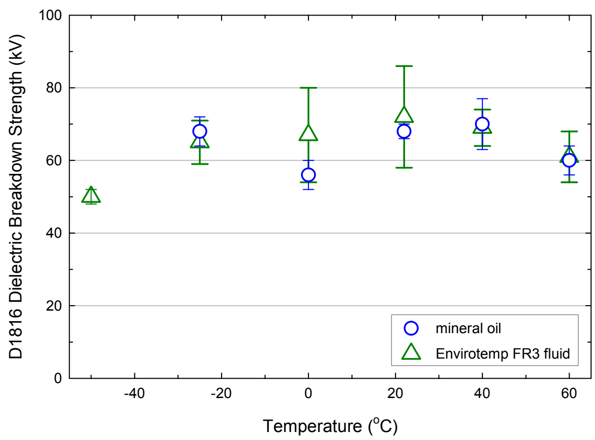


Figure 14. Dielectric breakdown strength *versus* temperature for mineral oil and Envirotemp FR3 fluid.

1.4 Effect of voltage distribution in insulation structure

"The dielectric strength of solid insulation (in this case Kraft insulation impregnated with dielectric fluid) is close to an order of magnitude higher than the fluid itself. Thus the weak material in the insulation structure is the fluid. By bringing the permittivity of the liquid and solid insulation closer together more of the dielectric stress will be distributed in the solid material. This will reduce the stress in the fluid, which typically sets the design clearance." *T. Prevost, presentation of [4]*

An example is given in Figure 28.

ε_1=permittivity fluid
mineral oil $\cong$ 2 FR3 fluid $\cong$ 3

ε_2=permittivity solid insulation
solid insulation $\cong$ 4

$Z=(d_1/\varepsilon_1) + (d_2/\varepsilon_2)$
Let $d_1 = d_2 = 5$mm

$E_1= U/(\varepsilon_1 * Z)$

$E_2= U/(\varepsilon_2 * Z)$

U= Applied Voltage
Let U = 100 kV

E_1= Stress fluid

E_2= Stress in solid insulation

Mineral oil:
E_1= 13.33 kV/mm
E_2= 6.67 kV/mm

Envirotemp FR3 fluid:
E_1= 11.43 kV/mm
E_2= 8.57 kV/mm

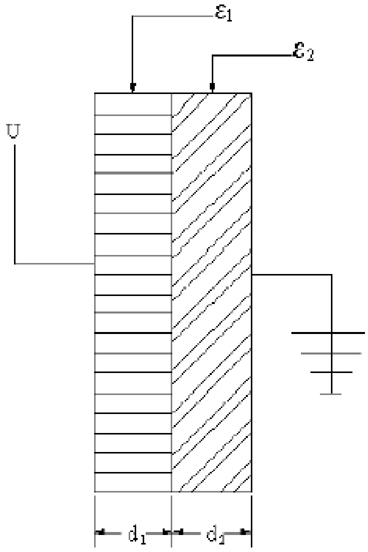


Figure 28. Dielectric breakdown strength *versus* temperature for mineral oil and Envirotemp FR3 fluid. *from T.A. Prevost presentation of [4]*

1.5 Effect of temperature on power factor and dielectric constant

The dielectric constants of mineral oil and Envirotemp FR3 fluid as a function of temperature are shown in Figure 14. The University of Hannover [2] values are the average dielectric constant for a range of water contents. The error bars represent the maximum and minimum dielectric constants. Envirotemp FR3 fluid was tested at water contents of 30, 50, 200, and 500 mg/kg; mineral oil was tested at 11, 20, and 40 mg/kg. Figures 15-17 show the dielectric constants of impregnated solid insulation versus temperature.

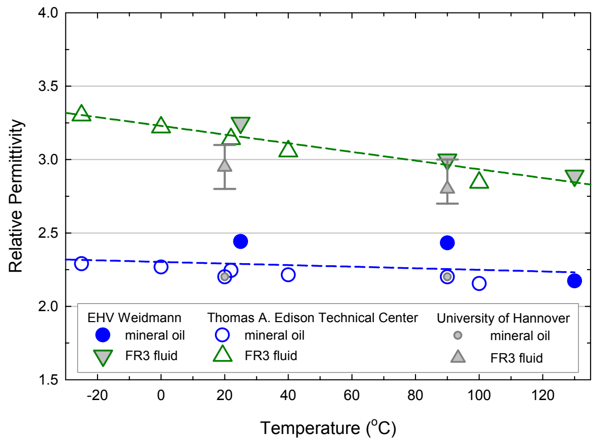


Figure 14. Relative permittivity *versus* temperature of mineral oil and Envirotemp FR3 fluid.

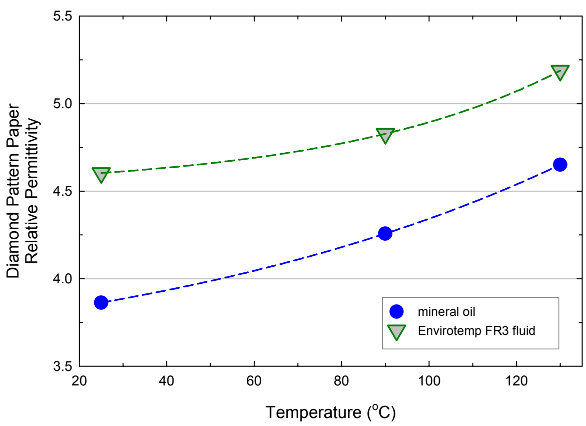


Figure 15. Relative permittivity *versus* temperature of Kraft paper impregnated with mineral oil and Envirotemp FR3 fluid.

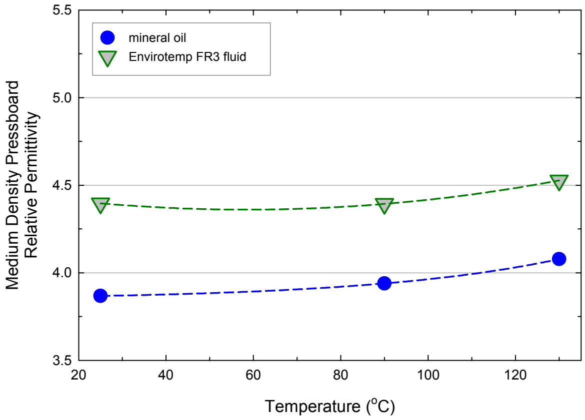


Figure 16. Relative permittivity *versus* temperature of T-IV pressboard impregnated with mineral oil and Envirotemp FR3 fluid.

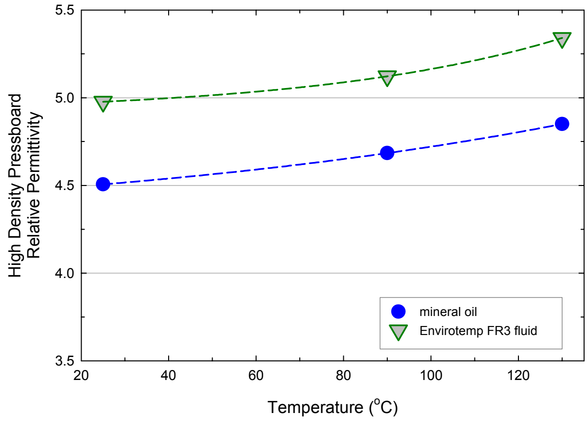


Figure 17. Relative permittivity *versus* temperature of Hi-Val pressboard impregnated with mineral oil and Envirotemp FR3 fluid.

Dissipation factors of mineral oil and Envirotemp FR3 fluid as a function of temperature are shown in Figure 18. Again, the University of Hannover [2] values are the average dielectric constant for a range of water contents, and the error bars represent the maximum and minimum values. Figures 19-21 show the dissipation factors of impregnated solid insulation versus temperature.

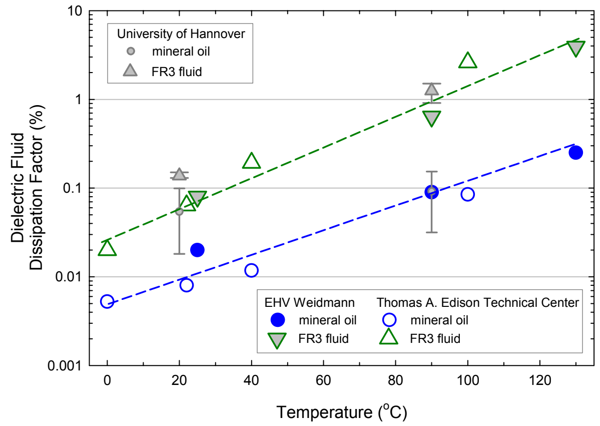


Figure 18. Dissipation factor *versus* temperature of mineral oil and Envirotemp FR3 fluid.

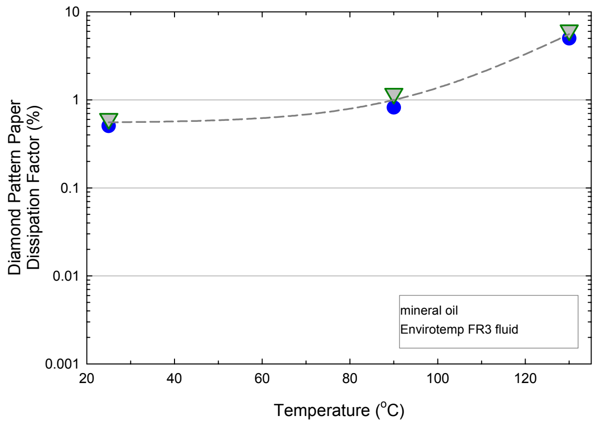


Figure 19. Dissipation factor versus temperature of Kraft paper impregnated with mineral oil and Envirotemp FR3 fluid.

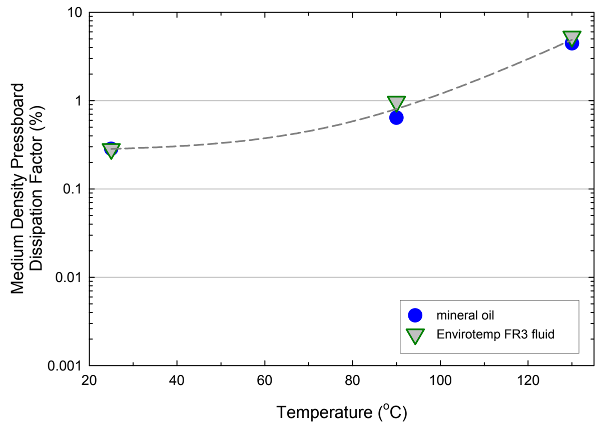


Figure 20. Dissipation factor versus temperature of T-IV pressboard impregnated with mineral oil and Envirotemp FR3 fluid.

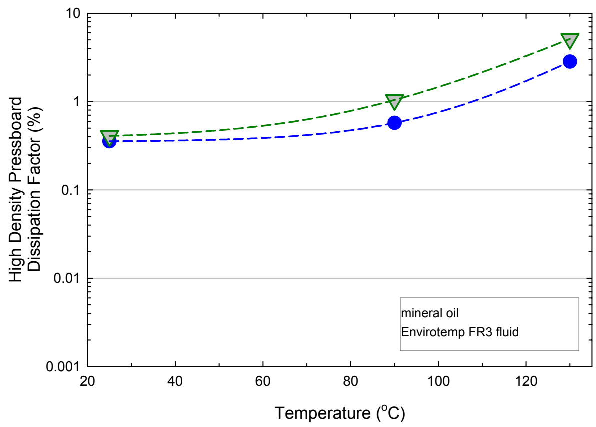


Figure 21. Dissipation factor versus temperature of Hi-Val pressboard impregnated with mineral oil and Envirotemp FR3 fluid.

1.6 Creep Withstand Capabilities

AC and impulse creep withstand tests were performed by EHV Weidmann [4]. Their electrode configuration is shown in Figure 27. The geometry gives a non-uniform field with the highest stress along the pressboard-fluid interface. The electrode and test specimen are designed to minimize the effect of oil wedges.

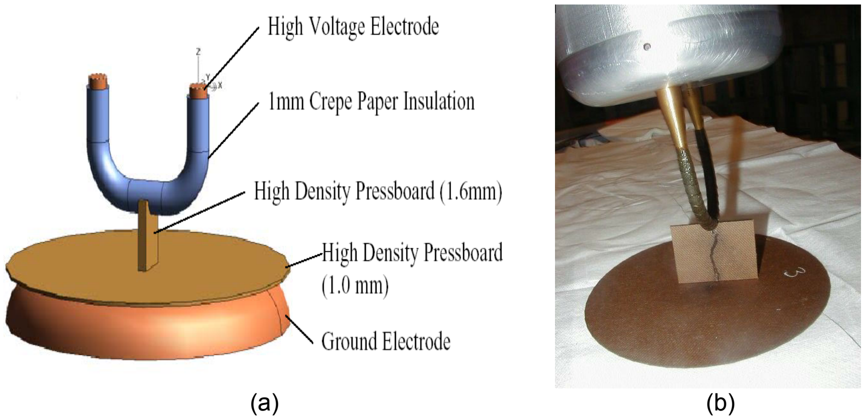


Figure 27. EHV Weidmann creep electrode design (a) and photo of creep breakdown (b). [4]

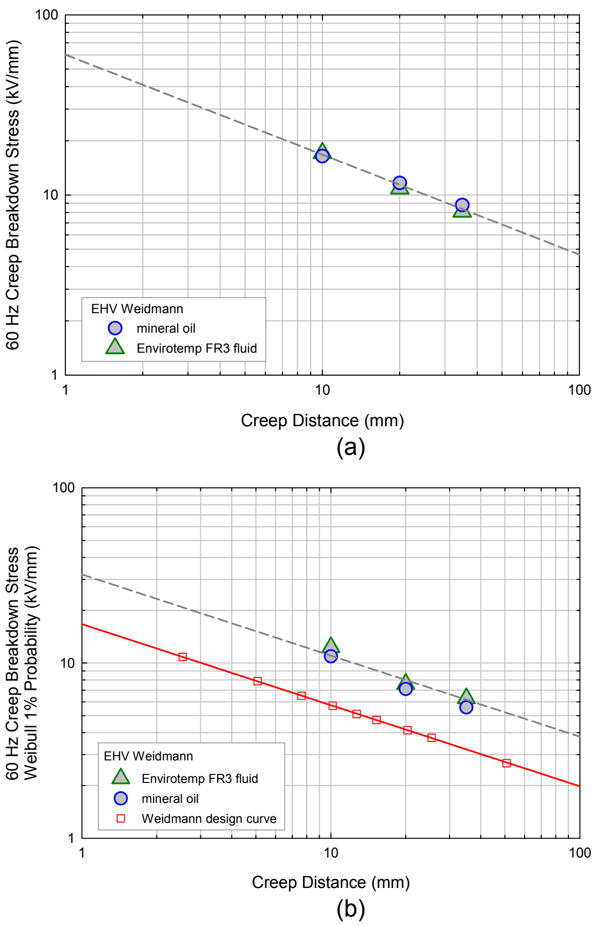


Figure 22. 60 Hz creep strength of mineral oil and Envirotemp FR3 fluid: (a) shows test values and (b) shows the calculated Weibull 1% probability.

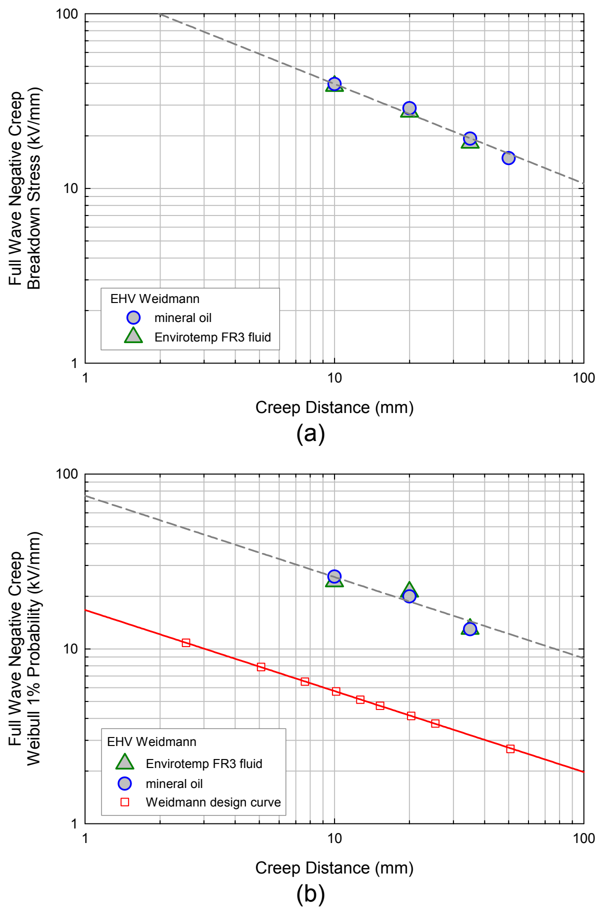


Figure 23. Full wave negative creep strength of mineral oil and Envirotemp FR3 fluid: (a) shows test values and (b) shows the calculated Weibull 1% probability.

For AC creep withstand (Figure 22) and negative full wave impulse creep withstand (Figure 23), the Weibull 1% probability is calculated and compared to the published Weidmann creep curve. Figure 24 shows the results to date for positive full wave impulse creep withstand. Tests completed to date demonstrate that the creep strengths of mineral oil and Envirotemp FR3 fluid are, for all practical purposes, equivalent.

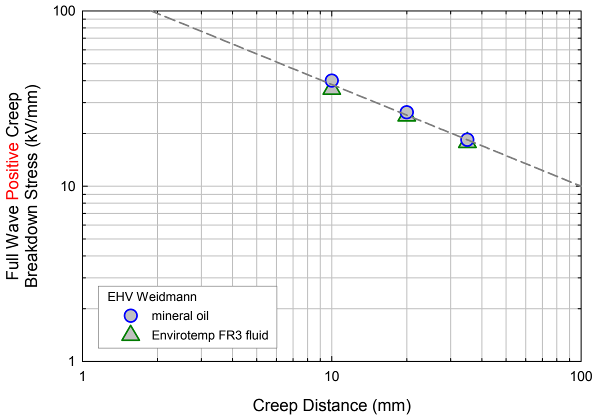


Figure 24. Full wave positive impulse creep withstand of mineral oil and Envirotemp FR3 fluid

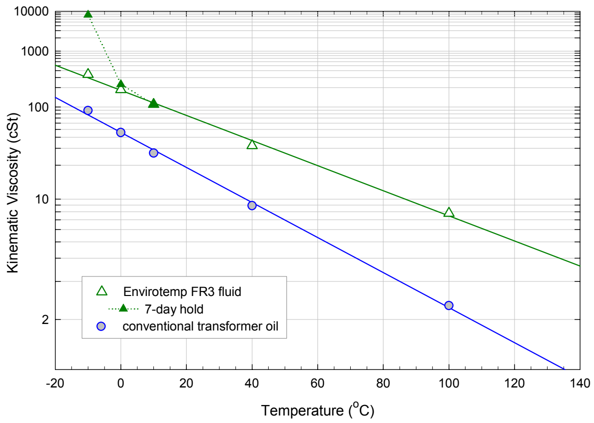


Figure 25. Viscosity *versus* temperature for mineral oil and Envirotemp FR3 fluid

2. Thermal properties

2.1 Viscosity at low temperatures

Many variables affect the low temperature flow characteristics of Envirotemp FR3 fluid. The low temperature viscosity depends not only on the temperature, but also time at temperature, the rate of cooling, and the fluid volume. Figure 25 shows the viscosity versus temperature curves for mineral oil and Envirotemp FR3 fluid. Comparing the 7-day hold values to the standard viscosity shows the time at temperature effect.

(Another Cooper Power Systems' product, R-Temp fluid, has a pour point similar to that of Envirotemp FR3 fluid, but its viscosity is considerably higher. R-Temp fluid had the same cold flow concerns, but has had no field issues in 30+ years of cold climate applications.)

3. Ageing

3.1 Oxidation inhibitors

Envirotemp FR3 fluid contains an additive package that includes a proprietary oxidation inhibitor at 0.4 wt%. The ASTM D4768 gas chromatography method for determining the inhibitor content in insulating liquids can be used to determine the inhibitor content in Envirotemp FR3 fluid.

3.2 Transport atmosphere

Tests using transformer power factor models are currently underway to evaluate the effects of dry air transport of transformers using Envirotemp FR3 fluid. The pressboard models, impregnated with mineral oil and Envirotemp FR3 fluid, emulate the geometry of power transformer coils on a small scale (Figure 26).

Figure 26. Example of power factor model used in tests to evaluate dry air transport of Envirotemp FR3

3.3 Long term ageing fluid properties

A number of side-by-side accelerated aging tests have been conducted using Envirotemp FR3 fluid and mineral oil. One series of tests used transformer construction materials in the proper proportions to evaluate material compatibility. The tests, run at multiple temperatures and times, show the changes in fluid properties over 4 IEEE "normal" lifetimes, the rough equivalent of 86 years of operation at rated load (Figures 27-34).

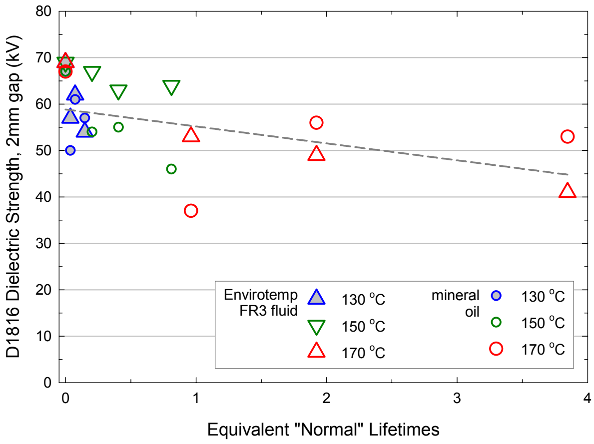


Figure 27. Dielectric breakdown strength *versus* time for mineral oil and Envirotemp FR3 fluid.

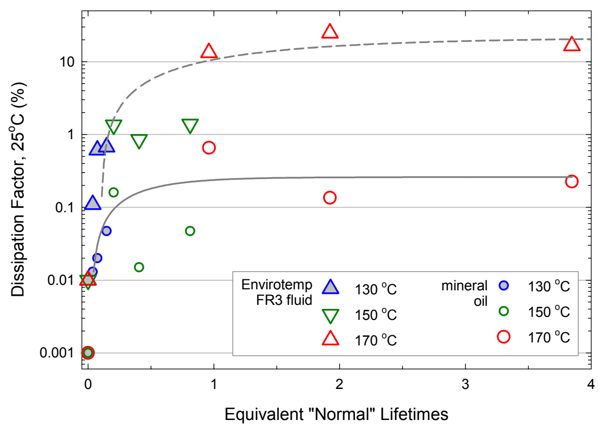


Figure 28. Dissipation factor *versus* temperature for mineral oil and Envirotemp FR3 fluid.

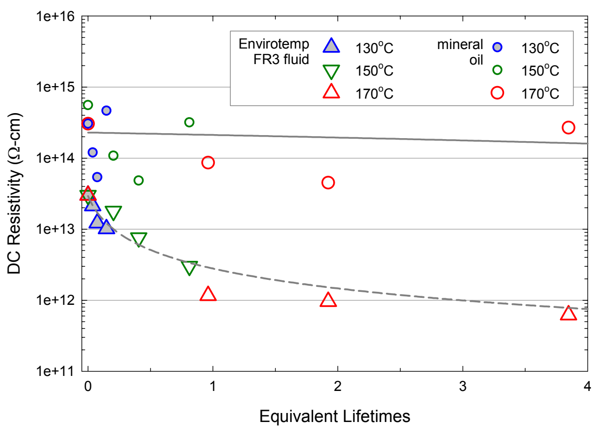


Figure 29. Resistivity *versus* time for mineral oil and Envirotemp FR3 fluid.

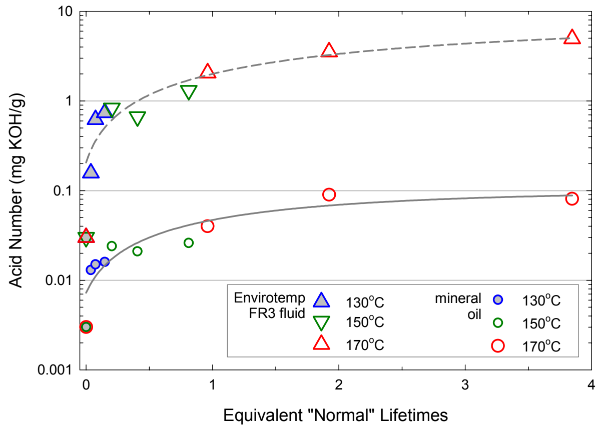


Figure 30. Acid number *versus* temperature for mineral oil and Envirotemp FR3 fluid.

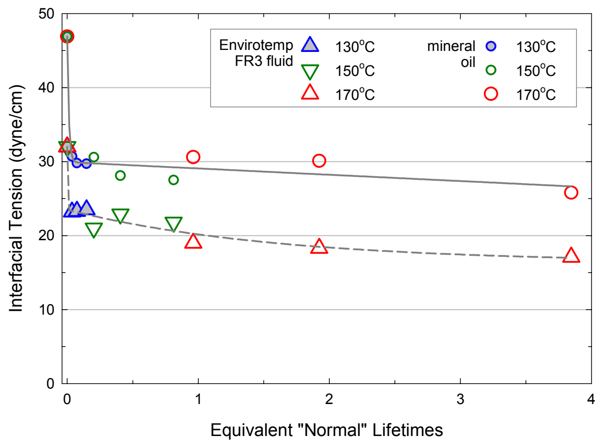


Figure 31. Interfacial tension *versus* time for mineral oil and Envirotemp FR3 fluid.

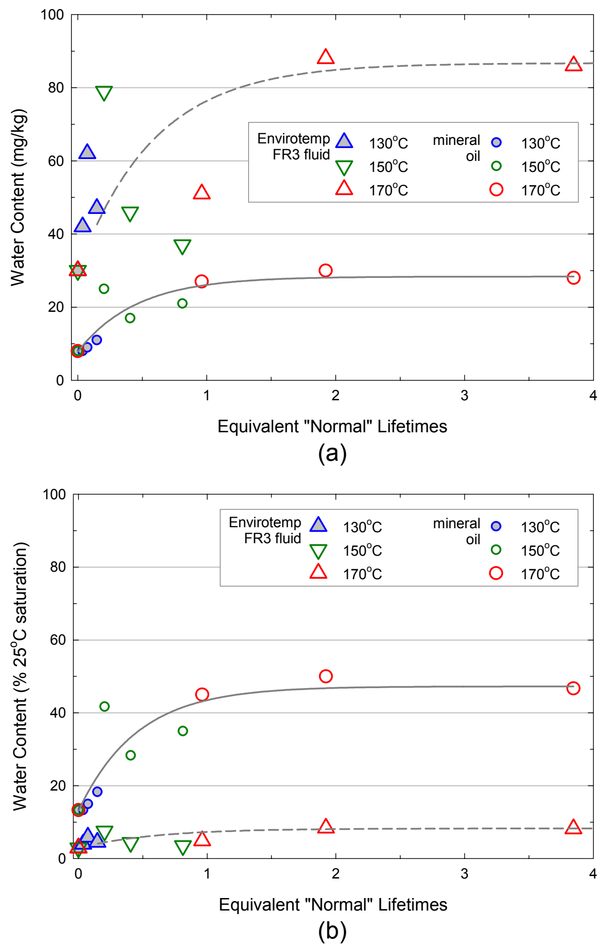


Figure 32. Water content *versus* time as (a) absolute water content and (b) relative water content of mineral oil and Envirotemp FR3 fluid.

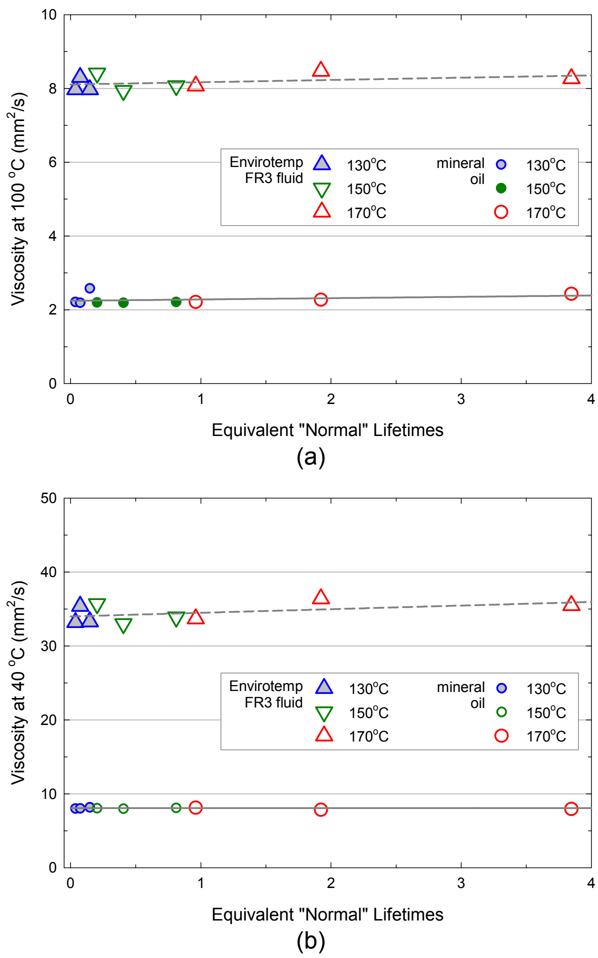


Figure 33. Kinematic viscosity *versus* time at (a) 100°C and (b) 40°C of mineral oil and Envirotemp FR3 fluid.

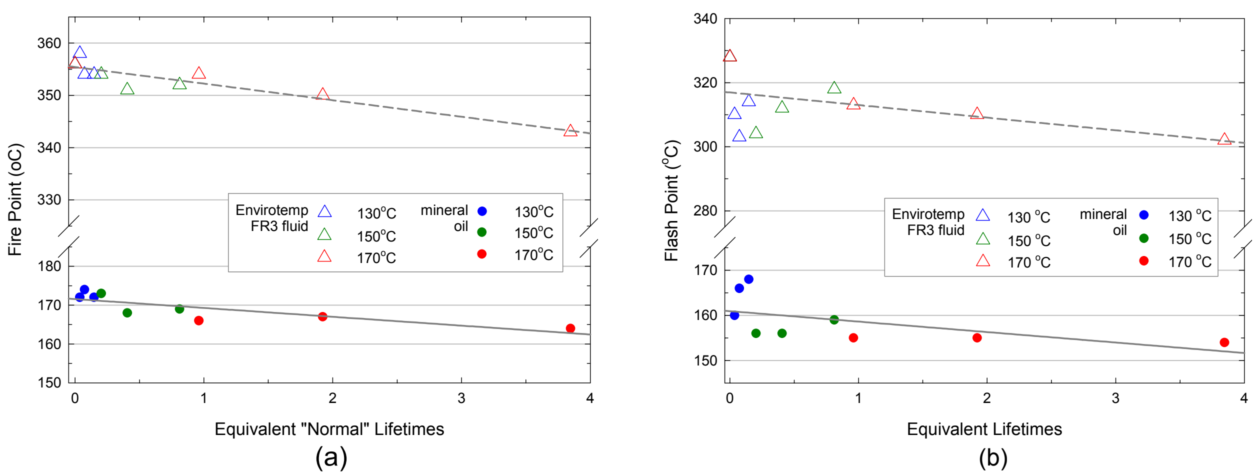


Figure 34. Flash point (a) and fire point (b) *versus* time of mineral oil and Envirotemp FR3 fluid.

Figure 35 shows the dielectric breakdown strength versus dissipation factor at 25°C for Envirotemp FR3 fluid. The fairly small decrease in dielectric strength indicates the high dissipation factor is due to larger polar molecules resulting from Envirotemp FR3 fluid thermal degradation instead of conductive particulate contaminants.

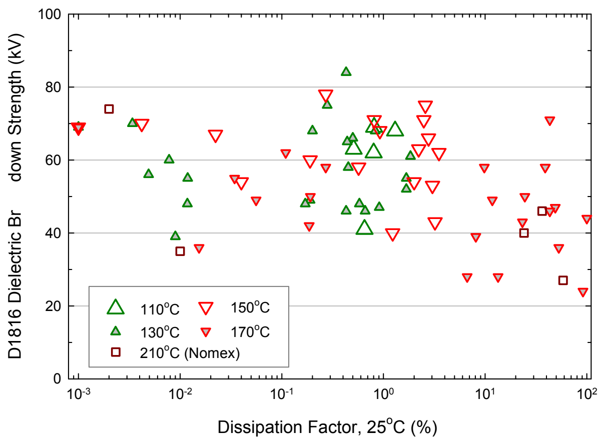


Figure 35. Dielectric breakdown strength *versus* dissipation factor Envirotemp FR3 fluid 2mm gap.

The transformers having the longest continuous service are installed at a Cooper Power Systems factory in Waukesha, Wisconsin. These transformers, both 225 kVA 3P and installed in 1996, have been constantly loaded at about 90% of nameplate rating and periodically monitored. The fluid properties are shown in Figures 36-42. Several laboratories have tested the fluid samples over the years, accounting for some of the variations seen. Except for resistivity (Figure 40), which shows a moderate decrease over time, the properties remain essentially unchanged. Of note is the viscosity (Figure 37). Viscosity is the definitive indicator of oxidation in Envirotemp FR3 fluid. The unchanging viscosity demonstrates absence of fluid oxidation in the transformers.

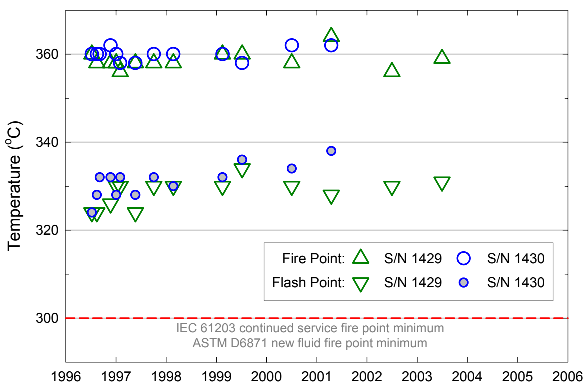


Figure 36. Flash and fire points over time of new transformers filled with Envirotemp FR3 fluid.

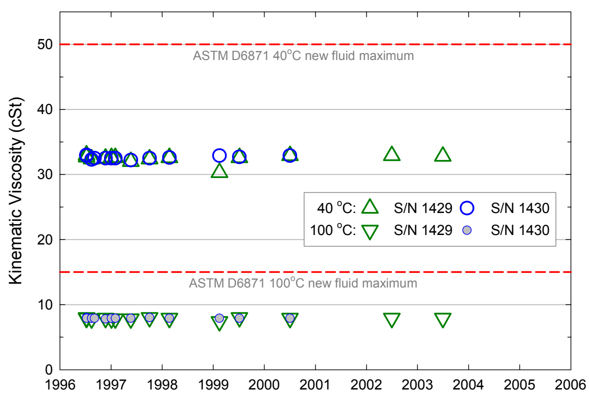


Figure 37. Kinematic viscosity over time of new transformers filled with Envirotemp FR3 fluid.

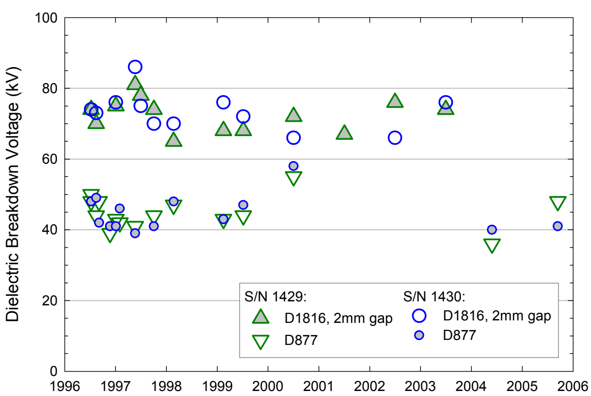


Figure 38. Dielectric breakdown strength over time of new transformers filled with Envirotemp FR3 fluid.

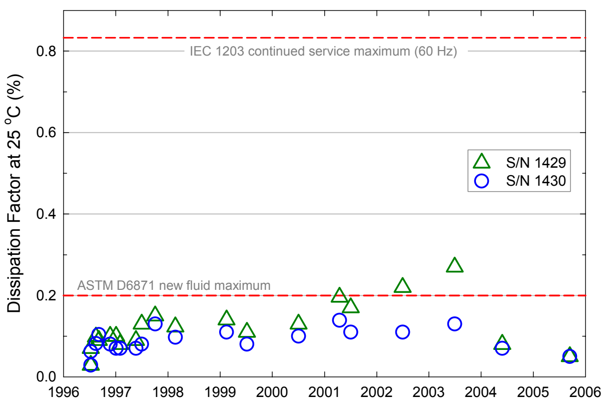


Figure 39. Dissipation factor over time for new transformers filled with Envirotemp FR3 fluid.

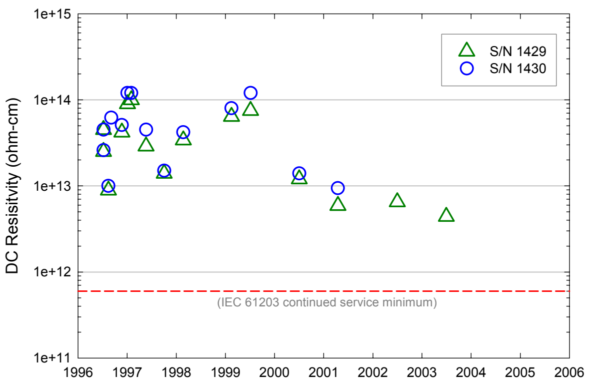


Figure 40. Resistivity over time of new transformers filled with Envirotemp FR3 fluid.

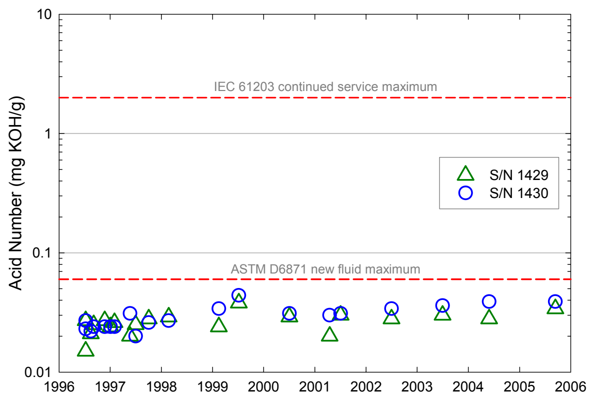


Figure 41. Acid number over time of new transformers filled with Envirotemp FR3 fluid.

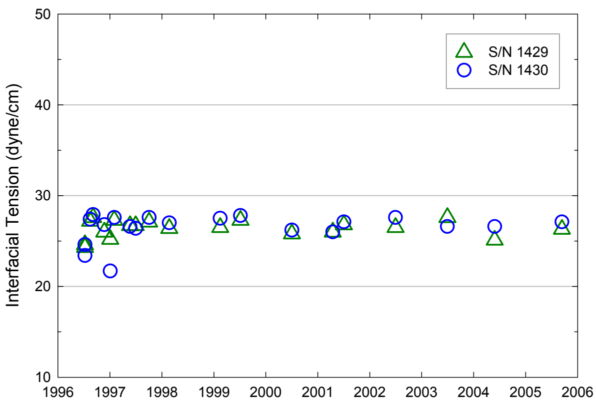


Figure 42. Interfacial tension over time of new transformers filled with Envirotemp FR3 fluid.

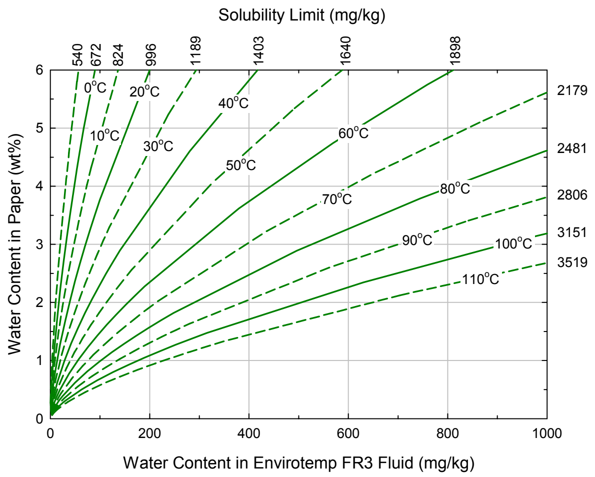


Figure 43. Water content in Envirotemp FR3 fluid in equilibrium with water content in thermally upgraded Kraft paper based on vapor pressure of water ("Piper" chart).

3.4 Impact of moisture and dissolved oxygen on ageing

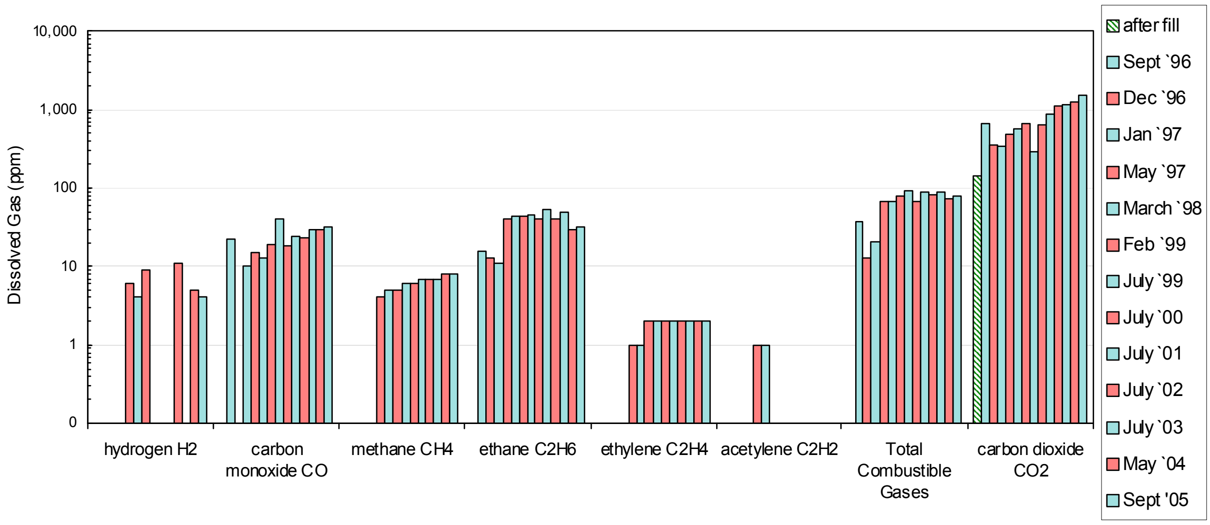
Increasing water content in the solid insulation increases its aging rate (thermo-hydrolytic degradation). The solubility of water in Envirotemp FR3 fluid is higher than that of mineral oil, shifting the equilibrium and causing water to migrate from the paper into the fluid. Figure 43 shows the effect of the equilibrium shift and its drying effect on the solid insulation. The influence of the water shift is discussed in [10,11].

3.5 Dissolved oxygen

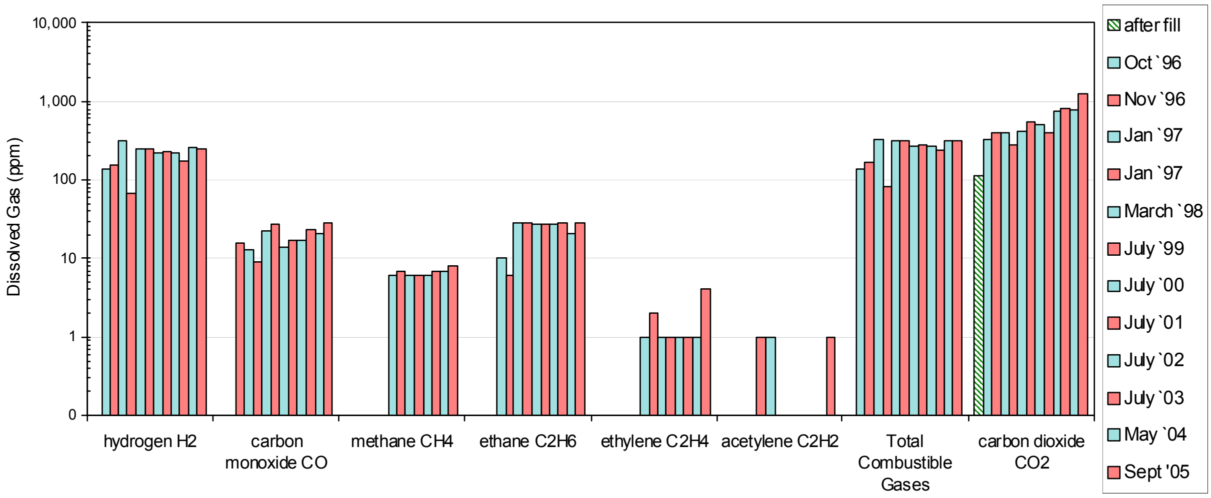
Dissolved oxygen in and of itself is not a problem. The amount of oxygen that can be dissolved into Envirotemp FR3 from the headspace or as a result of small leaks is insignificant in terms of fluid stability. The concern instead is long-term (years) free access to oxygen. Cooper Power Systems does not recommend applying Envirotemp FR3 fluid in free-breathing equipment. Transformers using conservators fitted with bags or membranes, nitrogen preservation systems, and sealed designs in general are suitable applications of Envirotemp FR3 fluid.

3.6 Causes of dissolved gas

Just as with mineral oil, gases in Envirotemp FR3 fluid are formed during normal aging processes, thermal breakdown, operation of fuses or switches, by electrical defects, or during abnormal events. The Envirotemp FR3 dissolved gas guide [16] contains analysis recommendations and examples of normally operating and faulted transformers.



(a)



(b)

Figure 44. Dissolved gases over time of new 225 kVA distribution transformers filled with Envirotemp FR3 fluid: (a) S/N 1429, (b) S/N 1430. Note the fairly high initial gas content. Fluid for power transformers is typically more thoroughly processed.

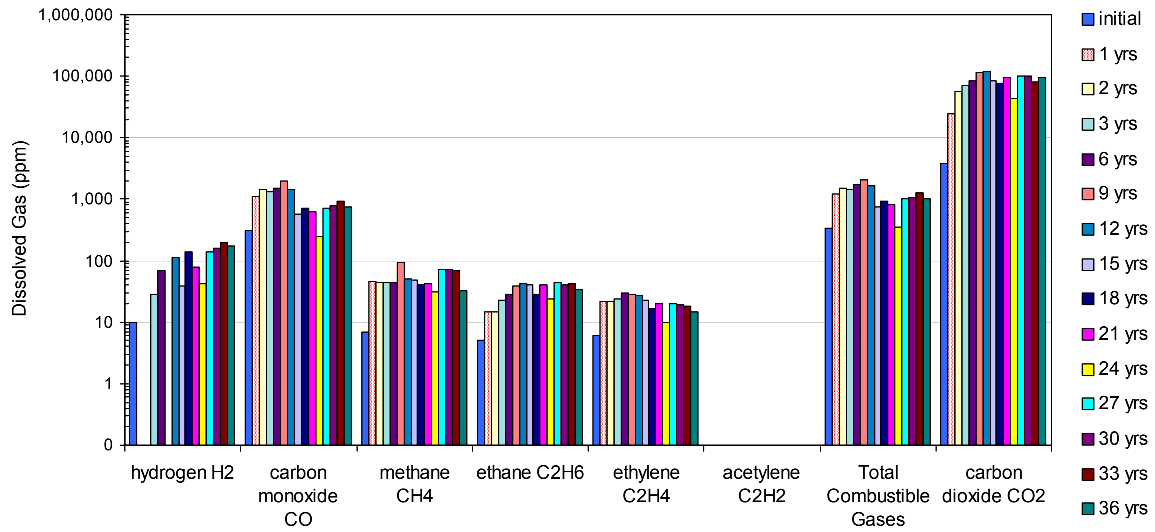
3.7 Typical dissolved gas spectra

Dissolved gases over time for the two transformers described in 3.3 are shown in Figure 44. Both have a higher proportion of ethane than is typical for a normally operating mineral oil transformer – a signature of Envirotemp FR3 fluid [16].

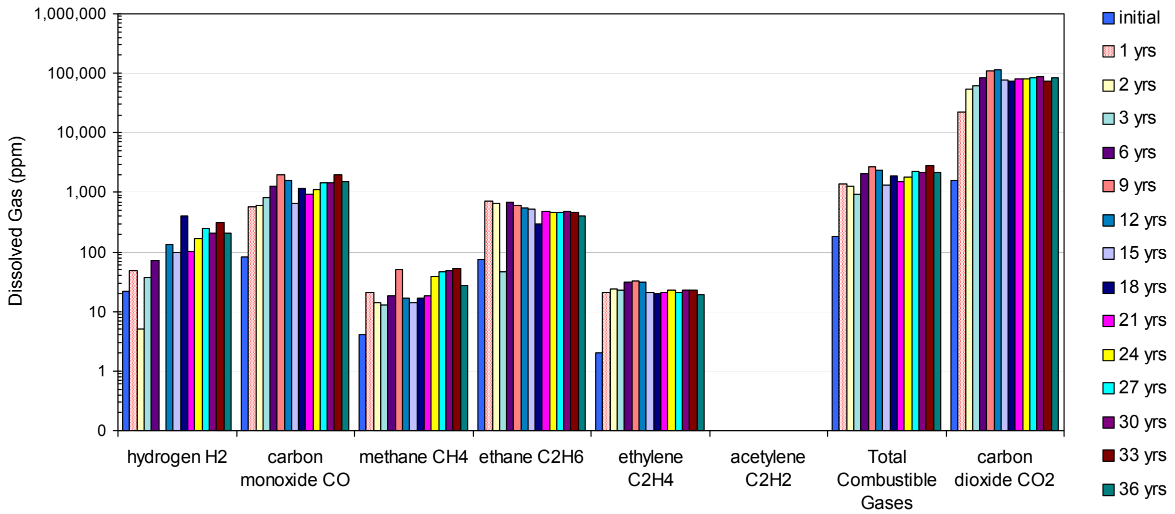
3.8 Dissolved gas and ageing

To help develop an understanding of the gases dissolved in Envirotemp FR3 fluid as transformers age, two sets of transformers were aged at 137°C, one set filled with mineral oil and the other with Envirotemp FR3 fluid for the equivalent of 36 “normal” years. At 137°C, one IEEE "normal" year is equivalent to 672 hours. Fluid samples for dissolved gas analysis were periodically taken. The gas results are shown in Figure 45.

The gas generation rates as well as the quantities and proportions of gases in the mineral oil and Envirotemp FR3 fluid are strikingly similar. Other than the characteristically higher proportion of ethane in the Envirotemp FR3 fluid compared to mineral oil, the gases over time are comparable.



(a)



(b)

Figure 45. Dissolved gas *versus* time. Test transformers filled with (a) mineral oil and (b) Envirotemp FR3 fluid were run at an hottest spot temperature of 137°C using the IEEE C57.100 method. One IEEE "normal" year of 21.54 years is represented by 672 hrs at 137°C represents.

3.9 Sensitivity to oxygen of immersed material in air

Although Envirotemp FR3 fluid in bulk is relatively immune to oxidation due to air exposure, thin films of the fluid can oxidize to form a polymer coating. It is the metal surfaces coated with thin films that are prone to polymerization. A metal surface with a thin coating of Envirotemp FR3 fluid exposed to shop air may become tacky in a matter of days. Porous surfaces, such as paper and pressboard, impregnated with Envirotemp FR3 fluid can be exposed for months without becoming tacky. They will, of course, absorb water from the atmosphere.

Following a sequence of tests, a large test tank filled with Envirotemp FR3 was put into a warehouse without a cover, and was promptly forgotten. After several years, it was discovered and the fluid tested. Aside from elevated dissipation factor and water content values, the fluid was still in good condition. No film was seen on the surface of the fluid. There was no change in viscosity, the definitive indicator of oxidation in Envirotemp FR3 fluid.

Ongoing experiments use the power factor models described in 3.2 to assess the effects of hot air drying on impregnated surfaces.

An effect of hot air oven processing of Envirotemp FR3 fluid-impregnated coils was inadvertently determined for us. Two transformers manufactured using Envirotemp FR3 fluid were tested for power factor. The power factors of both transformers were higher than typically found in mineral oil transformers. The power factor specification limit for mineral oil, 0.5%, was used as the limit for these units. Because the dissipation factor of Envirotemp FR3 fluid is higher than that of mineral oil, the power factor of the transformer also increases. Assuming a problem existed, the transformers were reworked as if they were impregnated with mineral oil. The coils were oven-dried and the transformer retested. The power factor of the transformers went up due to the increase in dissipation factor of the Envirotemp FR3 fluid as some oxidation occurred, instead of down as expected. This process is used to dry mineral oil coils to lower the transformer power factor. It also dried the Envirotemp FR3 fluid coils, but the increase in power factor due to increased dissipation factor was larger than the reduction in power factor due to drier insulation.

3.10 Normal gassing

Dissolved gas levels in normally operating transformers filled with Envirotemp FR3 fluid are similar to those found in equivalent mineral oil transformers. A feature unique to Envirotemp FR3 fluid is its higher proportion of ethane compared to that found in normally operating mineral oil transformers [16].

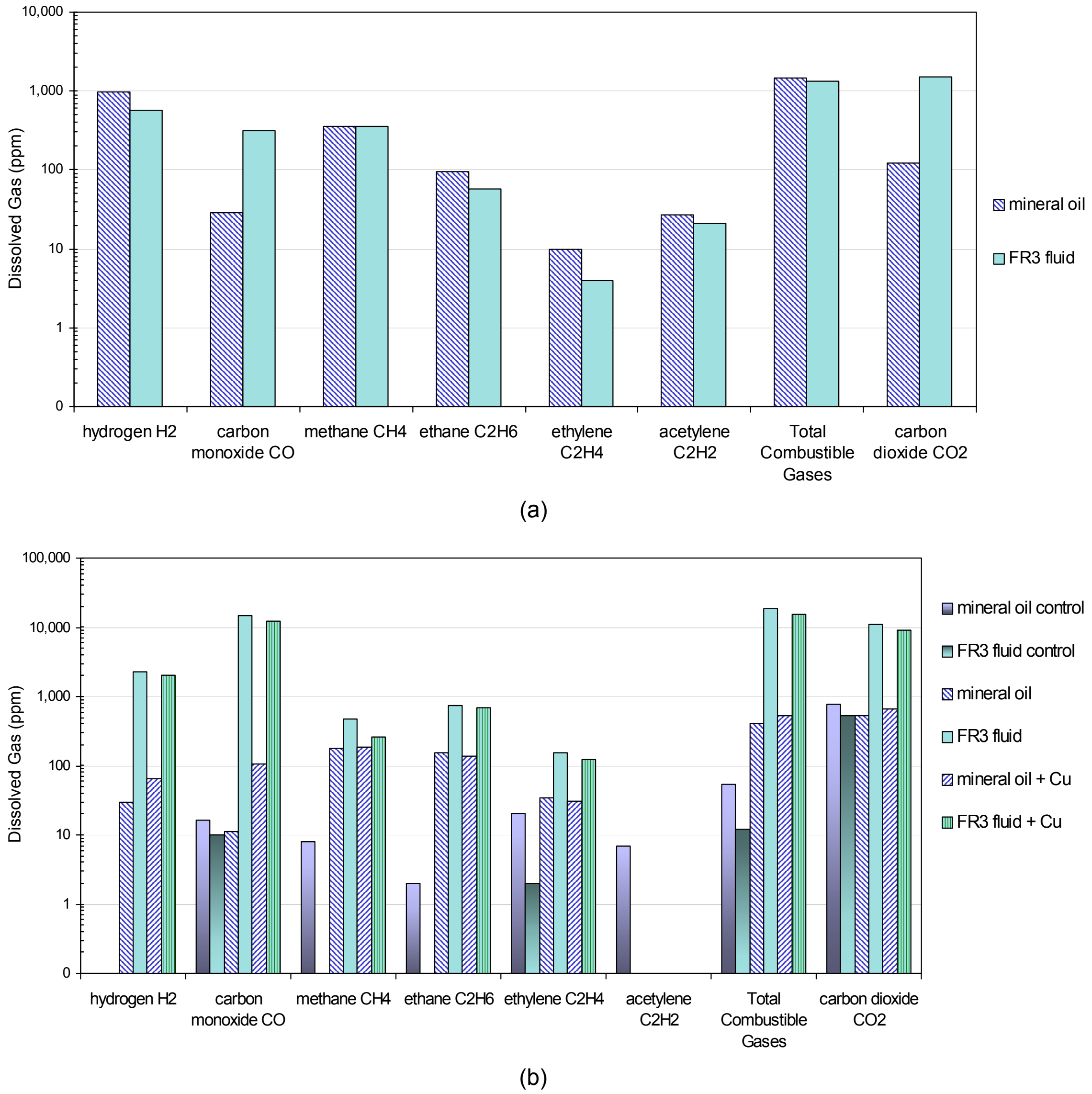


Figure 46. Mineral oil and Envirotemp FR3 fluid subjected to (a) partial discharge and (b) thermal stress [12]

3.11 Effectiveness of gas extraction

Degassing Envirotemp FR3 fluid is done in the same way using the same equipment as used for mineral oil. In order to keep the mineral oil flow rate through the processor and the same transformer set time after filling, Envirotemp FR3 fluid should be heated to 80-85°C, compared to 60°C temperature typically used for mineral oil processing. If higher temperature is not feasible, lower pressure in the degasser or slower flow rate can be used.

3.12 Interpretation of dissolved gas data

In general, the same basic interpretations of gas content used for mineral oil are used for Envirotemp FR3 fluid [16]. The IEC "Duval" method has been the most reliable fault identification method for Envirotemp FR3 fluid. Combinations of combustible gas generation rate and gas proportions, along with the Duval method, are recommended. Applications of these methods are given in the examples of [16].

Figure 46 shows the results of subjecting mineral oil and Envirotemp FR3 fluid to partial discharge and thermal stress [12].

4. General properties

4.1 Fluid preservation

Envirotemp FR3 fluid is not suitable for long-term use in true free-breathing equipment. A transformer equipped with a nitrogen preservation system or a conservator fitted with a bag or membrane is suitable, as are sealed tank designs in general.

4.2 Materials compatibility

CPS has run multiple compatibility studies and found that Envirotemp FR3 fluid, relative to mineral oil, has similar compatibility with materials used in the manufacture of transformers.

Core & Coil Materials
core steel
bare copper
bare aluminum
polyvinyl Formvar
    copper magnet wire
    aluminum magnet wire
    conical mandrel
Kraft paper
    pressboard
    diamond paper
    plain paper
    tubing
    crepe tubing
vulcanized fiber sheet
polyamide bias tape w/o
    epoxy
polyvinyl acetate adhesive

Group A Materials
thermo set epoxy
Rynite 530 (PET)
high temperature Nylon
Rostone thermoset
    polyester
fiberglass/epoxy
GPO3 polyester/glass
    laminate
Amodel 1133
polyphthalimide
Mylar film (PET)
Masonite
porcelain - radio glaze
Nylon tie wrap
Carri-strap

Group B Materials
Rosite 3250
PVC wire jacket
Storm Trapper epoxy
    coating & wires
pine block

Switchgear Components
tin-plated bus bar
silver-plated bus bar
Nylon tie wraps
fiberglass string
fiberglass string
bottle bushing
CT protector
cover gasket – wide
cover gasket – narrow
bushing gasket
GPO-3 polyester
semaphore window
auxiliary switches
shaft seal o-ring
semaphore gasket
bottle disc
tank connector
tank connector gasket
CT with wire leads

Elastomers
Buna-N
Nitrile NBR
Nitrile HNBR
Epichlorohydrin
Viton
Neoprene (used)
Cork/neoprene (used)

Sealants
Locktite PST592 pipe sealant
Locktite Vibra-Seal
Permatex 51D pipe joint
    compound

Core Banding
Glass / Polyester
Dacron / Epoxy
Green Polyester Bands
Black Nylon Bands

Adhesives
PVA
Casein
Epoxy
Cyanoacrylate
Anaerobic (Thread lockers)
Acrylics (Tapes)

Tapes
polyester/glass with
thermo set rubber adhesive
thermosetting acrylic adhesive
Kraft paper w/ wheat gum adhesive

Miscellaneous
polyethylene naphthalate (PEN)
Rynite 350
HTN primary bushing
tap changer
bayonet fuse
Epoxy Paint (Two Part)
Core Epoxy
Phenolic (DETC)
Heat Shrink (Polyester)
Laminated Wood
TX Block Material
Nylon (6/6) Ty-wraps, Banding
Yoke Band Insulation
CTC (Bonded)
Epoxy Paint (Two Part)
Core Epoxy

4.3 Water absorption during maintenance and on-site drying

Water absorption from the atmosphere is shown in Figure 47. In terms of absolute water content, Envirotemp FR3 fluid absorbs water at a faster rate than does mineral oil. In terms of relative water content, mineral oil absorbs water at a faster rate. The same precautions taken to minimize water absorption by mineral oil during maintenance should be taken for Envirotemp FR3 fluid.

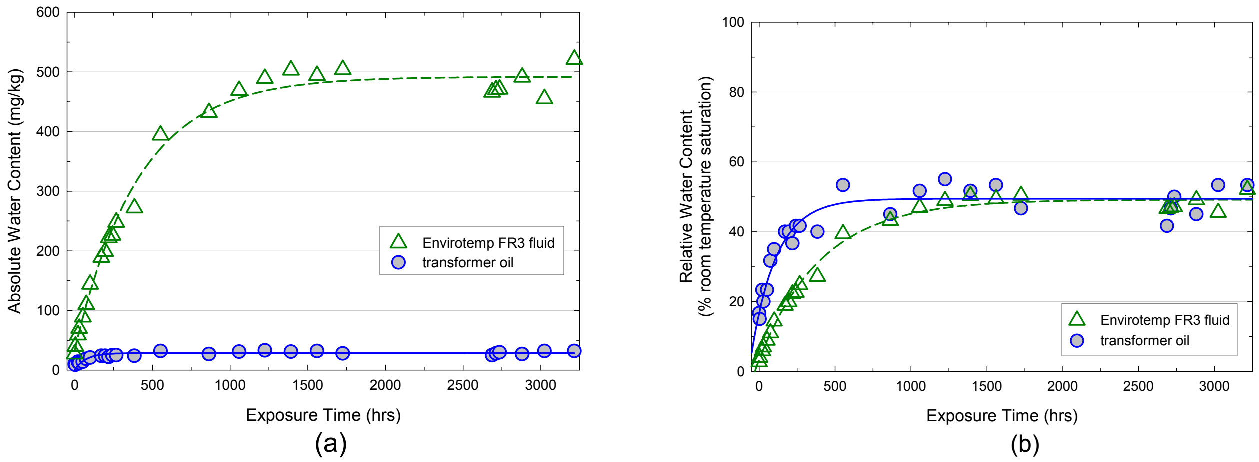


Figure 47. Water absorption from laboratory ambient atmosphere of mineral oil and Envirotemp FR3 fluid as (a) absolute water content and (b) relative water content.

4.4 Measures to avoid polymerization

Water uptake is almost always more of a concern than oxidation. Polymerization (oxidation leads to the formation of oligomers, which eventually form polymers) is most likely to occur when thin films of Envirotemp FR3 fluid on metal surfaces are exposed to air and sunlight (UV radiation). In transformers, a free-breathing system will take years to show an increase in viscosity, the definitive indication that oxidation is occurring. Long before the viscosity increases, the dissipation factor will increase greatly, so ample warning is given in transformers routinely sampled.

Maintenance and repair tasks are most likely to expose thin films of Envirotemp FR3 fluid to the atmosphere. Ideally, components impregnated with Envirotemp FR3 fluid or having thin films on the surface will be immersed in Envirotemp FR3 fluid or mineral oil. The components could be rinsed with mineral oil or stored in plastic bags of low oxygen permeability. Do not dry components in hot air ovens.

4.5 Traces of other liquids

Envirotemp FR3 fluid is compatible with most dielectric fluids except silicone. The two do not mix, and when put together separate into two phases. Silicone oil, even in low concentrations, may cause foaming during the degassing process. Changes in Envirotemp FR3 fluid properties with mineral oil content are shown in Figures 48-50.

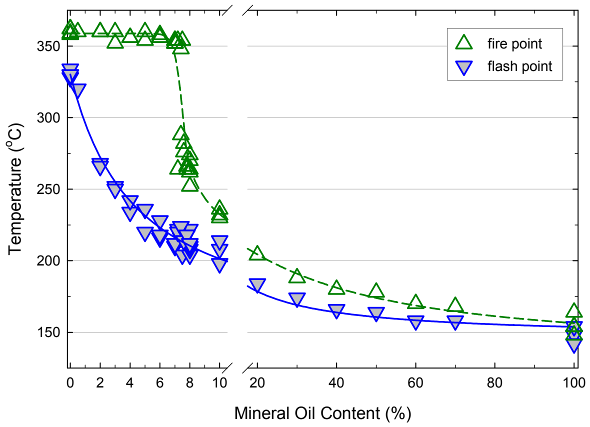


Figure 48. Flash and fire points *versus* mineral oil content in Envirotemp FR3 fluid.

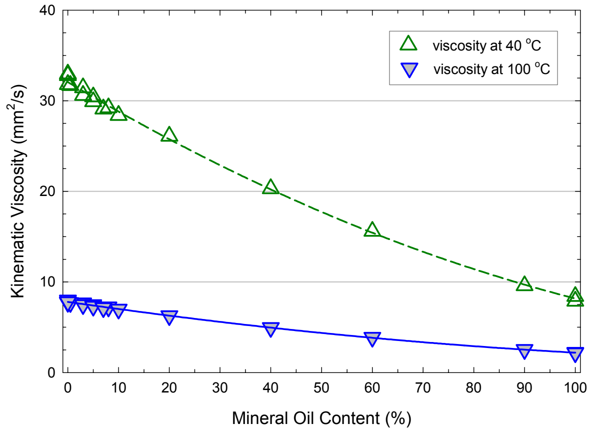


Figure 49. Kinematic viscosity *versus* mineral oil content in Envirotemp FR3 fluid.

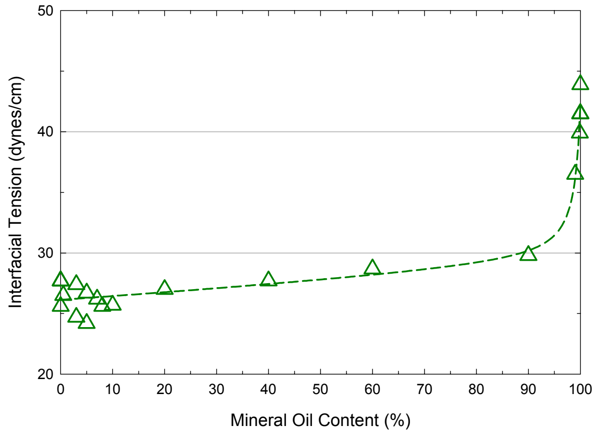


Figure 50. Interfacial tension *versus* mineral oil content in Envirotemp FR3 fluid.

4.6 Aging rate of thermal upgraded paper

Significant reductions in the aging rates of plain Kraft, cotton/Kraft, and thermally upgraded Kraft are seen. Full-scale transformer accelerated aging tests, using the IEEE C57.100 method, are described in [5]. These tests qualified the Envirotemp FR3 fluid/thermally upgraded Kraft paper insulation system for 65°C average winding rise applications. Extending the tests qualified the insulation system as a 75°C average winding rise system.

The results obtained in the full-scale tests led to an in-depth study of Envirotemp FR3 fluid interactions. Sealed tube studies using the IEEE C57.100 method showed a much slower aging rate of the thermally upgraded Kraft paper in Envirotemp FR3 fluid [6]. Plain (not thermally upgraded) Kraft also show a significant decrease in aging [7], as did cotton/Kraft paper [8]. The previous studies focused on new paper. Retrofill simulations were conducted showing a change from the aging rate of paper/mineral oil to the aging rate of paper/Envirotemp FR3 fluid after the retrofill [9]. The mechanisms responsible for the reduced aging rates are proposed in [10,11].

The thermally upgraded Kraft paper/Envirotemp FR3 fluid aging rates are applied to ANSI standard transformer designs [13,15] using the aging equation derived from the sealed tube studies [14].

4.7 Electrostatic charging and streaming electrification

The higher dissipation factor and lower resisitivity of Envirotemp FR3 fluid compared to those of mineral oil should reduce the electrostatic charging and streaming electrification tendencies. Cooper Power Systems is planning experiments to verify this.

5. Handling / oil processing

5.1 Processing rigs

Standard mineral oil processing rigs are commonly used with good results to process Envirotemp FR3 fluid. The rig should be drained of mineral oil and flushed with Envirotemp FR3 fluid. It is then ready for Envirotemp FR3 fluid processing. When finished, drain the Envirotemp FR3 fluid and flush with mineral oil to return the rig to mineral oil use. Mineral oil is typically processed at about 60°C. To keep the same mineral oil flow rate through the processor and set time for the filled transformer, the Envirotemp FR3 fluid should be processed around 80-85°C. The fluid degasses easily at that temperature. If higher temperature operation of the rig is not possible, a reduced flow rate may be needed.

5.2 Impregnating solid insulation

Envirotemp FR3 fluid penetrates solid insulation more slowly than does mineral oil. Allow double the mineral oil impregnation time for Envirotemp FR3 fluid at the same temperature. Impregnation times of laminated TX-2 is given in [17].

5.3 Influence of other oils and synthetic liquids during degassing

Avoid contamination with silicone oil. Most other dielectric fluids are compatible with Envirotemp FR3 fluid and will degas normally.

5.4 Disposal methods

Envirotemp FR3 fluid is suitable as base stock used for biodiesel fuel production. Local lubrication oil recyclers, restaurant grease recyclers, or fat rendering operations may also be possible. Envirotemp FR3 fluid can be burned for heat recovery only if diluted to 10% or less in mineral oil. It is not a hazardous waste for landfill disposal. If contaminated with hazardous materials, it must be treated as such.

5.5 Hydrolytic stability

Envirotemp FR3 fluid, like other esters, can undergo hydrolysis. The hydrolysis reaction gives free fatty acids. These acids typically are present in Envirotemp FR3 fluid and result in acid numbers higher than those seen in mineral oil. The acid number quantifies the amount of acid but does not advise its reactivity. Long chain fatty acids are less reactive than the shorter chain organic acids found in mineral oil. A discussion of hydrolysis in Enirotemp FR3 fluid is given in [11].

5.6 Processing for water content

The water content of Envirotemp FR3 fluid is reduced in the same way as in mineral oil. Water contents below 50 mg/kg are easily achieved. See 5.1.

5.7 Vapor phase processing

Cooper Power Systems has not had the opportunity to use vapor phase processing of Envirotemp FR3 fluid coils. Envirotemp FR3 fluid is compatible with the kerosene type oils used in vapor phase. Consult the manufacturer of the vapor phase equipment for recommendations.

References

[1] T.C. Wei, T.R. Blackburn, “A Report of the Partial Discharge Test Conducted on Envirotemp FR3 Fluid for Cooper Power Systems”, School of Electrical Engineering and Telecommunications, University of New South Wales, June 2004

[2] E. Gockenbach, H. Borsi, B. Dolata, “Research project on the comparison of electric and dielectric properties of natural Ester fluid with a synthetic Ester and a Mineral based transformer oil: Report No. 2 (Partial

discharge behaviour, permittivity and dissipation factor tan d)", Institute of Electric Power Systems, Division of High Voltage Engineering, Schering-Institute, University of Hanover, Germany, Sept.-Nov. 2005

[3] D. Martin and Z.D. Wang, "A Comparative Study of the Impact of Moisture on the Dielectric Capability of Esters for Large Power Transformers", IEEE/DEIS Conf. on Electrical Insulation and Dielectric Phenomena, Oct. 15-18, 2007, Kansas City, USA

[4] T.A. Prevost, "Dielectric Properties of Natural Esters and their Influence on Transformer Insulation System Design and Performance", IEEE/PES Transmission and Distribution Conf., May 21-26, Dallas USA

[5] C. P. McShane, G.A. Gauger, and J. Luksich, "Fire Resistant Natural Ester Dielectric Fluid and Novel Insulation System for Its Use", IEEE/PES Transmission & Distribution Conf., April 12-16, 1999, New Orleans, USA

[6] C.P. McShane, K.J. Rapp, J.L. Corkran, G. A. Gauger, and J. Luksich, "Aging of Paper Insulation in Natural Ester Dielectric Fluid", IEEE/PES Transmission & Distribution Conf, Oct. 28 - Nov. 2, 2001, Atlanta, USA

[7] C.P. McShane, K.J. Rapp, J.L. Corkran, G. A. Gauger, and J. Luksich, "Aging of plain Kraft paper in natural ester dielectric fluid", IEEE/DEIS 14th International Conf. on Dielectric Liquids, July 7-12, 2002, Graz, Austria

[8] C.P. McShane, K.J. Rapp, J.L. Corkran, and J. Luksich, "Aging of cotton/Kraft blend insulation paper in natural ester dielectric fluid", TJ|H2b TechCon Asia-Pacific Condition Based Maintenance & Diagnostic Conf., May 7-9, 2003, Sidney, Australia

[9] C.P. McShane, J.L. Corkran, K.J. Rapp, and J. Luksich, "Aging of paper insulation retrofilled with natural ester dielectric fluid", IEEE/DEIS International Conf. on Electrical Insulation and Dielectric Phenomena, Oct. 19-22, 2003, Albuquerque, USA

[10] K.J. Rapp, C.P. McShane, and J. Luksich, "Interaction Mechanisms of Natural Ester Dielectric Fluid and Kraft Paper", IEEE/DEIS 15th International Conf. on Dielectric Liquids, June 26 - July 1, 2005, Coimbra, Portugal

[11] A.W. Lemm, K.J. Rapp, and J. Luksich, "Effect of Natural Ester (Vegetable Oil) Dielectric Fluid on the Water Content of Aged Paper Insulation", EIA/IEEE 10th Insucon International Electrical Insulation Conf., May 24-26, 2006, Birmingham, UK

[12] L. Lewand, "Laboratory evaluation of several synthetic and agricultural-based dielectric liquids", Doble International Client Conference, 5E, 2001, Boston, MA USA

[13] S. Durian, "Dielectric Fluid Relative Thermal Performance", Engineering Development Report TP03-DR-006, Cooper Power Systems, May 21, 2003

[14] J. Luksich, "IEEE Loading Guide A and B Factors for Envirotemp FR3 Fluid and Thermally Upgraded Kraft Insulation", Engineering Development Report TP03-DR-009, Rev. 1, Cooper Power Systems, June 12, 2003

[15] S. Durian, "Comparative Loading, Thermal, and Aging Performance of Thermally Upgraded Paper in Mineral and Envirotemp FR3 Fluid", Engineering Development Report TP03-DR-017, Cooper Power Systems, July 14, 2003

[16] "Envirotemp FR3 Fluid Dissolved Gas Guide", R900-20-19, Cooper Power Systems, August 17, 2006

[17] T. Prevost, "Oil Impregnation Rate of Cooper FR3 Oil", Wicor International Technical Report 3206, EHV Weidmann, February 6, 2006