FR3™

envirotemp™
ester dielectric fluids

Cargill®

Disclaimer

All information, statements, recommendations and suggestions in this presentation are believed to be true and accurate but are made without guarantee, express or implied.

Further distribution, on-line publication or reproduction requires a written authorization from Cargill.

WE DISCLAIM, TO THE FULLEST EXTENT PERMITTED BY LAW, ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE and FREEDOM FROM INFRINGEMENT.

The information, statements, recommendations and suggestions contained herein are subject to change without notice. Tests conducted by Cargill labs unless otherwise noted.

Cargill at a glance

More than 155,000 employees
Located in 70 countries

Speaking
65+
languages

150+
years of experience

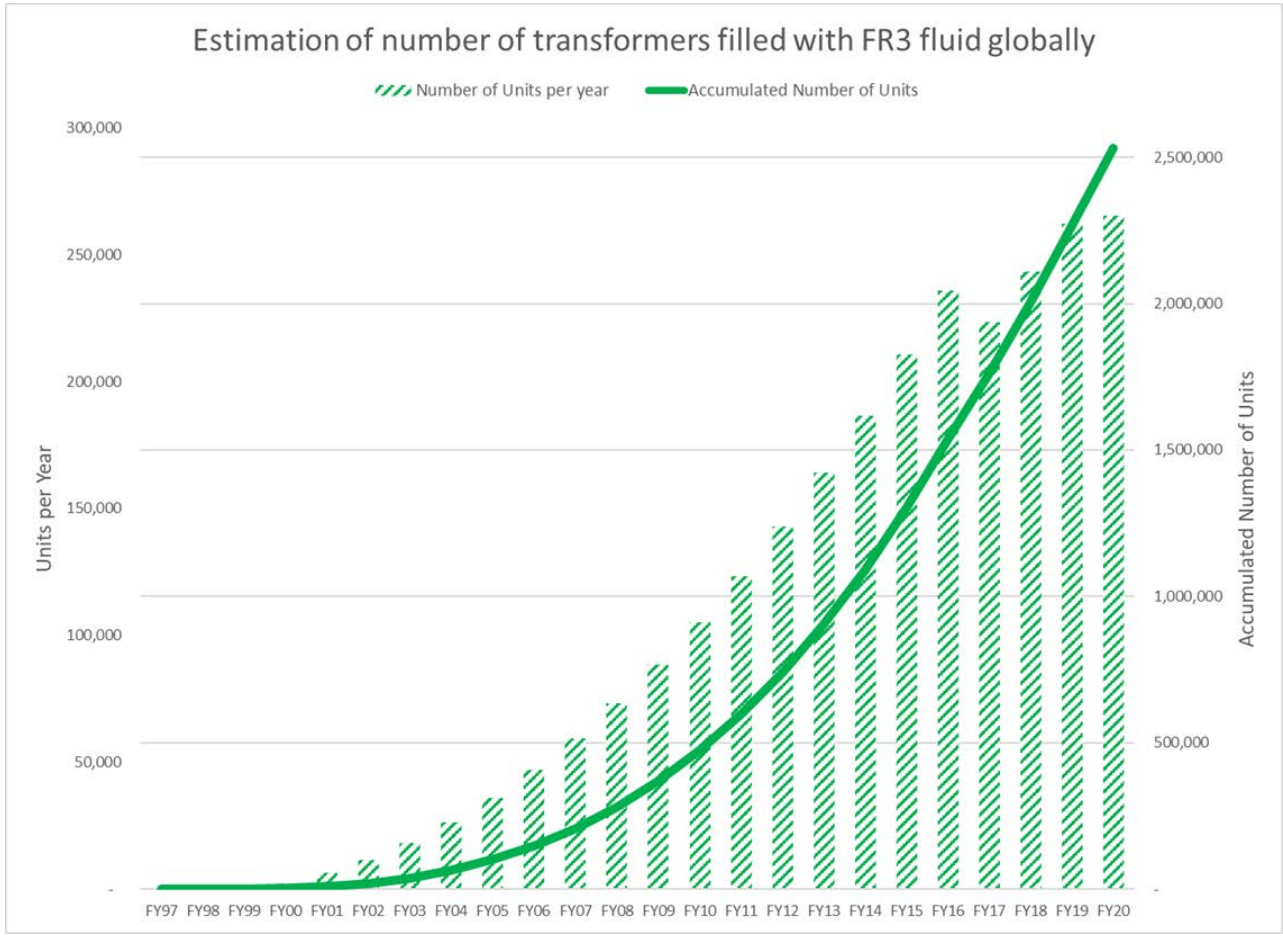

FR3™
envirotemp™
ester dielectric fluids
360 fluid

History Overview

Alternative liquids → replacing PCBs

- 1st gen = HMWH (R-Temp) – Mid 70s
- 2nd gen = Synthetic esters – Early 80s
- 3rd gen = Natural esters – Early 90s

- HMWH production discontinued in 2003
- Synthetic ester → niche applications
- Natural ester → latest development, largest market share



Global installations - proven

Over 2.5 million FR3™ fluid-filled transformers in service globally

- Many major utilities around the globe are mainly purchasing new units filled with FR3™
- 50,000 power transformers
- 15,000 retrofills
- Other installations include data centers, solar, wind, and network transformers

FR3 fluid approved for all voltage classes and transformer types

- HV testing validates usage through 765kV
- Siemens 420 kV energized in 2013, Germany
- 345kV hydropower generators (GSU) for Bureau of Reclamation, US
- 420kV transmission lines in Italy

Industry recognition

- 2013 Presidential Green Chemistry Award
- 2013 EPA Design for the Environment (DfE) designation
- USDA Bio Preferred Program
- EPA Environmental Technology Verification California Environmental Technology Certification
- FERC ruling – retrofills with FR3 fluid may be capitalized

What triggered life studies?

- **From 1995 to 1998 a “Lockie Test” was performed to validate the FR3™ fluid + paper system for 65°C AWR**
- For Cooper Power System, nowadays Eaton, transformer designers it was considered as a required “Due Diligence”.
- Main focus was to sell transformers filled with the new fluid, not commercializing the fluid. A comprehensive validation program was performed to mitigate any risk.
- Early version was named “HV-7” as in the photo here, where one can clearly see the darker color of the paper in the mineral oil transformer. Both transformers had same aging time, exceeding 5x the unit of life.
- Both transformers were approved, in all 3 temperatures.

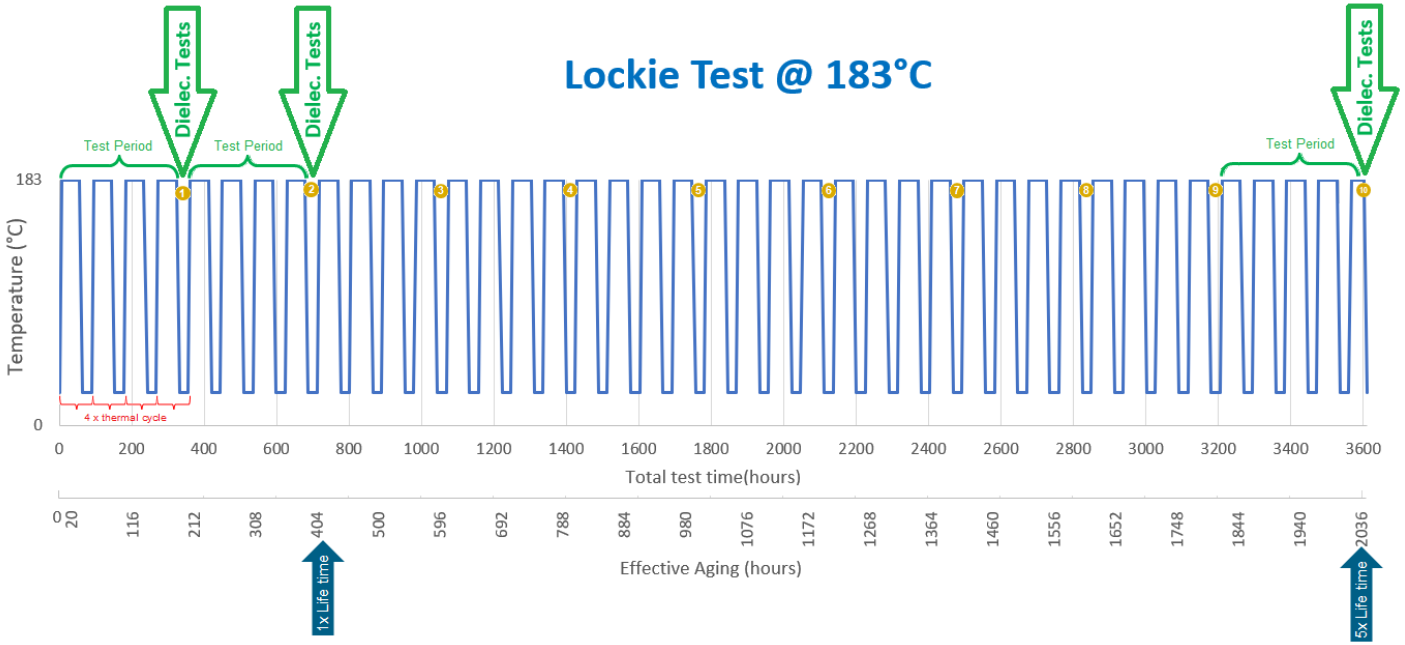
Transformers from cell A (167°C) after 5x nominal life

Accelerated Aging Tests - FR3™ fluid

- Lockie Method (IEEE C57.100): Accelerated aging and dielectric tests in actual transformers
- Three sets of 5 distribution transformers endured 10 periods of 4 thermal cycles of short-circuit heating, reaching 167°C, 175°C and 183°C.
- Each group: 4 were FR3 filled and 1 had mineral oil
- After each period the transformers were tested. **To be approved in the test, they must reach 5x the IEEE unit of life.**

Test Results: FR3™+TUK approved

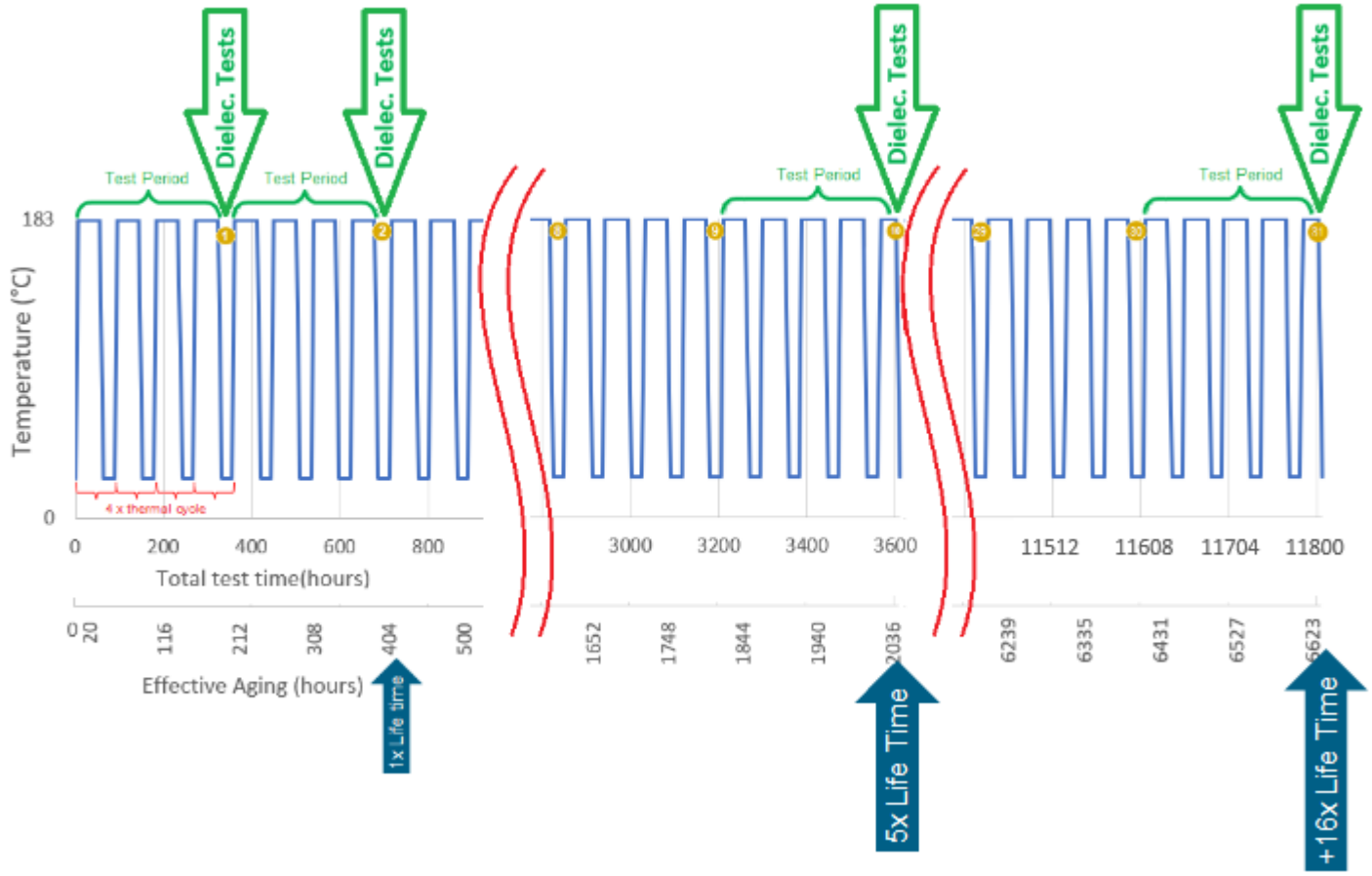
- All units of the 3 cells, reached 5x lifetime without major failures
- Chart presents the cycles and periods for the 183°C hotspot.
  - 180,000h @110ºC ≅ 400h @183ºC
  - 5x IEEE life = 2000h @183ºC
- Tests include:
  - Short Circuit: 25x rated current for 2s
  - Full Wave Impulse: 65% nominal
  - Applied Potential: 1 min / 65% nominal
  - Induced Potential: 400Hz, 130% rated, 7200 cycles



Test was extended after 5x!

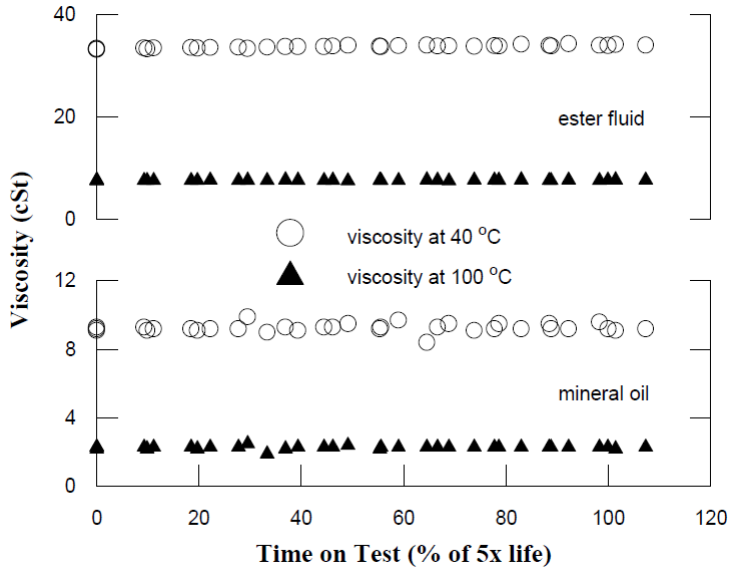
FR3™ reached 3.9x required life

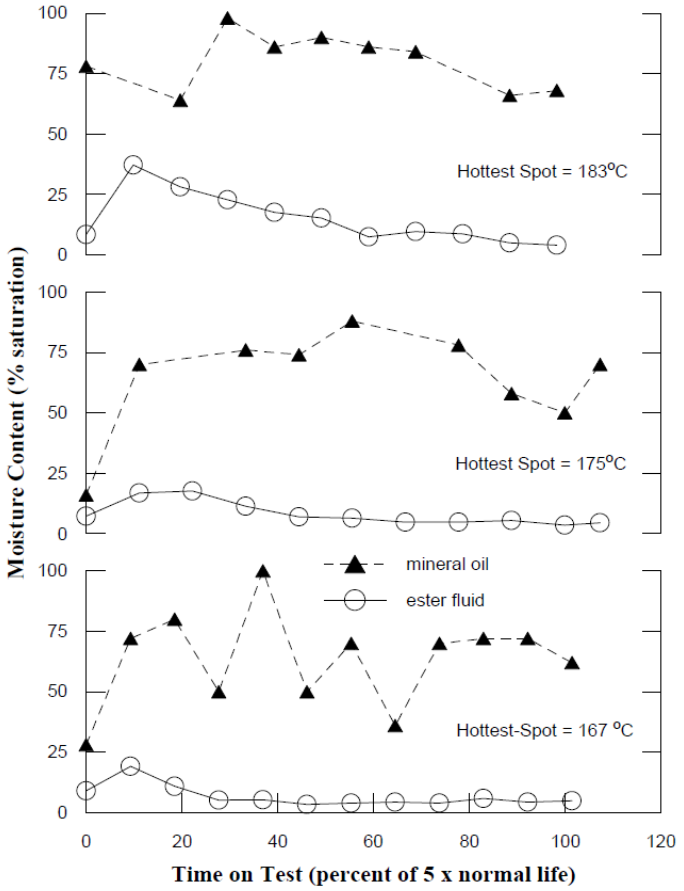
- Test extended for the FR3 filled units reached **mean time to failure**:
  - At 183°C → **16.5x** / 6,623 “peak hours”
- The last FR3 unit failed at **7800 peak hours**, representing **19.5x unit of life**
- Mineral oil units did not surpass 2000 peak hours 5x units of life
- **FR3 immersed unit lasted 3.9x longer than required for a 65°C AWR**
- **Clear advantage for transformer life when filled with FR3 fluid.**



Additional Test Results

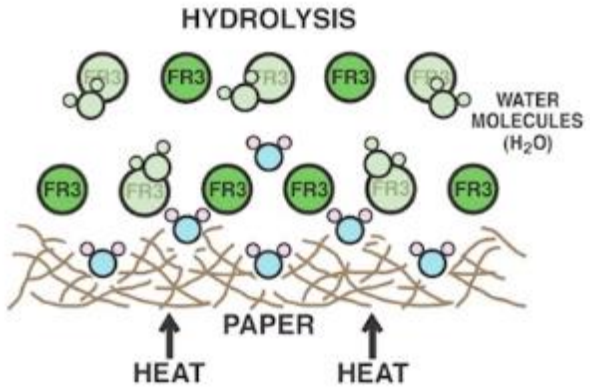
- Samples of the fluid were taken after the 5x lifetime
  - No trend of increasing viscosity
  - Moisture content behavior was different
- Fluid oxidation stability confirmed as exceeding requirements
- Continuous drying effect confirmed with loading cycles





Paper immersed in FR3™ liquid ages 5-8 times slower than in mineral oil

Higher moisture saturation + Hydrolysis = Water Scavenging



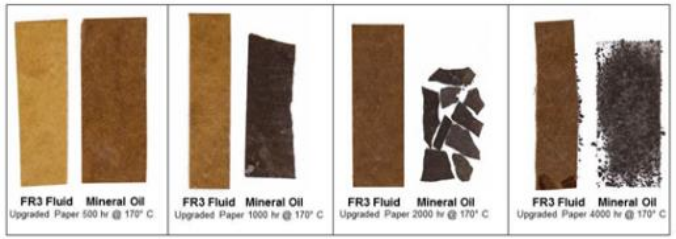
Hydrolysis

- Moisture removed from the windings is consumed by hydrolysis reaction. The byproducts are mild free-fatty acids (long chain), which are not harmful.
- FR3 liquid continuously “dries out" the paper, keeping it near orginal moisture content. Benefits for dielectric reliability.

Effect of FR3 liquid to the paper

- The aspect of the paper samples aged at same conditions but in different fluids is very clear. The rate of degradation is much lower when the paper is immersed in FR3 liquid.

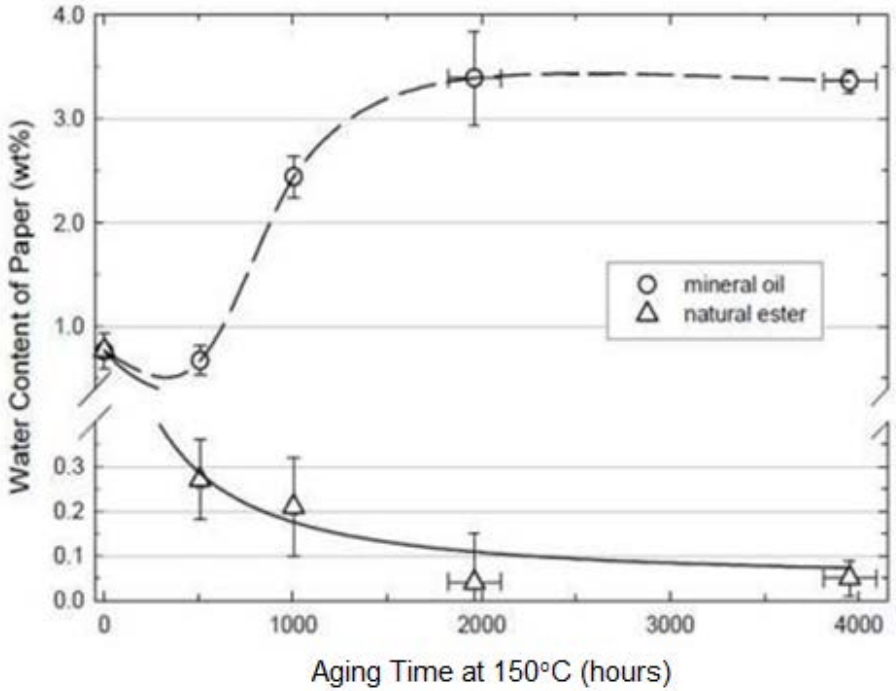
Accelerated Ageing Test
(FR3 liquid vs. Mineral Oil – side-by-side)



500 hours | **1000 hours** | **2000 hours** | **4000 hours**

Continuous drying effect

- Paper aging produces water → thermal induced
- Moisture affects not only paper aging, but also the dielectric capacity of insulation system
- In MO moisture stays in the paper. In FR3™ fluid, more moisture migrates to the fluid
- Moisture and temperature trigger hydrolysis → **excessive moisture is consumed**
- **Drier insulation has better dielectric performance**
- Bubbling effect is driven by moisture content in paper. **Dry paper mitigates the risk during overloads**
- **Reduce maintenance to dry the insulation system**



FR3™ & Envirotemp™ Fluids are:

Safer

- Risk of transformer fire mitigated by using a K-Class filled transformer

Sustainable

- Biodegradable
- Reusable

Reliable

- Robust solution
- Dielectric capacity preserved

Resilient

- Enhanced capability
- Continuous drying of paper