NWPPA
Northwest Public Power Association

Natural Ester Dielectric Fluid Overview

Envirotemp™ FR3™

NWPPA E&O ETF Meeting
Spokane, Wa.

April 11, 2016

Jeff Valmus

FR3™
ENVIROTEMP™ NATURAL ESTER FLUID

Cargill

What is Natural Ester Dielectric Fluid?

- Natural ester (dielectric fluid) insulating liquid is made from the oil of naturally grown vegetables

- Several different varieties have been made but the most widely used is FR3 which is made from soybean oil

- Initially designed to be an environmentally friendly alternative to less flammable dielectric fluids like PCBs and High Molecular Weight Hydrocarbons

- Commercially began using in transformers in 1996

Validated by industry

Meets IEEE and IEC standards

- More than 250 series of tests conducted on FR3 fluid
- IEEE C57.154 and IEC 60076-14 High temperature insulation system standard enables up to 85 rise new transformer designs

Classified as a less flammable fluid (K-class)

- Underwriters Laboratory
- FM Global

Environmental testing

- Carbon neutral according to BEES 4.0 lifecycle analysis
- Ultimately biodegradable by EPA
- Non-toxic and non-hazardous in soil and water by OECD

Industry recognition

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

Proven, global installations

Over 1,000,000 natural ester fluid-filled transformers in service globally

- 25,000 medium & large power transformers
- 15,000 indoor units
- 50,000 substations
- 10,000 retrofills

FR3 fluid approved for transformers up to 500kV

- HV testing validates usage through 500kV
- Siemens 420kV loaded in 2013, Germany
- 500kV transmission line for Electronorte, Brazil
- 345KV transmission line for Bureau of Reclamation, US

Over 100 utilities, including many complete adapters

- PGE, EWEB, SCL, PG&E, SMUD, etc.
- Many Munis, Coops, and RECs

Over 100 global OEMs applying and promoting technology

Types of installations

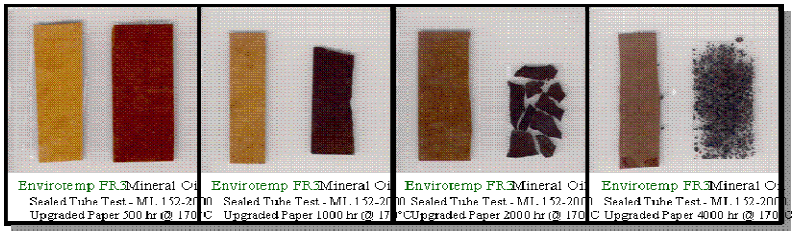
- Industrial/Commercial
- Utility
- Network transformers
- New and retrofill applications

How are Natural Esters different from mineral oil

- **Fire safety**
  - No fires, cleanup, downtime, or replacement costs
  - Protects nearby equipment and buildings
  - Greatly reduced risk to personnel
  - Reduced clearance requirements and preventative equipment

- **Environmental**
  - FR3 fluid produced from domestic soybeans
  - Environmental safety (no hazardous fumes, fires, reduced spill mitigation)
  - Petroleum independent
  - Reduced carbon emissions
  - Biodegradable/non-toxic, recyclable, and sustainable

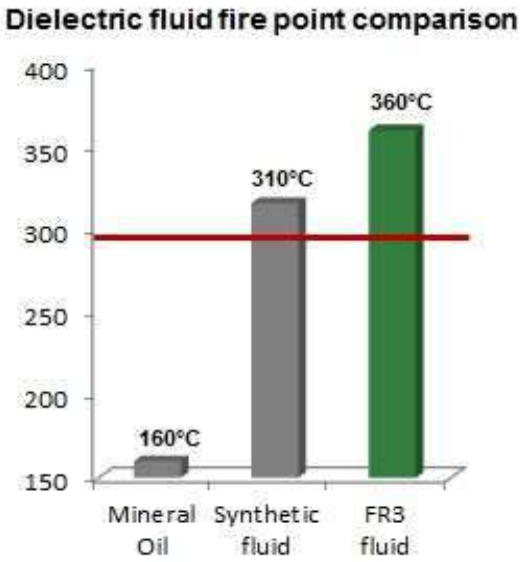
- **Optimized transformer performance**
  - Insulation system up to 8X* extended lifespan
  - Transformer asset extended lifespan
  - Increased overload capability
  - Enables smaller, lighter (75-85C rise) designs

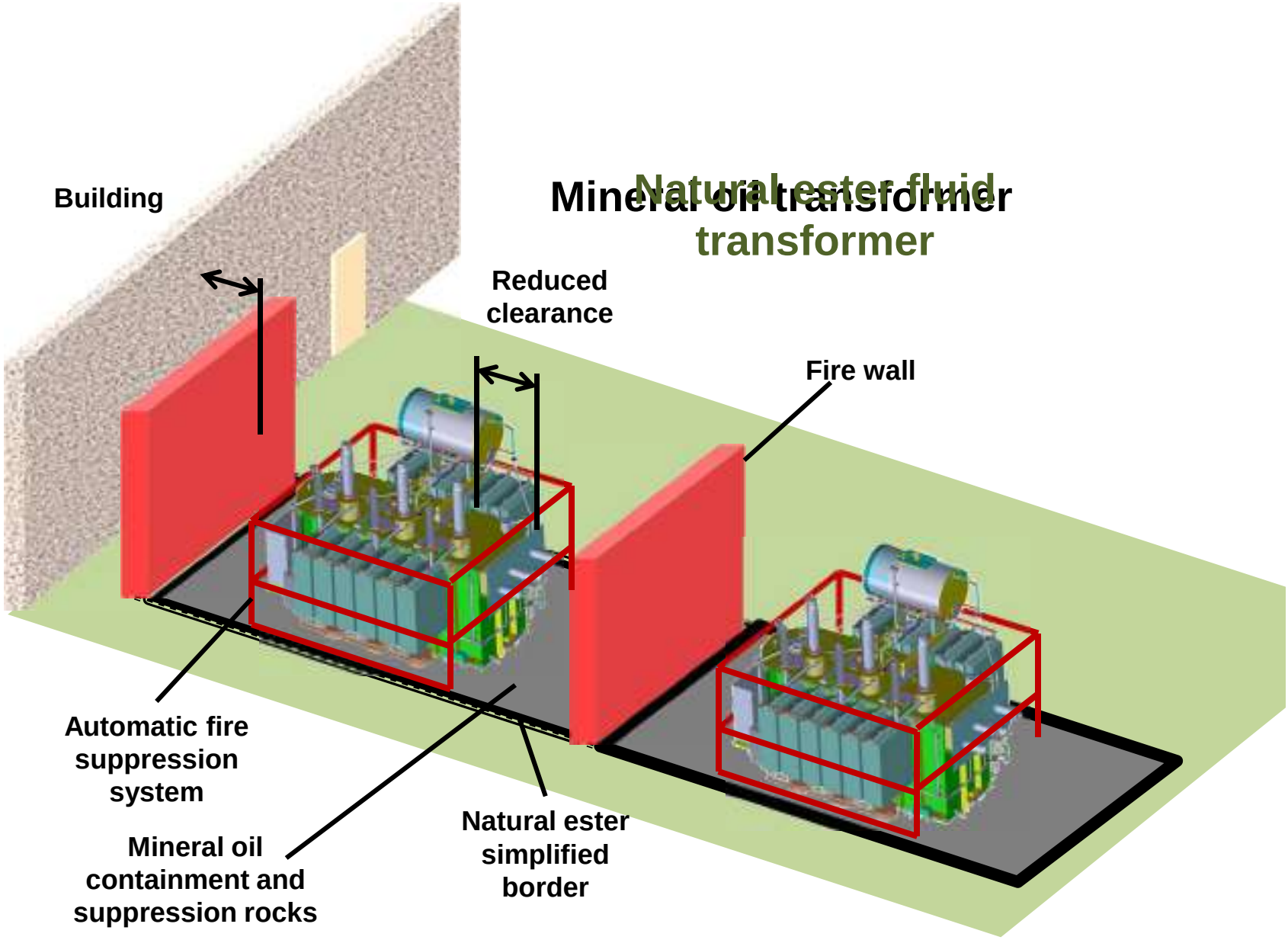


Fire point is most critical factor for transformer fire safety

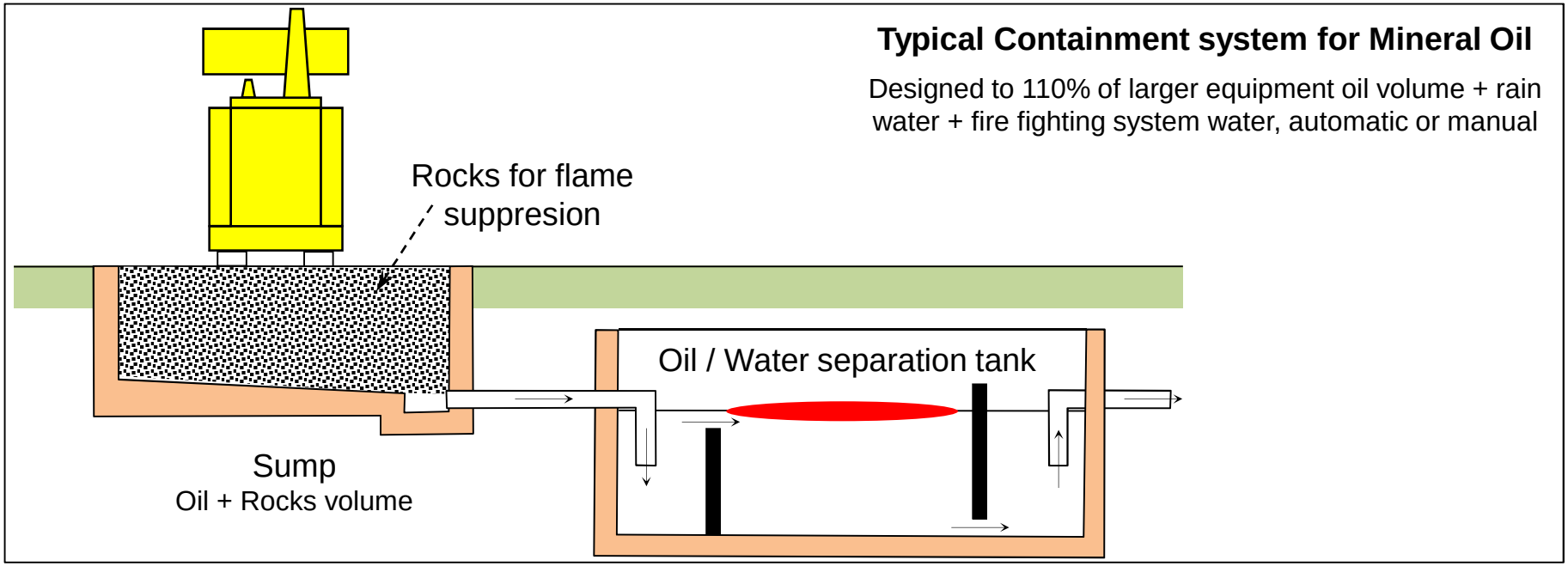
- Natural ester dielectric fluid fire point = 360ºC
- Zero fire history in natural ester fluid filled transformers*
- UL Classified and FM Approved*
- Eliminate deluge systems and fire walls
- Reduced clearances
- Simplified containment designs

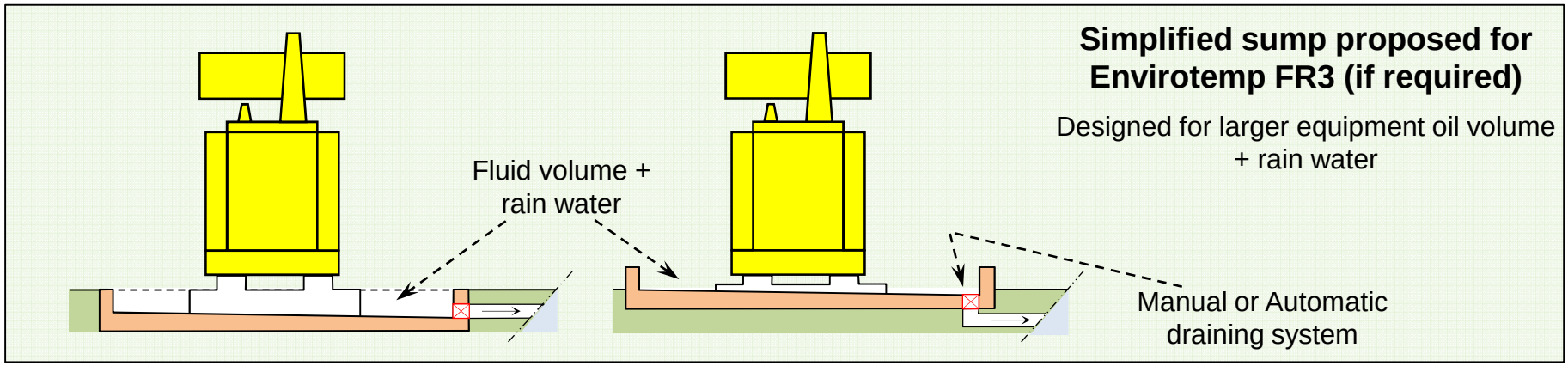
ZERO
TRANSFORMER FIRES
IMPROVED FIRE SAFETY




Building
Mineral oil transformer
Natural ester fluid transformer
Reduced clearance
Fire wall
Automatic fire suppression system
Mineral oil containment and suppression rocks
Natural ester simplified border

Simpler containment system



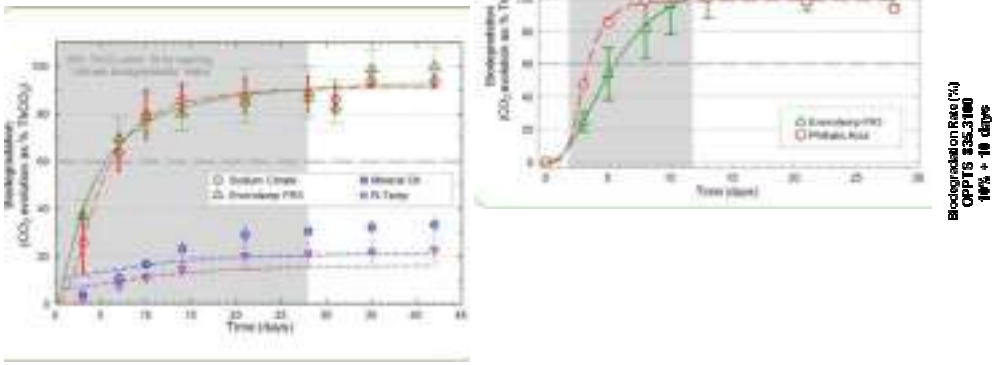


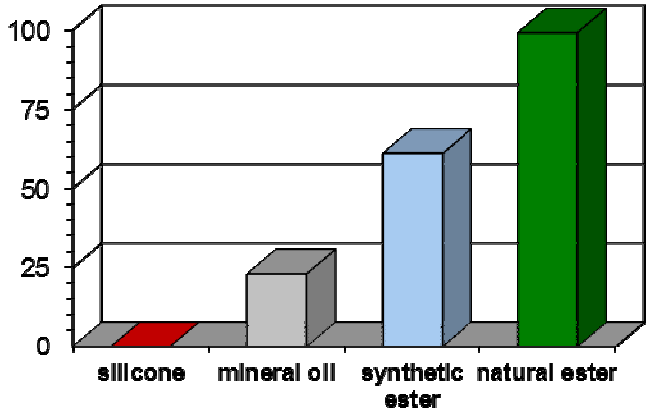
Natural ester fluid is a better choice for the communities you serve

- Made from a renewable resource
  - >98% vegetable oil
  - Carbon neutral*
  - Contains no petroleum, halogens, silicones or sulfurs
- Non-toxic, non-hazardous in water and soil
  - OECD oral and aquatic toxicity test
- Biodegrades in 28 days or less
  - Ultimately biodegradable according Environmental Protection Agency (EPA)
- Recyclable and Sustainable

* According to BEES 4.0 lifecycle analysis

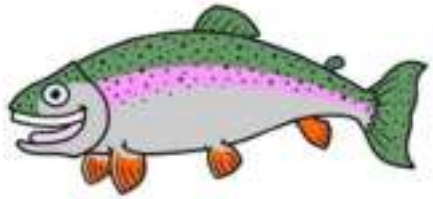
Best-in-class environmental properties





Biodegradable

Non-toxic



Acute aquatic toxicity of Envirotemp FR3 fluid

Test	Method	Dose (mg/L)	Mortality (# of fish)
Acute Aquatic Toxicity Lethality Using Rainbow Trout	OECD 203 Environment Canada	1,000 1,000	0 0
Acute Aquatic Toxicity	ASTM D608, OECD 203	10,000	0

Acute oral toxicity of Envirotemp FR3 fluid

Method	Test	Animals	Dose (mg/kg)	% Mortality Total
OECD 420	Sighting	1 F	2,000	0
	Main	5 F	2,000	0
		5 M	2,000	0

Animals	14 Day Average Body Weight (g) Initial	7 Day	Final
1 F	226.0	251.2	259.9
5 F	221.5	265.0	280.6
5 M	285.3	352.0	378.8

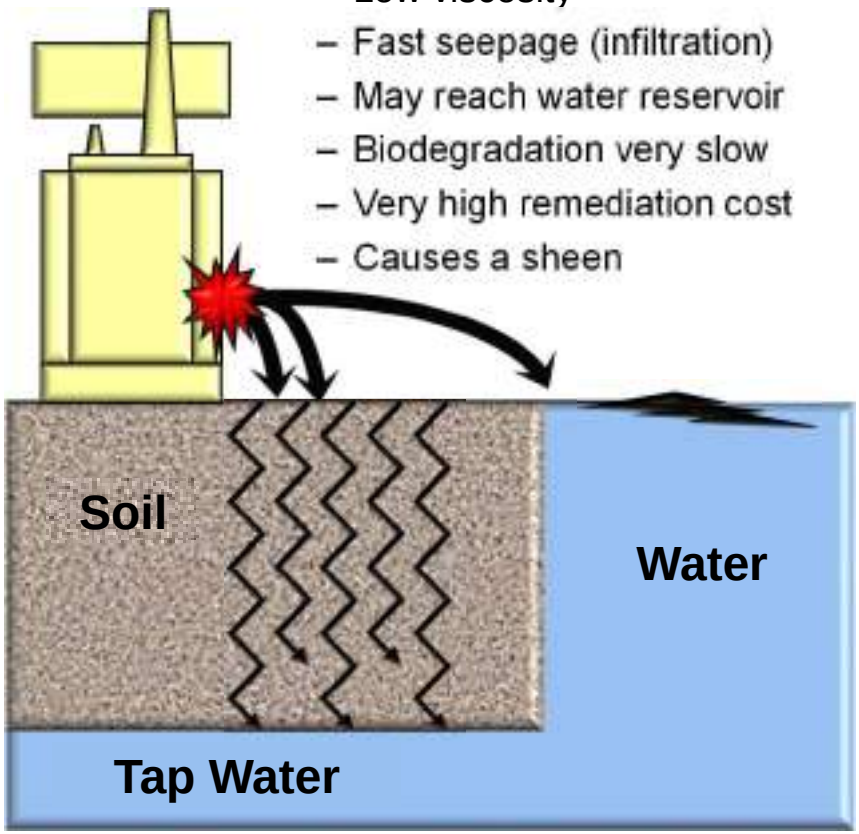
FR3 fluid is biodegradable and non-toxic on both soil and water.

Cargill

Using FR3 fluid results in simpler, less costly spill remediation

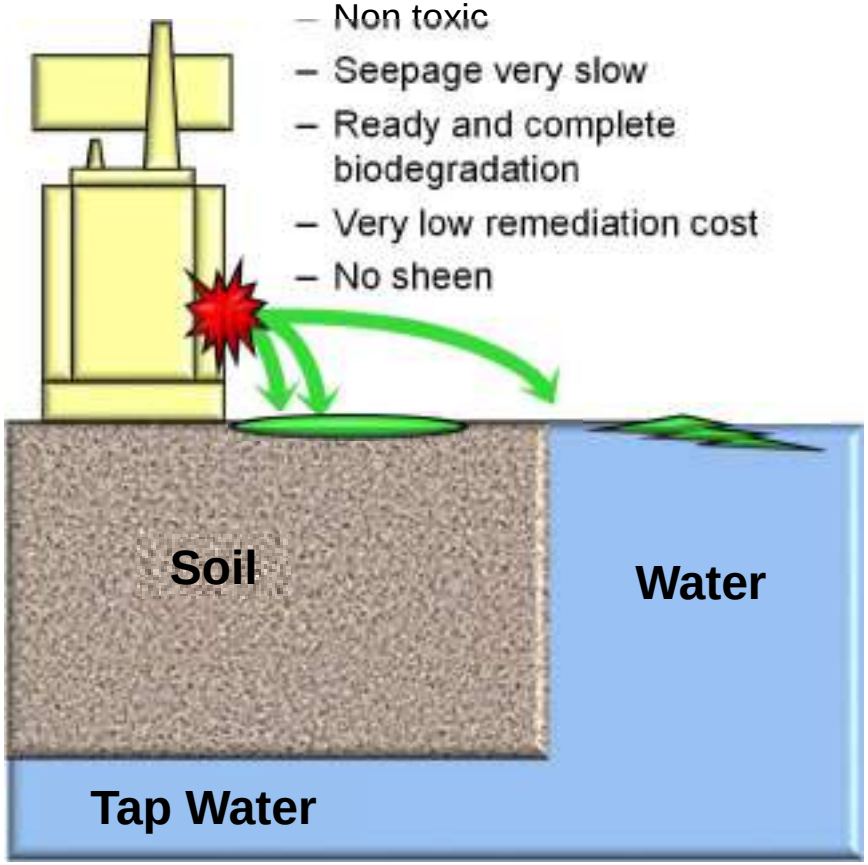
Mineral Oil

- Low viscosity
- Fast seepage (infiltration)
- May reach water reservoir
- Biodegradation very slow
- Very high remediation cost
- Causes a sheen



FR3 fluid

- Non toxic
- Seepage very slow
- Ready and complete biodegradation
- Very low remediation cost
- No sheen



Industry recognized best-in-class environmental fluid

GREEN CHEMISTRY CHALLENGE
A U.S. EPA Program

USDA CERTIFIED BIOBASED PRODUCT
PRODUCT 100%

USDA United States Department of Agriculture
BioPreferred℠

ETV

SAFER CHOICE
Meets U.S. EPA Safer Product Standards
epa.gov/dfesaferchoice

CALIFORNIA ENVIRONMENTAL TECHNOLOGY CERTIFICATION
CALCERT

BEES® 4.0

Cargill

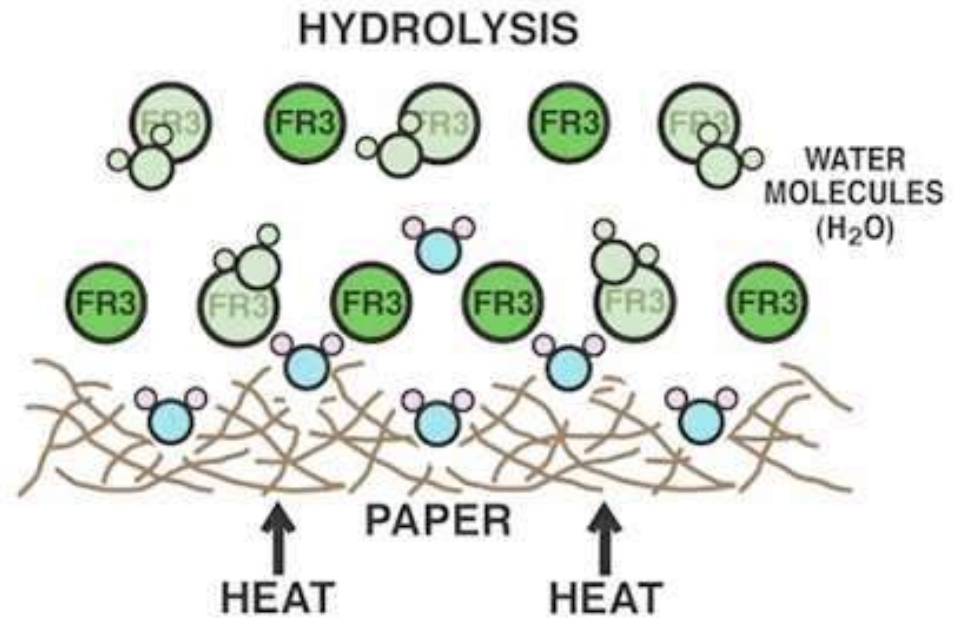
Transformer Design and Operational Optimization

Improve reliability: Extend insulation and asset life 5-8x longer than mineral oil

Unique chemistry of FR3™ fluid protects insulating paper by:

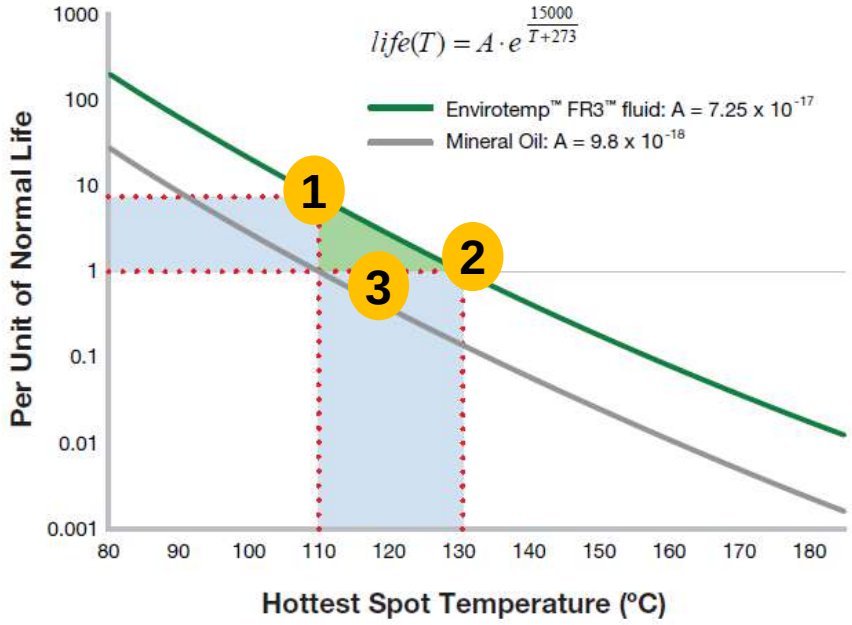
- Hydrolysis can absorb
- [illegible]
- [illegible]

Protecting life
one fac



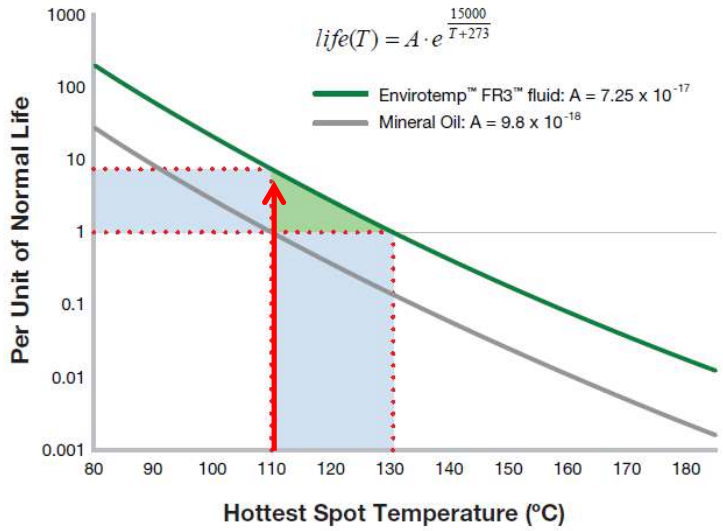
Life “Triangle” flexibility extends transformer life or increases load capacity

- IEEE C57.154 High temperature insulation system standard
  - Current standard 110ºC hot spot with 65 AWR limits transformer capability
  - FR3 fluid in TR designed for MO will extend insulation system life
  - Envirotemp™ FR3™ fluid-based insulation systems can be run 20ºC warmer without degrading life



Life Extension and Improved Reliability

- Insulation system will not be transformer failure mode
- Improved reliability and reduced catastrophic failure potential
- Extend residual life of transformer, while gaining fire and environmental safety



Life Extension:
SMUD achieves total cost savings through extended asset life

COMPARE MINERAL OIL 30-YEAR LIFE WITH 40-YEAR EXTENDED LIFE WITH FR3 FLUID

Transformer description	Purchase price	PV TOC with mineral oil dielectric (30-year life)	PV TOC with FR3 fluid (40-year life)	PV TOC difference	Present value benefit over purchase price
15kVA Pole Type	$385	$1,317	$1,187	$130	**34%**
50kVA 1 Phase Pad	$1,102	$3,001	$2,688	$313	**28%**
150kVA 3 Phase Pad	$4,385	$7,967	$7,026	$941	**21%**

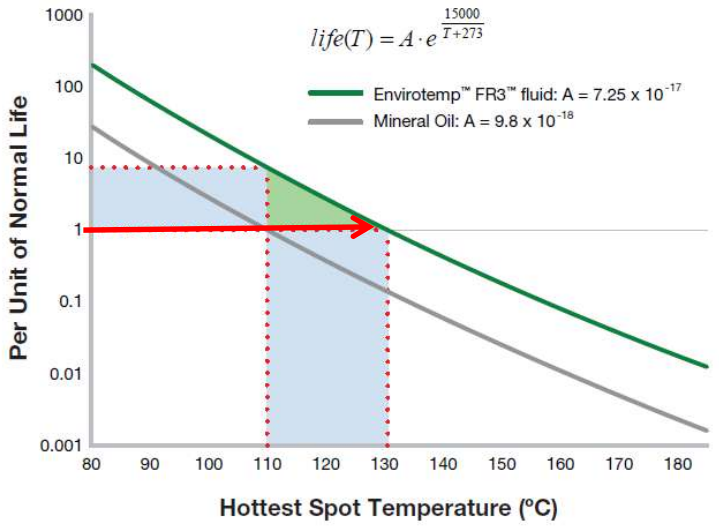
FINANCIAL ANALYSIS SUMMARY – Tampa Electric

56% SAVINGS OVER 40 YEARS. $8.7MILLION PER YEAR

ALL DISTRIBUTION PAD/POLE	MINERAL OIL	FR3 FLUID
NET PRESENT COST OF INVESTMENT (1ST COST)	$25,635,713	$21,203,178
NET PRESENT COST OF LOSSES (COL)	$164,032,188	$159,729,498
NET PRESENT TOTAL OWNING COST (TOC)	$189,667,902	$180,932,676
NET PRESENT SAVINGS ON FIRST COSTS		$4,432,535
FIRST YEAR % INCREASED FIRST COST		7.87%
% NET PRESENT SAVINGS ON FIRST COSTS		***28.77%***
NET PRESENT SAVINGS ON TOC		**$8,735,226**
% NET PRESENT TOTAL SAVINGS (FC&TOC ON INVESTMENT WITH FR3)		***56.70%***
5 NET PRESENT SAVINGS TO CUST (COL WITH FR3 VS COL WITH MINERAL OIL		2.62%
1P OVERHEAD POLE TX	MINERAL OIL	FR3 FLUID
NET PRESENT COST OF INVESTMENT (1ST COST)	$11,965,954	$9,868,006
NET PRESENT COST OF LOSSES (COL)	$68,696,825	$68,539,242
NET PRESENT TOTAL OWNING COST (TOC)	$80,862,779	$78,407,248
NET PRESENT SAVINGS ON FIRST COSTS		$2,097,948
FIRST YEAR % INCREASED FIRST COST		7.29%
% NET PRESENT SAVINGS ON FIRST COSTS		***35.50%***
NET PRESENT SAVINGS ON TOC		**$2,255,530**
% NET PRESENT TOTAL SAVINGS (FC&TOC ON INVESTMENT WITH FR3)		***40.24%***
5 NET PRESENT SAVINGS TO CUST (COL WITH FR3 VS COL WITH MINERAL OIL		0.23%
1P AND 3P PAD MOUNT TX	MINERAL OIL	FR3 FLUID
NET PRESENT COST OF INVESTMENT (1ST COST)	$13,669,760	$11,335,173
NET PRESENT COST OF LOSSES (COL)	$95,335,363	$91,190,225
NET PRESENT TOTAL OWNING COST (TOC)	$109,005,123	$102,525,428
NET PRESENT SAVINGS ON FIRST COSTS		$2,334,587
FIRST YEAR % INCREASED FIRST COST		8.36%
% NET PRESENT SAVINGS ON FIRST COSTS		***24.17%***
NET PRESENT SAVINGS ON TOC		**$6,479,695**
% NET PRESENT TOTAL SAVINGS (FC&TOC ON INVESTMENT WITH FR3)		***67.09%***
5 NET PRESENT SAVINGS TO CUST (COL WITH FR3 VS COL WITH MINERAL OIL		4.35%

Overload Capability

- Existing transformer land-locked (footprint)?
- At or above rated load?
- Ability to handle increased load with same equipment



SDG&E Overload Study

- In comparing a 50kVA unit at 65AWR MO allows for a four hour peak overload of 149% versus FR3 at 178% and 8 hour peak of 130% compared to 154%.

- A 50kVA FR3 unit at 75AWR allows for a 4 hour overload of 158% versus 149% for MO at 65AWR. Unit can be designed smaller and still have greater overload capacity.

- OEMs Conclusion:

"***FR3 65C increases overload by 25-30% over Mineral Oil 65C and FR3 75C increases overload by 5-10%.***"

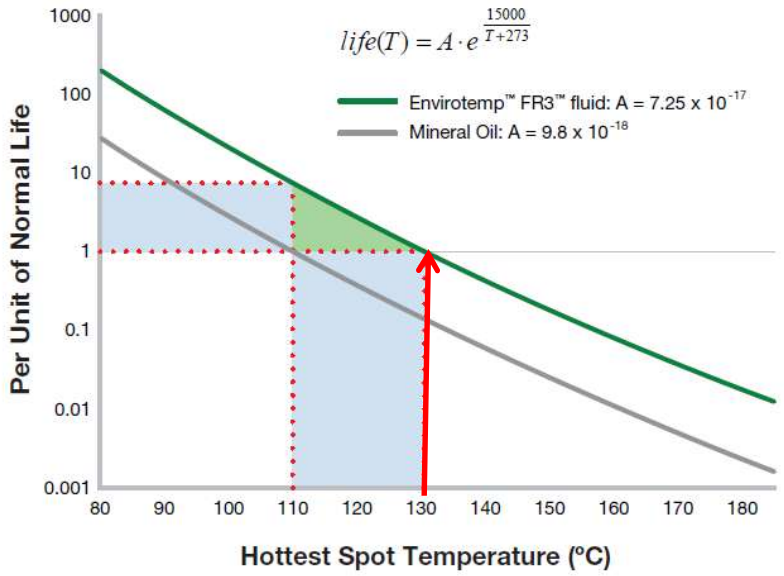
OEM Loading Capability of 50kVA Distribution Transformers Solar PV Peak Load Capability HECO

MO and FR3 50kVA 65C Rise	MO	FR3
Extra LOL per day	0.00%	0.00%
Base Equivalent Load	50%	50%
Peak Overload Duration (hrs)		
1	244%	282%
2	204%	235%
3	181%	209%
4	167%	193%
5	157%	181%
6	150%	173%
7	144%	166%
8	140%	161%
24	112%	130%

- FR3 is capable of 20-30% higher overloads than MO without sacrificing insulation life.

Transformer Optimization

- Reduce the size of the footprint
- Reduce first cost
- Reduce no load losses and optimize $/kv



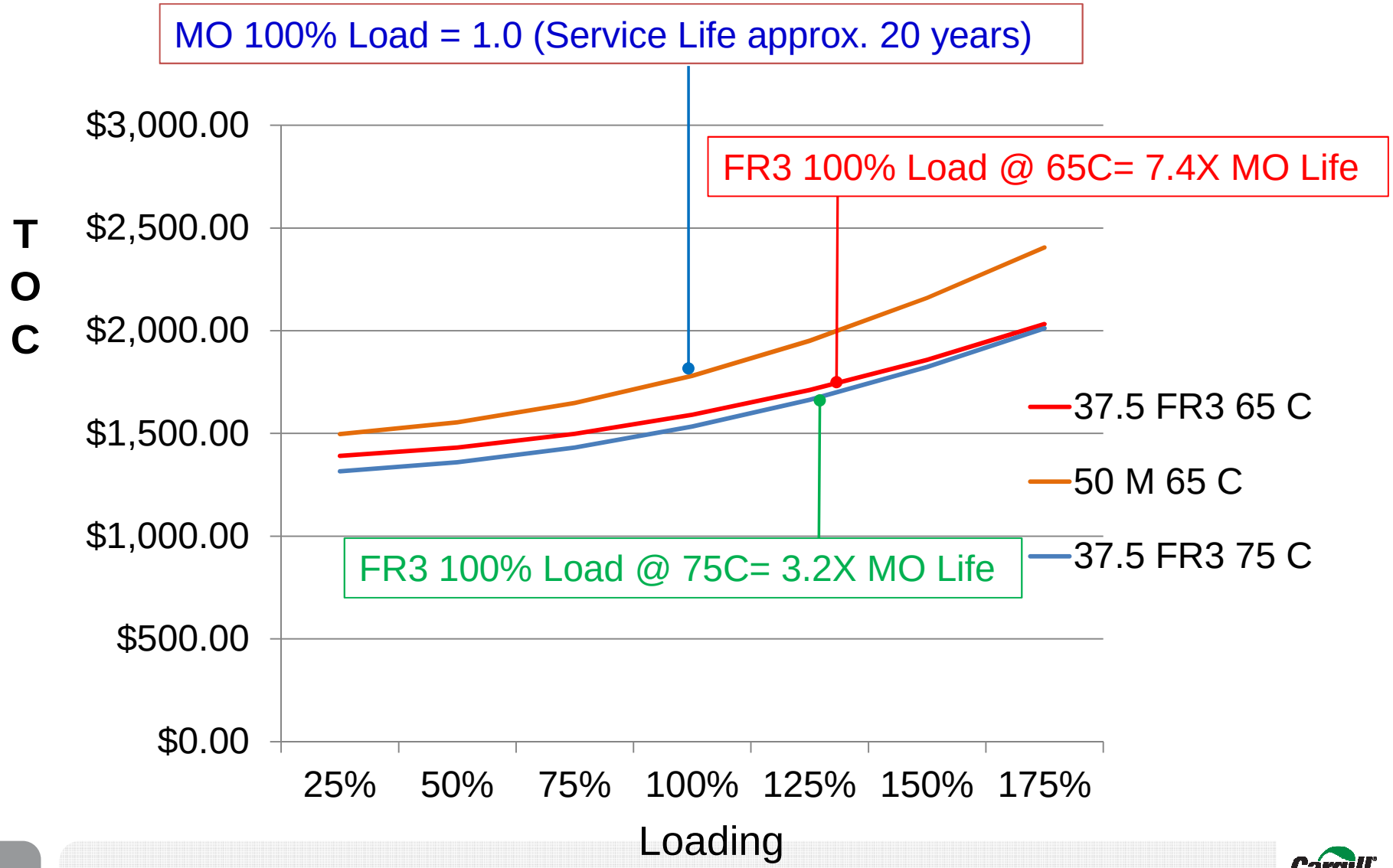
Example: Achieve first cost savings without sacrificing reliability

- Smaller installed kVA
- Improved Loss profile
- Less size and weight
- Longer life potential
- Improved reliability
- Assumptions:
  - $4.00/NL Watt
  - $0.50/LL Watt
  - TOC for FR3 fluid favorable

Current Behavior

	50 kVA	37.5 kVA	37.5 kVA
Fluid	MO	FR3	MO
AWR	65	75	75
Price	100%	89.4%	79.1%
NLL/LL	96/571	81/438	74/480
Weight (kg)	100%	78.9%	75.5%
Expected Life	1.0	1.6	0.3

Total Owning Cost v. Loading



CPFL in Brazil reduced first cost with more efficient distribution transformer design

BRAZIL'S LARGEST PRIVATELY-OWNED ELECTRICITY COMPANY MIGRATING ITS ENTIRE NETWORK TO FR3 FLUID. 5,000 GREEN TRANSFORMERS ALREADY IN OPERATION.

Conventional Three-Phase Transformer

Power: 45 KVA
Tensions at HT: 11400 V a 13800 V
Tensions at LT: 127/ 220V
Weight: 959 lbs.. (435kg)
Liters: 24 gal. (90 liters)
Price/kVA: **R$ 84.40**

Green Three-Phase Transformer

Power: 88 KVA
Tensions at HT: 11400 V a 13800 V
Tensions at LT: 127/220 V
Weight: 772 lbs.. (350kg)
Liters: 21 gal. (81 liters) (biodegradable oil)
Price/kVA (estimated): **R$ 53.40**

In Conclusion:

Natural Ester Dielectric Fluid

- Prevents fires from occurring in operating transformers
- Is environmentally friendly, renewable, recyclable and sustainable
- Is applicable for new and retrofill transformers and voltage regulators
- Provides for extended life and a lower overall cost with positive NPV
- Allows for smaller kVA installation with lower losses and initial costs
- Overload capability without additional loss of life

Thank You

Appendix

Fluid Comparison

Dielectric fluid comparison

	Mineral Oil	Natural Ester	Synthetic Ester	Silicone Oil
Diagnostic Capability	Yes	Yes	Yes	Less
Fire point	160°C	360°C	310°C	340°C
Biodegradability	No	Ultimately	Readily	No
Toxicity	Toxic	Non-toxic	Less toxic	Toxic
Biobased	No	Yes	No	No
Oxidation	Good	Limited (non-free breathing)	Good	Good
Aging	Average	Best	Better	Average
Cost	$	$$	$$$	$$

Fluid differences impact performance

Fluid Characteristics	Mineral Oil	FR3™ Fluid
Transformer performance	65 AWR 110ºC hottest spot	85 AWR 130ºC hottest spot Allows for overload or life extension
Reliability-dielectric strength	Dielectric strength declines as heat increases due to water saturation	Ability to hold 10 times more water Retains dielectric strength as heat increases Self Drying Hydrolysis “consumes” the water
Fire safety	Flash point 155ºC Fire point 160ºC	Flash point 330ºC Fire point 360ºC
Environmental footprint	Non-biodegradable Costly spill remediation	Non toxic, non-hazardous in soil and water Carbon neutral Biodegradable in 28 days
Field experience	120 years of field experience	20 years of field experience

Technology Comparative Summary

MINERAL OIL
- Low Temperatures
- Diagnostic Testing Capability
- Fires when happen major hazard
- Fire Hazard in Sensitive Areas
- Increasing Environmental Regulation
- Instability of Supply & Price
- Lowest Cost

NATURAL ESTER (FR3 FLUID)
- 100% Fire Safety
- Readily Biodegradable
- Sustainable, Renewable Supply
- Superior Moisture Tolerance
- Extends solid insulation lifespan
- Sealed transformer only
- Diagnostic testing capability
- Higher cost

SYNTHETIC ESTER
- 100% Fire Safety
- Readily Biodegradable
- Best Moisture Tolerance
- Low Temperature
- Superior Oxidation resistance
- Diagnostic testing capability
- Applicable in true free-breathing transformers
- Highest Cost

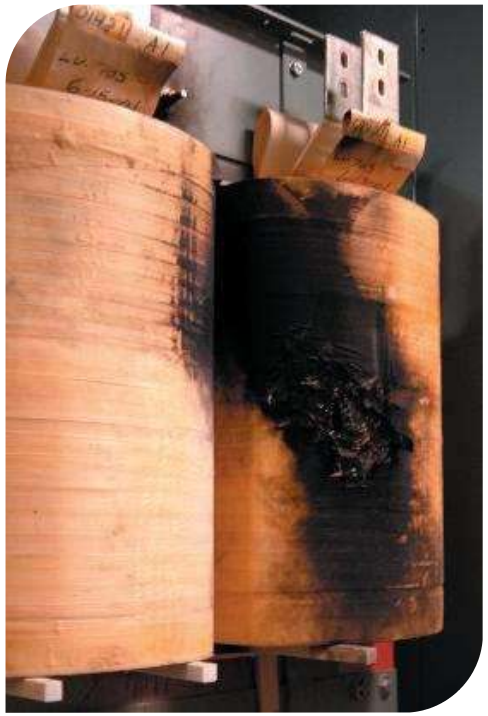
CAST RESIN DRY TYPE
- Main use Indoor Locations (susceptible to dirt/moisture)
- Higher Temperatures & Losses
- Sensitive to Overload & Harmonics
- Regular Cleaning Required
- Minimal Diagnostic Testing
- Service Life Concerns
- Large size
- Highest Initial & Operating Cost

SILICONE
- Good Fire Safety & Overall Reliability
- Low Temperature
- Not above 36kV
- Less Diagnostic Testing Capability
- Inferior Coolant & Dielectric
- Not Suitable as Switching Medium
- Not Biodegradable
- Higher Cost

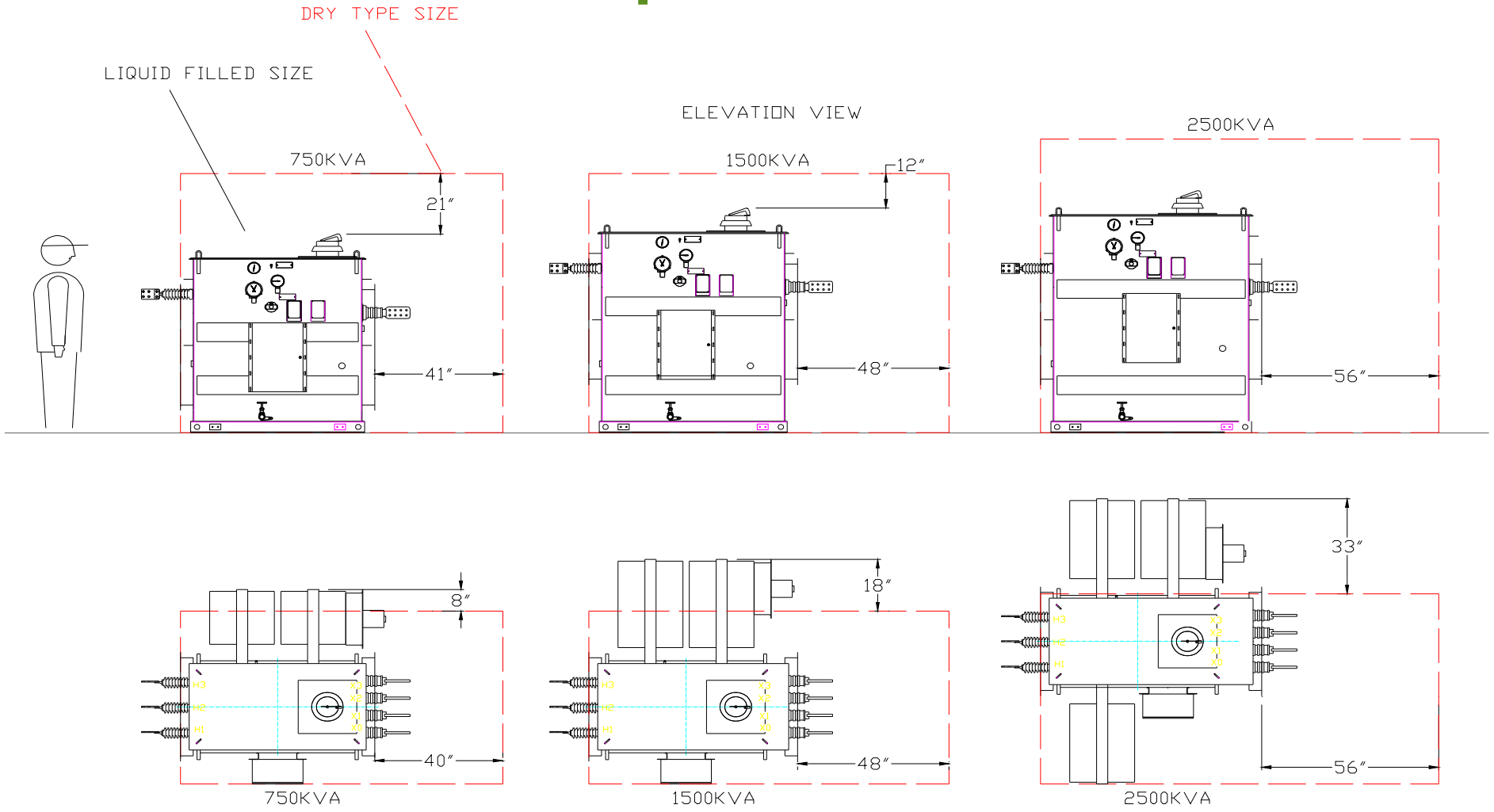
FR3 fluid-filled transformer advantages versus dry-type transformers

- Lower noise
- Lower temperature
- Higher efficiency
- Longer life
- Higher over loadability
- Higher BIL
- Full diagnostic capability
- Contamination resistance
- Improved fire safety
- Smaller footprint
- Lower initial price

Dry type transformers do burn!



Dry-type vs. less flammable liquid filled: Practical size comparisons



LIQUID SOURCE INFO:
COOPER POWER SYSTEMS PRIMARY OR SECONDARY UNIT TRANSFORMERS 210-15; CATALOG; P. 5

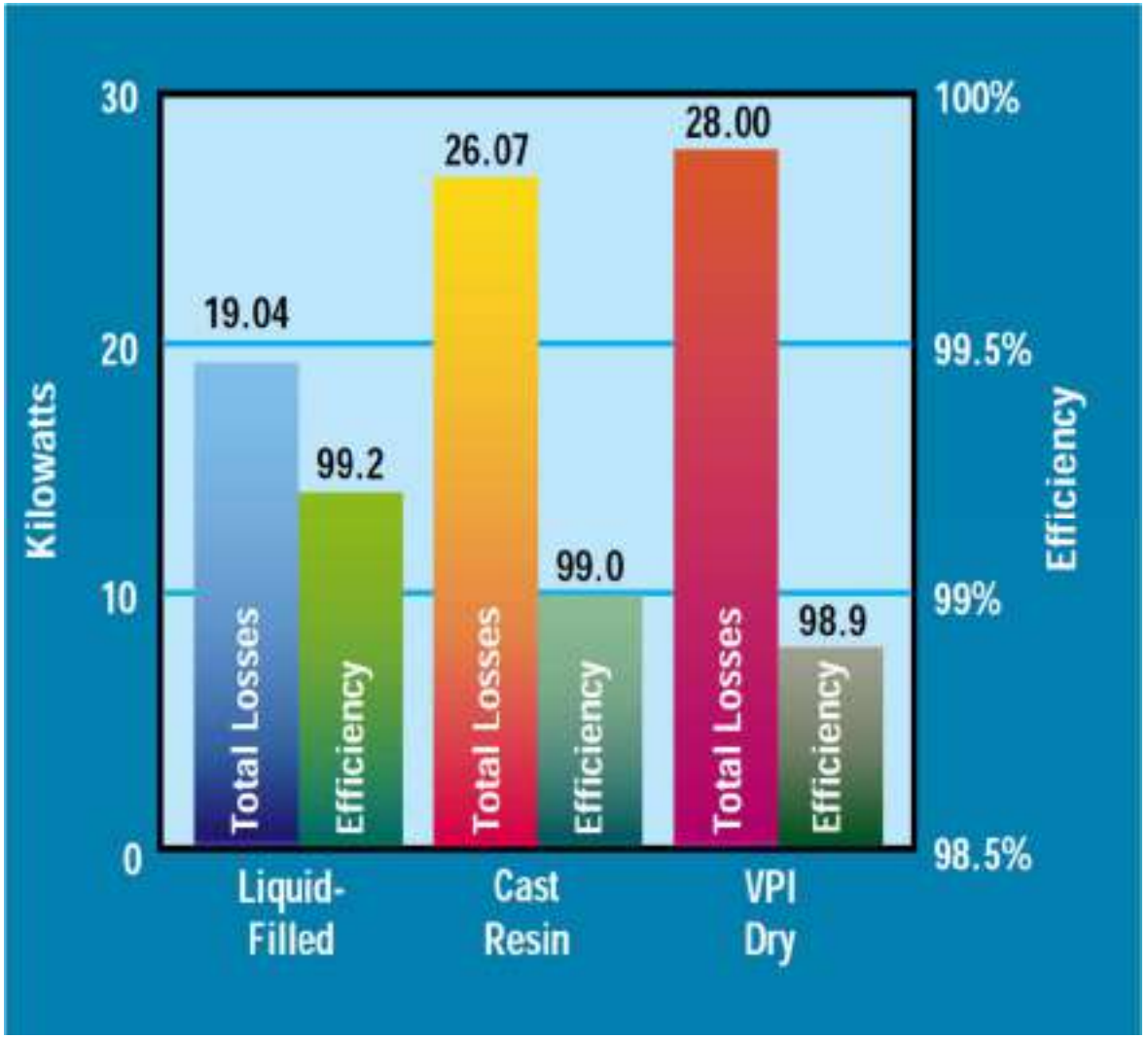
DRY TYPE SOURCE INFO:
ABB CAST COIL DRY TYPE DISTRIBUTION TRANSFORMERS; CATALOG; P. 6

Comparative transformer performance

EFFICIENCY

- Transformer energy efficiency is determined by dividing its nameplate rating by the sum of its nameplate rating plus its total losses

- A small difference in energy efficiency can be significant when valued over the life of the transformer



2500 kVA transformer

Cargill

Comparative transformer performance

EFFICIENCY

	Liquid	Cast	Dry
Total Losses @ 50% Load (kW):	6.76	12.18	12.25
kW·h Billing Rate: x	$0.06	$0.06	$0.06
Annual Hours: x	8760	8760	8760
Cost of Energy for Losses: =	$3,553	$6,402	$6,439
Excess Annual Energy Costs:	Base	$2,849	$2,886
10-Yr* Excess Energy Costs:	Base	$28,488	$28,855

ALSO: transformers losses are dissipated as heat, which must be removed from a controlled temperature environment by air conditioning. For both examples the 10-year air conditioning cost difference is ~$14,000

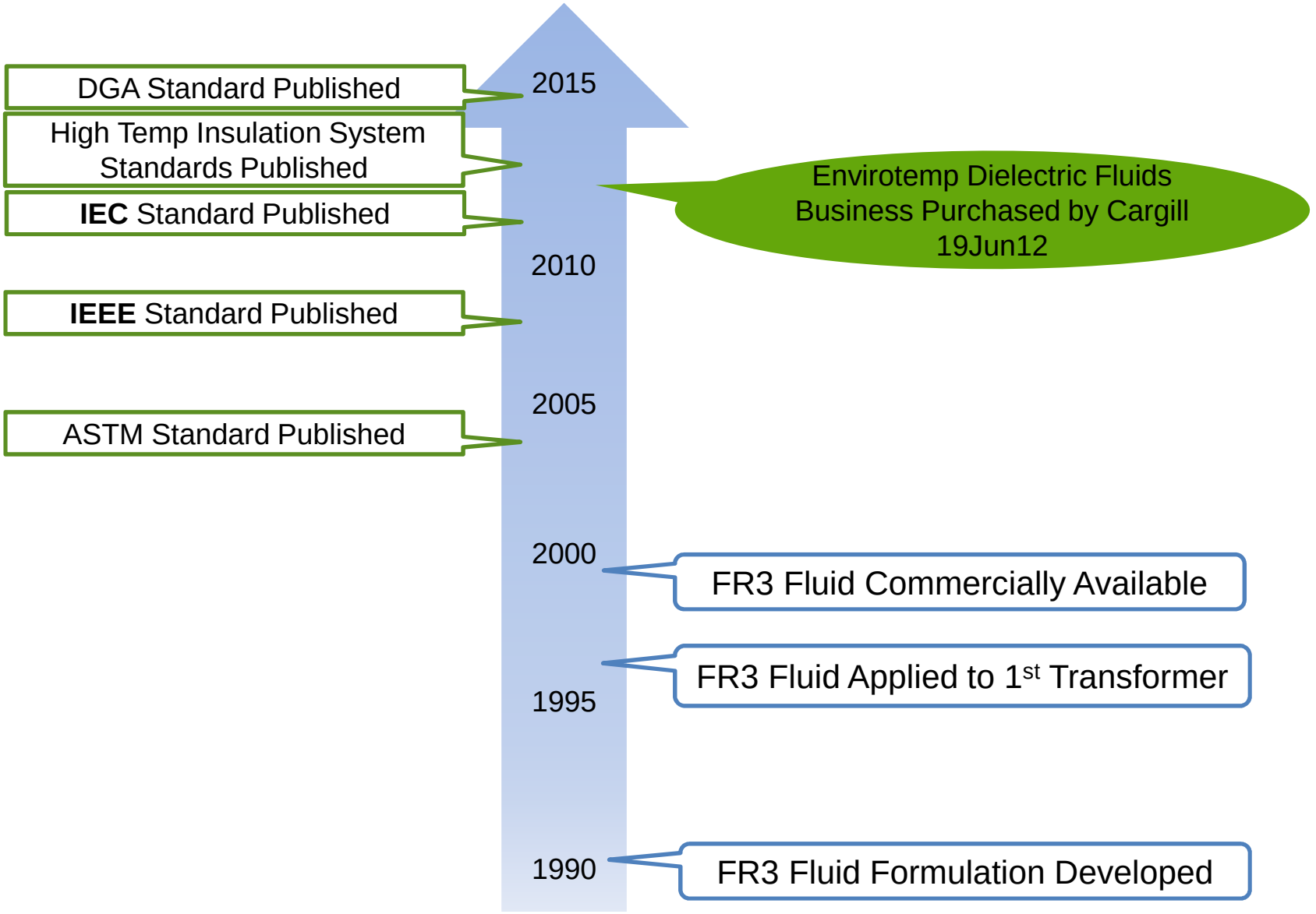
History

What Is Envirotemp™ FR3™ fluid?

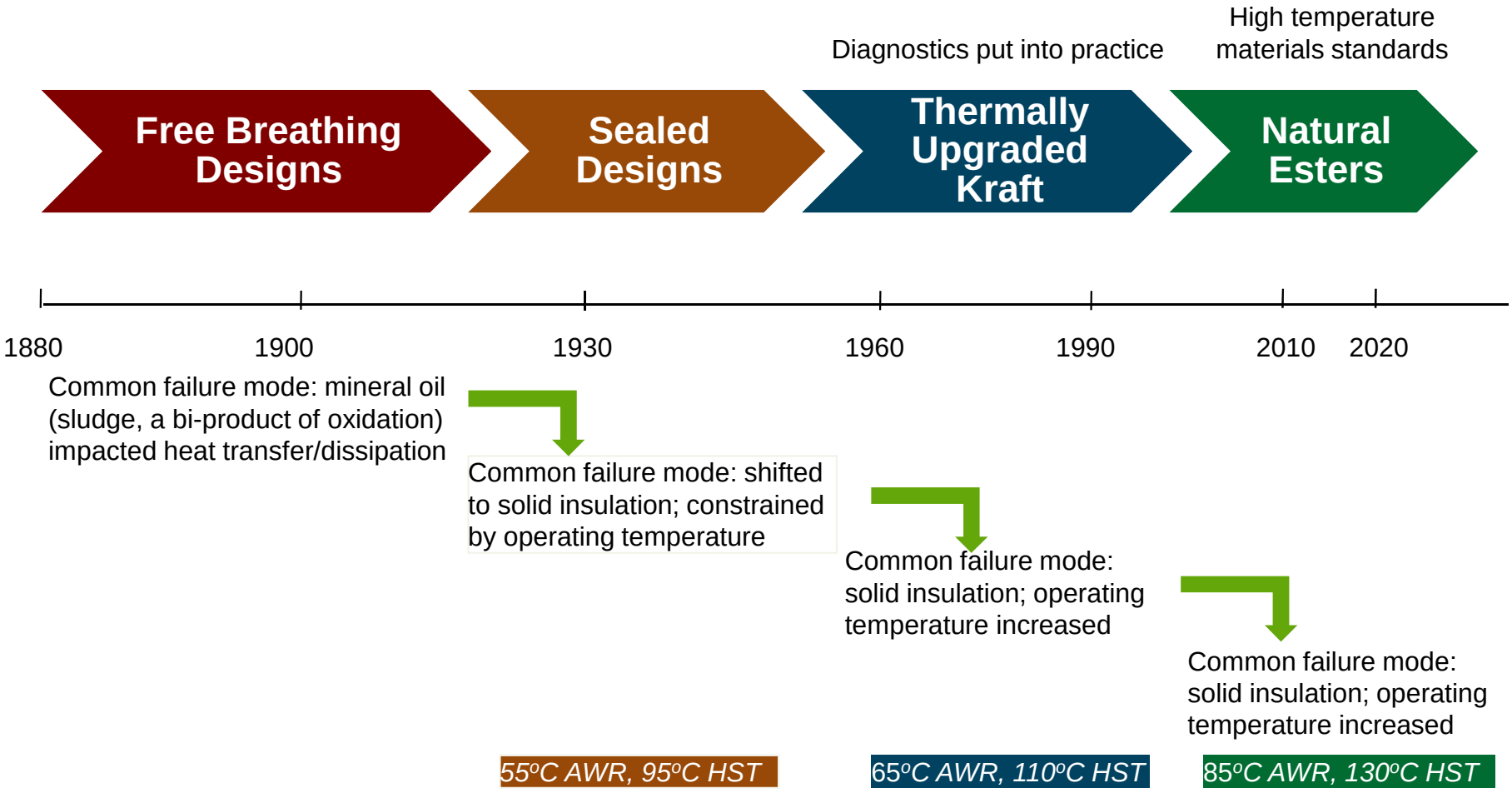
- Natural ester insulating liquid
- Vegetable Oil
  - A wide variety available
  - Not all “edible”
  - Biobased, sustainable supply
  - Key is to find balance between properties

Cargill

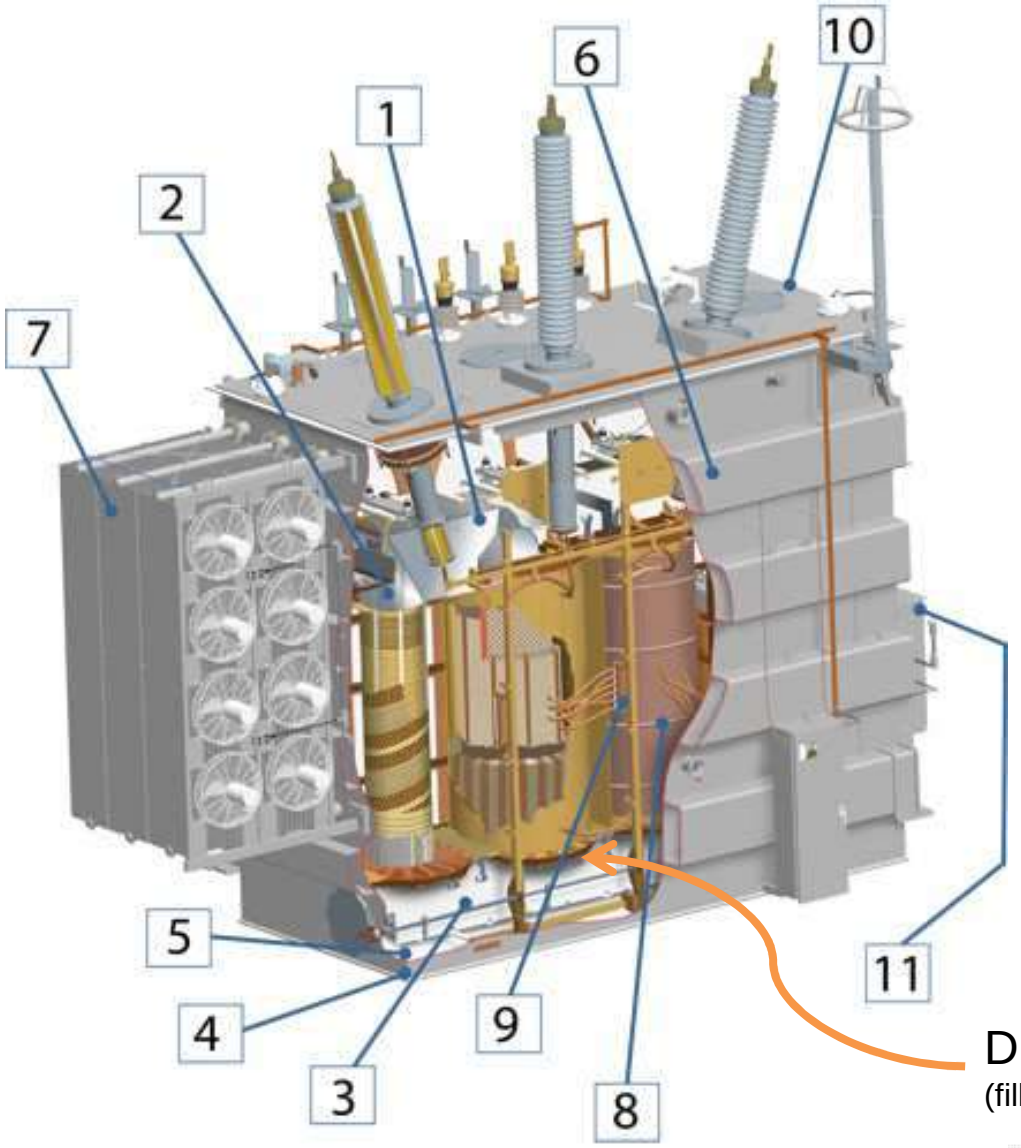
FR3 fluid timeline



Transformer history (1890-present)



Dielectric fluid is used inside of transformers



Dielectric Fluid Functions:

1. Electrical Insulator
2. Coolant

➢Diagnostic capabilities

Dielectric Fluid
(fills inside of tank)

Cargill

Transformer Design Constraints – Insulation System

Transformer insulation system is primary failure mode

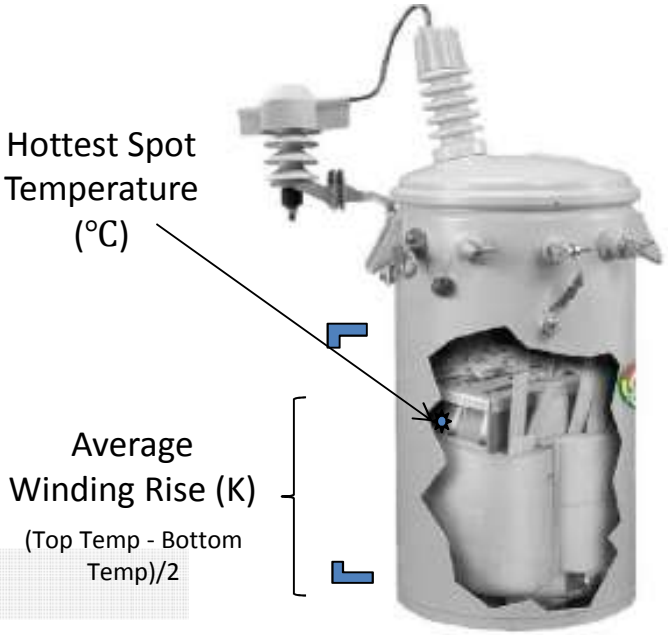
- Degrades over time, based upon temperature, loading degree/cycle, & contaminants (water & oxygen)

Design limits defined by insulation system hot spot temperature (HST)

- FR3 fluid demonstrates 20ºC additional thermal capability (compared to MO)

Economic value & opportunity

- FR3 fluid's thermal capability enables lower cost per kVA, longer life, reduced transformer price, and positive NPV.



Standards

Current List of Standards

	Natural Esters	Mineral Oil
New Oil	ASTM D6871 IEC 62770	ASTM D3487 IEC 60296
Use and Maintenance	IEEE C57.147	IEEE C57.106 IEC 60422
Transformers	IEEE C57.12.00 IEC 60076 series IEEE C57.154 IEC 60076-14	IEEE C57.12.00 IEC 60076 series IEEE C57.154 IEC 60076-14
Loading Guide	(use MO std)	IEC 60076-7
Dissolved Gases	IEEE C57.155	IEEE C57.104 IEC 60599

Fire

- FM Global Property Loss Prevention Data Sheets, 5-4 Transformers
- IEC 61936-1 Power installations exceeding 1 kV a.c. – Part 1: Common rules

Fire safety: FM Global risk mitigation

Table 2a. Separation Distance Between Outdoor Liquid Insulated Transformers and Buildings

Liquid	Approved Transformer or Equivalent	Liquid Volume gal (m^3)	Horizontal Distance[1] Two Hour Fire Resistant Construction ft (m)	Noncombustible Construction ft (m)	Combustible Construction ft (m)	Vertical Distance ft (m)	
Less Flammable (Approved Fluid)	Yes	N/A	3 (0.9)			5 (1.5)	distance from **transformer**
	No	≤ 10,000 (38) > 10,000 (38)	5 (1.5) 15 (4.6)		25 (7.6) 50 (15.2)	25 (7.6) 50 (15.2)	
Mineral Oil (or unapproved fluid)	N/A	< 500 (1.9) 500-5,000 (1.9-19) > 5,000 (19)	5 (1.5) 15 (4.6) 25 (7.6)	15 (4.6) 25 (7.6) 50 (15.2)	25 (7.6) 50 (15.2) 100 (30.5)	25 (7.6) 50 (15.2) 100 (30.5)	distance from **containment edge**

1) All transformer components must be accessible for inspection and maintenance.

Table 2b. Outdoor Fluid Insulated Transformers Equipment Separation Distance[1]

Liquid	Approved Transformer or Equivalent	Liquid Volume gal (m^3)	Distance ft (m)	
Less Flammable (Approved Fluid)	Yes	N/A	3 (0.9)	distance from **transformer**
	No	≤ 10,000 (38) > 10,000 (38)	5 (1.5) 25 (4.6)	
Mineral Oil (or unapproved fluid)	N/A	< 500 (1.9) 500-5,000 (1.9-19) > 5,000 (19)	5 (1.5) 25 (4.6) 50 (7.6)	distance from **containment edge**

1) All transformer components must be accessible for inspection and maintenance.

FR3 fluid in application

FR3 fluid has equivalent or superior dielectric strength to mineral oil

BASED ON THE PERFORMED TESTS AND SEVERAL PUBLISHED PAPERS, SEVERAL CONCLUSIONS CAN BE MADE:

	Envirotemp FR3 Fluid	Mineral Oil
Transformer Design		
turn-to-turn	=	=
coil-to-coil	=	=
bushing-to-tank wall	=	=
creep	=	=
tap changer selector rod	=	=
In-Service		
water contamination	+++	---
particulate contamination		
cellulose	++	--
copper	+	-
streaming electrification	++	--
bubble formation	+++	---

+ better = the same – worse

	Envirotemp FR3 Fluid	Mineral Oil
Electrode Geometry – Oil Gap		
uniform	=	=
mildly divergent	=	=
strongly divergent	-	+
Electrode Geometry – Creep		
mildly divergent	=	=
strongly divergent	-	+

FR3 fluid is compatible with common transformer materials

LIST BELOW SHOWS MATERIALS TESTED AND APPROVED WITH FR3 FLUID

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

Overload Capability:

SDG&E Loading Calcs DOE 2016 designs, 65C Nameplate 12kV with taps, 120/240 Conventional						
			4hr Peak Load -Normal LOL		8 hr Peak Load -Normal LOL	
kVA	Actual AWR	65C kVA	Mineral Oil	FR3	Mineral Oil	FR3
10	28.9	17.5	244%	280%	217%	252%
15	40.2	20.9	198%	229%	176%	203%
25	54.5	28.3	167%	195%	146%	171%
37.5	62.3	38.6	149%	176%	131%	155%
50	64.6	50.2	149%	178%	130%	154%
50	75.0	n/a	n/a	158%	n/a	138%
75	63.8	76.0	151%	180%	132%	156%
75	75.0	n/a	n/a	158%	n/a	138%
100	64.7	100.3	153%	184%	132%	157%
100	75.0	n/a	n/a	162%	n/a	140%
167	64.9	167.2	150%	181%	131%	156%
167	75.0	n/a	n/a	162%	n/a	140%

Loading Capability of Distribution Transformers 50kVA Solar PV Peak Load Capability HECO

50kVA Design	Current	MO 65C	FR 65C	MO 55C	FR 55C	MO 45C
Actual Winding Rise (C)	64.8	63.3	63.3	54.0	54.5	43.7
Peak Load with normal LOL	126	136	177	165	200	200
Peak Load with 5-10X LOL	167	173	200	200	228	234
Weight (lbs.)	630	604	604	650	625	742
Height (in)	40	40	40	44	42	44

- **Neither FR3 or MO 65AWR design could reach 200 percent overload for 4 hours without LOL.**
- **FR3 at 55AWR or MO at 45AWR could achieve desired overload conditions with LOL. Mineral oil unit would have to be taller and heavier than the FR3 designed unit**

Loading Capability of Distribution Transformers 25kVA Solar PV Peak Load Capability HECO

25kVA Design	Current	MO 65C	FR 65C	MO 45C
Actual Winding Rise (C)	58.4	49.0	49.0	37.5
Peak Load with normal LOL	131	170	200	213
Peak Load with 5-10X LOL	177	200	232	261
Weight (lbs.)	365	378	378	454
Height (in)	44	42	42	42

- **In the 25kVa design FR3 at 65 AWR could meet the design requirement.**
- **Would require MO unit to be designed at 45 AWR to achieve desired results.**
- **Weight of MO unit would be much heavier than FR3 unit.**

Testing

FR3 fluid performance and diagnostic testing is similar to MO with a few modifications

RULE OF THUMB – "WHAT DO YOU DO WITH MINERAL OIL?"

- Some traditionally acceptable indicator of mineral oil performance may not apply (interfacial tension)
- BDV and DDF are the best parameters to evaluate the general contamination
- FR3 fluid is a mixture of relatively polar triglycerides (long-chain fatty ester molecules)
    - Have unsaturation and ability to form hydrogen bonds
- Mineral oil is non-polar and hydrophobic
- Difference in basic chemistry accounts for disparate values

Performance Test	Modification	FR3 fluid vs. MO result	Notes (Refer G2300 p13)
Dielectric Breakdown Voltage	Stand time 30 minutes, ASTM: 2mm gap, IEC: 2.5 mm gap	Same	None
Water Content	Use relative saturation to compare different type of dielectric fluids	Higher	Maintains dielectric strength at higher absolute water contents
Viscosity	None	Higher	Indicator of oxidation

Diagnostic testing results and modifications

Diagnostic test	Test modification requirements	FR3 fluid vs. MO result	Notes (Refer G2300 p14-17)
Water Content	None	Higher	Helps dry transformer insulation
Dissipation Factor	None – meticulously clean cell if using for FR3 and MO	Higher	Higher transformer power factor
Acid Number	None	Higher	FR3 fluid generates long chain fatty acids that are mild and non-corrosive
Interfacial Tension	None	Lower	Not useful for FR3 fluid – use dissipation factor
Resistivity	None	Lower	Lower transformer insulation resistance
Pour Point	Heat fluid to 50C, cool to room temp	Higher	Effects low temperature mechanical movement
Gassing Tendency	None	NA	NA
Oxidation Inhibitor	Use GC instead of IR method Use DSC to evaluate inhibitor additives	NA	Replenish inhibitor if content falls below 0.12%
Oxidation Stability	Use IEC 62770 method	NA	NA
PCB Content	Packed column, sulfuric acid treatment	None	Not found in vegetable oils
Flash and Fire Points	None	Higher	Upgrades fire safety
Dissolved Gas Analysis	None	Different	Stray gases differ from mineral oil
Corrosive Sulfur	None	None	Not found in vegetable oils
Furanic Compound	None - for new FR3 fluid	Different	Interferences from degradation products
Particle Count	Dilute FR3 fluid 75% with filtered heptane or hexane	NA	Air bubbles in FR3 fluid may not dissipate and are detected as particles

Dissolved gas analysis in a nutshell

1. Refer to IEEE C57.155 for stray gassing levels
    - If only one data set, use IEEE C57.104 “Condition” method as first best guess (account for stray gassing)
    - If Condition warrants it, take another sample

2. Check gassing rate
    - Gassing rate low: done
    - Gassing rate significant: continue to 3

3. Use IEEE “Key Gases” method and Duval triangle method to diagnose

4. Use additional methods as needed

Cold Temperature

- FR3 fluid-filled transformers are currently energized and operating admirably in numerous “cold weather” locations
  - Northern Canada
  - Alaska, International Falls
  - Scandinavia
- Cold Start, Storage & Handling Guides Available
- Use recommended mineral oil ‘cold start procedures’

Missoula, Montana; FR3 fluid retrofill completed at -25°C.

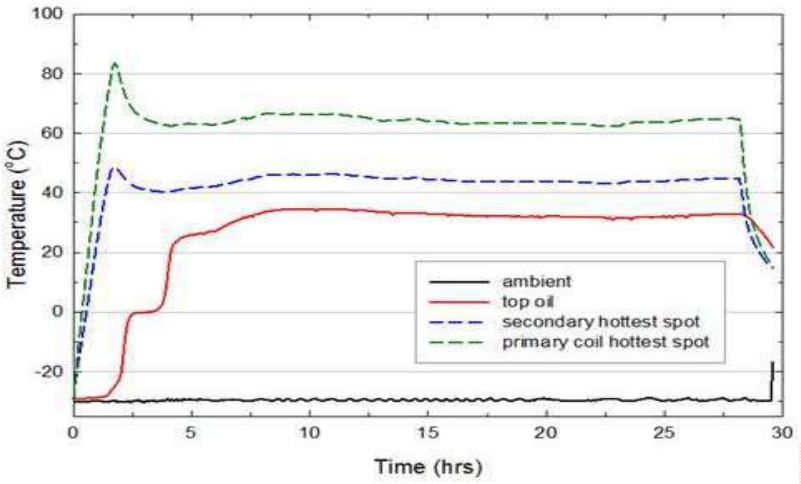
FR3 fluid maintains dielectric strength regardless of ambient temperature

POUR POINT DOES NOT DETERMINE FLUID PERFORMANCE IN COLD TEMPERATURES

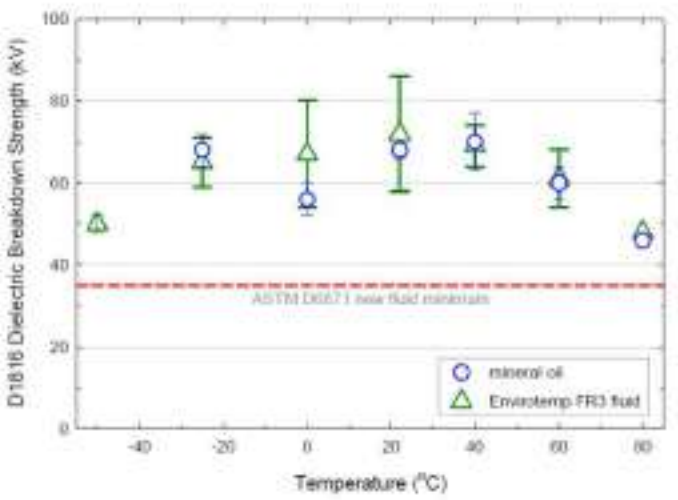
Inside of a transformer, the temperature of the fluid is dependent upon:

- **Ambient temperature**
- **Volume of Fluid**
- **Time at Ambient Temperature**
- **Rate of Cooling**

Energizing cold FR3 fluid transformer at full rated load causes no unusual temperatures

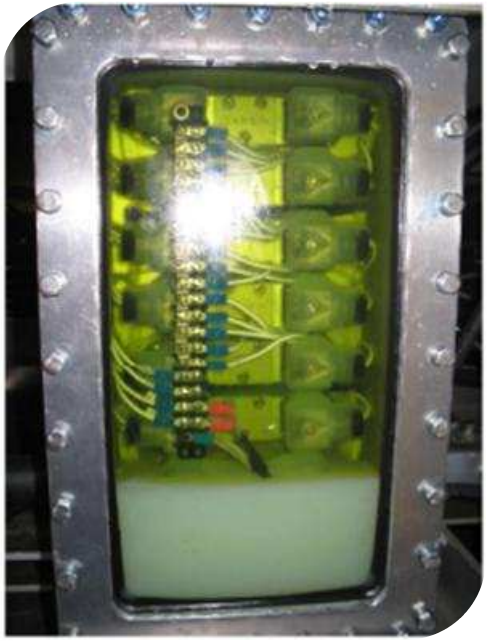


FR3 fluid breakdown voltage is maintained to at least -50 ˚C

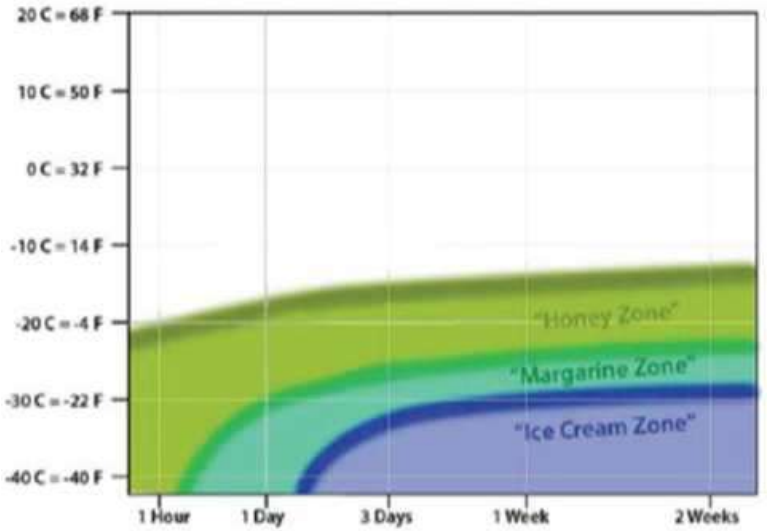


Follow IEEE cold start procedures

SAME COLD START PROCESS AS MINERAL OIL. DIFFERENT REASONS.

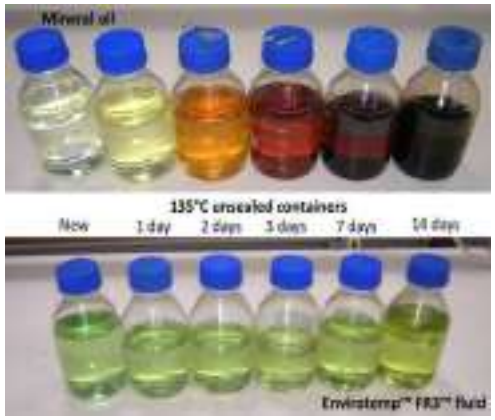


- Mineral oil contains free water
  - Use cold start procedure required used to avoid dielectric failure (heat slowly to dissolve water)
- FR3 fluid maintains dielectric strength however may thicken in extended transformer inactivity
  - Use cold start procedure required to regain viscosity (may hamper mechanical movement)
- The time required to gel is variable, dependent on volume of fluid, temperature and rate of cooling
  - E.g. Honey zone = -20°C for at least 2 weeks
  - No clear transition solid-liquid



Oxidation Stability

- FR3 is recommended in all non-free breathing transformers
- Both mineral oil and natural esters oxidize – takes years, not days
- The fluids oxidize differently
  - Products of mineral oil oxidation form sludge precipitates
  - Products of natural ester oxidation form oligomers (larger molecules) that stay in solution
  - Thin film polymerization is an avoidable concern that must be accounted for in handling procedures
- The long term effect on the transformer is the same: less efficient heat transfer



Cargill

Drying Process

DO NOT USE HOT AIR (DRYING) OVENS FOR IMPREGNATED ASSEMBLIES

- **Drying of new materials (not yet impregnated)**
  - No restrictions regarding oven types

- **Drying of impregnated materials**
  - Clean the surfaces using a compatible solvent (kerosene, alcohol or warm mineral oil)
  - Keep all insulation material immersed in insulation fluid or nitrogen gas
  - Wrap the windings and insulation materials completely using plastic film (stretch) for preventing contact with ambient air
  - Dry impregnated coils using hot FR3 fluid, kerosene vapors or nitrogen

Hot air oven is not recommended for previously impregnated materials, due to oxidation of thin films of FR3

Oxidation stability is a consideration for routine maintenance

REDUCE EXPOSURE TO AIR TO MINIMINZE POTENTIAL FOR THIN FILM POLYMERIZATION

- For smooth surfaces (e.g. steel), limit the exposure to air and UV to 7 calendar days
- For porous surfaces (e.g. paper), limit the exposure to air and UV to 20 calendar days
- Clean the surfaces using a compatible solvent (kerosene, alcohol or warm mineral oil, temp. >60°C)
- Keep all insulation material immersed in insulation fluid or
- Wrap the windings and insulation materials completely using plastic film (stretch) for preventing contact with ambient air
- Avoid hot air (drying) ovens

The Transformation

Tata Power: Designs 20MVA with capacity of 28MVA, 16% savings

THIRD LARGEST UTILITY IN INDIA – 2 20MVA TRANSFORMERS WILL BE PLACED IN FINANCIAL DISTRICT AS PART OF GOVERNMENT "SMART CITY" INITIATIVE

New transformer design

- Increased capacity by 8 MVA, while reducing the footprint by 17%
- Yields cost-savings of about 16%
- Reduces noise levels from 73 decibels to 59
- Increases fire safety
- Enhances the transformers' environmental profile

Next steps

- Exploring high temperature capabilities with new designs for greater performance efficiencies
- Incorporate first-ever pad-mounts in India (already converted power and distribution to FR3)

TATA POWER

First power transformer with FR3 fluid for Tata Power

Advantages available today and new advancements on the horizon

In the past

65C AWR/110 HST MO
Insulation failure mode

- 100 kVA
- 65°C AWR
- 110°C HST
- 20.55 years
- Insulation system likely failure mode
- 155°C fire point
- Petroleum based fluid
- Limited overload potential

Available today

75C AWR/120 HST FR3
Increased load capability

- 100 kVA
- **75°C AWR**
- **120°C HST**
- >20.55 years
- **Improved reliability - Robust insulation system**
- **Improved fire safety - 360°C fire point**
- **Best in class environmental properties**

Working towards

85C AWR/130 HST FR3
Reduced size/footprint

- 100 kVA
- **85°C AWR**
- **130°C HST**
- 20.55 years
- Improved reliability - Robust insulation system
- Improved fire safety – 360°C fire point
- Best in class environmental properties
- **Reduced initial price**