FIRE SAFETY

Fire Exposure

Fire Behavior

IEC K-Class fluids (high fire point dielectric fluids) are defined as having an open cup fire point greater than 300°C. Although not as fire resistant as non-flammable halogenated hydrocarbons (e.g. PCBs), they offer significantly better fire resistance than conventional mineral oil having a typical fire point of 160°C. Test results confirm the ability of all K-Class fluids to reduce the initial intensity of a transformer catastrophic failure and prevent an oil pool fire. A 30-year history of excellent fire safety for CPS R-Temp® fluid has confirmed that a 300°C fire point is sufficiently high for sensitive locations inside, on top of, and near or adjacent to buildings.

The most important property for determining fire safety of a transformer fluid is the fire point. When a liquid-filled transformer is operating at full load in a 40°C ambient the oil temperature is approximately 100°C. When electrical protection devices do not function as intended, heating from an internal arcing fault or chronic overloading can increase the fluid temperature and put conventional mineral oil at risk for ignition. The significantly higher fire point of Envirotemp FR3 fluid makes it virtually impossible to ignite it under realistic transformer conditions.

In more than 30 years of use in hundreds of thousands of transformers, a pool fire in R-Temp fluid has never been reported. Envirotemp FR3 fluid's fire point is 360°C vs. R-Temp fluid's 312°C. In small and large scale tests FR3 fluid's fire resistance properties have been shown to be superior to those of R-Temp fluid and it also has a flawless fire safety record. We can have even greater confidence in the fire resistance of FR3 fluid.

How Fluids Ignite

A fluid must reach its fire point and be exposed to an ignition source to ignite. As a fluid is heated, vapor concentration above the fluid increases. Vapors ignite initially and ultimately combustion is sustained on the fluid surface. In the Cleveland Open Cup test method, a small volume of fluid is heated using a standard test cup, heater and thermometer. A gas flame is periodically passed over the surface. Flash point is defined as when a flame appears on the fluid surface and propagates across the surface before self-extinguishing. Fire point is when the complete surface of the fluid stays ignited for at least 5 seconds. Lower fire point correlates directly to easier ignition. Auto-ignition temperature is usually around 50°C higher than the open cup fire point.

Once ignited, a pool of fluid will sustain fire if the heat of combustion is greater than the heat required to re-ignite. Since the heat of combustion of conventional mineral oil greatly exceeds that of re-ignition, it not only does not self extinguish, it also propagates fire across the complete surface of a pool. For high fire point fluids the heat of combustion is not sufficient to sustain ignition or propagate a pool fire. Even if ignited, once the heat source is removed, the fluid self-extinguishes.

When arcs occur under oil, a relatively small part of the energy goes to raise the fluid temperature. Heat is concentrated at the arcing point, but the larger pool of fluid serves as a heat sink and only a small amount of the fluid sees a large rise in temperature. Much of the arc energy is consumed tearing apart the fluid molecules, producing combustible gases.

Large Scale Tests

Fire behavior tests have been performed comparing R-Temp and Envirotemp FR3 fluids to conventional mineral oil simulating the possible ignition sources in transformers. Several of those tests, ranging from the late 1970s through 2002, will be discussed below. Although the test methods used were neither highly refined nor done in statistically significant numbers of trials, they model the complex processes involved in ignition of transformer oil and demonstrate the significantly better fire resistance of high fire point fluid. In the case of FM Global Testing, test methods were devised based on the combination of CPS transformer field and laboratory experience and FM's world-recognized fire science expertise. Most importantly, the lab results are supported by field experience with transformer failures, where mineral oil pool fires are common and fire resistant fluid pool fires with R-Temp and FR3 fluids have never been reported.

Some of the earliest tests in the archives of CPS (former RTE) Fluids, dating back to the late 1970s, include Time to Ignition and Self-extinguishment. Test videos compare R-Temp high fire point hydrocarbon and conventional mineral oil.

Time to Ignition

The Time to Ignition test uses a metal trough approximately 3 in (76 mm) by 12 in (305 mm) filled with the test fluid. One end of the trough is heated with a propane torch until ignition is achieved. The single source of heating is similar to the heating from an internal arcing fault in a transformer. Time to ignition was observed to be 1:10 and 16:40 for mineral oil and R-Temp fluid, respectively.

Self-Extinguishment

The Self-Extinguishment test uses a standard open cup fire point test apparatus to ignite fluid heated well above its fire point, and then allows the fluid to cool off in metallic well stand. Both temperature and time to extinguishment are monitored. The mineral oil does not self-extinguish, while R-Temp fluid does so in 2 minutes, 20 seconds.

Arc Ignition

In the 1990s, CPS conducted low voltage arc ignition tests where fluid was preheated and low voltage arcs were struck under the surface of the fluid. It was determined that mineral oil could be ignited with 806 kJ of arc energy with a preheat temperature of 110°C, while R-Temp fluid could not be ignited despite 2338 kJ of arc energy and a preheat temperature of 120°C. Arcs produce combustible gases that can ignite first and in turn ignite fluid vapors.

FM Global (formerly Factory Mutual Engineering and Research) specified and witnessed high voltage arc ignition tests conducted by CPS in 1994. For these tests a preheat temperature of 130°C was used to simulate the effects of an extended arcing fault in the fluid. The test apparatus included an arcing gap under the fluid and a 1/16 in. (1.6 mm) slit covered by a rupture disk to simulate the splitting of a tank weld seam that produces a spray mist of hot fluid and arc-produced combustible gases. In some trials road flares were ignited and placed in the spray to simulate an arcing cable ignition source. For mineral oil, pool fires were created. For R-Temp fluid only ignition of the spray was achieved, no pool fire. A detailed description of the tests can be found in the CPS Research Report, Final Report on FM-type Pool Fire Tests, dated January 11, 1995. These tests led to the establishment of lesser physical clearance, fire barrier and sprinkler requirements for transformers 10 MVA and below, when filled with high fire point fluid and protected against tank rupture.

Hot Metal Ignition

In 2002 FM approached CPS with the desire to expand its recognition of high fire point fluids to medium power transformers. The fact that the financial arm of FM Global had never paid a claim for damage caused by a high fire point fluid-filled transformer fire was important in proving fire safety. However, FM had to support that loss history experience with lab testing. The previous test set up modified the fire ignition source from sustained arcing to one unique to the high-energy faults that can occur in power transformers. Red-hot steel plates simulated core clamp or tank steel heated by induction from the fault. These tests included Envirotemp FR3 fluid and demonstrated its superior fire resistance to all other fluids, including silicone and R-Temp fluids. No ignition of FR3 vapors or fluid occurred. The tests also replicated the same mineral oil pool fire behavior, seen in previous tests. Successful completion of these tests led to FM recognition of K-class fluid as a fire safeguard in lieu of space separation, firewalls, or extinguishing systems. Transformers containing up to 10,000 US gallons (38,000 liters) of an approved fluid need only 5 ft (1.5 m) spacing from fire resistant structures and other equipment.

Auto-Ignition

The auto-ignition temperature is the temperature at which the fluid ignites in air without an external ignition source. The tests, performed by an independent laboratory per ASTM E659, show that Envirotemp FR3 fluid has the highest auto-ignition temperature of all K-Class fluids.

Table 1. Auto-ignition temperatures per ASTM E659

	Auto-ignition Temperature (°C)	
Fluid	Range	Average
mineral oil	225-228	226.5
R-Temp fluid	357-360	358.5
Envirotemp 200 fluid	373-376	374.5
DC 561 silicone oil	399-402	400.5
Envirotemp FR3 fluid	401-404	402.5

[x] "Process Safety Test Results and Interpretation for Envirotemp 200 Fluid, R-Temp Fluid, Tranelec Conventional Transformer Oil, Envirotemp FR3 Fluid, and DC 561 (Silicone Oil)", Report # R/5246/0105/NK, Chilworth Technology, Plainsboro NJ, February 1, 2005

Test Method: ASTM E659 "Standard Test Method for Autoignition Temperature of Liquid Chemicals"

IEC

IEC K-Class Dielectric Fluids per ISO 2592 method (essentially identical to ASTM D92)

Heat of Combustion: 40.81 ± 0.325 kJ/g

Gross Calorific Value - supposes that the water of combustion is entirely condensed and that the heat contained in the water vapor is recovered.

Net Calorific Value - supposes that the products of combustion contain the water vapor. The heat contained in the water vapor is not recovered (steam is allowed to escape).

NCV = GCV – latent heat of vaporization of water
= 38.3 kJ/g

∴ Envirotemp FR3 fluid is IEC K-2

Codes

NEC (NFPA 70): Commercial, Industrial & Government
IEEE 979: Utility (Mineral Oil-Filled Only)
NESC (ANSI C2): All Utility
NFPA 850: Generating Stations
FM Global: All Types

ANSI/IEEE 979 Clearance Requirements for Oil- Filled Transformers

KVA	Unit to Building
75 or less	10 feet
76-333	20 feet
> 333	30 feet

Alternative Fluids and Dry types not addressed

NFPA 850 Requirements for Supply Stations
Indoor
Mineral Oil: 3 hour fire rated barriers required for units with >100 gallons.
Dry: Without fire enclosures
Less-Flammable: 35 kV & below not addressed; above 35 kV requires 3 hour walls or vault

Outdoor
Mineral Oil: Oil volume, building construction, kVA/MVA, fire walls, suppression systems and relaying are key parameters. If >500 gallons 25 ft min. clearance
If no fire wall, 5 ft required from containment curbs to structures
Dry: Not addressed.
Less-Flammable: Separation required based on same parameters as m.o., but specific distances not stated

2002 NESC Requirements for Supply Stations

Indoor
Mineral Oil: Vaults and fire doors required 75 kVA and above.
Dry: Ventilated rooms without fire enclosures
Less-Flammable: May be installed to minimize fire hazard, amount of fluid & electrical protection shall be considered in selecting other possible safeguards

Outdoor
Liquid-filled: Less-flammable fluids, space separation, barriers, enclosures or sprinklers to be used based on degree of fire hazard.
Dry: Not addressed.

NEC Section 450-23
Listed Less-Flammable Liquid-Filled Transformers
Outdoor Requirements
Indoor Requirements
Per Factory Mutual
Per Underwriters Laboratories

Outdoor Clearance
Mineral Oil (450-27): One or more safeguards shall be applied according to the degree of fire hazard.

Less-Flam. (450-23): Less-flammable liquid-filled transformer shall be permitted to be installed attached to, adjacent to, or on the roof of buildings if they comply with all the restrictions provided for in the listing of the liquid.

FM Separation Distances
Table 8

New FM Recognition of Environmental Safety
Up to 2640 Gallons of Fluid: No containment required for "certified biodegradable" fire resistant fluids (based on US EPA ETV Certification). If exposed to navigable waterways, EPA regulations supersede FM.

Indoor Clearance Requirements per Factory Mutual:
FM Less-Flam Approved Transformer: Minimum 3 ft. from Walls.
Non-FM Less-Flam Approved Transformer: Min. 3 ft. from walls + room with min. 1 hr fire rating or with automatic sprinklers.
Dry Type Transformer:
Min 5 ft. from walls and 10 Ft Vertically
Barrier of non-combustible construction
When exposed to dusty or corrosive air:
Located in a pressurized room
Cooling air should be filtered/free of corrosive contaminants.

What is an FM Approved Transformer

Transformers must be manufactured and tested in accordance with ANSI/IEEE C57.12.00 and C57.12.90.
And…..
Transformers built in accordance with FM Approval Standard 3990.

Key Requirements of the FM Std.3990
FM Approved Nameplate
Tank pressure withstand of 15 psi for rectangular tanks and 20 psi for round tanks without rupture
Primary circuit overcurrent protection that limits I^2t let-through
Specific Pressure Relief Device
Pressure Relief Alarm Contacts
Indoors > 500 kVA
Outdoors > 2500 kVA
Neutral Ground Fault Sensing Relay for Secondary*
≥ 150 Volt
> 1000 Amps

References

[x] Institution of Engineers (India) Studies on Fuel Properties of Refined Soybean Oil, Soybean Ethyl Ester and Their Blends with Diesel to Assess Usefulness as CI Engine Fuel, MB Bol, TK Bhattacharya, TN Mishra, Vol 85, May 2004, IE(I) Journal-ID pp. 17-20

[x] A. Argeros, D. Pincus, Z. Shinar, A. Sultenfuss, “Heat of Combustion of Oils”, BE 210 Final Project, Group R4, University of Pennsylvania, April 30, 1998

[x] “Process Safety Test Results and Interpretation”, Report Number R/5246/0105/NK, Chilworth Technology Plainsboro, NJ, February 1, 2006

[x] Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations, NFPA 850, National Fire Protection Association, Quincy, MA, www.nfpa.org

Current Edition: 2005
Next Revision Cycle: Fall 2009
Document Scope: This document provides recommendations (not requirements) for fire prevention and fire protection for electric generating plants and high voltage direct current converter stations, except as follows: nuclear power plants are addressed in NFPA 803, Standard for Fire Protection for Light Water Nuclear Power Plants; and hydroelectric plants are addressed in NFPA 851, Recommended Practice for Fire Protection for Hydroelectric Generating Plants.

[x] Recommended Practice for Fire Protection for Hydroelectric Generating Plants, NFPA 851, NFPA 850, National Fire Protection Association, Quincy, MA, www.nfpa.org

Current Edition: 2005 Next Revision Cycle: Fall 2009
Document Scope: This document provides recommendations (not requirements) for fire prevention and fire protection for hydroelectric generating plants. The term "hydroelectric generating plant" also can be referred to as "station," "project," "unit(s)," "facility," or "site

[x] Performance Based Standard for Fire Protection for Advanced Nuclear Reactor Electric Generating Plants, NFPA 806, NFPA 850, National Fire Protection Association, Quincy, MA, proposed standard, www.nfpa.org

Current Edition: Proposed Standard Next Revision Cycle: Fall 2007
Document Scope: This standard provides minimum fire protection requirements for advanced nuclear reactor electric generating plants during all phases of plant operation, including shutdown, degraded conditions, and decommissioning.