TECHNICAL REPORT

TRANSFORMER FLUID FIRE TESTING WITH MINERAL OIL, R-TEMP, and ENVIROTEMP FR3

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ABSTRACT

Transformer fluid fire tests were conducted during the week of May 6 and 13, 2002 at the Thomas A. Edison Technical Center for Cooper Power Systems, in Franksville, Wisconsin. Mr. Paul Dobson, Engineering Specialist and C. D. Wolske, Engineering Specialist, FM Global witnessed the tests. The purpose was to determine whether spacing distances between transformers and between transformers and buildings for medium size transformers could be safely reduced. Medium size transformers are 10 to 100 MVA and may contain up to 10,000-gal (37.9 m^3) of fluid. The purpose of the separation distance is to reduce the possibility of fire exposure to nearby buildings and equipment in event of a fault in a transformer resulting in release of fluid and fire on the ground around the transformer. Previous tests and loss experience involving internal arcing indicated that the probability of fire from this cause was very low for Approved Less Flammable transformer fluids.

For medium size transformers in addition to arcing there is a concern that heated internal surfaces of the transformer could ignite the dielectric fluid.

The heated surfaces simulating an electrical fault ignited mineral oil. R-Temp and Envirotemp FR-3 did not ignite under the same test conditions. Separation distances for medium sized transformers can be safely reduced from distances now recommended in DS 5-4 *Transformers.* All components of the transformer must be accessible for maintenance and inspection.

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INTRODUCTION

When replacement fluids for PCBs were first introduced in the late 1970s and early 1980s fire loss experience was not available. It was known that replacement fluids presented more of a fire hazard than PCBs. For the first twenty years of usage replacement fluids were largely limited to small transformers. Small transformers are generally 10 MVA or less with fluid volumes of 1,000-gal (3.8 m^3) or less.

It is estimated that there are about 100,000 transformers in service containing R-Temp representing about 1,000,000 transformer years of operation. Two incidents have been reported resulting in release of fluid from the transformer. Neither incident resulted in ignition of the fluid. It is estimated there are about 500 transformers in service containing Envirotemp FR3 representing about 850 transformer years of operation. Most experience is for transformers less than 10 MVA.

Previous tests were conducted simulating fault conditions in a transformer. It was concluded that mineral oil could be ignited and would continue to burn as a pool fire following an internal fault. Under the same conditions and with an external source of ignition R-Temp would not burn under pool fire conditions. The conclusion of the test series was that a pool fire on the ground around the transformer is unlikely. These test results are reported in "Transformer Fire Testing with R-Temp and Mineral Oil"; J.I.#0D1Z1.CY, Sep 1997.

There has been little experience with medium size transformers containing FMRC Approved less flammable fluids. Seven units, from 30 to 60 MVA, have been in operation representing 42 transformer years of operation. For medium transformers there is the added concern that metal plates (surfaces) within the transformer can be heated during certain fault conditions. A metal plate, under rare conditions, can be exposed to extreme eddy currents generated by stray magnetic flux, resulting in plate temperatures as high as 1380°F (750°C).

The metal shape selected for the test was determined through consultation with individuals with backgrounds in transformer design, repair and maintenance. The thickest steel is likely to be the end frame and clamping frame on a 100 MVA transformer. This steel is about ½ in. (1.3 cm) thick. The area of steel heated was estimated at 6 x 6 in. (15.2 x 15.2 cm) based on internal inspection of failed transformers. It was decided that the test piece should be 9 x 9 x ½ in (22.9 x 22.9 cm x 1.3 cm) thick.

It is expected that this shape could be heated to a high temperature by an internal fault, or more likely by an electrical abnormality leading to a very high level of magnetic flux induced currents. The internal fault could in turn lead to rupture of the casing and drain fluid level so the hot metal surface would be partially exposed to air. Electrical abnormalities that could cause severe core saturation leading to extremely high stray magnetic flux resulting in high temperatures are as follows: 1) energization of two-phase windings with the same source phase voltage could cause severe core saturation leading to extremely high stray magnetic flux. This could occur by crossed wires on the supply side with only one phase protection opening. 2) core excitation by a supply voltage much higher than the rated nominal value. This could occur by incorrect setting of dual voltage switches at time of energization.

II

FIRE TEST CONDITIONS

Three fluids were tested. Conventional transformer oil was used as a baseline fluid to verify that test conditions were severe enough to result in ignition. Two FMRC Approved less flammable transformer fluids were also tested: R-Temp and Envirotemp FR3. A minimum of two tests were conducted for each fluid. The test arrangement was as described below and shown in Figure 1.

2.1 Test Arrangement

Tests were conducted in a rectangular steel tank 4' x 7' x 2' (1.2 x 2.1 x 0.6 m) deep. The tank contained approximately 110 gallons (0.42 m^3) of insulating fluid. The depth of fluid in the tank was 0.5 ft. (0.15 m) deep. The tank was insulated and provided with electric immersion heaters. A removable cover was kept in the closed position until just before the plate was lowered. The fluid was pre-heated to about 266°F (130°C) to represent a sustained low energy fault or a severely sustained overload.

2.2 Test Scenario

A 9" x 9" x 0.5" (22.9 x 22.9 x 1.3 cm thick) plate was heated to a minimum temperature of 1380°F (750°C) by two oxyacetylene torches. This represented steel on the end frame and clamping frame of a 100 MVA transformer. The flame heating simulates the temperature increase that can be caused in steel plates experiencing high and sustained flux currents. The plate was then lowered into the pre-heated fluid such that approximately two thirds of the plate was below the surface of the fluid. This to simulate a condition where an internal fault has occurred, the tank has ruptured and fluid has drained down to a level that exposes part of the plate.

Two of the three test series were witnessed by FM Global personnel at the Thomas A. Edison Technical Center in Franksville, Wisconsin. The results of the third test series were viewed on videotape.

2.3 Measurements

Tests were videotaped. Plate temperatures were measured and recorded at two locations within the plate. The fluid temperatures were monitored at a location near the immersion point about half way between the surface of the fluid and the bottom of the tank. The difference in fluid temperature from the top to the bottom of the tank was monitored at a second location. The second location had three thermocouples: one thermocouple was located one inch (2.5 cm) below the surface, one was located in the center and another was located one inch (2.5 cm) from the bottom of the tank (see Figure 1)..

Observations were made with regard to ignition of the fluid and spread of flame across the surface of the fluid following immersion of the hot plate in the fluid.

III

TEST RESULTS

3.1 CONVENTIONAL MINERAL OIL

Four tests (Tests 3,4,7,and 8) were witnessed involving conventional mineral oil (Tranelec). In three of the four tests oil ignited and flames spread across the surface of the oil in the tank. The fire was extinguished by closing the cover of the tank.

In tests #3, 7 and 8 oil ignited 22 s, 5 s, and 4 s after the hot plate was lowered in the fluid.

In test #4 the mineral oil did not ignite. Oil samples from Test #4 and a new shipment of oil were tested at the Thomas A. Edison Laboratory to determine whether there was a difference in fluid properties. Two tests were conducted on each sample to determine flash and fire points. The results shown in Table 1 do not show a difference in properties which would explain the difference between mineral oil in test #4 and the mineral oil in Tests 3, 7 and 8. There have been incidents in the field involving rupture of mineral oil insulated transformers by an electrical fault with no fire following. See Table 2 for a summary of the tests.

Table 1
Test Results for Mineral Oil from Fluid used in Test #4 compared to New Mineral Oil

Mineral Oil	Flash Point(1) (ASTM - D92)	Fire Point(1) (ASTM D - 92)
New Mineral Oil	313°F (156°C)	334°F (168° C)
Oil from Test 4	324°F (162°C)	338°F (170°C)

Note 1: The average of two tests

3.2 R-TEMP FLUID

Two tests were conducted with R-Temp (Tests 5 and 6). There was ignition of the fluid near the surface of the plate with flames extending a distance of about 3 in. (7.6 cm) from the plate. In Test #5 the flames self-extinguished in 25 s, in Test# 6 flames self-extinguished in 20 s. See Table 2 for a summary of the tests.

3.3 ENVIROTEMP FR3 FLUID

Test 1 involved pure Envirotemp FR3. Test 2 was a mixture of 95.5% FR3 and 4.5% mineral oil. The purpose of this test was to simulate retrofilling a mineral oil filled transformer in which the mineral oil had not been completely drained from the transformer. The fluid did not ignite in either test. More smoke was generated with the mixture of oil and FR-3 than with pure Envirotemp FR3. See Table 2 for a summary of the tests.

Table 2

Results for Mineral Oil, R-Temp and Envirotemp FR-3 Hot Surface Tests

Test No.	Fluid Tested	Temperature		Test Results
		Fluid near Metal Plate °F/°C	Center of Metal Plate @ Entry into Fluid °F/°C	
1	FR3	271°F (133 ° C).	1443°F (784°C)	No ignition
2	Contaminated FR3(1)	271°F (133 ° C).	1418°F (770°C)	No ignition
3	Mineral Oil	273°F (134°C).	1434°F (779°C)	Ignition after 22 s. Flame spread over surface.
4	Mineral Oil	266°F (130°C).	1443°F (784°C)	No ignition
5	R-Temp	270°F (132°C).	1455°F (791°C)	Localized flame near plate surface. Self-extinguished in 25 s. (2)
6	R-Temp	271°F (133°C).	1472°F (800°C)	Localized burning near plate surface. Self-extinguished in 20 s (2)
7	Mineral Oil	259°F (126°C).	1448°F (787°C)	Ignition after 5 s. Flame spread over surface.
8	Mineral Oil	262°F (128°C).	1466°F (797°C)	Ignition after 4 s. Flame spread over surface.

Note 1: 95.5% FR3 fluid and 4.5% mineral oil. This to simulate retrofill of a transformer containing mineral oil with Envirotemp FR3.

Note 2: Localized burning was observed within 3 in. (7.6 cm) of plate.

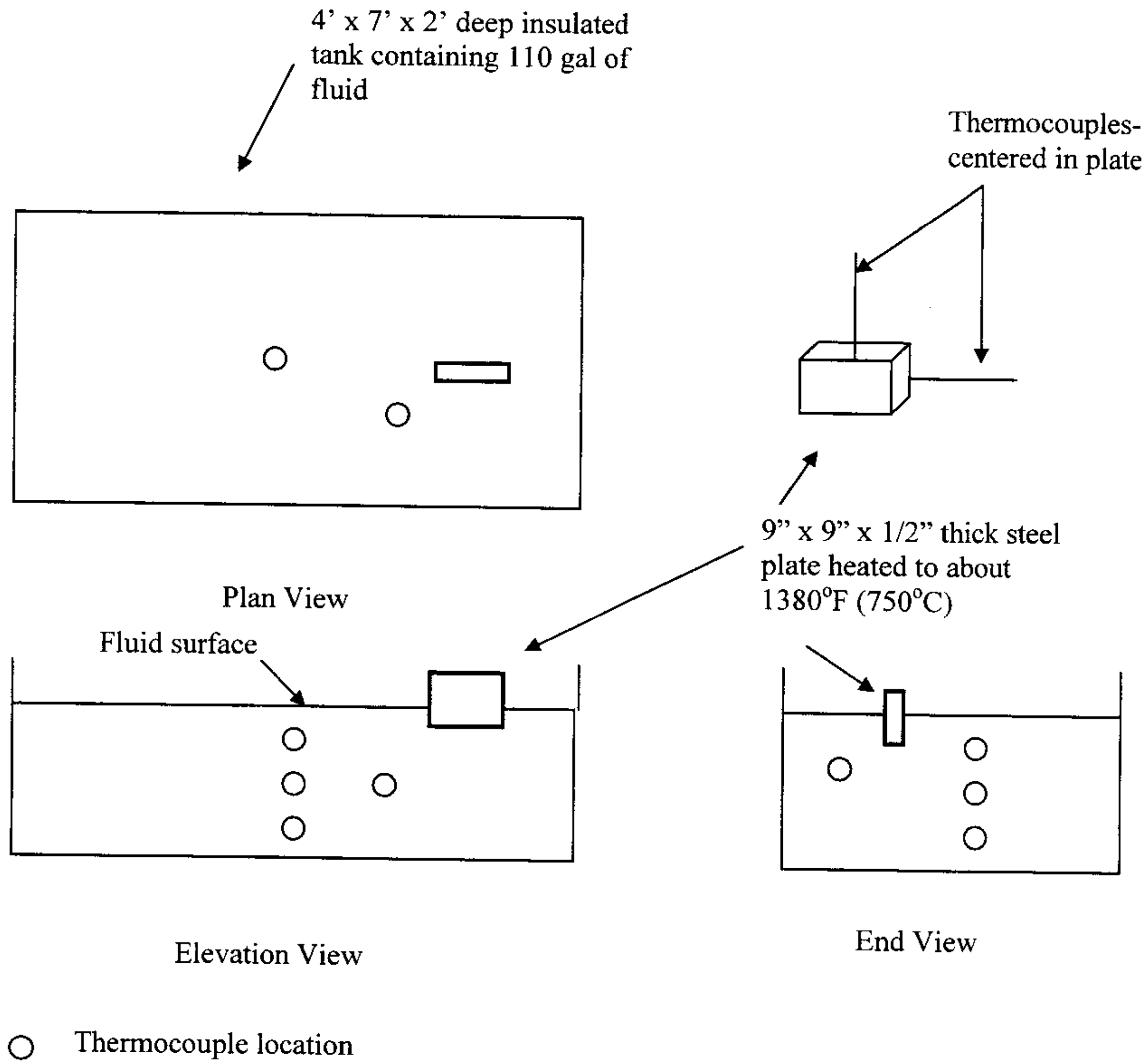

Figure 1
Test Arrangement Showing thermocouple location and heated steel plate in contact with fluid under test

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IV

SUMMARY AND CONCLUSIONS

A fire in a small or medium sized transformer tank containing an FM Approved less flammable transformer fluid caused by heated metal surfaces is unlikely. Previous testing indicated that a pool fire would be unlikely to occur following an electrical fault in a transformer and failure of the casing. Favorable loss experience indicates that separation distances for medium sized transformers for fire protection purposes can be safely reduced.

All transformer components must be accessible for inspection and maintenance.

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REFERENCES

Dobson, P.H., "Transformer Fire Testing with R-Temp and Mineral Oil", FMRC J.I. 0D1Z1.CY, September 1997