Fire test of Profile Plank for transformer pit fire protection

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Abstract

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A tests series of transformer pit fires was conducted to test the extinguishing capacity of a profile plank layer in the transformer pit. Three tests were performed with 90 °C and 140 °C transformer oil. In test 2, a 19 cm water bed was used to examine the involvement of rain water. The result showed that the profile plank extinguished the fire in a few seconds and the oxygen level was as low as 3.7 vol% 5 cm under the profile plank in the center of the transformer pit in test 3. The simulated rain water did not have any effect on the result.

Key words: transformer pit, transformer oil, fire, profile plank, thermocouples, gas analysis

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Preface

This work has been funded by Meiser Vogtland OHG, Oelsnitz, Germany, hereafter referred to as the client. The client was responsible for choosing, providing and assembling the equipment which were tested in the experiments.

Tarmo Karjalainen and Emil Norberg at SP are gratefully acknowledged for managing the instrumentation. Krister Palmkvist, Lennart Hällefors and Samuel Norlén at SÄRF (Södra Älvsborgs Räddningstjänstförbund – the federation of fire and rescue organisations centered around Borås) are gratefully acknowledged for managing the safety work during the tests and for recording IR-videos. SÄRF is also acknowledged for their hospitality during the tests which were performed at the SÄRF training center Guttasjön in Borås, Sweden. Meiser Vogtland OHG and Qlean Scandinavia AB are acknowledged for oil handling and cleaning of pit and profile planks. Qlean Scandinavia AB is the representative for the tested product in Sweden.

1 Introduction

A traditional method for improving fire safety at transformer stations is to fill the transformer pit with gravel. In the Swedish standard SS 421 01 01[1] it is written: “Företrädesvis skall anordningar som medverkar till släckning av eld i den utläckta vätskan användas, t ex genom ett lager av grovgrus (omkring 300 mm djupt och med en kornstorlek av omkring 40/60 mm) som släcker den brinnande olja som tränger in i lagret.”

which in English translates to

“Preferably arrangements that contribute to extinguish the fire in the leaked liquid shall be used, for example the use of a layer of stones (approximately 300 mm deep and with a grain size of about 40/60 mm) that extinguishes the burning liquid that enters the layer.”

There is a lack of a technology neutral requirements concerning the performance of the arrangement described above that should contribute to extinguish the fire of leaking flammable fluid. A review of national and international standards and guidelines shows that several documents address the problem of a fire in leaking transformer oil to various degrees but with no specific performance requirement [2-5]. This report presents a quantitative test (corresponding to possible technical requirements) of a specific arrangement under realistic failure conditions for a transformer rupture.

2 Experimental

The transformer pit, oil system, and instrumentation is described in Section 2.1 and the protocol followed during the tests is described in Section 2.2.

2.1 Experimental setup

The transformer pit was 4 meters by 3 meters and 1 meter deep. The transformer pit was built in concrete by the client according to current standards. A roof on the pit was constructed using profile plank which was placed 80 cm from the ground level, resting on angle bars as shown in Figure 1. A side view of the test setup is shown in Figure 2. The oil was stored in a tippable trailer with a total volume of 600 liters. The temperature measurement was conducted with five thermocouple trees. The thermocouple trees are named A-E and are shown in Figure 3. Each tree contained six thermocouples at 1, 20, 50, 75, 85 and 130 cm from the ground level. The thermocouples at 85 and 130 cm were above the profile plank. Gas sampling for CO, CO₂ and O₂ analysis was conducted at two positions 5 cm under the profile plank as shown in both Figure 2 and Figure 3. The gas sampling pipe is shown in Figure 4. Photographs of the test setup from above and below the profile plank are shown in Figure 5 and Figure 6, respectively.

Figure 1 Profile plank resting on angle bars.

Following symbols are used in Figure 2 and Figure 3:

- ✗ Gas sampling (CO , CO_2 , O_2)
- Thermocouple tree

Figure 2 Side view of the experimental setup.

Figure 3 Top view of the experimental setup.

Figure 4 Gas sampling pipe, the inlet is located 5 cm below the Profile plank.

Figure 5 Photo of test setup from above.

Figure 6 Photo of test setup from below the profile plank. The camera was directed to the left in Figure 2 and Figure 3, showing thermocouple trees A, B, and E.

The oil used was Nynas Transformer Oil – Nytro 10X which is a standard transformer oil. Data for the oil is given in Appendix B.

The scenario modeled correlates to a sudden accidental release of large oil quantities from a transformer under normal conditions. The maximum stipulated temperature increase is 60°C [6] and therefore the oil temperature is not expected to exceed 90°C. Therefore the oil temperature in Tests 1 and 2 was 90°C. For additional information the oil was heated

to the flashing point 140°C in Test 3. Water was added to the transformer pit in Test 2 in order to study the outcome of a release of oil into a pit pre-filled with rain water.

2.2 Experimental protocol

Each test started with filling the tippable trailer with a pre-determined amount of oil. The oil was then heated with external gas burners to a specific temperature as shown in Figure 7. When the right temperature was reached, the oil was ignited with a gas burner as shown in Figure 8. After a set pre-burn time the oil was tipped into the transformer pit. Figure 9 shows the burning oil two seconds before tipping the oil into the transformer pit. Figure 10 shows the sequence when the oil is tipped into the transformer pit. All three tests were performed in the same way but the input values were slightly different as explained below for each test:

Test 1:

- 400 l of oil
- Heated to 90 °C before ignition
- Pre-burn time 1:25 (min:sec)

Test 2:

- 370 l of oil
- Heated to 90 °C before ignition
- Pre-burn time 1:25 (min:sec)
- The transformer pit contained a 19 cm deep water bed

Test 3:

- 300 l of oil
- Heated to 140 °C before ignition
- Pre-burn time 1:50 (min:sec)

The reason why less oil was used in Test 2 than in Test 1 was that the inclination of the trailer was slightly higher and therefore 30 l of oil were removed in order to avoid excessive spilling of burning oil before tipping. The reason why less oil was used in Test 3 was that the oil expanded more due to the higher temperature.

A sequence of photographs of Test 2 is shown in Figure 7 to Figure 12.

Figure 7 Heating the oil with external gas burners.

Figure 8 Igniting the oil.

Figure 9 Before tipping the burning oil into the pit. (3:23 min:sec).

Figure 10 Tipping the burning oil into the pit. (3:25 min:sec).

3 Results and discussion

3.1 Visual observations

Figure 11 shows the flame height when the oil was tipped into the transformer pit. Figure 12 shows the effectiveness of the profile plank installation. The flames were extinguished after three seconds as shown on the clock in the lower right corner in both Figure 11 and Figure 12. The same visual observations were made in all three tests.

Figure 11 Seconds after the burning oil was poured into the pit. (3:29 min:sec).

Figure 12 All visible flames disappeared a few seconds after tipping the burning oil into the pit. (3:32 min:sec).

3.2 Gas temperatures

The results for the gas temperature measured by the middle thermocouple tree, tree A, are shown in Figure 13 to Figure 15. All thermocouple measurements, for all trees, are presented in Appendix A.

The temperature drops rapidly for both Test 1 and Test 2. For Test 3 the temperatures below the profile plank are elevated and fluctuate during a period of 2 minutes after tipping the oil. This indicates continued heat release due to the elevated oil temperature (140°C for Test 3 as compared to 90°C for Test 1 and Test 2). However, above the profile plank no significant differences in temperature can be observed between the tests.

For Test 2, with 19 cm water in the transformer pit, the temperatures are higher than for Test 1. A possible explanation for this is that the transient combustion below the profile plank is translated 19 cm upwards and therefore nearer the thermocouples.

Figure 13. Gas temperatures measured in the middle thermocouple tree for test 1. The oil temperature was 90°C and there was no water in the pit.

Figure 14. Gas temperatures measured in the middle thermocouple tree for test 2. The oil temperature was 90°C and there was 19 cm water in the pit.

Figure 15. Gas temperatures measured in the middle thermocouple tree for test 3. The oil temperature was 140°C and there was no water in the pit.

3.3 Gas concentrations

Gas concentrations at two positions in the transformer pit are shown in Figure 16 to Figure 18.

Figure 16. CO concentrations measured at the positions indicated in Figure 2 to Figure 4. The concentrations for all three tests are shown.

Figure 17. CO₂ concentrations measured at the positions indicated in Figure 2 to Figure 4. The concentrations for all three tests are shown.

Figure 18. O₂ concentrations measured at the positions indicated in Figure 2 to Figure 4. The concentrations for all three tests are shown.

4 Conclusions

As shown in Figure 11 and Figure 12, the presence of the profile plank extinguished the fire quickly in only three seconds. The fast extinction is partially due to the reduction in oxygen below the profile plank as shown in Figure 18. To promote this oxygen reduction it is important that the angle bars are fastened tight to the concrete wall to minimize leakage of air around the boundary of the construction.

In test 2, a 19 cm deep water bed was used to simulate rain water in the transformer pit. The visual observations and recorded temperatures and gas concentrations shown in Figure 13 to Figure 18 show that the water bed did not have any influence on the test result.

In test 3, 140°C oil was used. The higher temperature of the oil did not have any effect on the visible result, but higher temperatures were recorded in the pit and heat release continued for approximately 120 s as indicated by the increased temperatures, prolonged production of CO, CO₂ and consumption of oxygen compared to the other two tests.

Above the profile plank no significant differences in temperature can be observed between the tests. Indicating that the risk of flame spread from the pit to the surroundings is minimal in all cases.

References

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- [3] FM Global Property Loss Prevention Data Sheets 5-4 TRANSFORMERS. 2012.
- [4] NFPA 70: National Electric Code. 2011.
- [5] NFPA 850: Recommended practice for fire protection for electric generating plants and high voltage direct current converter stations. 2010.
- [6] IEC 60076-2 Power transformers - Part 2: Temperature rise. 1993.

5 Appendix A: Results

5.1 Test 1: oil temperature 90°C, no water

Figure 19. Gas temperatures measured in the thermocouple tree A for test 1. The oil temperature was 90°C and there was no water in the pit.

Figure 20. Gas temperatures measured in the thermocouple tree B for test 1. The oil temperature was 90°C and there was no water in the pit.

Figure 21. Gas temperatures measured in the thermocouple tree C for test 1. The oil temperature was 90°C and there was no water in the pit.

Figure 22. Gas temperatures measured in the thermocouple tree D for test 1. The oil temperature was 90°C and there was no water in the pit.

Figure 23. Gas temperatures measured in the thermocouple tree E for test 1. The oil temperature was 90°C and there was no water in the pit.

5.2 Test 2: oil temperature 90°C, 19 cm water

Figure 24. Gas temperatures measured in the thermocouple tree A for test 2. The oil temperature was 90°C and there was 19 cm water in the pit.

Figure 25. Gas temperatures measured in the thermocouple tree B for test 2. The oil temperature was 90°C and there was 19 cm water in the pit.

Figure 26. Gas temperatures measured in the thermocouple tree C for test 2. The oil temperature was 90°C and there was 19 cm water in the pit.

Figure 27. Gas temperatures measured in the thermocouple tree D for test 2. The oil temperature was 90°C and there was 19 cm water in the pit.

Figure 28. Gas temperatures measured in the thermocouple tree E for test 2. The oil temperature was 90°C and there was 19 cm water in the pit.

5.3 Test 3: oil temperature 140°C, no water

Figure 29. Gas temperatures measured in the thermocouple tree A for test 3. The oil temperature was 140°C and there was no water in the pit.

Figure 30. Gas temperatures measured in the thermocouple tree B for test 3. The oil temperature was 140°C and there was no water in the pit.

Figure 31. Gas temperatures measured in the thermocouple tree C for test 3. The oil temperature was 140°C and there was no water in the pit.

Figure 32. Gas temperatures measured in the thermocouple tree D for test 3. The oil temperature was 140°C and there was no water in the pit.

Figure 33. Gas temperatures measured in the thermocouple tree E for test 3. The oil temperature was 140°C and there was no water in the pit.

6 Appendix B: Transformer oil data sheet

Naphthenics Product Data Sheet Nynas Transformer Oil - Nytro 10X

97-04-21

PROPERTY	UNIT	TEST METHOD	GUARANTEED DATA		TYPICAL DATA
			Min	Max	
1. <u>Physical</u>					
Appearance		IEC 296	Clear, free from sediment		
Density, 20°C	kg/dm ³	ISO 12185		0.895	0.876
Viscosity, 40°C	mm ² /s	ISO 3104		8.0	7.6
Viscosity, -30°C	mm ² /s	ISO 3104		800	730
Flash Point, PM	°C	ISO 2719	140		144
Pour Point	°C	ISO 3016		-45	-60
2. <u>Chemical</u>					
Neutralization value	mg KOH/g	IEC 296		0.03	<0.01
Corrosive sulphur		ISO 5662	non-corrosive		
Aromatic content	%	IEC 590			7
Antioxidant, phenols	Wt %	IEC 666			0.3
Water content	mg/kg	IEC 814		30	<20
3. <u>Electrical</u>					
Dielectric dissipation factor at 90°C		IEC 247		0.005	<0.001
Interfacial tension	mN/m	ISO 6295	40		45
Breakdown voltage					
- Before treatment	kV	IEC 156	30		40-60
- After treatment	kV	IEC 296	70		>70
4. <u>Oxidation Stability</u>					
At 100°C 164h		IEC 1125A			
Neutralization value	mg KOH/g				<0.01
Sludge	Wt %				<0.005
At 120°C		IEC 1125B			
Induction period	h		150		>236
At 110°C 28 days		DIN 51554			
Beader test					
- Saponification number	mg KOH/g				0.15
- Sludge	Wt %				<0.005
- Dielectric dissipation factor at 90°C					0.003

NYTRO 10X is an inhibited transformer oil with extremely good electrical properties and very good oxidation stability. This product fully conforms to IEC 296(82), Class IA and IIA.

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