Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS1-10178

Development of Methodologies to Predict Incipient Faults in Power Transformers Related to Particles Contamination and Bubble Formation

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BRAZIL

Motivation

- Every occurrence in transformer leaves traces in insulating oil. So, What else can we look for?
- Different materials will be released to the oil depending on what transformer's part is affected. Particles or soluble substances such as:
  - ✓ Paper fibers from coils insulation, paperboard.
  - ✓ Metal particles from coils, core, couplings, contacts.
  - ✓ Soluble metal compounds from same elements at higher energy faults.
  - ✓ Organic compounds such as rubber, varnish, polymeric parts.
- Water containing cellulose favours bubble emergence on its surface at certain temperatures. in temperature gradient, hotspots, and water content.
- Insulating system dielectric strength can be drastically reduced when water droplets or bubbles pass through intense electric fields, which can lead to partial discharge or even insulation breakdown.

Objectives of investigation

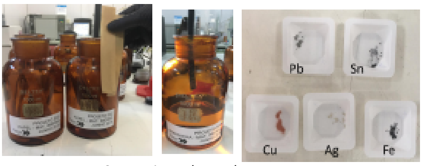
- Correlate transformer building materials degradation with insulating oil characteristics and faults origin.
- Induce bubble formation in insulating paper surface in an experimental model comprised of mineral insulating oil (MIO) and thermally upgraded kraft paper (TUK).

Method/Approach

- Samples, prepared in laboratory and taken from transformers in operation, were analysed by physicochemical tests, dissolved gas analysis including C3 and C4, volatile and furanic compounds determination, in addition to quantitative and morphological particle analysis (particle counting, particle quantification index and ferrography).
- Bubble formation dynamics upon sudden changes in temperature was evaluated in an experimental set up composed of MIO and thermally upgraded kraft paper (TUK).

Experimental setup

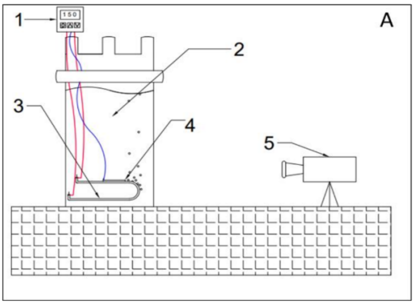
Contaminated oil samples as well as blank samples were thermally aged in an oven for 20 days at temperatures of 150 ºC and 180 ºC. Test at 180 ºC performed with high concentration of powder metals and filtered after aging. All samples were analyzed after heating.



Contaminated samples.

DGA - headspace.

Ferrography.



Schematic diagram of assembled experimental set up for bubble formation dynamic study, where 1: temperature controller; 2: glass vessel (reactor) containing MIO; 3: electrical resistance wrapped in two layers of TUK; 4: temperature sensor fixed between electrical resistance surface and inner paper layer; 5: digital camera recording bubble formation. (

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(continued)

Test results

DGA analysis of samples prepared in laboratory and samples from transformers.

Gas (ppm)	Sample									
	Blank [a]	Paper [b]	Rubber [c]	Metals [d]	Sample 1 [e]	Sample 2 [e]	Sample 3 [e]	Sample 4 [e]	Sample 5 [e]	Sample 6 [e]
H_2	32	15	18	38	124	94	20	517	48	1175
CO_2	1540	1389	1305	3538	11406	3346	7221	21401	1130	12576
C_2H_4	12	9	10	26	15	59	80	242	17	9
C_2H_6	54	117	60	110	119	3	9	679	146	293
CH_4	30	114	30	217	1316	2	8	341	22	675
C_2H_2	0	0	0	0	3	0	0	3	0	0
CO	163	141	173	516	414	80	397	743	90	145
C_3H_8	93	111	119	130	140	14	17	704	447	381
C_3H_6	28	18	30	58	21	35	31	666	122	52
C_4H_{10}	477	571	769	3167	103	502	782	725	455	172
CO_2/CO	10	10	8	7	28	42	18	29	13	87
Diagnosis	-	-	-	-	HTTF [f]	HTTF [f]	HTTF [f]	NO [g]	NO [g]	NO [g]

[a] Blank test: only MIO; [b] MIO contaminated with paper; [c] MIO contaminated with rubber; [d] MIO contaminated with copper, tin, lead and silicon steel); [e] Samples from transformers in operation. [f] HTTF: High Temperature Thermal Fault (>700 ºC); [g] NO: Normal Operation.

Physicochemical analysis of samples prepared in laboratory and samples from transformers.

Sample	Physicochemical parameter				
	Power factor (100 °C) (%)	Water content (ppm)	Dielectric strength (kV)	Interfacial tension (mN/m)	TAN (mg KOH/g)
Blank [a]	2.4	22	36	26	0.15
Paper [b]	1.5	29	26	32	0.05
Rubber [c]	663.8	22	38	24	0.14
Metals [d]	5.6	29	29	32	0.07
Sample 1 [e]	25.53	23	74	37	0.06
Sample 2 [e]	33.9	33	30	32	0.06
Sample 3 [e]	18.2	26	36	30	0.04
Sample 4 [e]	41.71	104	33	15	0.82
Sample 5 [e]	25.47	28	27	28	0.07
Sample 6 [e]	29.09	73	50	22	0.23

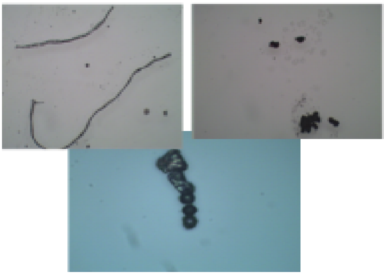
a Blank test: only MIO; b MIO contaminated with paper; c MIO contaminated with rubber; d MIO contaminated with copper, tin, lead and silicon steel); e Samples from transformers in operation.

PQI and particle counting of samples prepared in laboratory and samples from transformers.

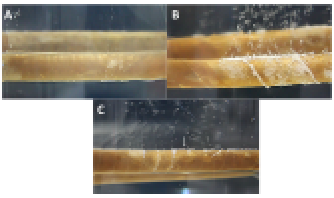
Sample	PQI	Total Particle Counting/mL
Blank [a]	6	64350
Paper [b]	7	137010
Rubber [c]	7	152143
Metals [d]	11	48253
Sample 1 [e]	8	8046
Sample 2 [e]	8	721
Sample 3 [e]	7	161
Sample 4 [e]	7	1578
Sample 5 [e]	8	5631
Sample 6 [e]	9	588256

a Blank test: only MIO; b MIO contaminated with paper; c MIO contaminated with rubber; d MIO contaminated with copper, tin, lead and silicon steel); e Samples from transformers in operation.

Ferrography.



Ferrography analysis of sample 6.



Bubbling and bubble accumulation on paper surface at tests: (a) test 1 (0.3% water content paper); (b) test 2 (0.9% water content paper) e; (c) test 3 (2.5% water content paper).

Conclusions

- Some samples, despite of having normal operation diagnosis via DGA, may present indication of fault or warning points for maintenance team when other parameters are analysed. For instance, samples with high power factor in relation to the expected considering oil oxidation stage, should be better investigated by complementary analyses, as it is an indication of oil contamination.
- Ferrography is an important tool for detecting and identifying insoluble particles resulting from incipient faults. Results allowed to conclude that particle analysis should be included in routine oil analysis, in the same frequency of existing physicochemical analysis.
- Abrupt changes in temperature favour bubble inception.

Acknowledgment

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