Revision of Loading Guide 57.91

Bubble Evolution

Section 7.2

Why It Should be Retained

By

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What Is the Bubble Evolution Equation?

- The equation enables computation of bubble evolution hot spot temperature during overload conditions.

- Bubble evolution is influenced by;
  - hot spot temperature during overload
  - moisture in insulation
  - hydrostatic pressure
  - gas content of oil

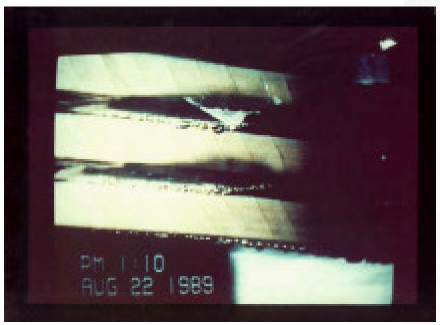
- The equation is applicable to both gas blanketed and conservator systems

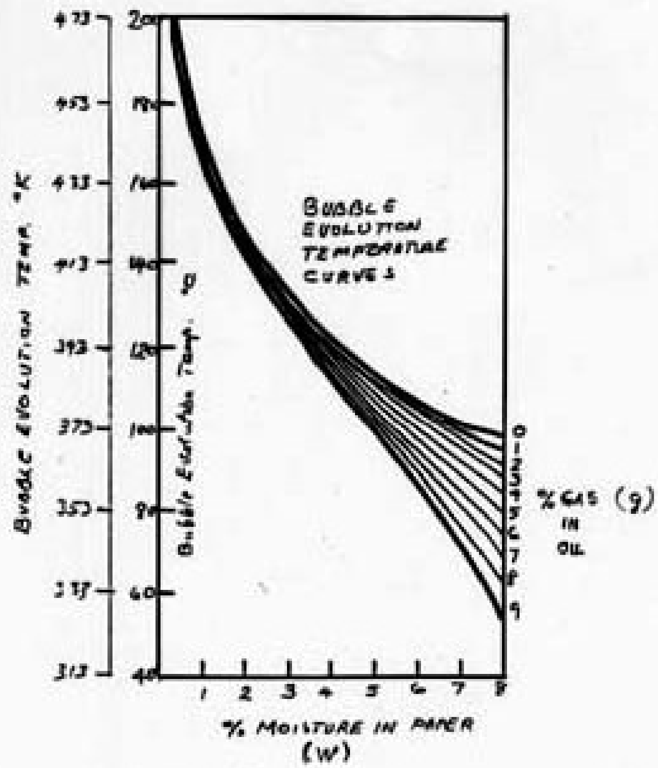
- The equation resulted from several years of research sponsored by Utilities and administered by EPRI

EPRI Reports EL-5384, Aug 1987; EL-6761, Mar 1990
EL-7291, 1992
IEEE Trans. Com. Presentation, Oct. 2000
IEEE T&D Conf. Paper, Oct 2002; IEEE Trans. Com

Bubble Evolution from Overload

Mathematical Relationship to Estimate Bubble Evol. Temp.





$$T(^\circ K) = \left[6996.7/(22.454 + 1.4495 \ln W - \ln P)\right] - \left[\exp(0.473\,W) \times \left(\frac{g}{30}\right)^{1.585}\right]$$

Bubble evol. Hot spot temp.
W: Water in Paper, %
g: Gas in Oil, %
P: Total ext. pressure, torr.

Based on EPRI Projects by
Westinghouse, ABB 1988-92
Proj. Leader: T. V. Oommen

Eqn in Section 7.2

$$\Theta_{bubble} = \left[\frac{6996.7}{22.454 + 1.4495 \ln W_{WP} - \ln P_{pres}} \right] - \left[\left(EXP^{(0.473 W_{WP})} \right) \left(\frac{V_g^{1.585}}{30} \right) \right] - 273 \quad (6)$$

where $?_{bubble:}$ Temperature for bubble evolution, ^{o}C

P_{press} : Total pressure, mm of mercury

W_{WP} : Percent moisture in paper (dry basis)

V_g : Gas content of oil, % (v/v)

The equation has been shown to fit all the experimental data with widely varying range of the variables.

It shows that bubble evolution should not occur in dry transformers at hot spots above 140C for both conservator and gas blanketed units. In other words, it is safe to overload dry units. However, short term insulation aging would occur.

See graphical plot

OBSERVED AND COMPUTED TEMPERATURES

TEST #	OBSERVED	COMPUTED (Revised Math. Model)
1	166ºC	168ºC
2	110	113
3	130	130
4	109	111
5	99	98
6	60	64
7	55	53
8	122	119
9	110	108
10	90	91
11	128	124
12	93	98
13	60	58
14	132	128

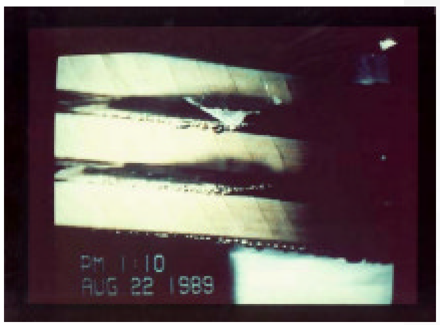
OBSERVED AND COMPUTED TEMPERATURES FOR PRIOR WORK

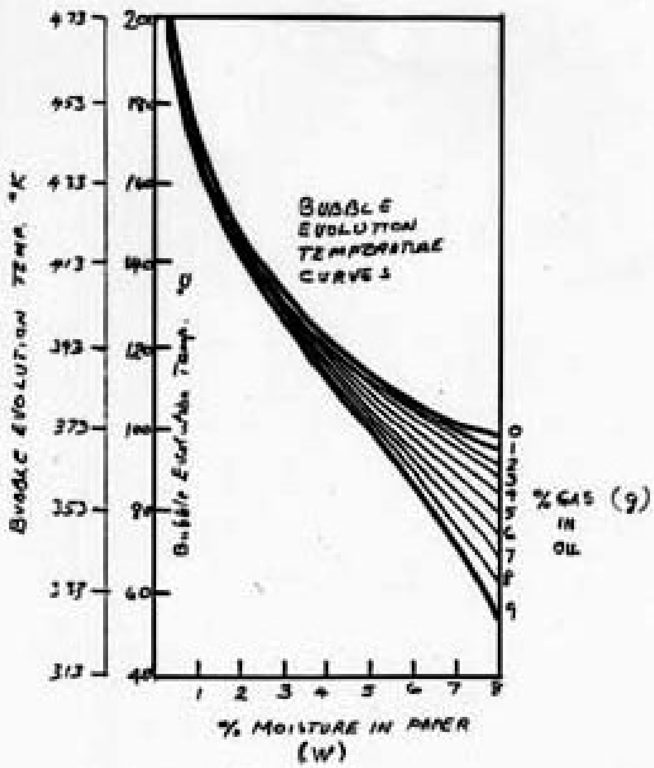
	OBSERVED	PREDICTED	
		Revised Model	Prior Model
	220ºC	224	213
	215	224	212
	209	191	153
	209	192	143
	204	209	154
	209	209	161
	211	208	165
High	158	153	151
moisture	160	164	110
models	131	134	87
	152	151	149
	158	149	98

Red: Gas saturated models

Bubble Evolution from Overload

Mathematical Relationship to Estimate Bubble Evol. Temp.





$$T(°K) = \left[6996.7/(22.454 + 1.4495 \ln W - \ln P)\right] - \left[\exp(0.473\,W) \times \frac{(g)^{1.585}}{30}\right]$$

Bubble evol. Hot spot temp.
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Answers to Objections In Using the Equation

1. **Eqn is complicated**

   Ans. ***Yes, it has several variables and contains exponential and power terms, but this is not unusual in engineering formulas.***

2. **Moisture in paper cannot be easily determined**

   Ans. ***Yes, it is difficult, but progress as been made in reliable estimations using methods such as 'water heat-run, and dielectric spectroscopy. The moisture in paper remains fairly stable, hence frequent estimations are not needed.***

   In water heat run, a field unit during shut down may be subjected to a 'heat run' for a few days to stabilize temperature; moisture equilibrium curves may then be used. Dummy samples may be used.

   In dielectric spectroscopy, time and frequency domain scan methods are being used for moisture estimation in filed units.

   The estimation of moisture in insulation is needed for insulation life prediction, hence the estimation methods will be refined.

   It is therefore unwise to abandon the equation which is the only tool to predict bubble evolution.