

IEEE Insulating Fluids Subcommittee

“IEEE Guide for Reclamation of Insulating Oil and Criteria For Its Use”

PC57.637 Revision Working Group

Chair Jim Thompson
Vice-Chair TV Oommen
October 26, 2010

MEETING AGENDA

- Introductions
- Patent Disclosure Request
- Old Business
 - Approval of Minutes of March 9, 2010 Meeting
- New Business
 - Moisture Dynamics in IEEE C57--Review
 - Working Group Assignments

IEEE-SA Standards Board Bylaws on Patents in Standards

6. Patents

IEEE standards may include the known use of essential patents and patent applications provided the IEEE receives assurance from the patent holder or applicant with respect to patents whose infringement is, or in the case of patent applications, potential future infringement the applicant asserts will be, unavoidable in a compliant implementation of either mandatory or optional portions of the standard [essential patents]. This assurance shall be provided without coercion and prior to approval of the standard (or reaffirmation when a patent or patent application becomes known after initial approval of the standard). This assurance shall be a letter that is in the form of either:

- a) A general disclaimer to the effect that the patentee will not enforce any of its present or future patent(s) whose use would be required to implement either mandatory or optional portions of the proposed IEEE standard against any person or entity complying with the standard; or
- b) A statement that a license for such implementation will be made available without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination.

This assurance shall apply, at a minimum, from the date of the standard's approval to the date of the standard's withdrawal and is

Inappropriate Topics for IEEE WG Meetings

- Don't discuss the validity/essentiality of patents/patent claims
- Don't discuss the cost of specific patent use
- Don't discuss licensing terms or conditions
- Don't discuss product pricing, territorial restrictions, or market share
- Don't discuss ongoing litigation or threatened litigation
- Don't be silent if inappropriate topics are discussed... do formally object.

If you have questions, contact the IEEE-SA Standards Board Patent Committee Administrator at patcom@ieee.org or visit <http://standards.ieee.org/board/pat/index.html>

This slide set is available at

Unapproved Minutes Working Group Meeting PC57.637 April 9, 2010

The working group meeting was conducted at 8 am on April 9, 2010 with 28 people in attendance with 16 of the 20 working group members present. This document was reaffirmed in 2007 and the PAR for revision was approved December 10, 2008. Working Group members Jim Thompson (chair) and TV Oommen (co chair) conducted the meeting. There was a request for patent declarations regarding the PC57.637 document and none given.

There was a motion to approve the October 27, 2009 Working Group minutes by Don Cherry and a second by Derek Baronowski. The approval of the minutes was unanimous. The discussion of the meeting included (a) Juan Castenellos' revision language on the introduction regarding the recommendation of new oil, rather than used reclaimed oil, in new electrical apparatus, and (b) Claude Beauchemin's text on the sulfuric compound testing and Polychlorinated Biphenyl testing per ASTM methods, to be inserted as footnotes of Table 2, and (c) Dave Sundin's text on the sections for definitions and askeral tradenames.

Ray Bartnikas asked if the life of the used oil was discussed in the guide. Currently the guide does not address that issue.

Respectfully submitted,

Chair Jim Allen Thompson

Co Chair TV Oommen

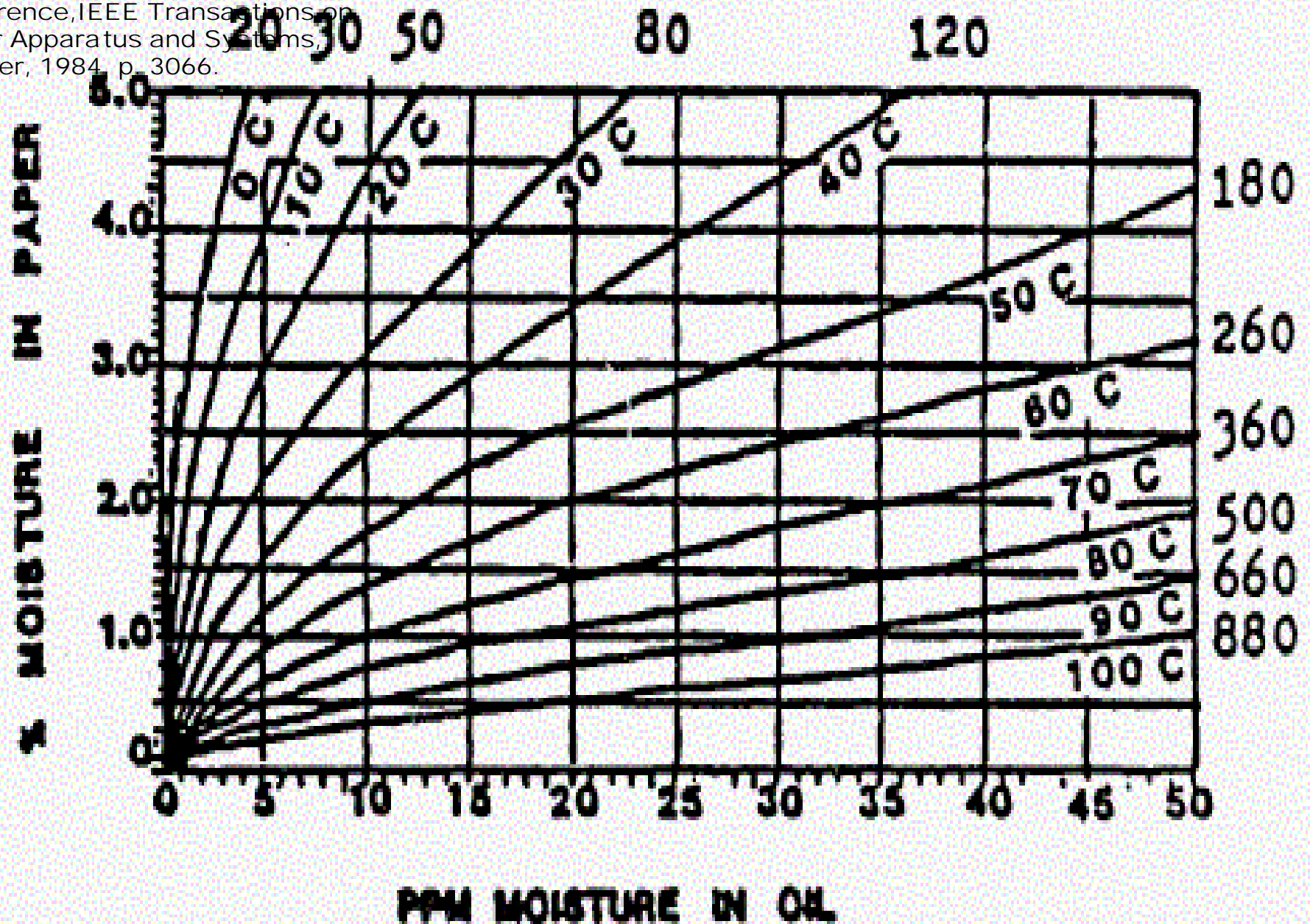
***Moisture Dynamics in
Transformers
Review***

**Jim Thompson
Chair
IEEE WG Meeting
PC57.637**

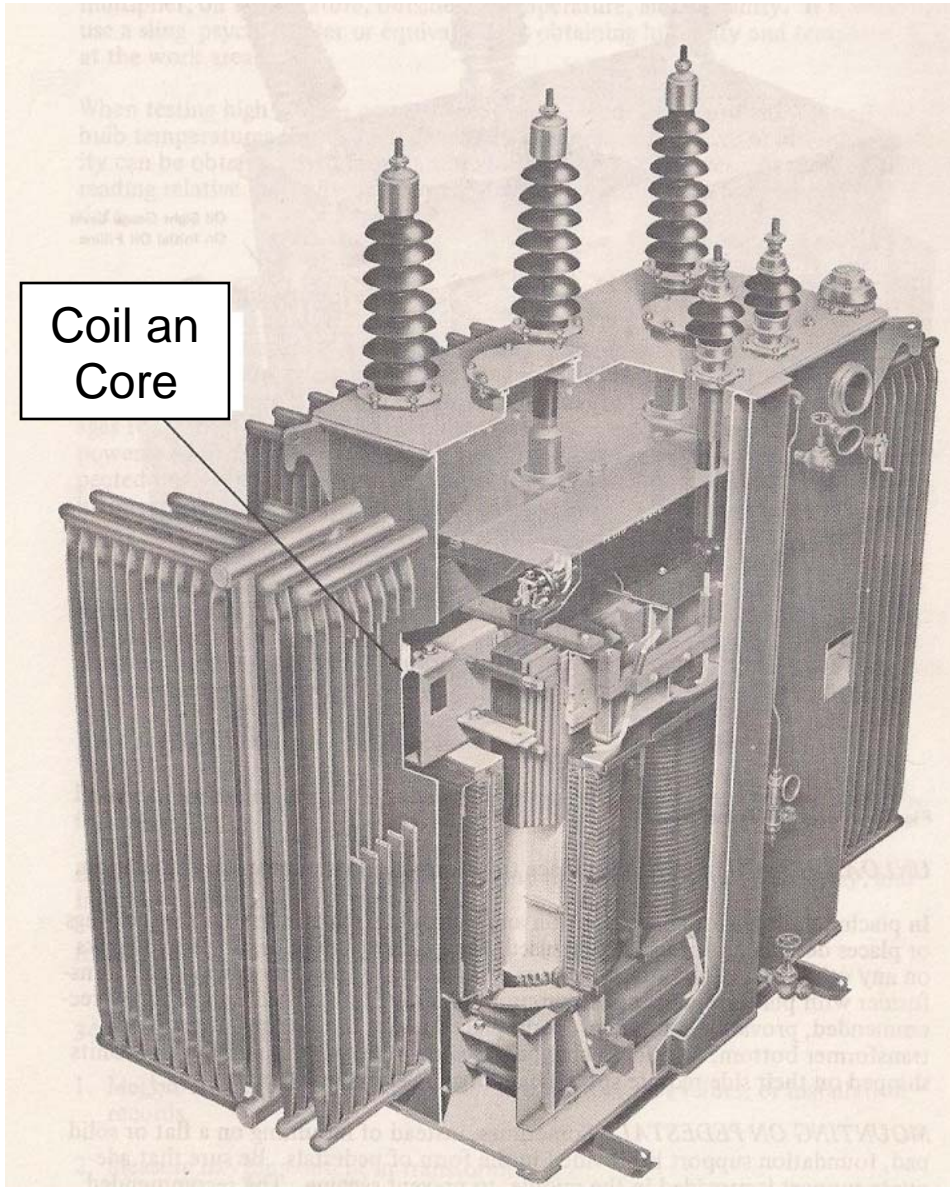
**October 26, 2010
Toronto, Canada**

Oommen, T.V., "Moisture Equilibrium Charts For Transformer Insulation Drying Practice," 1984 IEEE T & D Conference, IEEE Transactions on Power Apparatus and Systems, October, 1984, p. 3066.

Solubility Limit, PPM



Introduction



- The IEEE Standards - revision continues for moisture issues.
- An RC circuit analogy illustrates the diffusion % equilibrium times.
- Moisture varies with location and time due to temperature gradients.
- Take samples for oil moisture at bottom valve and record top oil temperature biannually.
- Caution - Energizing or re-energizing during cold weather reduces oil dielectric breakdown strength due to moisture levels approaching saturation. See IEEE C57.106-2006.

Status of IEEE Standards – October 26, 2010

IEEE Power Engineering Society - IEEE Transformer Committee

<http://www.transformerscommittee.org/>

Insulating Fluids Subcommittee

IEEE C57.106 -2006 “IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment” (Complete)

IEEE Standard 637 - 1987 “IEEE Guide for the Reclamation of Insulating Oil and Criteria for Its Use” (Under Revision)

Power Transformer Subcommittee

IEEE PC57.143 “Guide for Application for Monitoring Equipment to Liquid-Immersed Transformers and Components” (In Ballot/Under Revision)

Transformer Standards Subcommittee

IEEE PC57.152 “Guide for Diagnostic Field Testing of Fluid Filled Power Transformers, Regulators and Reactors” (Under Revision—Previously C57Std62)

Transformer Insulation Life Subcommittee

Task Force on “Determination of Moisture in Paper” (Review of Current Literature - Draft)

C57.106-2002 Problems

In an operating transformer: (1) measurements of the dynamic water-in-oil concentrations cannot be used in determining whether the oil (or paper) is suitable for continued use – the diffusion time constants are in the range of days and months and the transient state values move towards a new equilibrium point with every temperature change and (2) measurements of dynamic values of temperature cannot be used in evaluating dynamic water-in-oil concentrations to determine whether the oil (or paper) is suitable for continued use – the values change constantly due to load and ambient conditions and the measured temperature values can reach 70% of equilibrium values in a matter of a few hours while the measured water-in-oil concentration values are days or months away from reaching 70% of equilibrium values.

Transient State Water Concentration in Transformers

Bibliography

Fick, A, Ann. Phys. Lpz. 170 (1855). p. 59, as referenced by Crank, J., "The Mathematics of Diffusion," Clarendon Press, London, p. 4, 1956.

Institute of Electrical and Electronic Engineers, "IEEE Guide for Loading Mineral Oil Immersed Transformers – C57.91-1995," pp. 16 and 49, 1995.

Oommen, T.V., "Moisture Equilibrium Charts for Transformer Insulation Drying Practice," IEEE Transaction on Power Apparatus and Systems, Vol. PAS-102, No. 10, October, 1984.

Jost, W., "Diffusion in Solids, Liquids and Gases," Academic Press, New York, p. 37, 1955.

Zahn, M. et al., "Moisture Equilibrium in Transformer Paper-Oil Systems," IEEE Insulation Magazine, Vol. 15, No. 1, pp. 11-20, January/February, 1999.

8/5/2002

RE: Substation Survey

[REDACTED]
Line Superintendent
[REDACTED]
[REDACTED]

Enclosed are the results from the Substation Survey that was performed at the Municipal Substation for [REDACTED] on June 11, 2002. This Summary will cover the tests performed at the substation(s) and any anomalies that were detected from these tests. If any of the information covered in this report needs clarification as to its significance please do not hesitate to contact me for further clarification.

➤ Sonic and Ultrasonic Analysis

The sonic and ultrasonic levels for this transformer are in the expected range and not showing any significant differences when compared to similar units of like size and manufacture.

➤ Sound Levels

The sound levels and spectrums from this unit are in the expected range and not showing any significant differences when compared to similar units of like size and manufacture.

➤ Vibration Analysis

The majority of the vibration levels are higher than expected and the spectrums indicate some unexpected frequencies and harmonics. There is most likely some degree of looseness in the core/coil assembly. Continue to monitor for further change and watch for correlation to develop with other tests.

➤ Dissolved Gas Analysis

There are only two tests available for analysis. All levels tend to indicate an increase in the gas levels. Continue to monitor for further change and to establish generation rates.

➤ Fluid Analysis

The fluid quality for this unit is acceptable for continued use, however there is indication that the oil is oxidized and deteriorating. Acid levels are elevated, the interfacial tension is declining, and the moisture level is elevated. This needs to be monitored closely for further deterioration to prevent sludging of the oil. Oil processing will likely be required in the near future.

➤ Infrared Thermography

There were no infrared anomalies found at the time of this survey.

Fluid Quality	05/08/2002	06/20/2001	Limits
Sample No	2	1	
Fluid Temp C	28		
Acid Number	0.032 mg KOH/g	0.028	< .2
Interfacial Tension	29.4 mN/m	30.4	> 24
Dielectric Str (D877)	49.0 kV	44.0	> 26
Water	16 ppm	16	< 35
Water Saturation	21 % High		< 20
Color	2.5	2.0	< 3
Specific Gravity	0.889	0.890	
Fluid / PCB Cond	1/0	1/0	
Visual	Clear		

Result Interval (days)	365	Port or Tank Sampled by	MAIN	Test Lab	
Fluid Std	OILTRN TO 69 (IEEE)	Reason	DIAGNOSTIC	Test Date	
				Lab Ref No	

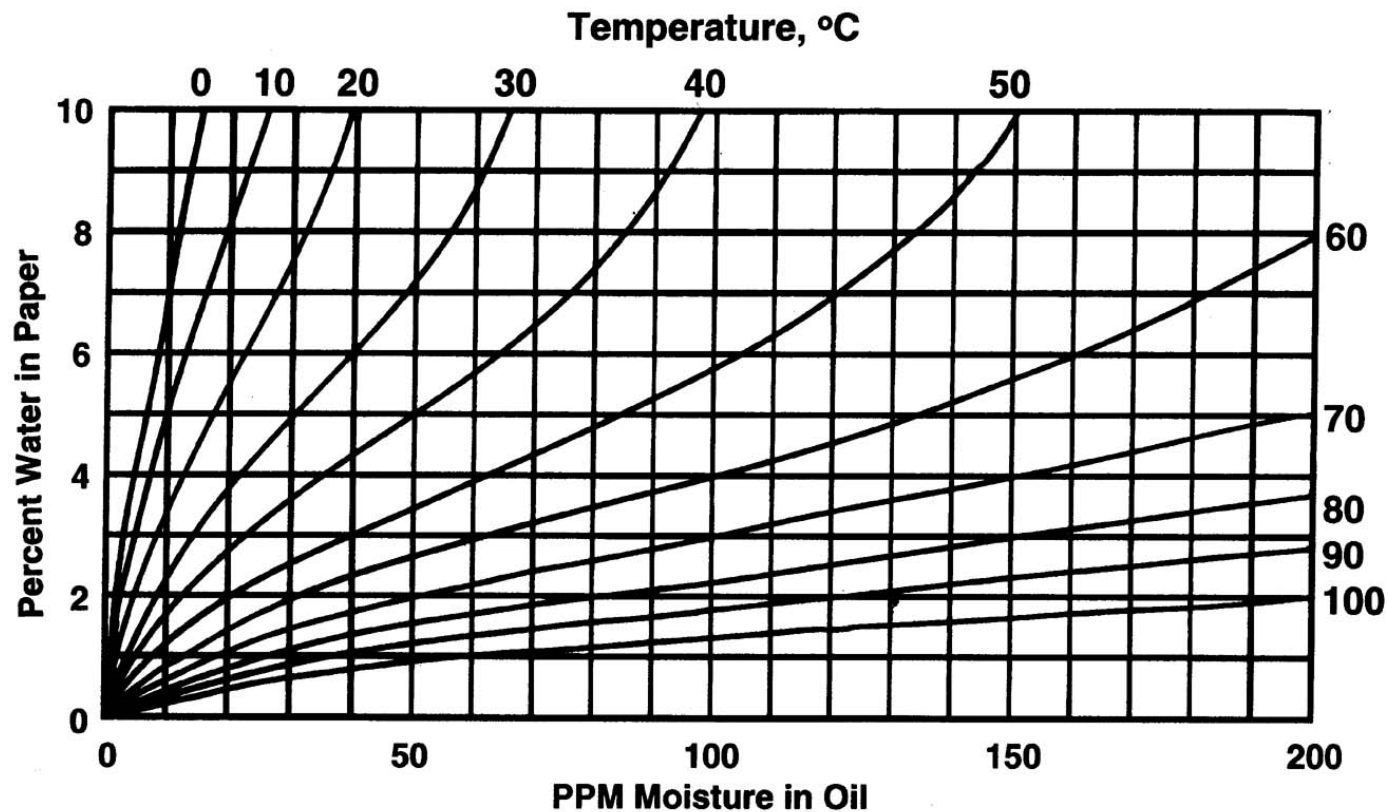
Fluid Quality Analysis Remarks

* The oil condition is satisfactory for continued use.

Report Date 08/01/2002

Moisture Equilibrium Curves

These show moisture in paper vs. moisture in oil at different temperatures.



Oommen Curves

Constructed by combining moisture sorption curves of paper and oil

Ref. Doble Conf. Paper 2003

PC57.106 Revision Power Point Presentation 2002

Time (Hours) ¹	Load (Per Unit Load) ¹	Ambient Temp (Deg.C) ¹	Hot Spot Temp (Deg.C) ¹	Top Oil Temp (Deg.C) ¹	Bottom Oil Temp (Deg.C) ¹	Top Oil %Water Saturation @ 30 mg/kg H2O/Oil (%) ²	Bottom Oil %Water Saturation @ 30 mg/kg H2O/Oil (%) ²	Mathematical % Difference (Between Top Oil and Bottom Oil) in %Water Saturation @ 30 mg/kg H2O/Oil (%)	Calculated Time Constant (tau) for H2O/Oil @ Top Oil, for 1/4 inch pressboard @ 1.5% Moisture (Hours) ³	Calculated Time Constant (tau) for H2O/Oil @ Bottom Oil, for 1/4 inch pressboard @ 1.5% Moisture (Hours) ³	Mathematical % Difference (Between Top Oil and Bottom Oil) in Time Constant (tau) for H2O/Oil, for 1/4 inch pressboard @ 1.5% Moisture (%)
0	0.730	30.0	89.9	74.1	48.0	8.0	18.6	133%	87	574	563%
1	0.640	29.5	82.7	69.5	45.0	9.2	20.7	125%	118	728	515%
2	0.624	29.2	77.9	65.4	42.4	10.4	22.7	118%	158	897	470%
3	0.608	29.0	74.5	62.5	40.6	11.4	24.2	112%	194	1039	437%
4	0.592	28.7	71.9	60.3	39.3	12.3	25.4	107%	227	1157	410%
5	0.576	28.5	69.7	58.6	38.2	13.0	26.5	104%	257	1268	393%
6	0.560	28.2	67.8	57.2	37.3	13.6	27.4	102%	285	1367	380%
7	0.620	29.8	68.7	56.6	37.7	13.9	27.0	95%	298	1322	344%
8	0.707	31.8	73.7	58.5	39.7	13.0	25.1	92%	259	1119	332%
9	0.793	33.9	82.4	62.7	42.9	11.4	22.3	96%	191	862	352%
10	0.880	35.9	92.3	68.5	47.1	9.5	19.2	103%	127	616	386%
11	0.930	37.1	100.4	74.9	51.3	7.8	16.6	113%	82	444	441%
12	0.980	38.4	108.0	80.9	55.4	6.5	14.4	121%	55	326	488%
13	1.030	39.6	115.7	86.6	59.5	5.6	12.6	127%	39	241	523%
14	1.070	40.0	122.3	92.0	63.1	4.8	11.2	134%	28	185	570%
15	1.100	40.0	127.7	96.6	66.1	4.2	10.2	141%	21	150	613%
16	1.100	39.6	130.0	99.8	68.0	3.9	9.6	147%	17	131	654%
17	1.070	38.2	128.4	100.8	68.2	3.8	9.6	151%	16	130	688%
18	1.040	36.8	125.7	99.6	66.9	3.9	9.9	154%	18	142	704%
19	0.987	35.4	121.0	96.7	64.6	4.2	10.7	153%	21	167	698%
20	0.933	33.9	115.1	92.6	61.3	4.7	11.9	152%	27	211	691%
21	0.880	32.5	108.6	87.9	57.7	5.4	13.4	149%	36	275	671%
22	0.830	31.7	102.1	83.0	54.3	6.2	15.0	143%	48	354	631%
23	0.780	30.8	95.9	78.4	51.1	7.0	16.7	137%	65	451	593%
24	0.730	30.0	89.9	74.1	48.0	8.0	18.6	133%	87	574	563%

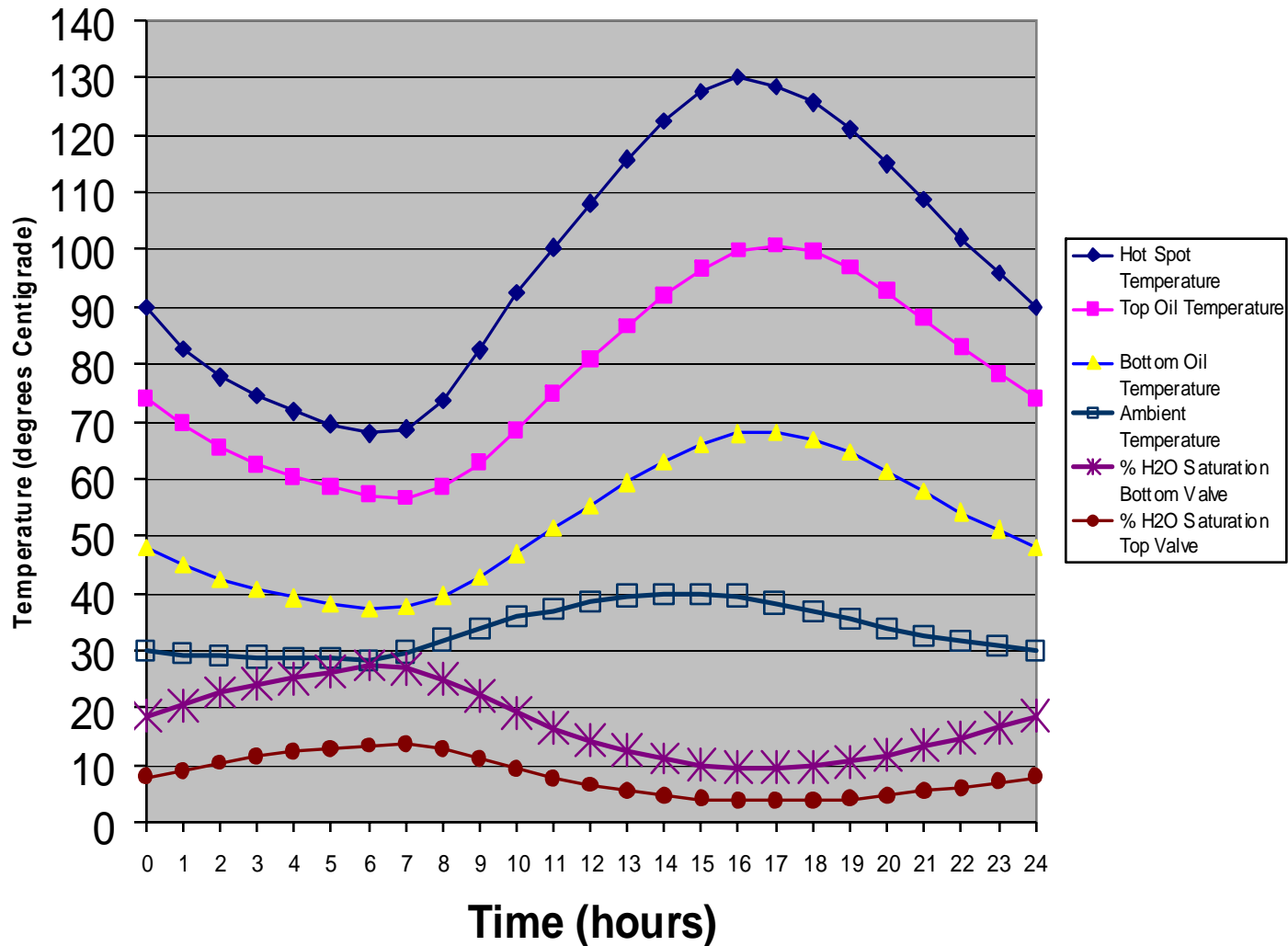
Note 1: Values from graph 1, source is IEEE Standards Collections, "Distribution, Power and Regulating Transformers," C57.91-1995, p.82, 1998.

Note 2: Values calculated from C57.106/D7 equations (1) and (2), p.17.

Note 3: Values calculated from Y. Du, M. Zahn, B.C. Lesieutre, and A.V. Marnishev, "Moisture Equilibrium in Transformer Paper-Oil Systems," IEEE Electrical Insulation Magazine, January/February 1999, equations (6), (7), & (9), pp.15-16.

PC57.106 Revision IEEE Meeting October 23, 2002 Oklahoma City, Ok

Graph 1 Transformer Temperatures Under Changing Load Conditions (see C57.91-1995,p.82)



Incorrect Version of IEEE 62 (now IEEE PC57.152 “Guide for Diagnostic Field Testing of Fluid Filled Power Transformers, Regulators and Reactors”)

IEC 60422 Mineral insulating oils in electrical equipment - Supervision and maintenance guidance

Table 2 – Guidelines for interpreting data expressed in percent saturation

Percent saturation water in oil adjusted to	Condition of cellulosic insulation
0 – 5 %	Dry insulation
6 – 20 %	Moderate wet, low numbers indicate fairly dry to moderate levels of water in the insulation. Values toward the upper limit indicate moderately wet insulation
21 – 30 %	Wet insulation
> 30 %	Extremely wet insulation

Source : IEEE 62:1995 (B6)

Source: IEEE Moisture Task Force October, 2010

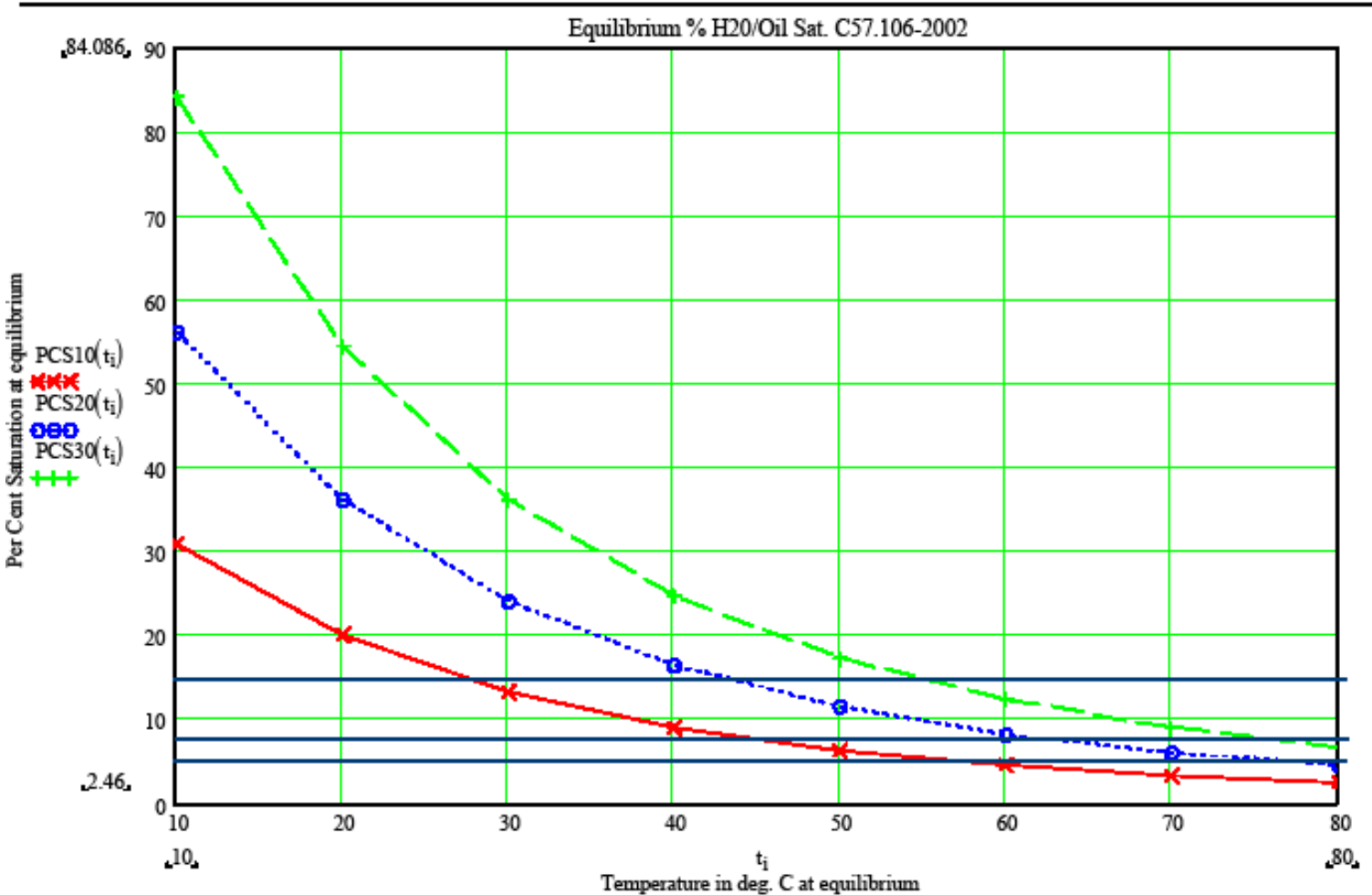
Annex A

(informative)

Bibliography

- [B1] Bruce, C. M., Christie, J. D., and Griffin, P., "Comparison of water equilibrium in silicone and mineral oil transformers," *Minutes from the 55th Annual Conference of Doble Clients*, Section 10-9.1, 1988.
- [B2] Du, Y., Mamishev, A. V., Lesieutre, B. C., Zahn, M., and Kang, S. H., "Moisture solubility for differently conditioned oils," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 8 no. 5, pp. 805–811, Oct. 2001.
- [B3] IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition, New York, Institute of Electrical and Electronics Engineers, Inc.^{9, 10}
- [B4] IEEE Std C57.12.90™ -1999, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.
- [B5] Oommen, T. V., "Moisture equilibrium curves—use and misuse," *Doble Conference Paper*, Apr. 2003.
- [B6] Oommen, T. V., "Moisture equilibrium in paper-oil insulation systems," *Proceedings 16th Electrical/Electronic Insulation Conference*, Chicago, IL, pp. 162–166, Oct. 5–6, 1983.
- [B7] Thompson, J. A., "Moisture diffusion in transformers—a thermodynamic model," *Technical Presentation for the IEEE/PES Transformers Committee, Spring 2004 Meeting*, Mar. 9, 2004.
- [B8] Ward B. W., Oommen, T. V., and Thompson, J. A., "Moisture estimation in transformer insulation," *Technical Presentation for the IEEE/PES Transformers Committee, Spring 2004 Meeting*, Mar. 9, 2004.

Problems with C57.106 - 2002



C57.106 Section 4.5 & Table 5 - 2006

Section 4.5 ... In addition, from a dielectric strength point of view reduced oil temperatures in a de-energized transformer could increase the moisture in oil percent saturation level enough to significantly reduce the dielectric breakdown strength of the oil – even at percent saturation levels below 100%. Consequently when energizing a new transformer or re-energizing any transformer during cold weather, caution should be taken so that the dielectric breakdown strength of the oil, referenced to the actual temperature of the oil in the de-energized transformer, is sufficient for service. Equations for moisture percent saturation values at various temperatures and for various oils are found in references (Bruce et.al. 1988 [B1] and Du et. al. [B7])...

Table 5—Suggested limits for continued use of service-aged insulating oil

Water content, ASTM D1533, mg/kg maximum (ppm) ^{b, c}	35	25	20
--	----	----	----

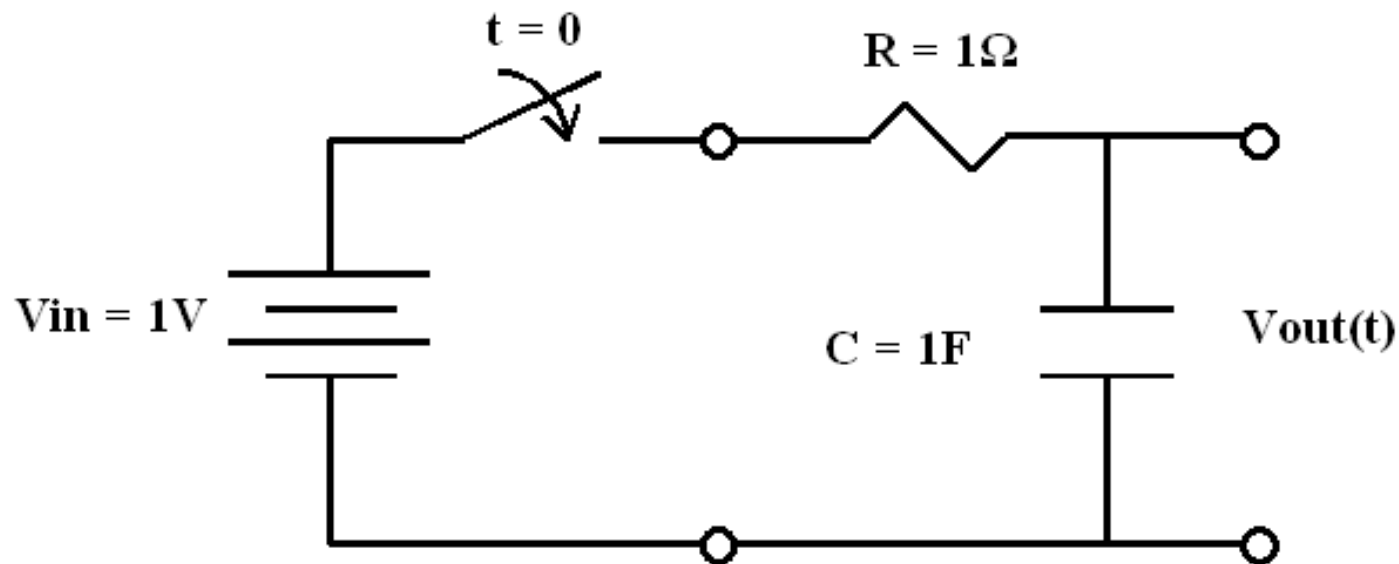
b. The ppm moisture values shown are based on consensus, also given in IEEE Std 637. These values should not be used to infer solid insulation dryness or dielectric integrity. The moisture in oil at a given time cannot be related to insulation moisture due to non-equilibrium conditions. From a dielectric strength point of view the moisture in oil limits given could be excessive at low temperatures due to high moisture in oil percent saturation levels. (See section 4.5). However in operating units the same moisture in oil levels might represent low moisture in oil percent saturation levels due to elevated oil temperatures.

c. Any significant changes from previous test data should be investigated.

Moisture Diffusion Model

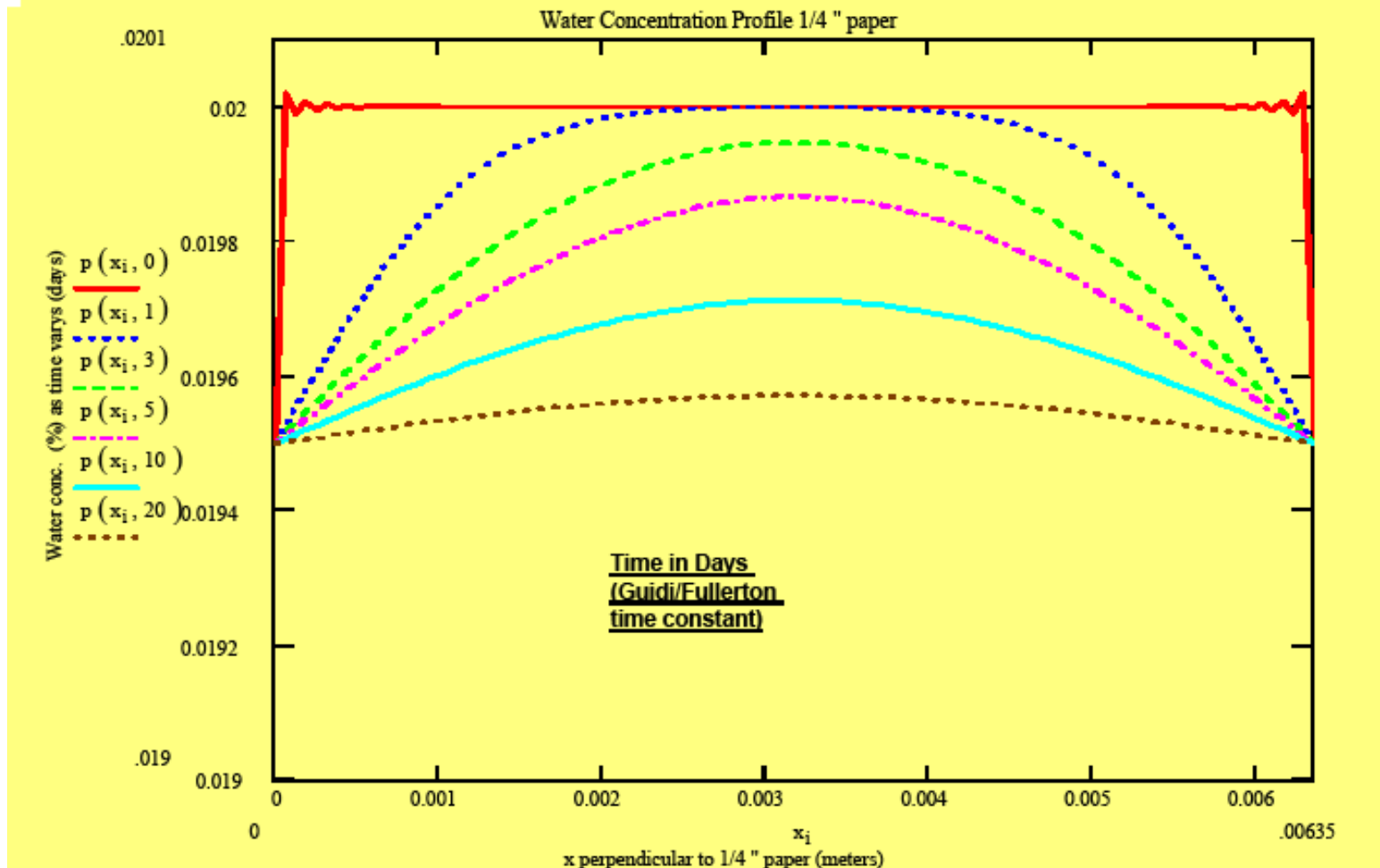
IEEE PC57.106 Meeting March 9, 2004

- Moisture diffusion time for a flat piece of paper in oil
- Moisture diffusion time constant (τ) and equilibrium ratio.
- Electrical analogy of a capacitor voltage.
- Temperature gradients cause wide ranges of moisture levels in the paper due to moisture migration
- Estimate moisture ranges using mass balance equations and equilibrium curves.

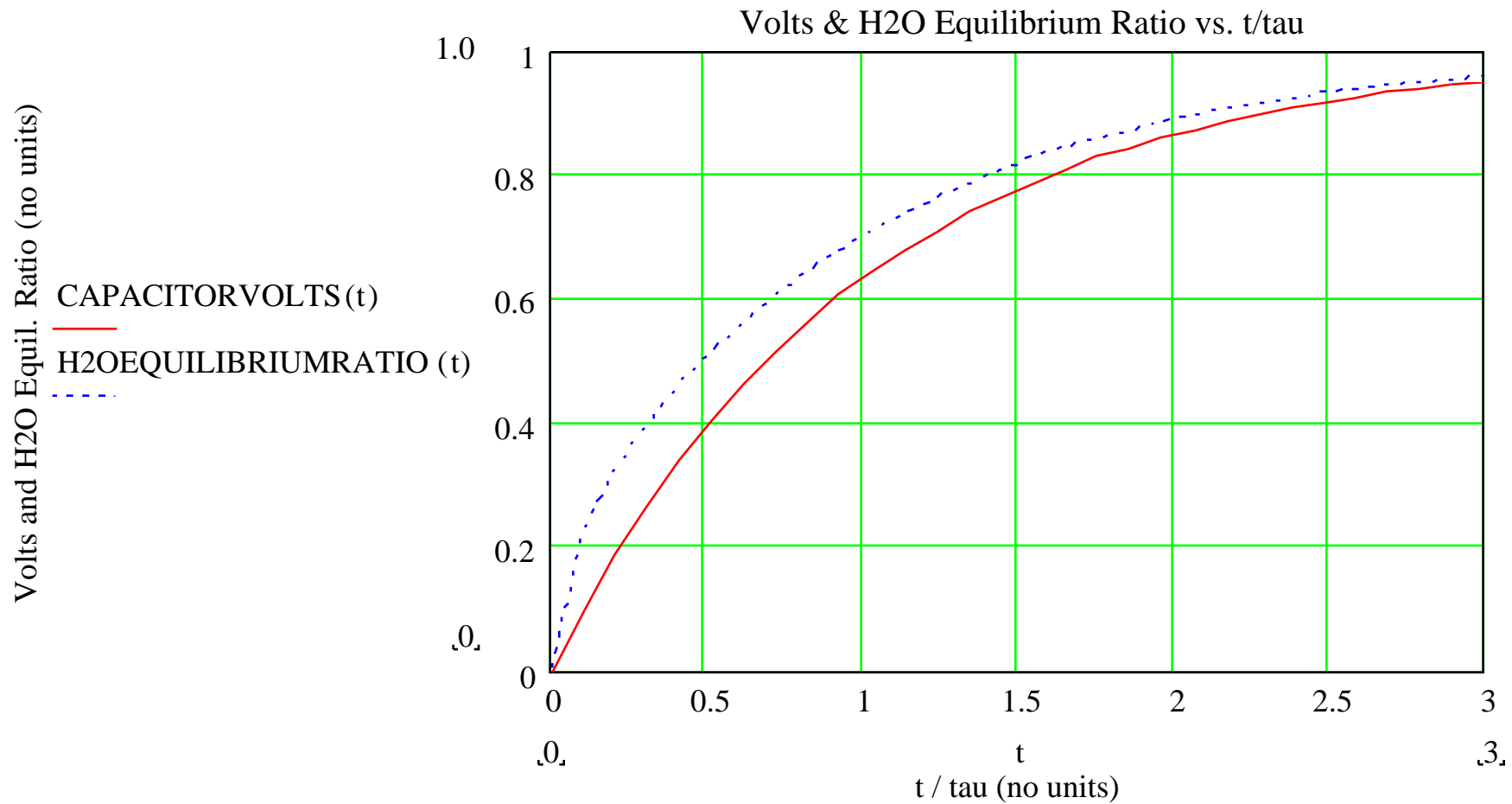


Concentration Profile in Flat Sheet

Concentration Profile of 1/4" paper with 2 % water and change from 50 deg. C to 70 deg. C.



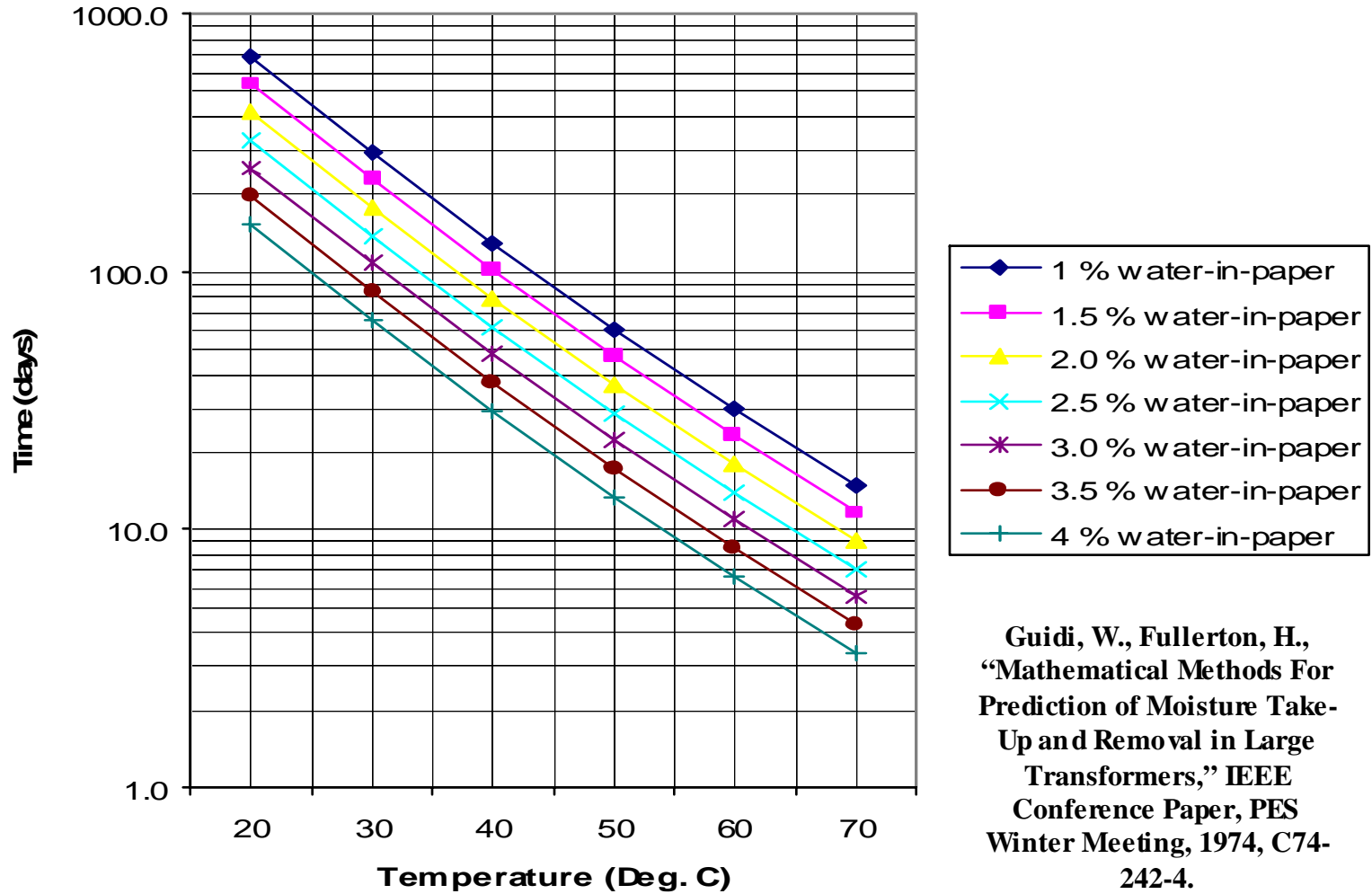
Analogy – Diffusion **tau** and RC **tau**



Thompson, J., "Transient State Water Concentrations in Transformers – Comments on IEEE C57.106," February 12, 2002.

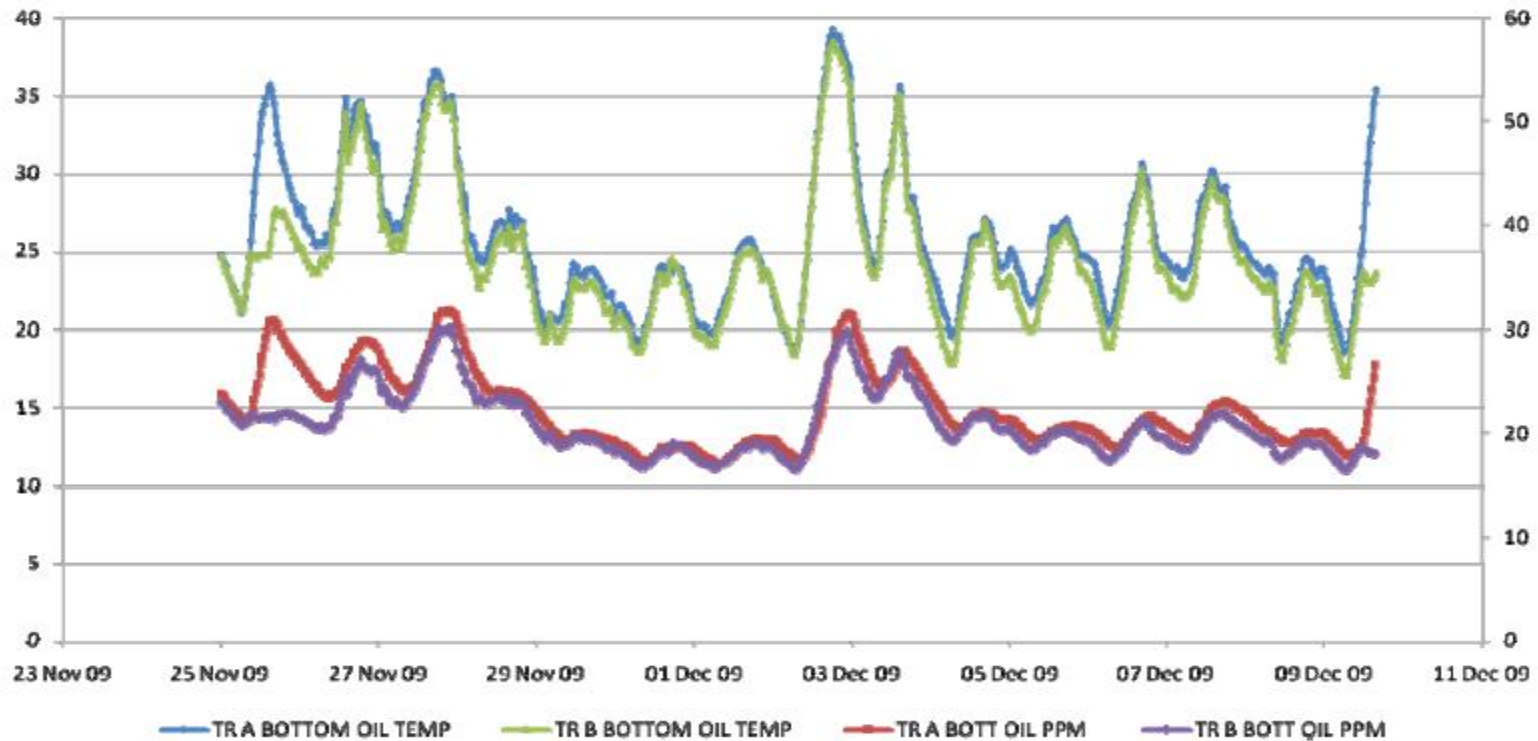
Diffusion Time Vs. Deg. C.

Diffusion Time Constants 1/4 inch (0.635 cm) Oil Immersed Kraft Paper *Ewart, 1960 & Guidi/Fullerton, 1974*



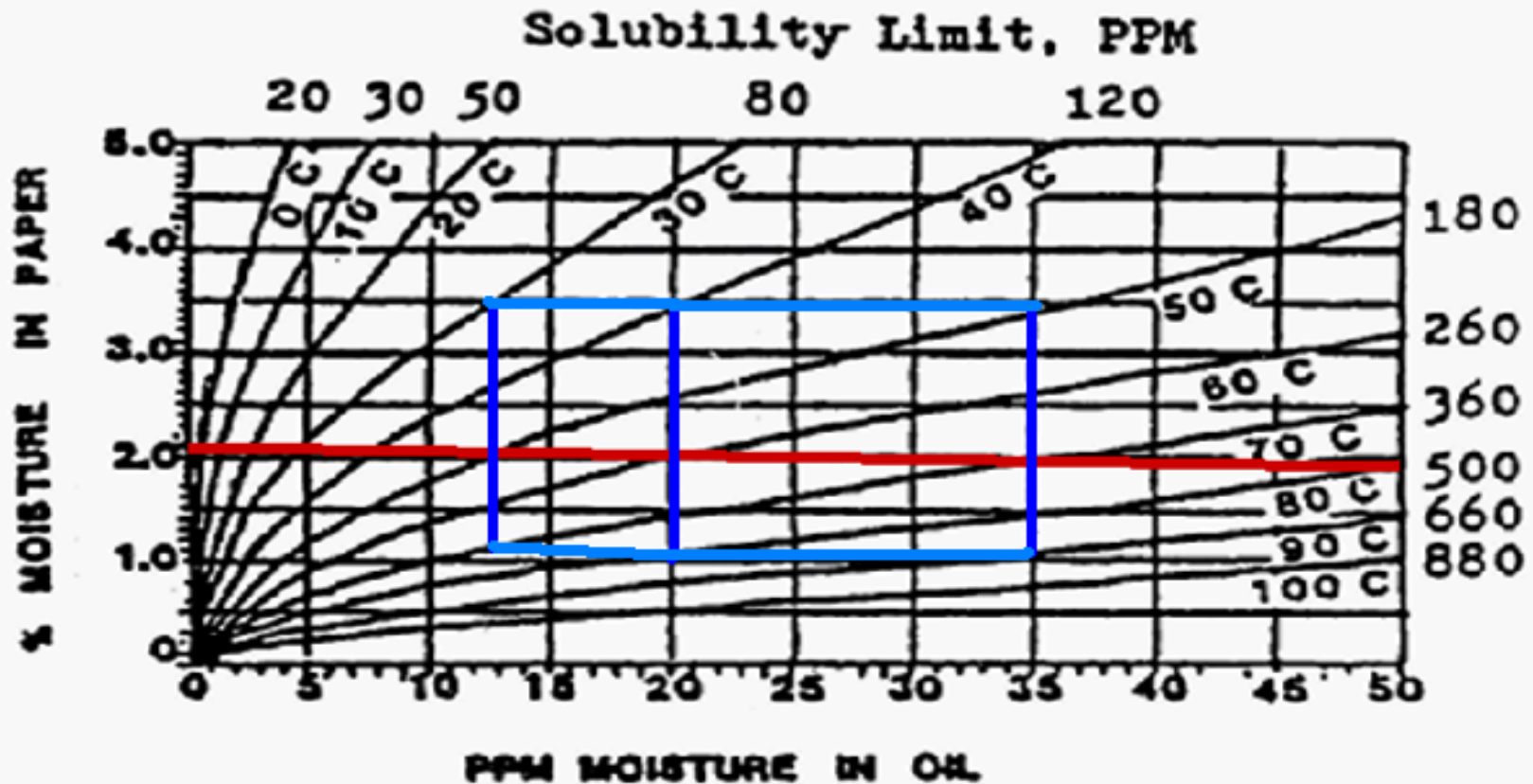
Example of Moisture Non Equilibrium

Relationship of bottom oil temperature and water content (ppm) on two transformers



Source: IEEE Moisture Task Force October, 2010

Moisture Range in Transformer



Nearly Horizontal Line is Mass Balance Equation at Equilibrium:
% Moisture in Paper = 2.0261 – Coil x (2004/106)
Window within blue lines represents dynamic moisture in paper values with dynamic temperatures and temperature gradients during moisture redistribution (± 20 degrees C. gradient)

Magnitude of Errors for Assumptions Made

Equilibrium:	$\pm 20\%$
Uniform oil distribution:	$\pm 15\%$
Oil solubility:	$\pm 100\%$
Uniform WCP distribution:	$\pm 20\%$
Temperature increase or decrease:	$\pm 20\%$
Equal temperature & moisture time constants:	$\pm 15\%$
All insulation has same sorption characteristics:	<u>$\pm 15\%$</u>
Sum of all Errors:	$> \pm 200\%^*$

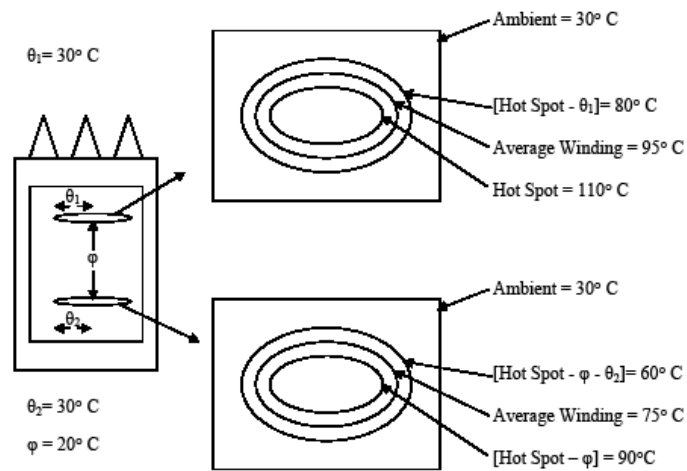
*Does not take into account sampling and actual KF measurement

**Source: MOISTURE ESTIMATION IN TRANSFORMER INSULATION,
T. V. Oommen, Jim Thompson and Barry Ward, Panel Session
IEEE Transformers Committee, Tuesday, March 9, 2004,
Sponsored by the Insulating Fluids Subcommittee**

Draft PC57.152 Moisture Section- 2008

- A model using this evaluation (*Moisture Diffusion in Transformers*, Thompson 2004) shows the moisture diffusion time constants are in the order of magnitude of weeks and months whereas typical temperature time constants from the IEEE loading guide for transformers are in the order of magnitude of hours.
- The thermograph model in Figure 1, illustrates a large temperature gradient (50 degrees C). The prediction of any single homogeneous moisture in paper value is invalid.
- Do not use moisture equilibrium curves to determine the dryness level of the solid insulation in an operating transformer (Oommen 2003).

Model of Isothermal Lines



ϕ = (Hot Spot Temp.) - (Maximum Temp. in Horizontal Plane at bottom of Coil)

$\theta_1 = 2 \cdot [(\text{Hot Spot Temp.}) - (\text{Avg. Winding Temp at Top Coil})]$

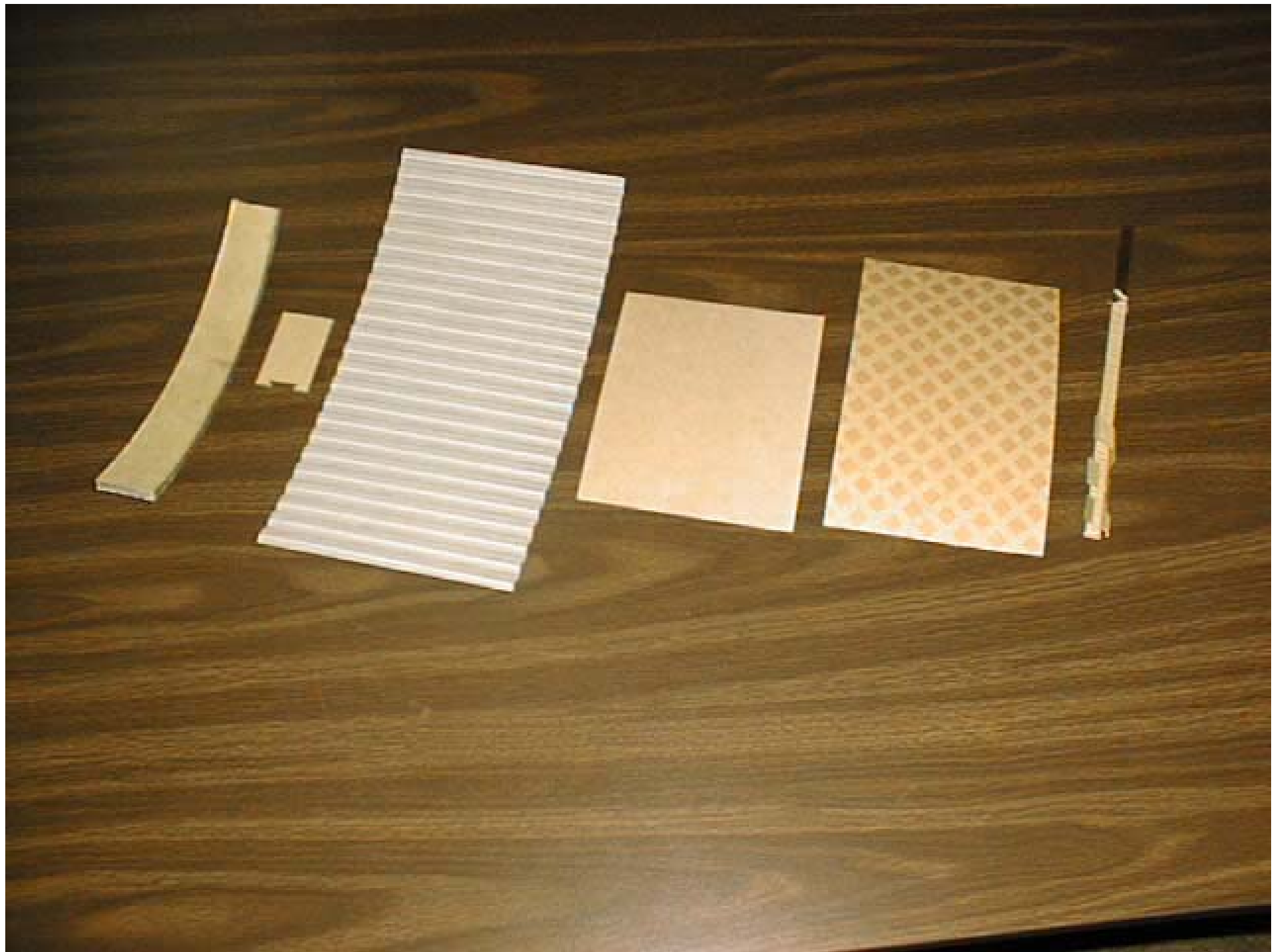
$\theta_2 = 2 \cdot [(\text{Hot Spot Temp.}) - (\phi)] - (\text{Avg. Winding Temp at Top Coil})$

Figure 1

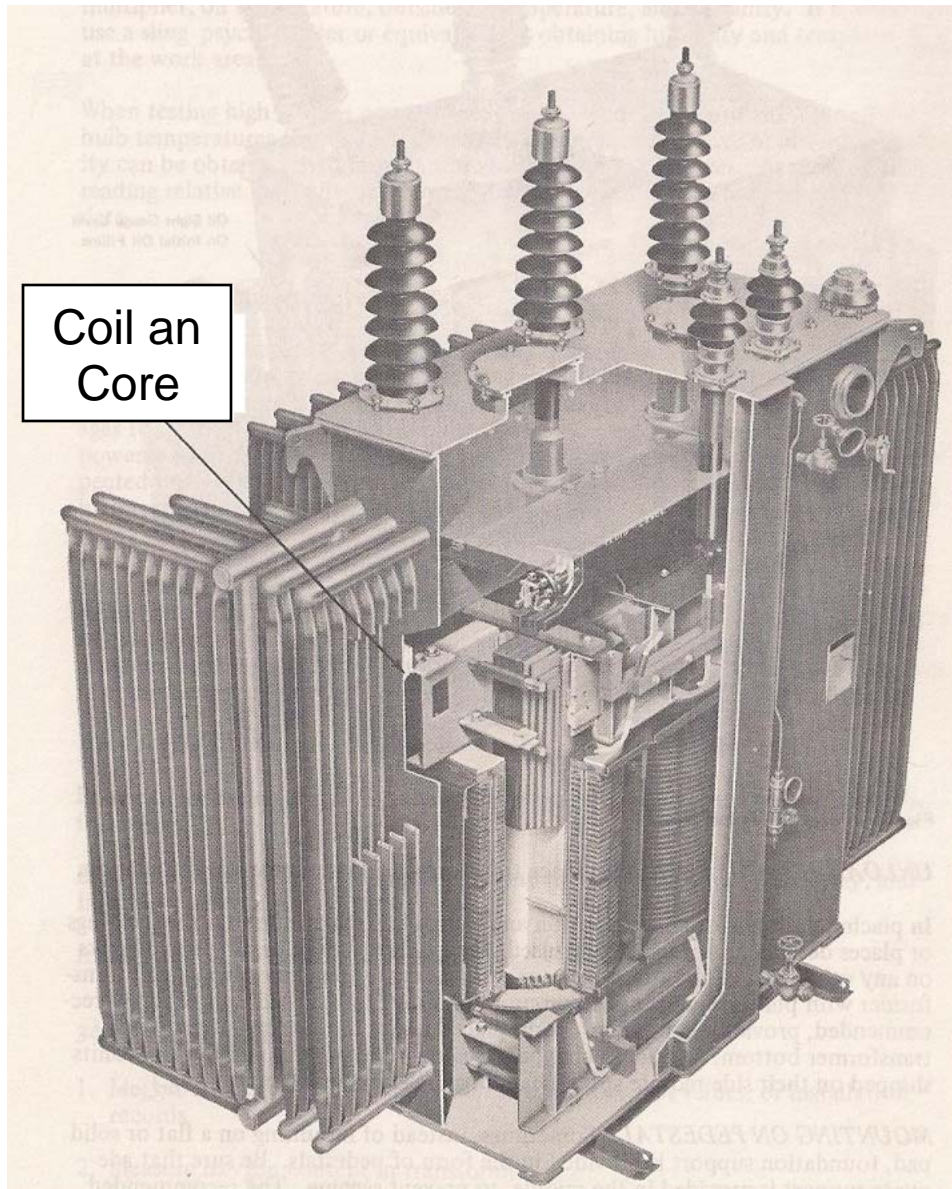
Model of Isothermal Lines and Temperature Gradients for Oil Filled 65°C . Rise Transformer at Constant Full Load and Constant Ambient Conditions







Summary



- The IEEE Standards - revision continues for moisture issues.
- An RC circuit analogy illustrates the diffusion % equilibrium times.
- Moisture varies with location and time due to temperature gradients.
- Take samples for oil moisture at bottom valve and record top oil temperature biannually.
- Caution - Energizing or re-energizing during cold weather reduces oil dielectric breakdown strength due to moisture levels approaching saturation. See IEEE C57.106-2006.

Working Group Assignments

- Starting point--C57.Std637-1985
Reaffirmed 2007
- PC57.637 PAR Approved December 10,
2008
- Assignment review

Scope

- IEEE Standard 637-1985 "IEEE Guide for the Reclamation of Insulating Oil and Criteria For Its Use" Reaffirmed 2007
- Scope: The Scope of this guide covers mineral insulating oil commonly defined as transformer oil; definition and description of reclaiming procedures; the test methods used to evaluate the progress and end point of the reclamation process, and what criteria recommended for the use of reclaimed oils are considered suitable. The guide does not cover the use of oil in new apparatus under warranty.

Draft and Cover Letter sent October, 2009

Dear WG member:

Attached is a Microsoft 2003 Word version of the PC57.637 Draft 1.A (October, 2009).

Please note that this document is an unapproved IEEE Standards Draft, subject to change, copyrighted by IEEE, and for working group activities.

Please consider working on a section or subsection, with the exception of the scope and title, that has not been assigned (see below).

Then please:

- 1) save the sections in Word (select "word document" from the pull down menu "save as type" when saving - otherwise the file grows to over 5 to 40 megabytes), and
- 2) copy and paste these changes to your document, and then
- 3) save and email the document to me at serve1@svtv.com while using "[yourname].d1B.PC57.637" for the file name. Please call if you have any questions. Thank you.

PC57.637 WG Assignments

Name	WG Section of PC57.637
Dave Sundin	Sections 3 and 5.1 and 5.2
Mark McNally	Section 4
TV Oommen	Sections 5.5 and 5.6
Juan Castellanos	Sections 5.4 and 7
Derek Baranowski	Sections 6.1 thru 6.6
Ed teNyenhuis	Sections 6.7 and 6.8
Claude Beauchemin	Sulfur Compounds in Oil
Clair Claiborne	Bibliography since 1969
Ryan Thompson	Section 5.3
Jim Thompson	Section 1
Open	Section 6.9