Sensitivity of the Hot Oil Moisture Assessment for PILC Cables to Test Conditions

Josh Perkel
Nigel Hampton

Spring 2011 ICC Meeting
St Petersburg, FL
May 23, 2011
Subcommittee F – Field Testing and Diagnostics
Introduction

• Hot Oil tests are the primary field method for determining moisture content on paper cable systems

• Utilities are concerned about the validity/accuracy of the hot oil test for replacement decisions

• Unclear what factors influence the test outcome

• Correlation of foaming level to moisture content
  – Does “high” foaming indicate unacceptable moisture?
  – Does no foaming indicate acceptable moisture?

• Moisture contents that would be unacceptable
Field Practices

Pouring

Kettle

Kettle method is included in standard but there are times when pouring is done when it is more important to maintain cable/splice integrity than oil test accuracy.

**Issues**
- Fluid viscosity impacts foam formation & heating
- Flame heating is not controlled in an external environment
- Absorbed moisture within the oil
- Heating from below relies on convection to attain uniform temperatures
- Pouring / transferring decreases the temperature of the fluid
- Time required to reach the specified temperature
Preparing Oil for Test

Elapsed Time [min]

Oil Temperature [deg C]

17 min
Why worry about Moisture?

Moisture increases dielectric loss (Tan δ)

\[ \Delta T \propto E^2 \varepsilon \tan \delta \]

where \( \tan \delta \) is a function of \( T, \text{Moisture} \)

Increased loss leads to insulation heating

- after Blodgett 1963
Temperature Rise Calculations

![Temperature Rise Graph]

Moisture Content [%] vs. Temperature Rise [deg C]

Voltage Class
- 15
- 25
- 35

ICC Spring 2011 Meeting – Subcommittee F
What temperatures do utilities use?
Test Program

Part 1: Hot Oil Test
• Investigate effect of key factors on results of oil tests
  – Tape Length – 3” or 6”
  – Oil Temperature – 120 °C, 140 °C, or 160 °C
  – Tape Location within cable core – Inside, Middle, or Outside
• Record for each test
  – Foaming type – None, Low, or High
  – Foaming Time [sec]

Part 2: Moisture Content
• Measure moisture (by weight) using analyzer
  – Tape location within cable core – Inside, Middle, or Outside
Analysis Areas

**Moisture Content**
Moisture content measurements using Moisture Analyzer

**Foaming Time**
Time required from tape submersion in oil to complete foaming (i.e. no more bubbles)

**Foaming Mode**
Qualitative assessment of the amount of foam that is generated – None, Low, or High.
Foaming Examples

Low Foaming

High Foaming

No Foaming
High Foaming – How often?

Tests [%]

Temperature [deg C]

ICC Spring 2011 Meeting – Subcommittee F
Analysis of Variance

• Experimental design used is full factorial

• ANOVA is used to analyze a response and determines:
  – Importance/significance of each factor
  – Size of the effect each factor has on the response

Factors
• Oil Temperature
• Tape Length
• Location in Cable Segment

Response
• Foaming Time
Foaming Time Distributions

* Includes Low and High Foaming ONLY
## ANOVA – Foaming Time

<table>
<thead>
<tr>
<th>Type</th>
<th>Factor</th>
<th>DF</th>
<th>F</th>
<th>Significance [％]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Effects</td>
<td>Tape Length</td>
<td>1</td>
<td>86.26</td>
<td>&gt; 99.9 %</td>
</tr>
<tr>
<td></td>
<td>Goal Temp</td>
<td>2</td>
<td>38.42</td>
<td>&gt; 99.9 %</td>
</tr>
<tr>
<td></td>
<td>Layer</td>
<td>2</td>
<td>5.82</td>
<td>99.7 %</td>
</tr>
</tbody>
</table>

R² Adjusted = 72.2 %
Main Effects – Foaming Time

- **Tape Length [in]**
  - Goal Temp
    - 160
    - 150
    - 140
    - 120

- **Foaming Time [sec]**
  - Layer
    - Inside
    - Middle
    - Outside
    - Goal Temp
      - 160
      - 150
      - 140
      - 120

ICC Spring 2011 Meeting – Subcommittee F
## ANOVA Summary

<table>
<thead>
<tr>
<th>Factor</th>
<th>Foaming Mode</th>
<th></th>
<th>Foaming Time</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Significant</td>
<td>Effect Magnitude [Rank]</td>
<td>Significant</td>
<td>Effect Magnitude [Rank]</td>
</tr>
<tr>
<td>Goal Temp</td>
<td>✓</td>
<td>1</td>
<td>✓</td>
<td>1</td>
</tr>
<tr>
<td>Layer</td>
<td>✓</td>
<td>2</td>
<td>✓</td>
<td>2</td>
</tr>
<tr>
<td>Tape Length</td>
<td>✓</td>
<td>3</td>
<td>✓</td>
<td>3</td>
</tr>
</tbody>
</table>
Moisture Content & Foaming Mode

Distributions make distinguishing moisture contents based on foaming mode difficult.
Closer Look - 160 °C Oil Test

High Foaming likely indicates moisture contents of 1.1 - 3.3 %
Foaming with <2% Moisture Content

Any foaming could be taken as an indication of high moisture.

Voltage Class [kV] | Temperature Rise [deg C]
---|---
15 | 1.3
25 | 1.8
35 | 2.5
Conclusions/Observations

• Hot Oil test for paper cables is affected by all test parameters
  – Oil Temperature
  – Tape Length
  – Location

• 160ºC gives the clearest discrimination
  – Tape in Kettle
  – At least 12 cm (6 in) long

• “High” foaming can be generated by moisture contents as low as 1% thus leading to premature replacement

• A direct moisture content measurement would be preferable to hot oil test.