TJ|H2b Analytical Services Pty Ltd

Condition-Based Assessment of High Voltage Electrical Equipment

Presented By: Antony Giacomin
Sales & Marketing Manager
AGENDA

- COMPANY BACKGROUND
- OIL CHEMISTRY
  - How gases are produced
  - How oil degrades
  - How this information is related to condition
- TJ|H2b’s DIAGNOSTIC PROTOCOLS (OIL):
  - BOA®
  - TASA®
  - TCA®
Origins

- 1972 – Research initiated at University in Sacramento
- 1978 – Analytical Associates formed
- 1995 – TJ|H2b Analytical Services formed
- 2001 – TJ|H2b in Melbourne commenced operating
Facilities

- USA
  - Sacramento, California
  - Madison, Wisconsin
  - New Orleans, Louisiana
  - Kennett Square, Pennsylvania

- Canada
  - Calgary, Alberta

- United Kingdom
  - Capenhurst, England

- Australia
  - Melbourne, Victoria

- Malaysia & Philippines
Diagnostic Evaluation

- Condition Assessment Programs
  - BOA®
  - TASA®
  - TCA®
  - BGA®
  - LTOS®
- Equipment Specific Problem Identification
Focus

TJ|H₂b Analytical Services focuses entirely on testing insulating materials and diagnosing high voltage equipment.
We help your equipment age GRACEFULLY...
Developments in Oil Diagnostics

"Oil is Blood" Concept can be applied to oil-filled equipment
FUNCTIONS OF OIL

- Provide electrical insulation
- Provide a cooling medium
- Protect the paper
- Use as a diagnostic tool
Typical Oil Molecule
Typical Oil Molecule

Paraffinic carbons (42 – 65 %)
Typical Oil Molecule

Napthenic carbons (15 – 53%)
Typical Oil Molecule

Aromatic carbons (5 – 20%)
Gases Produced from Oil

Increasing Energy
Fault Types

Partial Discharge

Pyrolysis (Thermal Decomposition)

Arcing
Gases Produced from Oil by PD
Gases Produced from Oil by Heating
Gases Produced from Oil by Arcing
Gases Determined by Gas Chromatography

- Hydrogen
- Methane
- Ethane
- Ethylene
- Acetylene
- Carbon Monoxide
- Carbon Dioxide
- Oxygen
- Nitrogen
Oxidation of Oil
Oxidation of Oil

\[ \text{R-} \backslash \text{C-C-C-C-C-C-H} + \text{O}_2 \rightarrow \text{R-} \backslash \text{C-C,C-C-C-C-C-H} \longrightarrow \text{R-} \backslash \text{C-C-C-C-C-C-H} + \text{OH} \]
OIL OXIDATION

- **CATALYSTS** (primary substances that increase rate of oxidation):
  - Oxygen
  - Moisture
  - Metals (especially Copper)

- **ACCELERATORS**:
  - Heat
  - Electric Stress

- **TERMINAL STAGE OF OXIDATION PROCESS**
  - Sludge (results in blocked cooling ducts & electrical failure)
Acidity as Oil-Quality Indicator

Graph showing the increase in acidity over years in service, with a service limit indicated at 0.5.
IFT as Oil-Quality Indicator

![Graph showing interfacial tension over years in service with a service limit marker.](image-url)
Correlation of Acid No. to IFT

\[ y = 147.45x^{-2.7345} \]
Water in Oil

- Water is produced internally as the products of pyrolysis and oxidation of cellulose
- Water ingress can occur
- Water can be present in three different forms:
  - Dissolved
  - Free
  - Emulsified
Relative Saturation of Moisture in Oil

RS < 100%  RS ≈ 100%  RS > 100%
Solubility of Water In Oil

The graph illustrates the solubility of water in oil as a function of temperature (°C). The x-axis represents temperature ranging from -40 to 50 °C, while the y-axis represents water solubility in parts per million (ppm) ranging from 0 to 250 ppm. The graph shows an upward trend indicating that the solubility of water in oil increases with increasing temperature.
## Solubility of Water in Oil

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Solubility (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>10</td>
<td>36</td>
</tr>
<tr>
<td>20</td>
<td>55</td>
</tr>
<tr>
<td>30</td>
<td>83</td>
</tr>
<tr>
<td>40</td>
<td>121</td>
</tr>
<tr>
<td>50</td>
<td>173</td>
</tr>
<tr>
<td>60</td>
<td>242</td>
</tr>
<tr>
<td>70</td>
<td>331</td>
</tr>
<tr>
<td>80</td>
<td>446</td>
</tr>
<tr>
<td>90</td>
<td>529</td>
</tr>
<tr>
<td>100</td>
<td>772</td>
</tr>
</tbody>
</table>
Dissolved Moisture

van der Waals
Dielectric Breakdown Voltage

- The dielectric breakdown voltage is the voltage at which the oil begins to conduct an electric current.
- The dielectric breakdown voltage is lowered by the presence of contaminants in the oil.
- The dielectric strength of oil is a function of the percent saturation.
Effect of Water on the Dielectric Breakdown Voltage

![Graph showing the effect of water content on breakdown voltage. The graph indicates a downward trend as water content increases.](image-url)
Why Optical Microscopy?
Charred Cork Gasket

Glass Fiber & Epoxy Char

Resister Housing Material
Copper Spheres

Composite fragment

Wood fiber
Insect head

Pollen grain

Feldspar grain

Quartz grain
PARTICLE ANALYSIS

Adding another dimension
Sources of Particles

- Events create a number of unique particles
- Manufacturing residues
- Operation residues
- Activity residues
- Foreign contaminants
Analyzing Particles

- Distribution
- Trending
- More thorough identification
Diagnostic Protocols

- **BOA®**
  - Breaker Oil Analysis

- **TASA®**
  - Tapchanger Activity Signature Analysis

- **TCA®**
  - Transformer Condition Assessment
OIL TESTING DIAGNOSTICS

Condition-Based Assessment

- Condition Codes determined by the interrelation of:
  - Dissolved Gas Analysis (DGA)
  - Particle Profiling
  - Oil Quality
    - Acidity
    - Interfacial Tension
    - Moisture
    - Dielectric Breakdown Voltage
    - Visual Examination
    - Oxidation Inhibitor
    - Furans
    - Power Factor
CONDITION CODES

Typical Application of Condition Codes:

Code 1: No action required

Code 2: 25% contact wear / onset of fault

Code 3: 50% contact wear / fault developed
Monitor

Code 4: 75% contact wear / fault serious
Schedule a maintenance

Code 4* Urgent action required
BOA®

Breaker Oil Analysis
Traditional Interpretation of DGA Data uses

- Levels of individual fault gases
- Levels of total dissolved combustible gases
- Rates of individual gas generation
- Rates of total dissolved combustible gas generation
Interpretation of DGA Data in Switching Devices

- Levels and apparent rates are dependent upon the
  - amount of switching
  - equipment design
  - type of ventilation
Comparison of Maintenance Approaches

Percent Of Total Units

Fixed-Interval       Condition Based

0       5       10       15       20
## BOA® Case Study

<table>
<thead>
<tr>
<th>DGA</th>
<th>PARTICLE PROFILE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td><strong>ppm</strong></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>3430</td>
</tr>
<tr>
<td>Methane</td>
<td>123627</td>
</tr>
<tr>
<td>Ethane</td>
<td>32002</td>
</tr>
<tr>
<td>Ethylene</td>
<td>135258</td>
</tr>
<tr>
<td>Acetylene</td>
<td>4260</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>930</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>4952</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>51201</td>
</tr>
<tr>
<td>Oxygen</td>
<td>4515</td>
</tr>
</tbody>
</table>

## OIL QUALITY

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>88 ppm</td>
</tr>
<tr>
<td>Dielectric</td>
<td>17 kV</td>
</tr>
<tr>
<td>Acid #</td>
<td>.425 mg KOH/g</td>
</tr>
<tr>
<td>IFT</td>
<td>17.7 dynes/cm</td>
</tr>
<tr>
<td>Color</td>
<td>&lt; 3.5</td>
</tr>
</tbody>
</table>
BOA® Assessment

Code 4*

An extreme abnormal dissipation of energy is noted. This is a terminal indication of fault or wear activity. Extreme heating is indicated.
TASA®
Tapchanger Activity
Signature Analysis
FAILURE RATES

- Published failure rates for transformers worldwide typically fall in the 1-2% range.
- Load tap changer failures typically account for up to 25% of transformer failures.
Arc Spheres
Copper Scuffing Wear
Silver Scuffing Wear

Gear Wear
Silver Abrasive Wear

Copper Scuffing Wear
Silver Scuffing Wear

Arc Spheres
Distribution of Equipment by Condition Code

- Code 1: 86%
- Code 2: 7%
- Code 3: 3%
- Code 4: 4%
Vector (New Zealand)

- 110/33 kV 30 MVA transformer
- 17 step on load tapchanger
- Critical Unit - Supplies Pacific Steel’s Arc Furnace
- Maintained with visual inspection in December, 2001
- TASA in Aug-02 revealed 4* (confirmed with repeat sample)
## Dissolved Gas Analysis

<table>
<thead>
<tr>
<th>Gas</th>
<th>01-Aug-02 (ppm)</th>
<th>17-Jul-02 (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1583</td>
<td>1428</td>
</tr>
<tr>
<td>Methane</td>
<td>2326</td>
<td>2003</td>
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<tr>
<td>Ethane</td>
<td>362</td>
<td>672</td>
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<tr>
<td>Ethylene</td>
<td>4699</td>
<td>3133</td>
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<tr>
<td>Acetylene</td>
<td>149</td>
<td>436</td>
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<tr>
<td>Carbon Monoxide</td>
<td>457</td>
<td>415</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>1855</td>
<td>1673</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>79307</td>
<td>79848</td>
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<tr>
<td>Oxygen</td>
<td>27963</td>
<td>26043</td>
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</tbody>
</table>

**CODE**

<table>
<thead>
<tr>
<th></th>
<th>01-Aug-02</th>
<th>17-Jul-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODE</td>
<td>4*</td>
<td>4</td>
</tr>
<tr>
<td>Particle Size</td>
<td>1-Aug-02 Count</td>
<td>17-Jul-02 Count</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>5 to 15</td>
<td>60200</td>
<td>38325</td>
</tr>
<tr>
<td>15 to 25</td>
<td>4480</td>
<td>6915</td>
</tr>
<tr>
<td>25 to 50</td>
<td>1380</td>
<td>2315</td>
</tr>
<tr>
<td>50 to 100</td>
<td>75</td>
<td>220</td>
</tr>
<tr>
<td>&gt; 100</td>
<td>5</td>
<td>10</td>
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</table>
# Vector – Pacific Steel

<table>
<thead>
<tr>
<th></th>
<th>08-Aug-02</th>
<th>17-Jul-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1816</td>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>kV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acid No.</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>mg KOH/g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IFT</td>
<td>33.2</td>
<td></td>
</tr>
<tr>
<td>mN/m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color No</td>
<td>2.0</td>
<td></td>
</tr>
</tbody>
</table>


Tap Changer Lay out
Centre phase changeover fixed and moving contacts in the changed over position
Close up of centre phase moving contact
Centre phase moving holding pin assembly and new parts
TASA® CASE STUDY

Dissolved Gas Analysis

<table>
<thead>
<tr>
<th>Gas</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>175</td>
</tr>
<tr>
<td>CH4</td>
<td>28</td>
</tr>
<tr>
<td>C2H6</td>
<td>9</td>
</tr>
<tr>
<td>C2H4</td>
<td>85</td>
</tr>
<tr>
<td>C2H2</td>
<td>199</td>
</tr>
<tr>
<td>CO</td>
<td>139</td>
</tr>
<tr>
<td>CO2</td>
<td>968</td>
</tr>
<tr>
<td>N2</td>
<td>89135</td>
</tr>
<tr>
<td>O2</td>
<td>30006</td>
</tr>
</tbody>
</table>
# TASA® CASE STUDY

## Particle Count

<table>
<thead>
<tr>
<th>Size (µ)</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 to 15</td>
<td>18016850</td>
</tr>
<tr>
<td>15 to 25</td>
<td>851750</td>
</tr>
<tr>
<td>25 to 50</td>
<td>290150</td>
</tr>
<tr>
<td>50 to 100</td>
<td>5310</td>
</tr>
<tr>
<td>&gt; 100</td>
<td>70</td>
</tr>
</tbody>
</table>
TASA® CASE STUDY

TASA Assessment: Code 3

Sampling Interval:
Recommended re-test in 90 days

Comments:
No abnormal dissipation of energy is indicated. However, there is an advancing wear-out condition. Evaluate for worn or damaged parts. Plan for maintenance.
TASA® CASE STUDY

DGA supported finding of normal timing sequences, spring pressures and contact alignment. The particle count indicated advanced wear. A ninety day re-test protocol was reasonable under these circumstances.