About Your Host's

Gerald Sellers
- Lab Manager – Shermco Oil Analysis Laboratory
- 30+ Years of Experience
- Entire career has been within the oil analysis profession.
- gsellers@shermco.com

Understanding Dissolved Gas Analysis

Presented By:
Gerald Sellers
DGA & LIQUID INSULATION TEST

- Transformer Condition Assessment:
  - Transformers are critical assets for utilities.
  - Failures are costly.
  - Obtaining max operational life is vital
  - Dielectric Fluid testing is primary diagnostic tool used to determine transformer condition.
  - Accurate condition assessment is vital.

Could this have been Prevented?

DGA & LIQUID INSULATION TEST

- GOALS Of This Session:
  - Increase knowledge of insulation tests.
  - How to evaluate gas & liquid tests results.
  - Identify gases and what causes them.
  - Learn to read a DGA report & understand what it is telling you concerning the condition of the unit.
  - Understanding observations & corrective actions.
DGA & LIQUID INSULATION TEST

• 3 Types of Fluid Tests
  • Fluid Quality: Contamination, Oxidation & Degradation
  • Furans: Cellulose Insulation Quality & Degradation
  • DGA: Faults, Cellulose Degradation & Operational errors

DGA & LIQUID INSULATION TEST

• Vital Components of Condition Assessment:
  • Operational Knowledge of Equipment
  • Operational Age
  • Operational Loading – Constant, Variable & Seasonal
  • Historical Data and trending patterns

DGA & LIQUID INSULATION TEST

• Causes of Cellulose Degradation:
  • Heat: Overloading & insufficient cooling
  • Water: High content in cellulose
  • Oxygen: Oxidative degradation
  • Development of Furans
DGA & LIQUID INSULATION TEST

• Cellulose Oxidation / Aging Tests:
• Fluid Quality Test: Color, Acid, & IFT
• Furans: Degree of Polymerization / Age rate
• Dissolved Gas Analysis (DGA): CO

DGA & LIQUID INSULATION TEST

• Prevention of Cellulose Degradation:
• Heat: Maintain cooling system
• Eliminate Harmonics: Overheating
• Water: Keep oil dry, head space integrity
• Oxygen: Head space integrity, Inhibitor

DGA & LIQUID INSULATION TEST

• Cellulose (Solid) Insulation
• Cellulose:
• Linear chain of Glucose molecules
• Degree of Polymerization (DP):
• Average number of glucose molecules that make up a cellulose polymer
**DGA & LIQUID INSULATION TEST**

- Paper Quality is based on DP:
- DP of Paper
  - New Paper before processed: 1200-1300
  - New Transformer Paper > 1000 DP
  - Weak / Brittle Paper: <250 DP
  - Considered as “End of Life” of the paper and the transformer

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**DGA & LIQUID INSULATION TEST**

- Measuring DP of Physical Paper:
  - ASTM Method D4243
  - Paper is digested into a slurry
  - Viscosity of slurry is measured/Related DP
  - High Viscosity = Long polymer / High DP
  - Low Viscosity = Short polymer / Low DP
  - High DP = Strong Paper = Tensile strength

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**DGA & LIQUID INSULATION TEST**

- Furans: Breakdown product of paper
  - Cellulose = Glucose = Pentose = Furfural
  - Heat, oxygen or water, in the right combination, cleaves glucose bonds, decreasing the DP of the paper.
  - For each broken bond, one Furan molecule is formed and three water molecules are formed.
DGA & LIQUID INSULATION TEST

<table>
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<th>Age of Oil</th>
<th>Oil Age of Oil</th>
<th>Test year</th>
<th>Test year</th>
<th>Reservoir Age</th>
<th>% Oil at Evacuation</th>
<th>Maximum % Oil</th>
<th>Furfural</th>
<th>Diagnosis</th>
<th>Property Status</th>
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<td>30 years</td>
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<td>No</td>
<td>100%</td>
<td>Minimum</td>
</tr>
</tbody>
</table>

Good Furan Report

Marginal Furan Report
DGA & LIQUID INSULATION TEST

• DGA Compliments Furan Cellulose Condition Assessment
• DGA, Carbon Monoxide “CO”:
  • Localized charring of paper.
  • CH4 “Methane” or other gas formation occurs.
  • Furans: Large surface area degradation.
  • CO also formed but at low levels.

DGA & LIQUID INSULATION TEST

• How often to Test for Furans:
  • New Installation: Baseline Data
  • New Unit: Once every 3 Years
  • Once a year when trending data shows an issue developing with Carbon Monoxide and Carbon Dioxide
  • Upper Limits: CO>1400, CO2>10,000 ppm
  • Exception: Silicon CO>1000, CO>20,000

DGA & LIQUID INSULATION TEST

• Dissolved Gas-in-Oil Analysis:
  • Gases generated by degradation of fluid or cellulose.
  • DGA – Critical Transformer Test:
    • Detects most internal faults, some external faults and some operational errors.
    • Helps evaluates oil preservation systems.
DGA & LIQUID INSULATION TEST

• Dissolved Gas Analysis (DGA):
• Chromatography: Technique for separation and identification of chemical mixtures.
• Gas Chromatograph (GC): Analytical instrument used for the separation of chemical mixtures such as gases, combustible and atmospheric.

DGA & LIQUID INSULATION TEST

• DGA Methods Used:
• ASTM D-3612  DGA Analytical Method
• 3 methods used for extraction of gases
• Method A: Vacuum extraction (Mercury)
• Method B: Direct injection into GC
• Method C: Headspace
• All methods are used and have + & -

DGA & LIQUID INSULATION TEST

• Types of Dissolved Gases:
• Atmospheric Gases: (N2, O2, & CO2)
• Cellulose Breakdown Gases: (CO & CO2)
• Fluid Breakdown Gases: (H2, CH4, C2H6, C2H4, & C2H2)
• Leak Testing Gas: Helium, Nitrogen.
• Due to cost and supply of Helium, not used as much in newer units for leak test.
DGA & LIQUID INSULATION TEST

- Atmospheric Gases: N2 & O2 Evaluation of oil preservation system.
- Nitrogen Blanket Transformers:
  - Normal Ratio – 10 to 60+
  - Minimum Ratio - > 10
  - Suspect Ratios - <10
  - Open Breather, Leaking Head Space - <4
- Atmospheric Ratio = 4 (80:20)

DISSOLVED GASES

- Incorrect sampling compromises sample validity. Bubbles in sample increase oxygen and decrease hydrogen, carbon monoxide and methane.
- Validation of sample quality: Can be detected by high oxygen, ratio of nitrogen/oxygen, large changes of TDG, loading level and top oil temperature.
DGA & LIQUID INSULATION TEST

- CO & CO2: Cellulose Breakdown
- Carbon Monoxide Limits:
  - CO <350 ppm - Normal
  - >350 ppm - High loading
  - >500 ppm – Suspect charring of paper
- Confirm with hydrocarbon gases, hydrogen or methane produced with carbon monoxide.
- CO2/CO ratio > 4 not a valid diagnostic tool.

DGA & LIQUID INSULATION TEST

- Key Gas Diagnostics:
- Basis of ratio diagnostic guides (IEEE) and Duval’s Triangle.
- Known temperature range for production of gases and gas ratios.
DGA & LIQUID INSULATION TEST

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DGA & LIQUID INSULATION TEST

• Fault Diagnostics Uses:
  • Knowledge of XFMR or LTC, type, function, operating conditions, fluid quality test, furans and cellulose condition.
  • Key Gases: Fault temperature and fault class.
  • Rate of formation of TDCG and individual gases. IEEE C57.104 and table 3 TDGC concentration and rate of generation.
DISSOLVED GASES

- Hydrogen (H2) Formation:
  - Electrolysis of Water (H2O – H2 + O2)
  - Rusting (Fe + H2O = FeO2 + H2)
  - PD (Hydrocarbons – H2)
  - Core Iron Hot Spot
  - Static Electrification (High oil flow; pumps)
  - Catalytic formation: H2O + Galvanized steel
  - Alternative Fluids (Additives)

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DISSOLVED GASES

- Hydrogen (H2) Catalytic formation:
  - A galvanized (zinc coated fitting plus high moisture will form H2 in a DGA sample and drain valve of unit.
  - Hydrogen can be formed by a chemical reaction with the breakdown of water reacting with the zinc coating of the fitting.
  - Do not use galvanized sample fittings.

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DISSOLVED GASES

- Methane CH4
  - Low rate of formation at full loading
  - Moderate Rate: Overloading, cooling system compromised, low fluid level (Below radiators), blocked radiators or oil ducts in winding, retro-filled with high viscosity liquid insulation (FR3, Bio-Temp, R-Temp) and harmonics
  - High Rate: By product of high heat faults
DISSOLVED GASES

- Increases of Methane CH4:
- Blockage of natural air flow preventing sufficient cooling.
- Generally you will see an increase of methane gas during the summer months.
- Low oil levels due to improper flow of oil through radiators.

DISSOLVED GASES

- Viscosity & Methane Gas Formation:
- Heat transfer is a critical function of fluid.
- Viscosity: Fluids ability to flow and dissipate heat.
- High viscosity fluid can increase temperature from 5°C to 10°C. So expect to see increases when using FR3, R-Temp, Bio-Temp, Silicone or any other Natural Ester based oil.
- Winding cooling ducts matched to fluid viscosity.

DISSOLVED GASES

- Dielectric Fluid
- Mineral oil
- FR3
- R-Temp
- Silicone

Viscosity
8-12 @ 40°C
35 Max @ 40°C
120-140 @ 40°C
35-40 @ 40°C
DISSOLVED GASES

- Ethane C2H6 Generation:
  - Moderate temperature heating >250°C
  - Undersized Conductor
  - Defective Conductor Crimps
  - By-product of higher temp hot spots
  - Not considered a Key Gas
  - Not used in Duval’s Triangle

DISSOLVED GASES

- Ethane Gas Generation:
  - High Temperature Hot Spot 350 - 700°C
  - Circulating currents between core and tank. Second ground or flux shield issue
  - Circulating current in windings. CO usually elevated as paper degrades.
  - Connection with insufficient contact, tap connection, bolted connections or weak spring.
  - Core iron saturation causing magnetic flux heating.

DISSOLVED GASES

- Acetylene C2H2 Gas Generation:
  - ARCING !!!! Temperature 700 to 1800°C +
  - Any increase in acetylene warrants investigation!
  - Winding failure causing shorted turns
  - External power surge to unit
  - Sparking between loose contacts
  - Failed insulation on bolts

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DISSOLVED GASES

- Partial Discharge in Oil:
  - Key Gas: Hydrogen H2
  - Ratio of gases formed by PD
    - H2 - 86.0% of Combustibles
    - CH4 – 13.0% of Combustibles
    - CO - 0.2% of Combustibles
    - C2H6 – 0.5% of Combustibles
    - C2H4 – 0.2% of Combustibles
    - C2H2 – 0.1% of Combustible

DISSOLVED GASES

- Low Temperature – Non Fault Heating:
  - Key Gas: Methane CH2
  - Ratio of gases formed by PD
    - H2 – 3.0% of Combustibles
    - CH4 - 90.0% of Combustibles
    - CO – 5.0% of Combustibles
    - C2H6 – 2.0% of Combustibles

DISSOLVED GASES

- Over heated Joint/Contact Circulating Currents:
  - Key Gas: Ethylene C2H4
  - Ratio of gases formed at >350 C
    - C2H4 – 63.0% of Combustibles
    - C2H6 - 17.0% of Combustibles
    - CH4 - 16.0% of Combustibles
  - Note: Ethylene is 3 to 4 times the concentration of the other 2 hot metal gases
DISSOLVED GASES

• Arcing in Transformer Oil:
  • Key gas Acetylene C2H2
  • Ratio of gases formed by arcing:
    • H2 – 60.0% of Combustibles
    • C2H2 – 30.0% of Combustibles
    • CH4 – 5.0% of Combustibles
    • C2H6 – 1.6% of Combustibles
    • C2H4 – 3.3% of Combustibles
  • Note: With H2 being twice the level of C2H2 the key gas for arcing is still C2H2. Hydrogen takes the least amount of energy to be produced.

DISSOLVED GASES

• Concentration of Gases Formed/Detected:
  • Things to Consider:
    • Surface area involved: (pin point or large surface)
    • Time: (One time, Intermittent or active)
    • Volume of fluid in tank (v-gas/v-fluid =ppm)
    • Gas Solubility: % in fluid verse % in headspace
    • Headspace Pressure: (changes with fluid temperature)
    • Fluid Type: (Oil verse Silicone verse Natural Esters)

DISSOLVED GASES

• Ratio Analysis of Fault Gases:
  • Hydrocarbon Gas Ratios
    • CH4 /H2 - Methane/Hydrogen
    • C2H6 / CH4 – Ethane/Methane
    • C2H4 / C2H6 – Ethylene/Ethane
    • C2H2 / C2H4 – Acetylene/Ethylene
    • C2H6 / C2H2 – Ethane/Acetylene
  • Indicates temperature of fault and energy.
  • Faults have specific ratio patterns.
TRANSFORMER

DISSOLVED GASES

• DGA Diagnostic Tools & Guides Used:
  • Key Gases
  • Ratio Guides: Duval’s Triangle, Roger’s ratio, and Dorenberg’s.
  • Rates of Formation: IEEE C57.104 using table 1 and 3 as a guide.
  • DGA is not an exact science, just a snap shot of what’s happening at the time the sample was taken.

DISSOLVED GASES

• Things to Keep in Mind Concerning DGA
  • Proper representative sample needed
  • Consistent sampling conditions desired.
  • If sampled in the summer months, try to keep sampling schedule routine. Drastic changes will be seen from summer samples to winter samples.
  • Temperature and pressure has a lot to do with gas levels seen in the DGA.
  • Summer samples with higher ambient temps, higher gas levels leached out into oil.
  • Winter samples with lower ambient temps, lower gas levels, gases drawn back into windings and paper.
**DISSOLVED GASES**

- Proper sample extraction is vital to accurate DGA diagnosis.
- Proper flushing of drain valve is vital for accurate and representative determination of gases and fluid quality properties reported.
- One of the most important testing that can be performed on the unit without having to open it up or take unit out of service.
- Consistent sampling needed to provide accurate trending results of units.
- If fault suspected, best to sample after 24 hours of fault to insure equilibrium of gases has been established.

**OIL QUALITY PROPERTIES**

- Tests Performed on Oil Quality Bottle:
  - Dielectric D-877 or D-1816
  - H2O (Moisture)
  - IFT (Interfacial Tension)
  - Specific Gravity
  - Power Factor (25C or 100C)
  - Color
  - Visual- Sediment
  - TAN (Total Acid Number)
  - Furans & PCB’s
  - Inhibitor Content
  - Metals & Particle Count
OIL QUALITY TESTS

• What is the importance of water testing:
  • Dielectric strength of materials
  • Rate of paper aging – directly proportional to water content
  • Bubble formation during overloads
  • Condensation during cool down
  • Production of Furans
  • Relative Saturation of Paper

TRANSFORMER PICTURES

OIL QUALITY TESTS

• Effects of Water:
  • Dielectric strength substantially lowered when water content of paper/pressboard is 2 to 4% or higher.
  • Relative Saturation of liquid dielectric is >50%.
  • Bubble evolution influenced by water content in paper during loading.
OIL QUALITY TESTS

• Where is water located:
• Most of the water is located in the solid insulation, (wood, paper & pressboard)
• Entry Points: Residual after processing, manufacturing, installation, maintenance, leaks, preservation system and from the development of Furans.

OIL QUALITY TEST

• The 5 stages of Water:
• Dissolved: Water in solution interspersed between hydrocarbon molecules.
• Free Water: Water that is not in solution and is high enough concentration to form water droplets and separate from the oil.
• Emulsified: Water that is suspended as clusters of water molecules. It gives oil a cloudy, milky appearance.
• Trapped Water: Water held on non-cellulosic surfaces due to surface chemistry.
• Bound Water: Water held in polar oil/paper degradation by-products.
• Note: Oil molecules can hold up to 500 ppm water before forming droplets and separating from the oil.

Issues to avoid!

[Image of issues to avoid]
OIL QUALITY TESTS

• Determination of Water Concentration:
  • Karl Fisher & Precipitation %
  • Solubility of Water in Oil: Is defined as the amount of dissolved water an oil can hold at a specific temperature.
  • Solubility changes significantly with temperature.
  • Example: Solubility of water in oil at 10°C is 36 ppm, whereas at 90°C it is 592 ppm.
  • As oils age and accumulate amounts of acids and other polar compounds solubility increases.

TRANSFORMER PICTURES

OIL QUALITY TESTS

• Relative Saturation %:
  • Relative saturation is the amount of water measured in the oil in relation to the solubility level at that temperature recorded at the time the sample was taken. This is why it is so important to take a temperature reading when sample is taken.
  • Example: XFMR @ 85°C and tested water @ 30 ppm. To determine the RS, 30 ppm would be divided by the solubility level at 85°C which is 517 ppm multiplied by 100 (30 ppm/517 ppm x 100) Relative Saturation = 5.8%
OIL QUALITY TESTS

- Dielectric Breakdown:
- Water
- Particles: Optical microscopy, particle count, emission spectroscopy, scanning electron microscopy and atomic absorption spectroscopy.
- Particle Counting: Counted in distinct sizes from 5 microns to 100 microns

Does it work?

DEHYDRATION

- Why Process Dielectric Fluid
- Remove Particulates/ Causing low Die.
- Remove Water
- Remove Unwanted Gases
DEHYDRATION

- Processing Using Filtration Only
- Removes Particulates Only
- Certain Filters Remove Free Water Only
- Doesn’t Remove Dissolved Water Effectively

DEHYDRATION

- Processing Oil Using Vacuum, Heat & Particulate filtration
- Removes Particles
- Removes Water
- Removes Dissolved Gases

DEHYDRATION

- Processing Oil (Energized or DE energized)
- Process More Effective with Equipment Energized
- Not all Equipment Can Be Processed Energized
• Oil Quality and Integrity are an important part of maintaining your electrical assets.
• It is a low cost and high return for the investment.
• Helps maintain reliability when most needed.
• Contact us with any special needs or questions.
• THANKS