ESTER-BASED DIELECTRIC FLUIDS FOR ENHANCED TRANSFORMER RELIABILITY AND ASSET LIFE EXTENSION

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Agenda

• Introduction to ester-based dielectric liquids
• ISO 55000 and Health Index
• Installation phase – reducing capital costs
  • Fire properties and protection measures
  • Environmental protection
• In service phase – extending asset lifetime
  • Paper lifetime experiments
  • IEEE and IEC guidance on asset life with esters
What is an Ester?

- The term ‘ester’ comes from chemical linkage formed from the reaction of an alcohol & an acid
- Synthetic esters are manufactured from chemicals
  - Carefully selected acids and alcohol to give chosen properties
- Natural esters are derived from plant oils
  - Refined seed oils
  - Examples include Rapeseed, Soya, Sunflower
Key Benefits of Ester-based Liquids

• Increased Fire Safety
• Greater Environmental Protection
• Superior Moisture Tolerance
• Longer Paper Lifetime
• No Corrosive Sulphur
ISO 55000

- Effective management of assets is critical for any business
- Especially true for T&D networks
  - Large numbers of assets
  - Large variation in age and condition of assets
  - Uninterrupted supply of electricity is vital to homes and businesses
- ISO 55000 is a set of new standards for asset management
- ISO 55000 is to asset management as ISO 9000 is to quality management
- One tool for asset management is the Health Index
Fluid Fire Properties

- Fire safety is critical for new equipment installations
- IEC classifies fluids by fire point and low heat value
- Expensive fire protection measures are needed for mineral oil
- Use of K-class fluids can reduce fire protection requirements

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Flash Point (ISO 2719 - Pensky)</th>
<th>Fire Point (ISO 2592 - COC)</th>
<th>IEC 61039 Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral Oil</td>
<td>150˚C</td>
<td>170˚C</td>
<td>O1</td>
</tr>
<tr>
<td>Synthetic Ester</td>
<td>260˚C</td>
<td>316˚C</td>
<td>K3</td>
</tr>
<tr>
<td>Natural Ester</td>
<td>270˚C</td>
<td>360˚C</td>
<td>K2</td>
</tr>
</tbody>
</table>
FM® Global Guidance Example

**KEY**
- MINERAL OIL TRANSFORMER
- ESTER TRANSFORMER
- CONTAINMENT
- 2-HOUR FIRE RESISTANT BARRIER
- AREA OF SUBSTATION

**NOTES**
Transformers contain between 19,000 and 38,000 liters of fluid.
Spacing based on FM Global Datasheet 5-4, April 2014.
Drawn to scale.
Spacing based on fire clearances only.

The diagram illustrates the guidelines for placing transformers in a building with non-combustible construction, keeping a safe distance from the transformer area and ensuring proper containment and fire-resistant barriers.

**Building with Non-Combustible Construction**

**FM Approved Fluid**
Environmental Impact

- Lowering environmental impact may reduce containment requirements
- Ester fluids are far more biodegradable than mineral oil
- Local regulations apply for containment
- Concessions may be available for ester fluids
- Berlin distribution network uses esters in water protection areas without bunding
Comparative Biodegradation Rates

- **Natural Ester**
- **Synthetic Ester**
- **Mineral Oil**

Biodegradation is measured as a percentage over time (in days) from 0 to 30 days.
Where Moisture Originates

• The atmosphere
  • Can ingress through headspace in breathing transformers
  • Through leaks in sealed units
  • During maintenance

• The paper
  • As paper ages due to oxidation it releases water
Ester Structure and Interaction with Water

Water Structure

Basic Ester Structure

Hydrogen Bonding
Moisture Saturation Limit

- **MIDEL7131**
- **MIDELeN**
- **Mineral Oil**

![Graph showing moisture saturation limit vs temperature](image)
Breakdown Voltage vs. Moisture @ 20°C
Weidmann Paper Testing Setup

1: Aging vessel with nine independent test chambers
2: Test chamber (volume: 20 dm³; wall area: 60 dm² made of sand blasted steel sheet)
3: Glass expansion tube
4: Steel bellow
5: Flow baffle
6: Heater
7: Sensor for temperature control
8: Temperature measurement
9: Cooling coils
10: Outlet valve
11: Material samples (specimens)
12: Copper sheet; surface: 3 dm²
13: Core steel; surface: 6 dm²
14: Thermal insulation
Pressboard DP Value 150°C Sealed
IEC Kraft Paper Lifetime

Ref: IEC 60076-14 Ed.1 Sept 2013
Pressboard Water Content 150°C Sealed

- Natural Ester 1
- Natural Ester 2
- Natural Ester 3
- Natural Ester 4
- Synthetic Ester
- Mineral Oil 1
- Mineral Oil 2
- Mineral Oil 3
- Mineral Oil 4

Month

Pressboard Water Content (%)
Longer Paper Lifetime

• Based on the IEC 60076-14 curve paper will last around five times longer

• Being conservative distribution transformer could last ten years longer with ester than mineral oil

• Lifetime extension will depend on tank condition etc. as well as paper life
Better Overload Resistance

• Based on the IEC 60076-14 curve an ester transformer can run 15°C hotter with the same lifetime as a mineral oil transformer

• This allows higher normal running temperature

• Temporary overload temperature can also be higher

• Ester fluids have a much higher flash point than mineral oil, allows safe running at higher temperatures
Conclusions

- ISO 55000 will demand more focus on asset management
- Tools such as health index provide a way to assess fleets of transformers
- Ester fluids have the potential to help asset managers
- Reduce overall capital installation costs
  - Improved fire safety
  - Reduced environmental impact
- Have a beneficial impact on paper lifetime
  - Reduce lifetime costs by providing longer life
  - Alternatively provide greater flexibility via increased loading