# Retrofilling Experiences with Ester Transformer Liquids: Enhancing Performance, Safety, and Sustainability

**Abstract:** The retrofilling of transformers with ester-based insulating liquids offers substantial benefits in terms of fire safety, environmental sustainability, and operational performance. This paper explores case studies and technical findings that highlight the advantages of ester liquids over traditional mineral oil, detailing retrofilling processes and outcomes.

**Keywords:** esters, fire safety, power transformers, electric utilities, substation, refurbish, retrofill, biodegradable, cold climate

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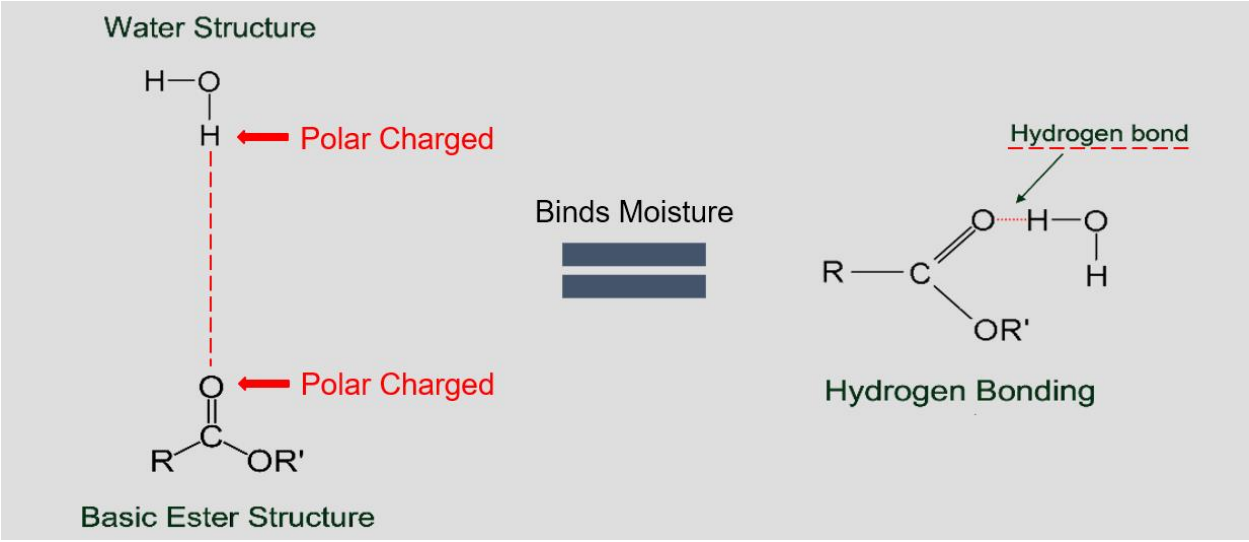
**Introduction:** Transformers traditionally use mineral oil as an insulating medium. However, the industry has increasingly turned towards ester-based alternatives due to their superior fire safety, environmental benefits, and ability to extend transformer life. This paper presents practical insights into retrofilling transformers with ester liquids, showcasing case studies from various industries.

**Ester Liquid Properties** Ester liquids, both synthetic and natural, are distinguished by unique molecular properties that enhance transformer performance. Key attributes include:

- **Moisture Management:** Esters bind moisture, mitigating insulation degradation.
- *Figure 1: Ester Molecular Chemistry Advantage.*



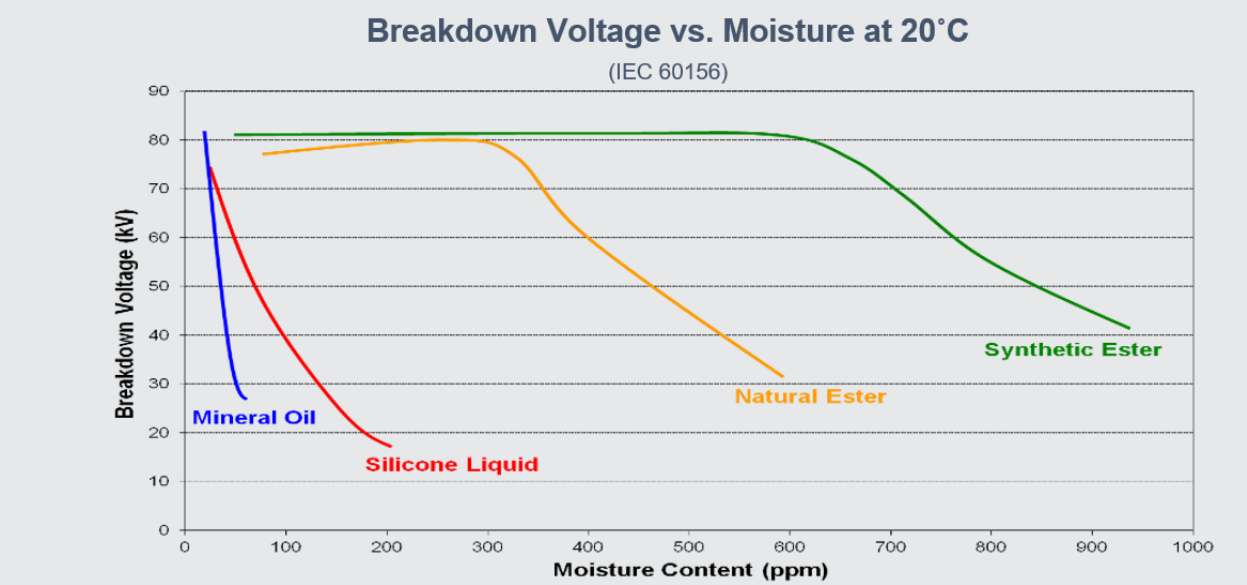



*Figure 2: Breakdown Voltage vs. Moisture PPM at 20C Advantage.*

- **Ester Chemistry:** Cellulose Insulation Aging Benefit

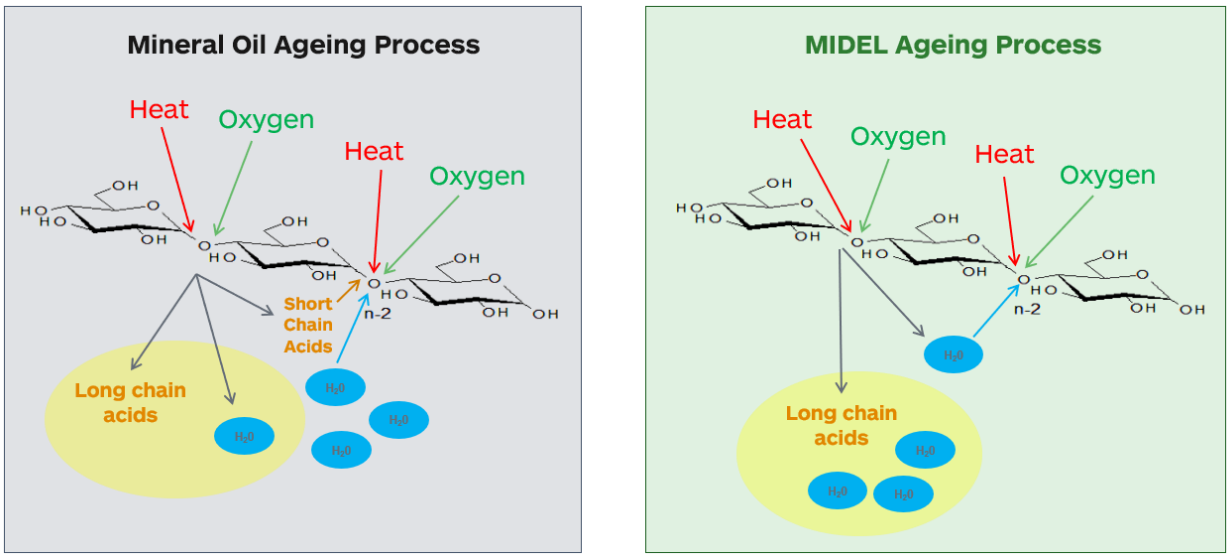



*Figure 3: Breakdown Voltage vs. Moisture PPM at 20C.*

- **Esters & Paper Lifetime:** Longer Life or Higher Load Benefits

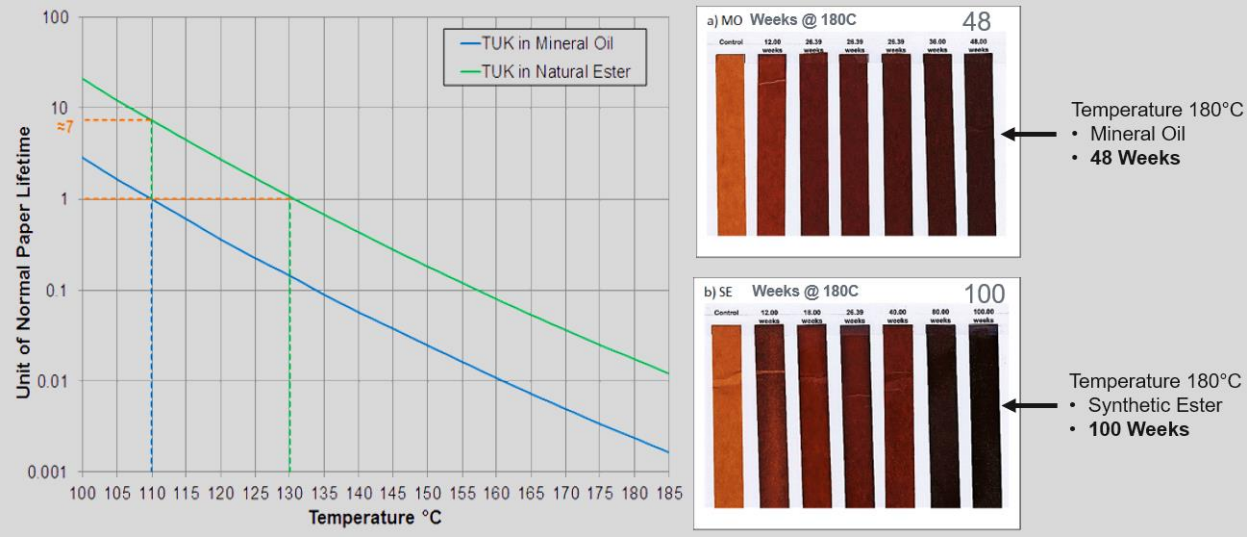



*Figure 4: Life vs Temp and Accelerated Aging.*

- **Fire Safety:** High fire points (>300°C) reduce fire risks.
- **Environmental Sustainability:** Esters are biodegradable, minimizing ecological impact.

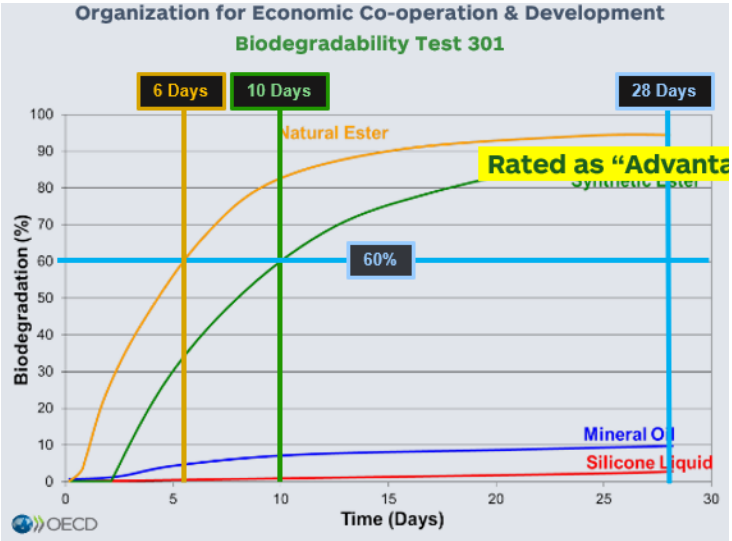



*Figure 5: OECD Test 301 for Biodegradation of Transformer Liquids.*

- **Cold Temperature Performance:** Synthetic esters maintain liquid state at temperatures as low as -56°C.

Physical State of Ester Fluids in Cold Temperatures

| Temperature | Soy-Based Natural Ester | Canola-Based Natural Ester | Synthetic Ester |
|---|---|---|---|
| 0°C | Liquid | Liquid | Liquid |
| -5°C | Liquid | Liquid | Liquid |
| -10°C | Solid Deposits | Liquid | Liquid |
| -18°C | Solid | Liquid | Liquid |
| -25°C | Solid | Solid Deposits | Liquid |
| -31°C | Solid | Solid | Liquid |
| -40°C | Solid | Solid | Liquid |
| -56°C | Solid | Solid | Solid |

*Figure 6: Cold Temperature State of Esters.*

**Retrofill Candidate Assessment:** The retrofilling process involves replacing the transformer's mineral oil with ester liquid. However, first the candidacy of the units in question must be assessed.

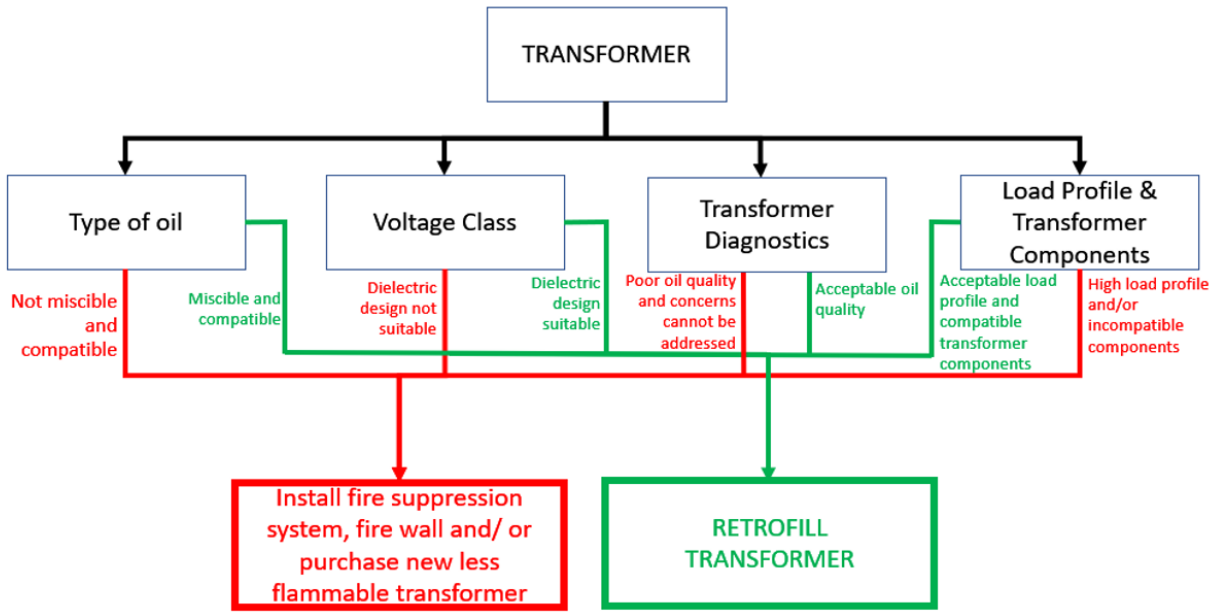



*Figure 7: Retrofilling decision tree.*

**Retrofill Process Overview:**

Key steps include:

1. Pre-retrofill checks to assess transformer suitability.
2. Draining existing mineral oil and performing a hot flush with MIDEL ester to remove residual oil.
3. Refilling the transformer with ester liquid, ensuring minimal residual mineral oil.
4. Conducting post-refill testing to verify insulation resistance, breakdown voltage, moisture content, and fire point.
5. Energizing the transformer under no-load conditions before returning to service.

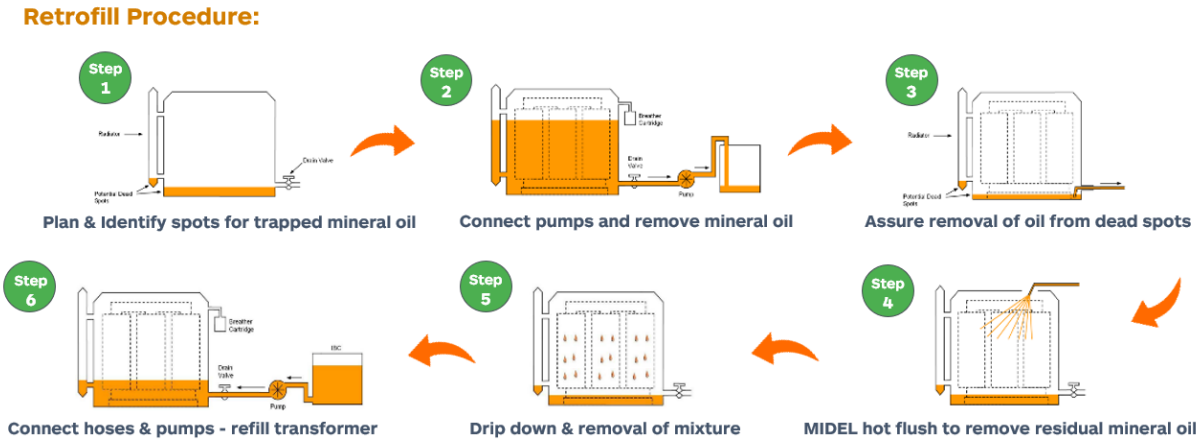



*Figure 8: Retrofill Process.*

**Case Studies**

1. **Electric Utility, Texas, USA:** Eight 750 KVA transformers containing toxic Wecosol fluid were leaking and created environmental risk. They were retrofilled with natural ester. This enhanced environmental safety and mitigated toxicity risks while keeping them fire safe.
2. **Chemical Manufacturing Facility, Gulf Coast, USA:** A 1500 KVA transformer near a sensitive environmental area was retrofilled with canola-based ester, addressing environmental and fire safety concerns. The unit was in close proximity to wetland area and major waterway.
3. **Eastern USA Utility:** An 84 MVA transformer on an island in an environmentally sensitive location was retrofilled with synthetic ester, improving fire safety and extending operational life. The unit was very near a building with people and critical infrastructure.

**Retrofilling MythBusters (refuting false claims in the market):**

1. The residual mineral oil content of the transformer will be between 3% to 5%
    - Experience shows less than 3% is typically achieved when proper process is followed
2. If the fire point of the ester liquid drops below 300°C, the entire volume of liquid would need to be replaced
    - Calculation can be performed to remove and replenish the appropriate amount of the mixture
3. Synthetic ester cannot be used to retrofill transformers in the field
    - Globally, thousands of transformers have been retrofilled on-site with SE
4. Unless the ester is heated, a cold start in an ester filled transformer may result in excess hot spots
    - Lower pour point ester liquids reduce/eliminate cold temperature performance issues

**Benefits and Key Takeaways:** Retrofilling with ester liquids to replace mineral oil or other transformer liquids provides:

- Enhanced fire safety, reducing risk and insurance costs.
- Improved transformer performance and loading capacity.
- Reduced environmental impact through biodegradable fluids and low toxicity.
- Increased ROI via extended equipment lifespan and reduced maintenance.

**Conclusion:** Ester-based retrofilling presents a compelling case for utilities and industries seeking to improve transformer safety, sustainability, and performance. As the electrical industry evolves, ester liquids offer a future-proof solution for enhancing transformer resilience and reducing environmental impact.

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**References**

- IEEE C57.147 Maintenance Guide for Natural Esters
- ASTM D2112 Oxidation Test
- "Alternate Insulating Fluids for Power Transformers," 2019 R&D Study, US Bureau of Reclamation