Alternative Transformer Fluids
Energy Management - Transformers

www.siemens.com/transformers/ester
The challenge:

Alternative fluids are on the rise all over the world. Just like politics and science, the energy industry is working on trendsetting solutions that ensure the safety and sustainability of the environment and population. One way of doing this is by exploiting renewable energy sources.

But the efficiency and use of renewable resources in assets and equipment is also considered important. Alternatives to mineral oil are often used in environmentally protected areas and locations with a special need for fire safety.

Our contribution:

Siemens Transformers has been one of the first manufacturers building transformers filled with ester instead of mineral oil. Having started with distribution transformers, small power transformer units were also insulated with ester soon after. The ratings grew bigger, and in addition to synthetic ester research and development for natural ester filled transformers started.

Today, Siemens Transformers is the partner of choice for customers worldwide when it comes to substituting mineral oil. Maybe your transformer will be our next project?
Why go alternative?

When Siemens Transformers started working with alternative fluids, customers were usually forced to substitute mineral oil due to external circumstances like environmental protection, nearby lakes or drinking water reservoirs. Fire safety measures were also sometimes a reason to go for alternatives.

Today the capabilities of esters are nearly unlimited, as are the reasons why transformer operators decide to choose these fluids. They are used in almost any application and any location. Their benefits are just as numerous.

As the ageing performance of esters outweigh those of mineral oil, transformers may be operated at higher temperatures than conventionally filled units. This is also proposed by IEC 60076-14, where over temperatures and hot spot temperatures for winding designs using thermally upgraded paper are considered already.

Transformer operators rely on the expertise of Siemens Transformers for decades when it comes to their assets. If you want to leverage the advantages of your alternative insulated units as well, make use of our know-how and consultancy.
Esters in all product classes

Today Siemens Transformers use ester in distribution and power transformers of all sorts. Our extensive and in-depth research in our own labs allows us to fill even smaller ratings of HVDC-transformers with ester instead of mineral oil.

Being the innovation leader in the transformer industry, we strive to be the first to provide our customers with innovative solutions in terms of ester-usage and we are keen on working with you to meet your challenges in this regard.
Higher fire safety

- Higher flash and fire point
- Fire point above 300°C
- K class rating (IEC 61100 / 61039)
- Lower gas conversion factor
- Tank rupture prevention

Lifetime extension

- Slower decrease in the degree of polymerization
- High capability to take water from cellulose
- Dielectric strength unaffected by water
- Higher temperature limits

Smaller Footprint

- Eliminate rocks, grating, and support steel
- Change containment size
- Shorter bus duct length

Cost savings

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings from design difference</td>
<td>$ 655,494</td>
</tr>
<tr>
<td>Bio-oil transformer extra costs</td>
<td>-$ 275,450</td>
</tr>
<tr>
<td>Total savings</td>
<td>$ 390,044</td>
</tr>
</tbody>
</table>

OPEX savings

- Lower annual insurance premiums
- Lower losses during operation due to shorter bus duct length
Technical benefits

We differentiate between three types of alternative fluids:
• Silicone oil (fully synthetic)
• Synthetic ester (derived from chemicals)
• Natural ester (derived from plant seed oils)

What they all have in common is that they extend the transformers lifetime – if the unit is calculated, designed and manufactured with the highest quality imaginable.

The degree of polymerization decreases slower with alternative fluids than with the use of mineral oil. All fluids mentioned above have a high capability to take water from the cellulose insulation of the active part, while their dielectric strength is unaffected by water. Their chemical characters also allow for higher temperature limits, which is a benefit for the operation of any kind of transformer.

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristics</th>
<th>Disadvantages / Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral oil</td>
<td>Made from non-renewable resources</td>
<td>• Limited biodegradability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Low fire point</td>
</tr>
<tr>
<td>Silicone liquid</td>
<td>Fully synthetic</td>
<td>• High flash point</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Self-extinguishing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High thermal stability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High viscosity at high temperatures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Poor lubrication properties</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Limited biodegradability</td>
</tr>
<tr>
<td>Synthetic ester</td>
<td>Derived from chemicals</td>
<td>• Higher oxidation stability than nat. ester</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Strongly hygroscopic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Better cold temperature performance than nat. ester</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Readily biodegradable</td>
</tr>
<tr>
<td>Natural ester</td>
<td>Made from plant seed oils (e.g. soya, canola, sunflower)</td>
<td>• Less paper aging than mineral oil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Higher flash and fire points than syn. ester</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Best renewability for processing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Readily biodegradable</td>
</tr>
</tbody>
</table>
Benefits regarding safety and 0-harm

“0-harm-policy and safety are core values of most companies within the energy industry. This includes the safety of their staff as well as the mitigation of such risks for the public and the environment.

The higher flash and fire points of alternative fluids add to that risk mitigation, as well as the K class rating (acc. to IEC 61100 / 61039) and a lower gas conversion factor.

Higher oil flash and fire points make operation safe and protect valuable assets; lower gas conversion factors reduce risk of tank rupture.

These characteristics lead to a high acceptance of transformers filled with natural esters, especially but not only in urban areas and environmentally protected locations.
Financial benefits

The special characteristics of alternative fluids like their high flame and flash point and biodegradability as well as their dielectric hygroscopic features and oxidation stability lead to financial benefits in OPEX.

CAPEX

The initial price for an ester-filled-transformer is usually higher due to material price and design adjustments. However, the higher investment can often be balanced with savings in the construction of the transformer location. Distances and fire safety equipment can often be reduced.

OPEX

Besides the smaller footprint and lower construction costs some insurance companies lower their rates for ester-filled transformers. They mean a lowered risk for safety and environment, which may lead to lower annual insurance premiums.

<table>
<thead>
<tr>
<th>GT GSU:</th>
<th>ST GSU:</th>
<th>2x UAT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformers Price w/ Mineral Oil</td>
<td>+ $139,250</td>
<td>+ $76,200</td>
</tr>
<tr>
<td>$1,624,998</td>
<td>$1,134,500</td>
<td>$654,000</td>
</tr>
</tbody>
</table>

Increased unit price due to special filling equipment, price for biodegradable oil, design adjustments

Reduced power plant costs by elimination of fire walls, rocks, grating, support steel and change of containment size

$3,415,250 12.5% Total Cost Reduction $3,024,206
Reliable and safe transformers for all branches & applications

- Traction Transformers for railway locomotives
- Distribution Transformers for the cavern of a hydro power plant
- Distribution Transformers for Wind Turbines
- Natural Ester at 420 kV Power Transformer
- Mobile Resiliency Units for emergency situations
- Distribution Transformers for Germany
- Hermetically sealed Power Transformer with natural ester
- O & G: Converter-Transformer with Synthetic Ester
- Power Transformer with waste heat utilization
- Power Transformers for Operation on Ships
- Traction Transformers for highspeed trains
- Oil & Gas: Firesafe Power Transformer with ester insulation
- Ester-filled Transformers for Russian LNG
- Substation Transformer Mexico
- Innovation: Ester insulation for HVDC transformers
Application
Railway Locomotives

Insulation
Synthetic Ester

Benefits
• Environmental protection
• Green image
• Gain operational knowledge

Technical data
Rated Power: 6,2 MVA
Rated Voltage: 12/12,5/25/4x1,957
Rated Frequency: 25/60/60
Application

Distribution Grid

Insulation

Synthetic Ester & FR3

Benefits

• Environmental friendliness
• Enhance operational experience

Technical data

>100 Transformers for different ratings from 160 – 630 kVA
Application
Highspeed Trains

Insulation
Synthetic Ester

Benefits
• Sustainability
• Green image

Technical data
Rated Power: 2,2 MVA
Rated Voltage: 15/2x0,95
Rated Frequency: 16,67
Application
Hydro power plant

Insulation
Synthetic Ester

Benefits
- Biodegradability
- Renewable resources for renewable generation
- Longer lifetime of hygroscopic insulation
- State-of-the-art technology

Technical data
four GSUs
Ratings:
121,33 (122) / 60,6 (61) / 60,6 (61) MVA
Voltage levels:
433√3 / 16,8 / 16,8 kV
Application
Transformer Substation / Medium power grid
First regulated PT with nat. ester

Insulation
Natural Ester

Benefits
• Fire safety (high flame- and flash-point)
• Biodegradability
• Green image
• Innovation to gather operational experience

Technical data
40 MVA (107/21 kV)
Hermetically sealed tank
Application
Oil & Gas
Network transformer

Insulation
Synthetic Ester (MIDEL 7131)

Benefits
• Fire safety
  (high flame- and flash-point)
• Sustainability in products

Technical data
• 125/156,25 MVA KNAN/KNAF
• 132 kV / 34,5 kV ± 10 %
  with Vacutap OLTC
• Sergi Transformer Explosion
  Prevention System
Application
Windpower

Insulation
Cellulose-based or aramid synthetic ester

Benefits
• Environmental protection
• Small in size
• Fire protection
• Units can be recycled

Technical data
Transformers for different ratings and voltages applying to all windturbine classes
**Application**
Oil & Gas - Converter Transformer
acc. IEC 61378

**Insulation**
Synthetic Ester (MIDEL 7131)

**Benefits**
- Fire safety
  (high flame- and flash-point)
- Environmental protection
- Atex-Certification for Ex-Zone 2 IIA/IIB T3
- 4 low voltage systems in double tier for feeding a 24 pulse converter

**Technical data**
- 16 / 4x 4 MVA KNAN
- 33 kV / 4x 2,0 kV ± 5 % with NLTC
- Core with intermediate yokes
- Sergi Transformer Explosion Prevention System
Application
Oil & Gas – LNG-Project

Insulation
Synthetic Ester (MIDEL 7131)

Benefits
• Fire safety
  (high flame- and flash-point)
• Biodegradability
• High Temperature Operation
• Moisture Tolerance

Technical data
• Up to 125 MVA
• 35 kV and 110 kV
Application
Substation, 420-kV-level

Insulation
Natural Ester

Benefits
• Biodegradability / Environmental protection
• Publicity / Green image
• Longer lifetime of hygroscopic insulation
• Small Footprint
• Innovation: First Power Transformer for 420-kV-Level

Technical data
Rating: 300 MVA
Voltage level: 420 kV
Application
Substation, 400-kV-level
Innovation: first synthetic ester filled unit at 400 kV

Insulation
Synthetic Ester

Benefits
• Environmental protection
• Publicity / Green image
• Longer lifetime of hygroscopic insulation
• Small Footprint
• Low Noise Design
• Utilization of waste heat

Technical data
Rating: 240 MVA
Voltage level: 400 kV
Application
Substation

Insulation
Synthetic Ester

Benefits
• Biodegradability
• Safety in Operation

Technical data
Rating: 2 x 30 MVA
      2 x 60 MVA
Voltage level: 85 kV / 230 kV
Application
Transformers for operation on ships

Insulation
Synthetic Ester

Benefits
- Biodegradability
- Longer lifetime
- Small Footprint

Technical data
Rating: 50 MVA
Voltage level: 34,5kV
Application
Mobile, versatile and quickly installable spare transformers

Insulation
Synthetic Ester

Benefits
• Biodegradability
• Small Footprint
• Fire safety

Technical data
6 x 100MVA single phase
a) 335-136-13.8 kV
b) 132-68-13.8 kV
**Application**

- HVDC and HVDC plus Transformers
- HVDC demonstrator insulation arrangement using Ester successfully tested in 2015

**Insulation**

Natural & Synthetic Ester

**Benefits**

- Safety in operation
- Higher flash and fire point
- Lower thermal load of the transformer
- Biodegradability
- Extended life time

**Technical data**

HVDC-application with ester possible up to 500kV DC
Subject to changes and errors. The information given in this document only contains general descriptions and/or performance features which may not always specifically reflect those described, or which may undergo modification in the course of further development of the products. The requested performance features are binding only when they are expressly agreed upon in the concluded contract.