Industry NAVIGATOR

SUSTAINABLE DEVELOPMENT STRATEGIES FOR T&D

CONFERENCE 2025

Sustainable oil treatment for longer transformer life

10 April 2025

Marius Grisaru, Senior Independent Consultant

MICAFLUID

Agenda

- 📜 Historical perspective
- 🧪 Transformer oil testing
- ⚠️ Consequences of poor maintenance
- 🌿 Ester vs. mineral oil

- ⚙️ Oil treatment & maintenance
- 📊 Advanced monitoring & applications
- ✅ Conclusions & takeaways

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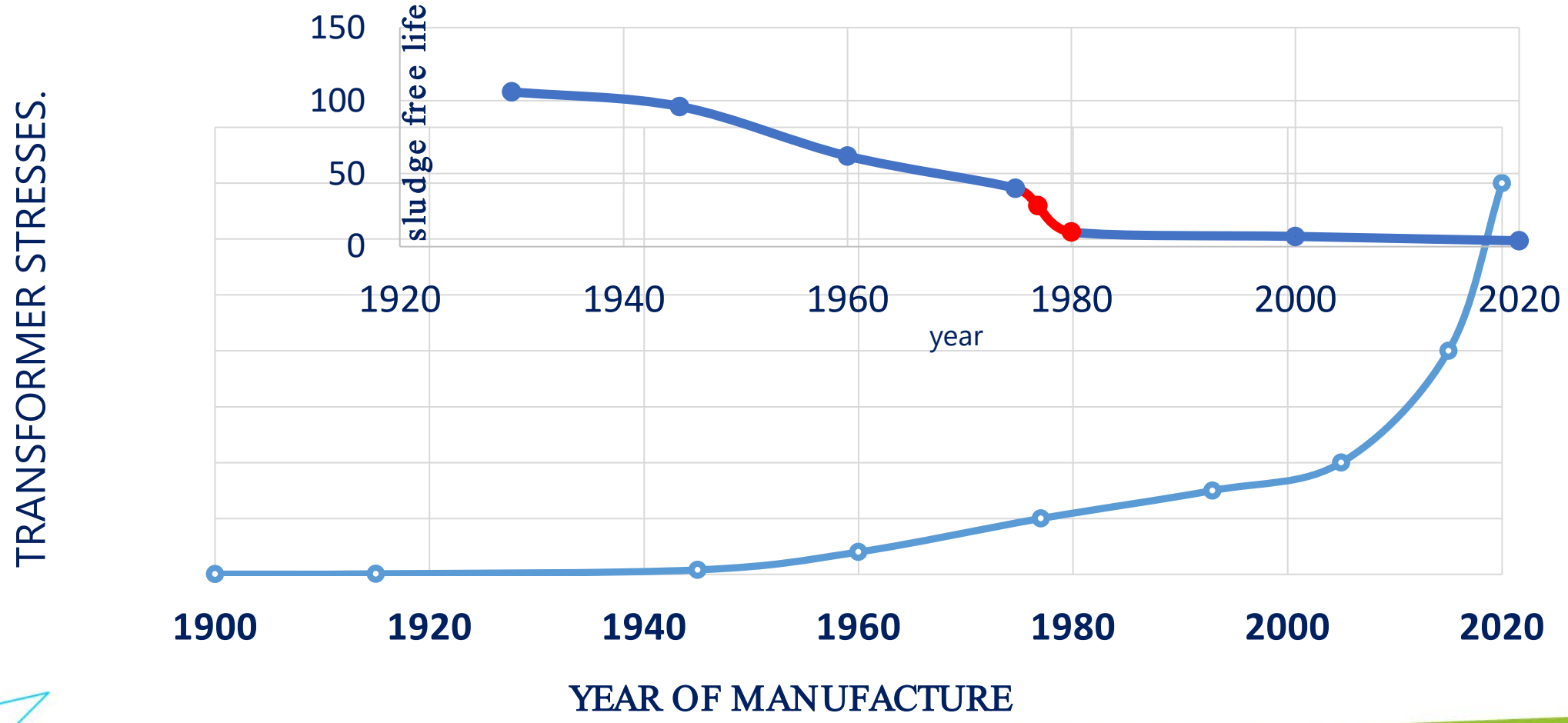
Oil versus Air as medium insulation - 1892* vs 2000

Feature	Oil (1892)	Oil (Modern)	Air (1892)	Air (Modern)
Insulation Performance		• Good dielectric strength • Insulation • Self-healing properties	• Superior to oil for high-tension currents, even with humidity • High insulation resistance • Low electrostatic capacity	• Excellent dielectric strength when dry • Low dielectric losses • Environmentally friendly
Practical Application	* Fills gaps in insulation	• Widely used in transformers, switchgear, and other high-voltage equipment • Different types of oils are available with varying properties (mineral, silicone, ester)	Difficult to keep dry	• Used in gas-insulated switchgear (GIS) and transmission lines • Requires careful design to prevent surface discharges and ensure adequate spacing
Maintenance		• Requires regular monitoring and maintenance • It can degrade over time due to oxidation, contamination, etc.		• Minimal maintenance compared to oil • Sensitive to contamination
Safety		• Flammable • Potential environmental hazards		• Non-flammable • No risk of spills or leaks
Cost		* Can be expensive, especially for specialized oils	* Less expensive than oil	* Can be expensive

*J. B. Williams, "Oil Versus Air as an Insulating Medium," *Trans. Am. Inst. Electr. Eng.*, vol. 9, no. 1, pp. 601-613, Jun. 1892

Timeline of oxidation stability of mineral oil



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The purpose of oil treatment, 100 years ago

Initial preparation

- Heating to expel moisture and air:
- Vacuum treatment (for paraffin oil):
- Storage and handling
- Exclusion from air

In-service considerations

- Self-renewal for insulators
- Expansion and contraction
- Limitations and challenges

Overall, the maintenance of insulating oils at the beginning of the last century focused on initial purification and protection from moisture and air.

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Adopted limits for routine test for in-service oils

IEC60422, 2024 vs 1989

Good condition for in-use oil	< 72.5 kV	72-170 kV	> 170 kV
Acidity mg KOH / g	Less than 0.15	0.1	0.1
Break down voltage kV	More than 40	50	60
Colour and appearance	< 2, and clear and without visible contamination		
Water content mg / kg	Less than 30	20	15
Dielectric dissipation factor at 90 C°	Not required	0.1	0.1
Inhibitor content	0.16 % (above 40 % from initial conc.)		
Interfacial tension*	> 28 inhibited, > 22 uninhibited		

Good condition for in-use oil	< 72.5 kV	72-170 kV	> 170 kV
Acidity mg KOH / g	Less than 0.5		
Break down voltage kV	More than 30	40	50
Colour and appearance	Clear and without visible contamination		
Water content mg / kg	Less than 30	40	20
Dielectric dissipation factor at 90 C°	0.3	1.0	0.2
Inhibitor content	Not existent		
Interfacial tension* - not routine	> 15 inhibited		

- * routine test in IEC
- Reference values for operative action only at IEC60422

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Key topics of transformer oil testing

- **Quality assurance:** ensuring oil meets industry and regulatory standards
- **Condition monitoring:** detecting aging, oxidation, and contamination
- **Fault detection:** identifying operational issues such as overheating or partial discharge
- **Maintenance planning:** determining the need for oil treatment or replacement
- **Regulatory compliance:** meeting corporate, insurance, and environmental requirements

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Recommended oil testing phases in transformer operation

Test	Before Energization	First Year (6 & 12 mo.)	Routine (1-2 yrs)	Special Conditions
Dielectric breakdown voltage	> 70 kV	> 60 kV	> 60 kV	If BDV drops suddenly
Water content (ppm)	≤ 10 ppm	≤ 10 ppm	≤ 15 ppm	If moisture detected
Acidity (mg KOH / g)	≤ 0.03	≤ 0.05	≤ 0.10	If excessive acidity
Interfacial tension (mN/m)	≥ 35	≥ 30	≥ 30	If oil aging suspected
DDF	≤ 0.015 at 90°C	≤ 0.015 at 90°C	≤ 0.1 at 90°C	If oxidation suspected
Dissolved gas analysis (DGA)	For treatment efficiency	Baseline & trend analysis	Routine analysis	If abnormal gassing
Antioxidant inhibitor	As in the new oil	> 60 % of original value		For inhibited oil
Passivator	As in the new oil	70 mg / kg and stable, (rate of decrease < 10 mg / kg / year		If added or declared
Resistivity at 90 ºC (GΩm)	> 100	> 10		With DDF
Corrosive Sulfur (IEC 62535)	Negative	Negative	Not routine	If deposits found
Flash Point	As in the new oil	Decrease < 10 %		

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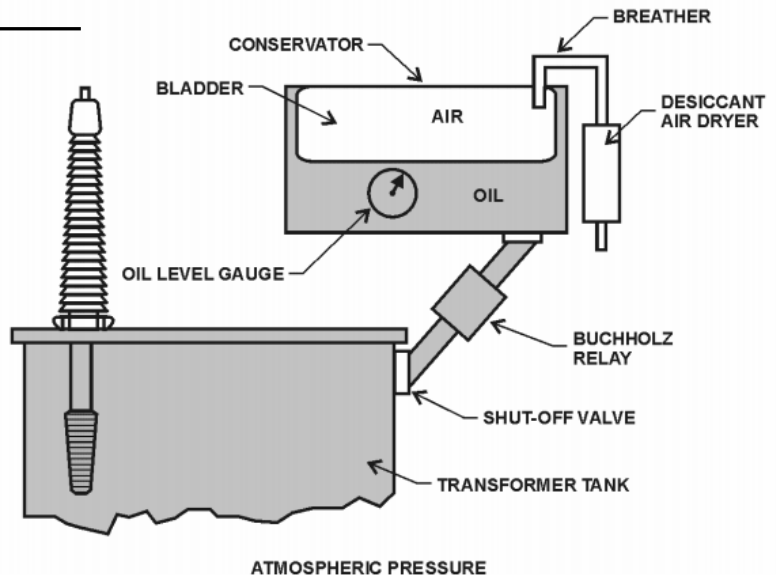
Modern transformers with a bladder in the conservator are more prone to sludge

Transformer type	Approximate time period before sludging begins
Transformers with free air access	10 years
Transformers with conservators	15 years
Transformers bolted tight (sealed) with no nitrogen	50 years
Transformers with nitrogen over oil	67 years

Ref: Maintenance of liquid insulation, 1990, Western area power administration, power system maintenance manual, chapter 10

bladder = tire

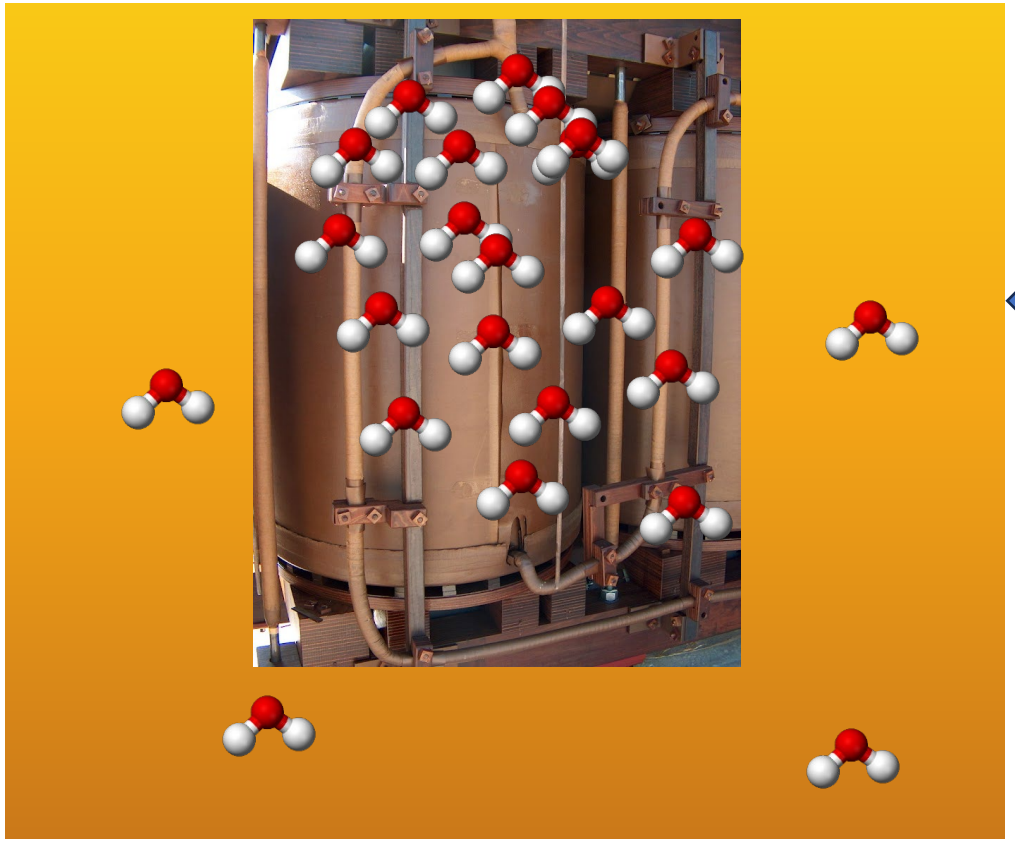


Water distribution in power transformer at two temperatures

25 °C

H_20

70 °C



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The consequence of undehydrated cellulose

Failed transformer due to excessive moisture in cellulose insulation at 4.30 am

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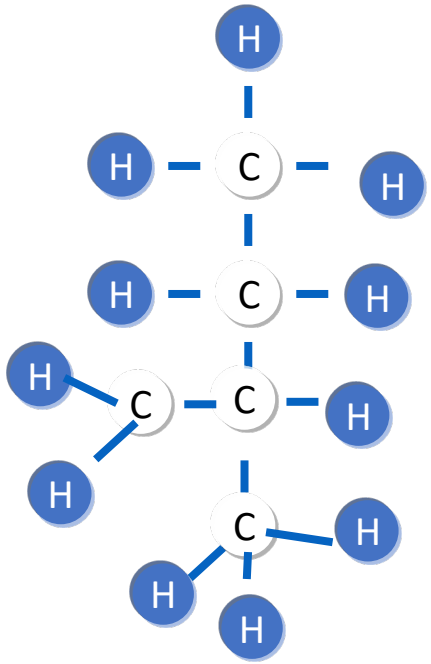
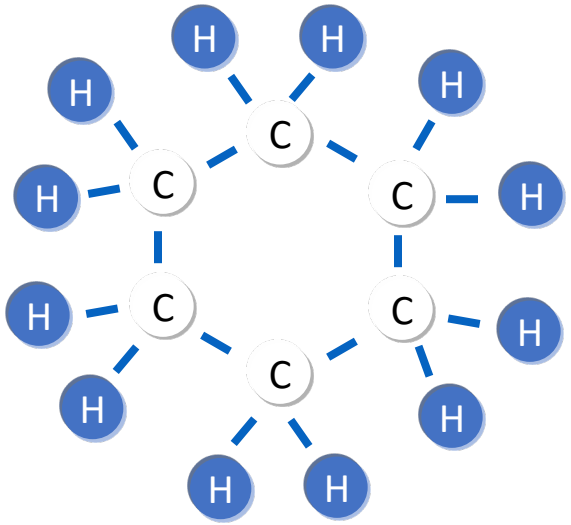
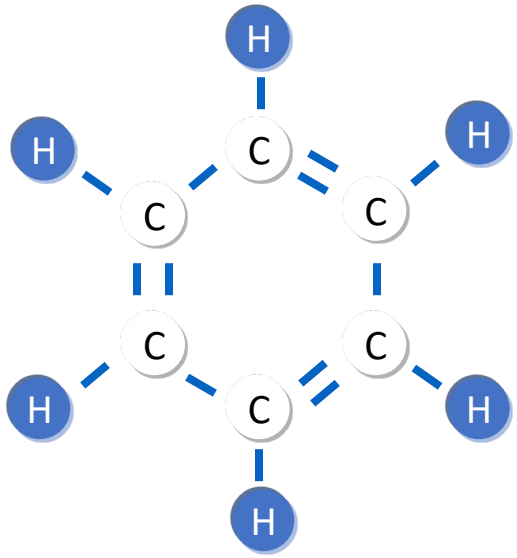
Oil molecules types



Iso-Paraffins



Naphthenes



Aromatics

Saturation, electron abundance, **instability**, solubility

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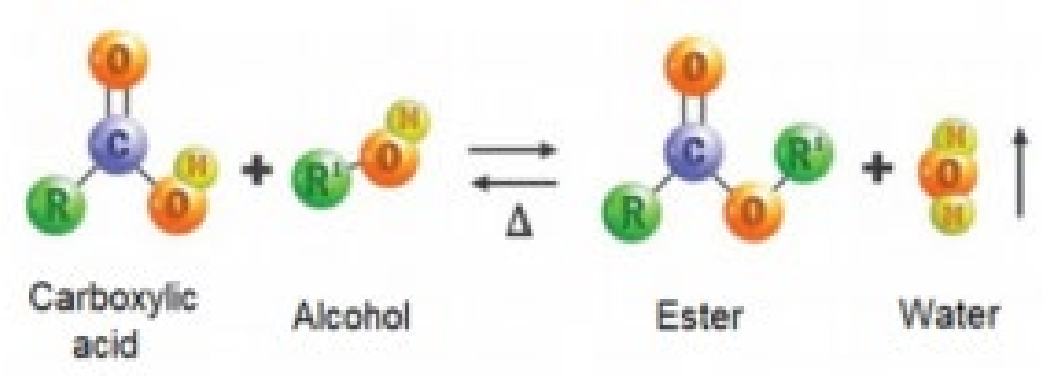
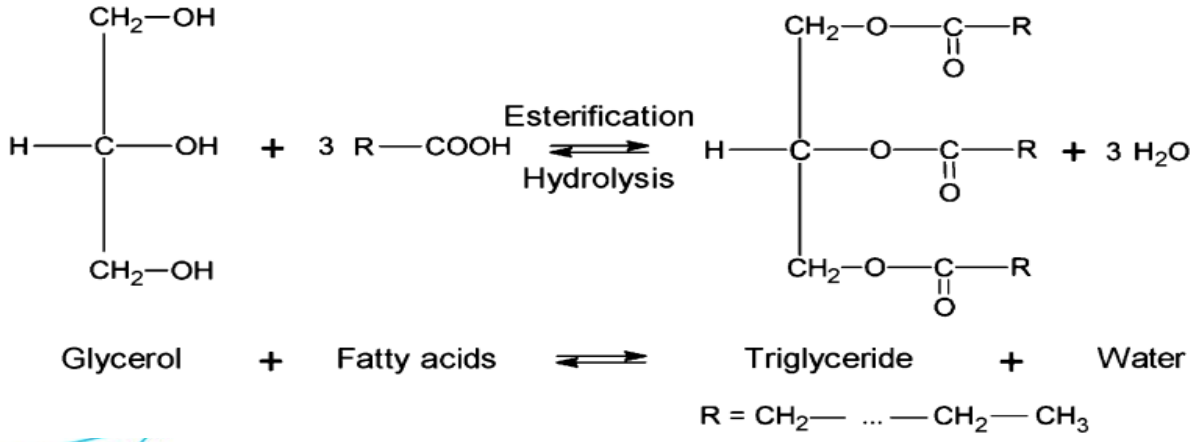
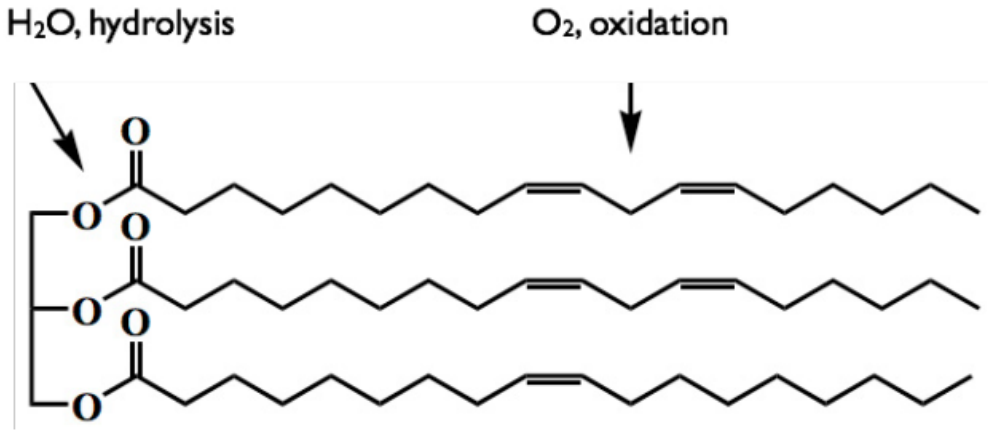
Esters are fatty compounds in liquid state
Three formation and decomposition mechanisms







And pyrolysis as mineral oils

	Ester linkages	Approx. water saturation at 23°C (ppm)	Approx. water saturation at 60°C (ppm)	Difference in ppm
Mineral oil	0	55	120	65
Silicone oil	0	220	800	580
Natural ester	3	1100	2000	1900
Synthetic ester	4	2600	5000	3000

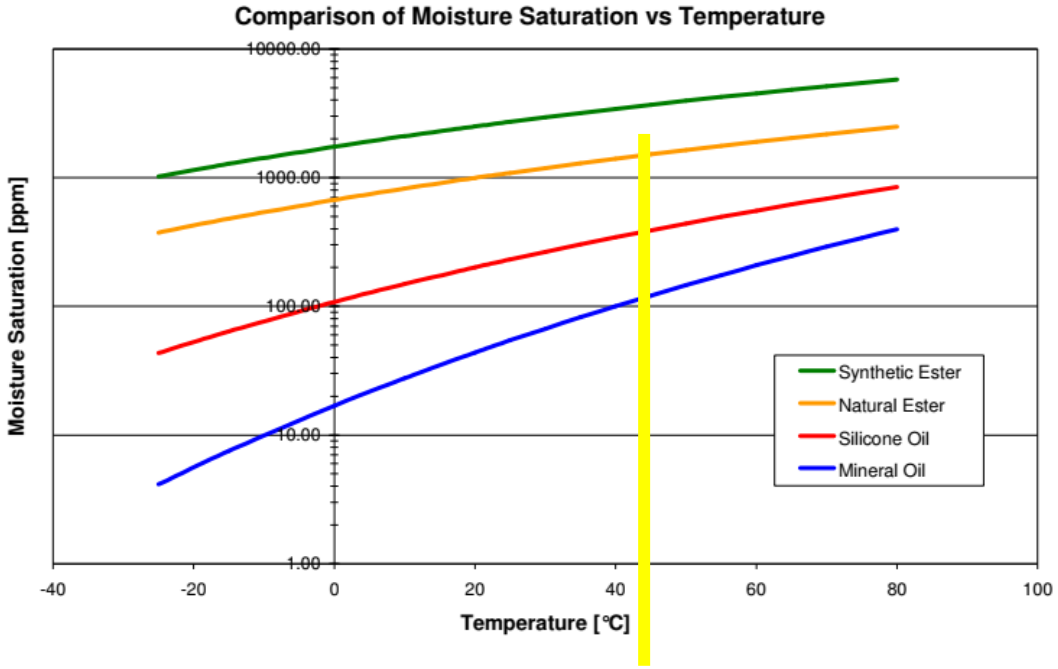
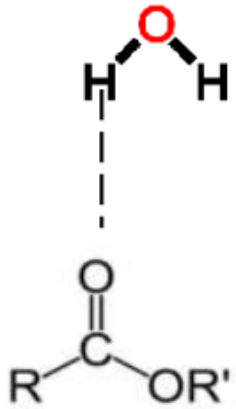


Figure 3.8 – How moisture saturation varies with temperature



Hysteresis of absorption and desorption process !?

Possible existence of free water during temperature cycles – definitely unwanted consequences!

Routine oil tests | Limits, frequency

For representative power transformers

Oil test	Limits for inhibited mineral oil	Limits for Natural ester liquid
DGA	Total gas for Non free breathing 2 % *	Similar
Break down voltage IEC60156 kV	More than 60	Similar
Inhibitor content IEC60666**	0.16 % (above 40 % from initial conc.)	Above 70 % initial conc.
Water content mg / kg	Less than 15	Less than 100
Furan compound	0.1 PPM	Similar
Interfacial tension IEC 62961 (mN / m)	Higher than 28	Higher than 20
Acidity mg KOH / g - IEC 62021	Less than 0.10	Less than 0.30
Color and appearance	Clear and without visible contamination	Similar
Dielectric dissipation factor 90C° IEC 60247	Less than 0.001	Less than 0.15
Potentially corrosive sulphur IEC 62535	Negative	Negative
Viscosity	Special test	Less than 10% increase
PCB IEC 61619	Less than 2 PPM	Similar
Passivator IEC60666	Less Than 5 PPM	Similar

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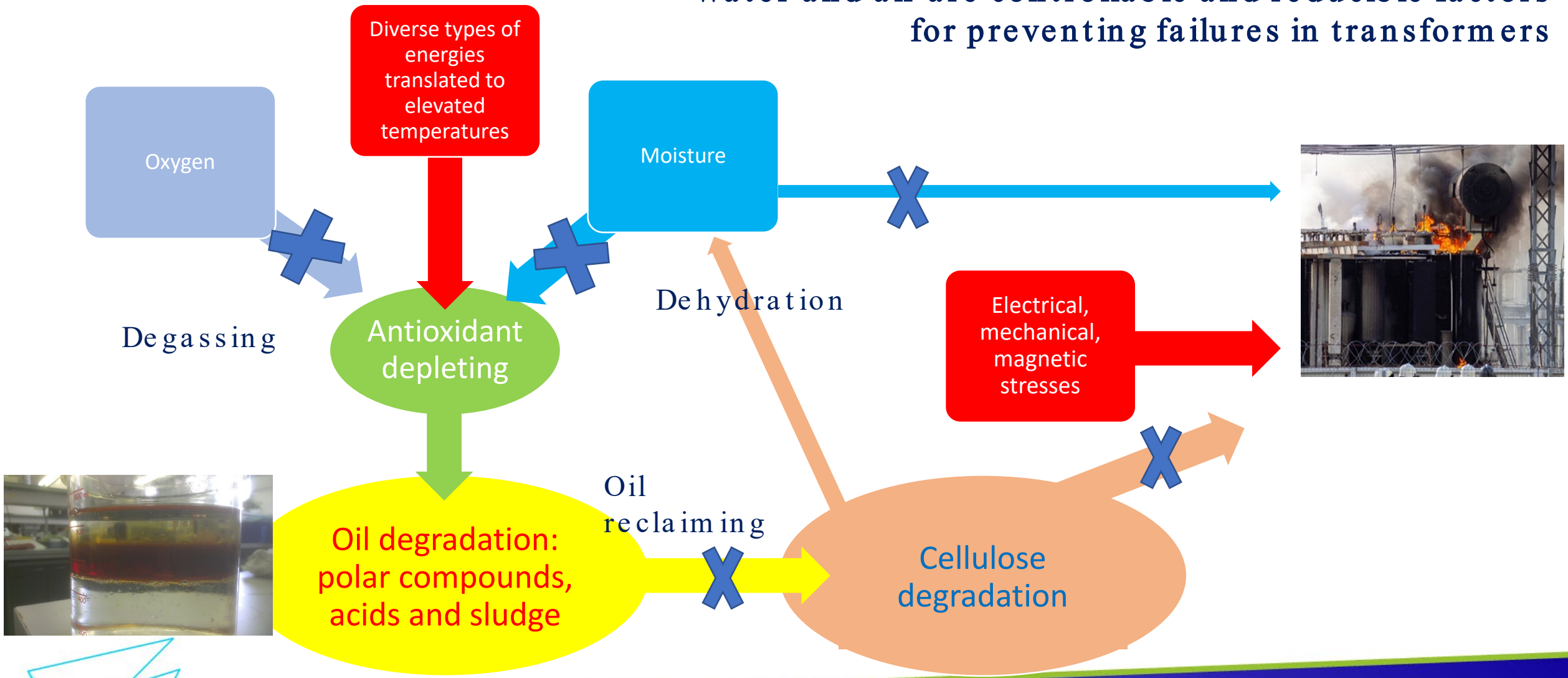
Water and air are controllable and reducible factors for preventing failures in transformers



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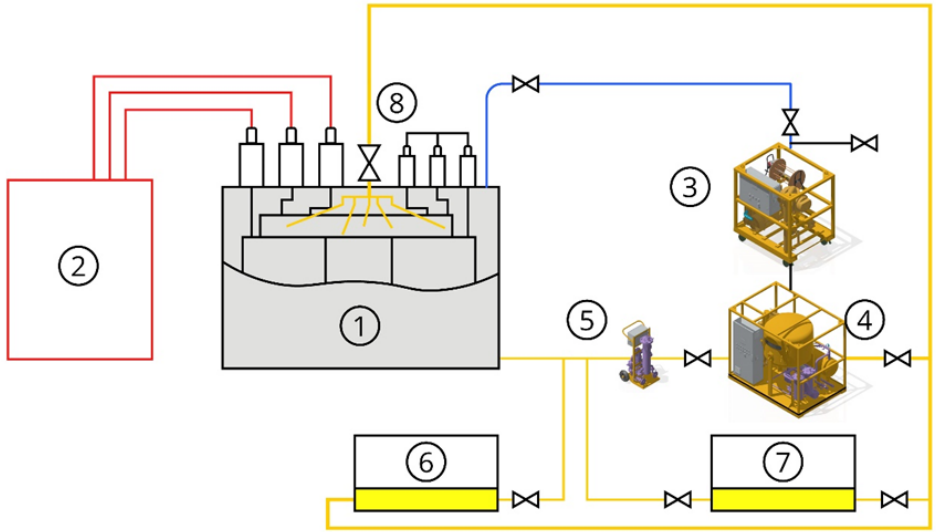
Efficiency Reduction of water quantity inside transformers

Parameter	Measure	Initiate oil treatment	Target values
Water content	ppm	20< or 30<	<10
Break down voltage	kV	<40 or <50	60<

In case water in oil and water in cellulose exceeds acceptable limits, dehydration is required.



1. Transformer
2. LFH unit
3. Vacuum unit
4. Oil treatment plant
5. Feeding pump
6. Used oil tank
7. Waste oil tank
8. Hot oil spray

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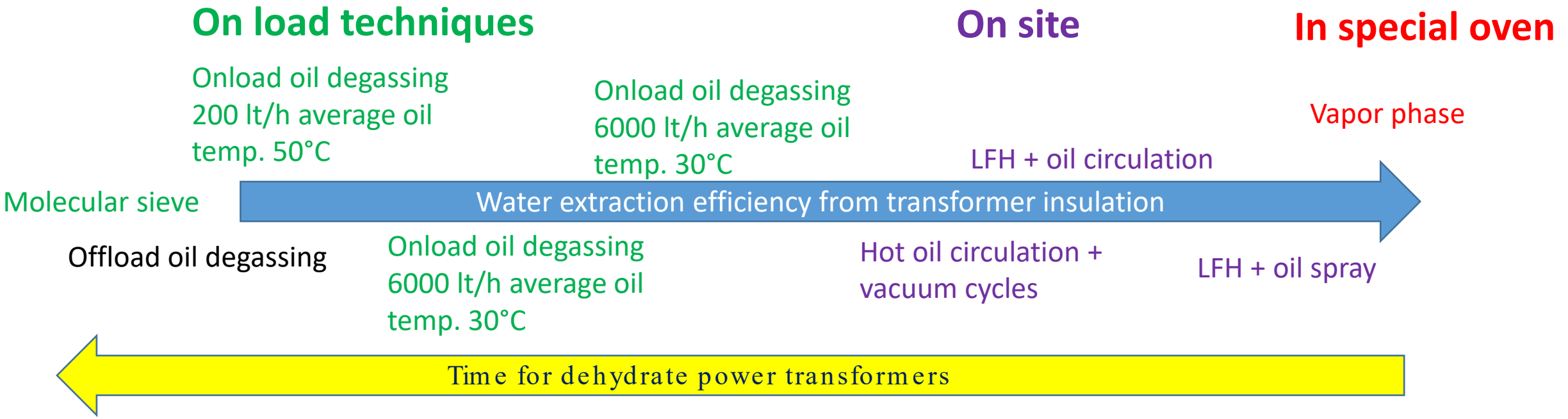
Different techniques for transformer oil drying



Adapted from: Koestinger, P. A. U. L., et al. "Practical experience with the drying of power transformers in the field, applying the LFH technology." Report A2-205, CIGRE (2004).

LFH = LOW FREQUENCY HEATING

IEC 60422-2024: Criteria for Oil Treatment

Oil replacement

- Criteria for replacement:
  - PCB contamination (IEC 61619)
  - Severe sludge formation or unacceptable sediment levels
  - DBDS (Dibenzyl Disulfide) content too high, requiring removal
- Recommended treatment:
  - Complete oil change if contamination or severe degradation is present

Treatment actions based on test results

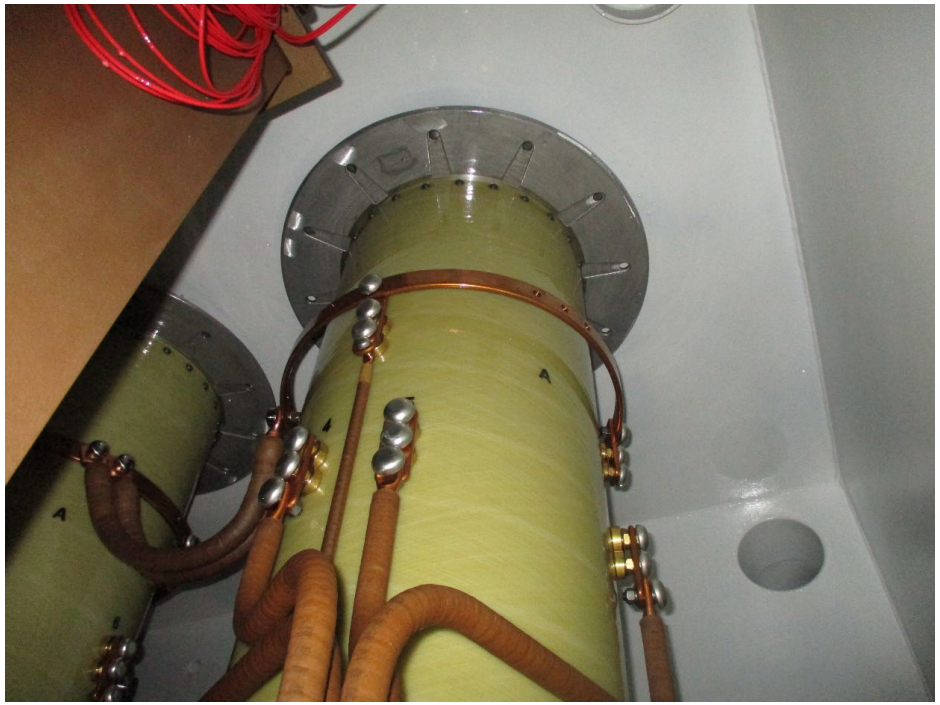
Test parameter	Most stringent requirement	Recommended treatment
Dielectric breakdown voltage	> 55 kV (before filling), > 30 kV (routine), > 55 kV (after filling)	Reconditioning (filtration, vacuum drying)
Water content (ppm)	≤ 20 ppm (before filling), ≤ 25 ppm (routine), ≤ 10 ppm (after filling)	Reconditioning
Acidity (mg KOH / g)	≤ 0.10 (before filling), ≤ 0.10 (routine), ≤ 0.05 (after filling)	Reclamation*
Interfacial tension (IFT)	≥ 35 mN / m (before filling), ≥ 30 mN/m (routine), ≥ 35 mN / m (after filling)	Reclamation*
Dissipation factor (Power factor)	< 0.05 (< 5 %)	Reclamation*
Oxidation inhibitor content	≥ 0.10 % (before and routine)	Add Inhibitor
Corrosive sulfur	Negative result required	Chemical treatment or reclamation
DBDS content	Must be minimized	Removal using KPEG process
PCB contamination	Below detection limit	Oil replacement

* decision for reclamation should be based on collaborative evidence from all three parameters - acidity, DDF, and IFT

IEEE C57.106-2015
Criteria for oil treatment for tap changer

Load tap changers (LTC)

- Criteria for treatment:
  - Dielectric breakdown voltage (ASTM D1816) falls below limits
  - Water content (ASTM D1533) exceeds limits
- Recommended Treatment:
  - Reconditioning or oil replacement



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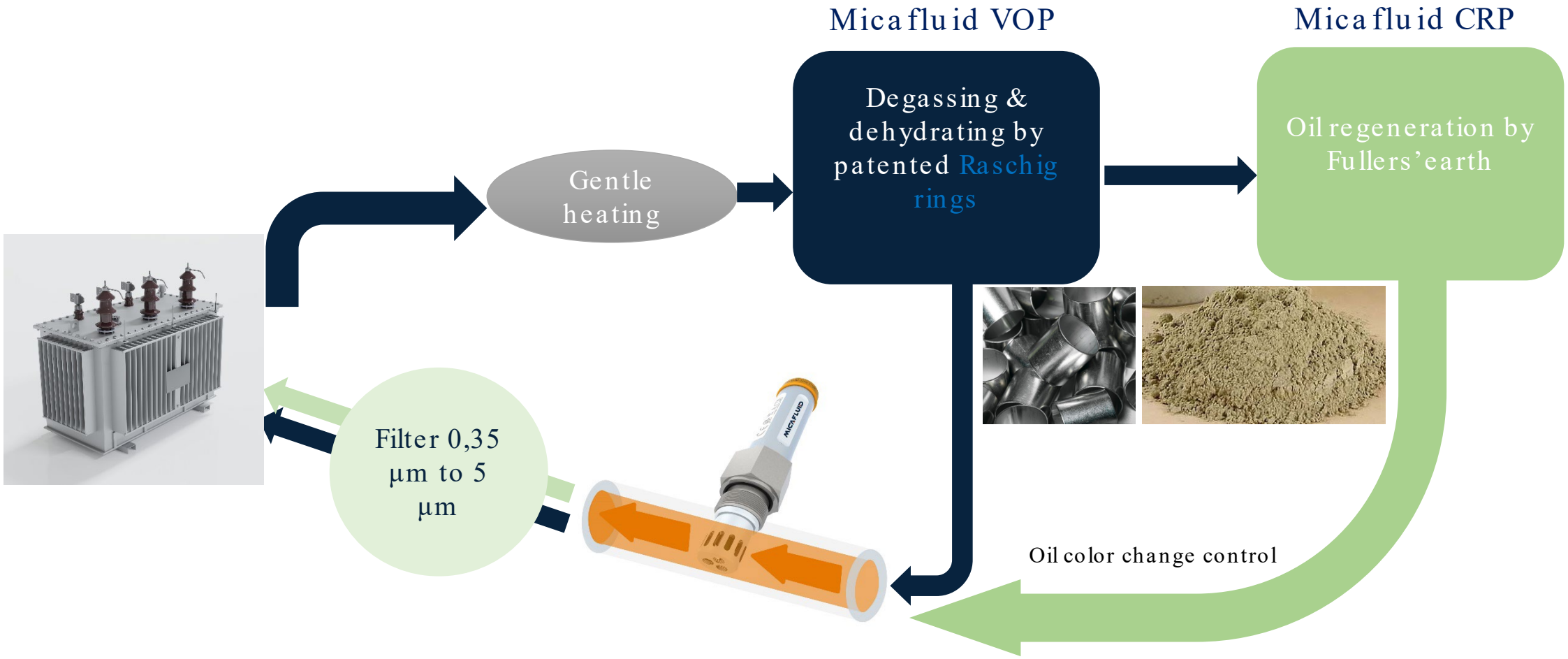
Oil treatment - Advanced approach:



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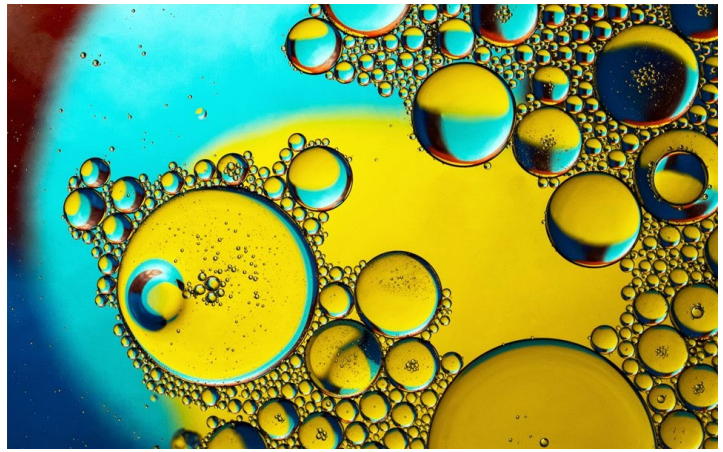
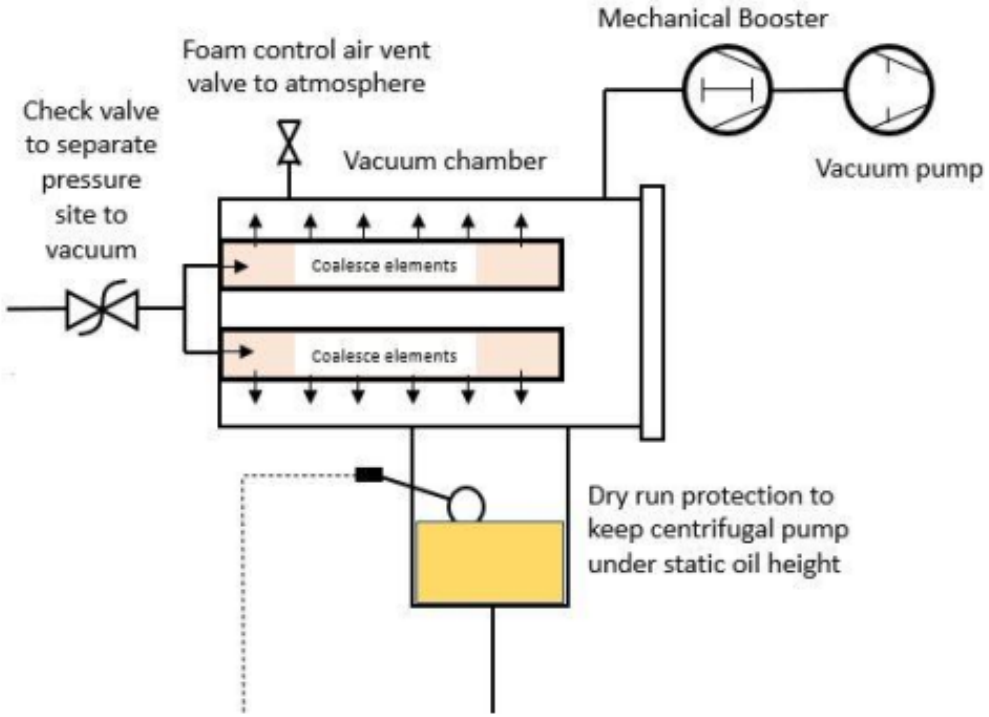
Coalescence method for degassing

Coalescing system

- Operating pressure less 0.1mbar exceeds vapor pressure limits of oil
- High pressure drop requires an inlet pump
- Small surface reduced efficiency
- Excessive foaming requires breaking vacuum
- Micro bubble coalescence inside transformer tank
- High-cost maintenance





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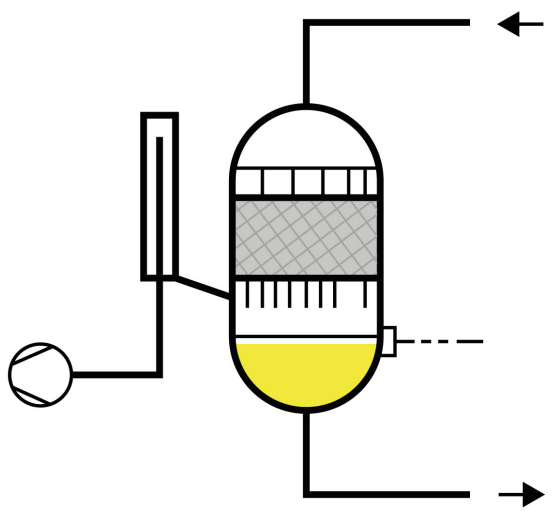
Thin film degasser by Raschig ring

Most adequate method for power transformers

Thin film degassing

- Operating vacuum within vapor pressure limit of dielectric fluid
- No inlet pump required even for high viscosity oils
- 60 % larger surface area compared to other technologies on the market
- Foam reduction without breaking vacuum, no micro bubbles
- Maintenance free degasser



Chemical Industry Examples

Full inline monitoring for complete monitoring of procedure

In-line gas and water content measurement

VZ212A applied on a VOP plant to measure water and total gas content

In-line Tan Delta measurement

VZ220A applied on a VOP plant to measure Tan Delta

In-line breakdown voltage measurement with MicaSonic™

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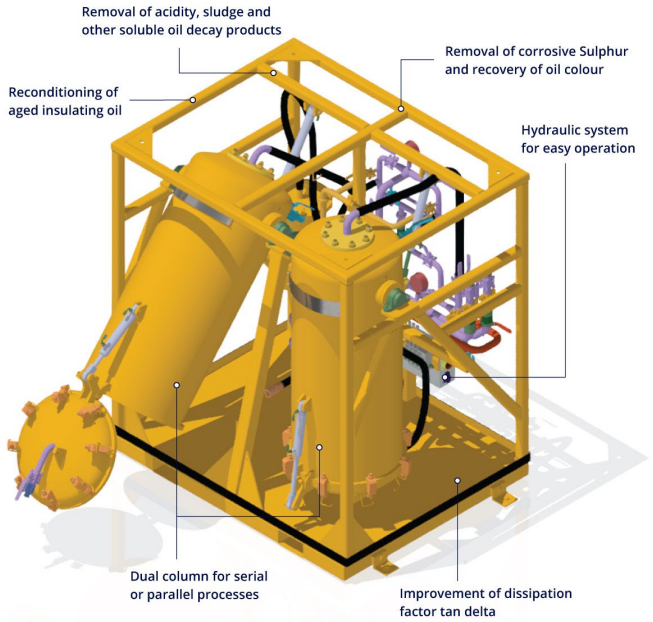
The only effective treatment for improving the dielectric properties of aged oils is regeneration with Fullers earth

Oil regeneration unit type Regeneration CRP

Parameter	Measure	Initiate oil treatment if:	Target values- mineral oils
Interfacial tension (IFT)	mN / m	< 32 (TB413)	35 <
Acidity	mgKOH / gm	0.1<	< 0.03
Oxidation index	IFT / acidity	< 600 (TB413)	
Dissipation factor	@ 90°C	0.05 < (TB413)	< 0.015 or < 0.01

TB413 - Insulating Oil Reclamation and Dechlorination, CIGRE2010



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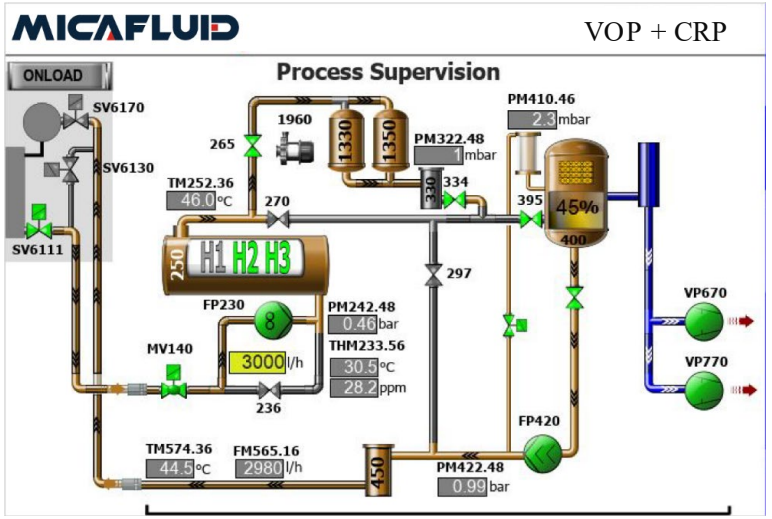
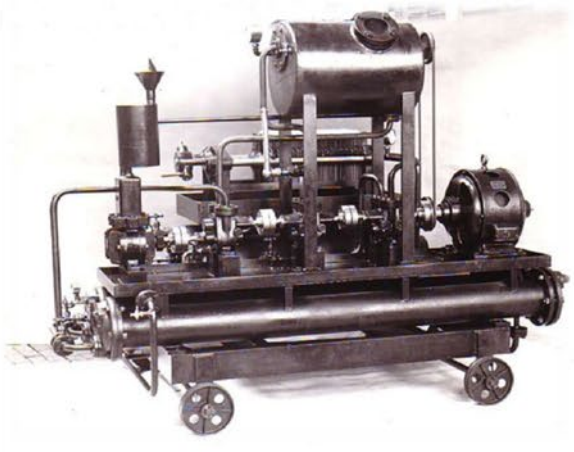
MICAFLUID past, present and future





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Conclusions and takeaways

- 🔍 Regular testing & diagnostics
- ⚖️ Compliance & industry standards
- ⚙️ Advanced treatment enhances performance
- 🔬 Oil condition directly impacts transformer life

Together with the right **technology partner**, a **significant contribution** can be made to the **environment** while **saving money,** when adequate and **timely oil treatment** is done within the **transformer's life-cycle**.

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