

UNDERSTANDING TRANSFORMER OIL TREATMENT TECHNOLOGIES

**Different Problems. Different Solutions.
Right Process. Right Time.**

Transformer oil is more than just an insulating liquid – it is the life-support system for the transformer insulation.

Over time, oil gets contaminated and its properties deteriorate due to heat, oxygen, moisture, electrical stress and aging by-products. If not managed, degraded oil accelerates insulation aging and can lead to costly failures.



The key to transformer reliability is understanding which degradation mechanism is dominant and applying the right treatment technology.

WHAT MAKES TRANSFORMER OIL DETERIORATE?



PARTICLES

Dust, metal, carbon, fibers, sludge



MOISTURE

From air ingress, leakage, or condensation



GASES

Dissolved air, oxygen, nitrogen, CO₂ and others



ACIDS

Formed due to oxidation and degradation



SLUDGE

Oxidation products and contaminants accumulate



OXIDATION

Accelerated by heat, oxygen and lack of inhibitors

FIVE MAJOR OIL TREATMENT APPROACHES

Each process targets specific contaminants and addresses specific failure mechanisms.



OIL FILTRATION

Removes solid particles and sludge to improve oil cleanliness.

Cleaner Oil



OIL RECONDITIONING

Improves overall oil condition by removing moisture, gases and particles.

Better Oil Performance



OIL REGENERATION

Restores aged oil by removing acids, sludge precursors and oxidation products.

Restored Oil Chemistry



OIL DEHYDRATION

Removes dissolved and free water to reduce moisture content.

Drier Oil



CONTINUOUS MOISTURE MANAGEMENT

Continuously controls moisture migration and maintains favorable oil-paper equilibrium.

Healthier Insulation for Longer Life



No single process solves every problem. Understanding the difference is the first step towards an effective transformer oil and insulation management strategy.

OIL FILTRATION AND OIL RECONDITIONING

Filtration and reconditioning are the most commonly used oil treatment processes in the industry. They focus on improving the physical condition of the oil by removing unwanted solids, moisture and dissolved gases.



1. OIL FILTRATION

Purpose: Remove solid contaminants and improve oil cleanliness.



What It Removes
Dust, carbon particles, metal particles, fibers and sludge.



Typical Equipment
Cartridge filters, depth filters, and portable filtration carts.



When to Use

- After maintenance or repairs
- High particle count or visible contamination
- OLTC oil cleaning



Key Benefits

- Improves oil cleanliness
- Enhances dielectric strength (BDV)
- Reduces risk of flashover and insulation wear



Limitation: Does not remove moisture, dissolved gases or acids. It does not improve insulation moisture in paper.



2. OIL RECONDITIONING

Purpose: Restore oil to acceptable operating condition by removing multiple contaminants.



What It Removes
Particles, moisture, dissolved gases (air, oxygen, nitrogen, CO₂), and some volatile contaminants.



Typical Process
Combination of filtration, vacuum dehydration and degassing (vacuum treatment).



When to Use

- High moisture or high %RS
- Low BDV or high tan δ
- High dissolved gas content
- Commissioning and after transportation



Key Benefits

- Improves dielectric strength
- Reduces moisture and dissolved gases
- Enhances overall oil performance



Limitation: Improvement is often temporary if the cellulose insulation remains wet or if moisture ingress continues.

FILTRATION vs RECONDITIONING

Parameter	Oil Filtration	Oil Reconditioning
Particles	✓✓✓ Removes effectively	✓✓ Removes effectively
Moisture	X No	✓ Removes (via vacuum dehydration)
Dissolved Gases	X No	✓ Removes (via vacuum degassing)
Acids / Oxidation Products	X No	Partial (only some volatile/polar compounds)
Inhibitor Content	No effect	Usually no significant effect
Typical Frequency	As needed	Every 5 - 15 years (varies by condition and climate)



OIL REGENERATION (OIL RECLAMATION)

Oil regeneration is an advanced treatment process designed to restore the chemical properties of aged transformer oil. It removes acidic, polar and oxidized compounds that accumulate over time due to thermal and oxidative stress.



Goal: Restore the oil chemistry close to new oil and extend useful life of the transformer.



WHAT IT REMOVES



Acids
(high TAN)



Oxidation
products



Sludge
precursors



Polar
contaminants



Color bodies
and varnish
forming species



KEY BENEFITS

- Reduces acidity (TAN)
- Improves Interfacial Tension (IFT)
- Restores oxidation stability
- Improves dielectric strength
- Extends oil life and delays oil replacement



TYPICAL PROCESS CONFIGURATION



Pre-Filtration
(Particle
Removal)



Heating
(Improves separation
efficiency)



Vacuum
Dehydration
& Degassing



Adsorbent
Treatment
(Fuller's Earth
or similar media)



Polishing
Filtration
(Fine Filter)



The combination of heat, vacuum and adsorbent media removes undesirable compounds and restores oil chemistry.



IMPORTANT: INHIBITOR REMOVAL

Regeneration using adsorbent media (e.g., Fuller's Earth, activated clay) also removes natural and added antioxidant inhibitors such as DBPC (2,6-Di-tert-butyl-p-cresol).



WHY INHIBITOR LOSS MATTERS

- Inhibitors protect oil from oxidation.
- Low inhibitor level increases the rate of acid and sludge formation.



RECOMMENDATION

- Always test inhibitor (DBPC) concentration after regeneration.
- Replenish inhibitor to the recommended level as per manufacturer guidelines.

TYPICAL IMPROVEMENTS AFTER REGENERATION*

Parameter	Typical Improvement
TAN	50-90% reduction
IFT	Significant improvement
Color	Much lighter
Oxidation Stability	Restored
BDV	Improved

*Results vary depending on oil condition and process efficiency.



WHEN TO CONSIDER OIL REGENERATION

- High acidity (high TAN)
- Low Interfacial Tension (IFT)
- Dark or dirty oil
- High oxidation by-products
- Sludge or varnish formation
- Aged oil with long service life
- Before major life extension programs
- Before critical service or uprating



Oil regeneration is one of the most effective ways to restore aged oil chemistry, but it does not address moisture in cellulose insulation. For long-term moisture control, **continuous moisture management is essential.**



OIL DEHYDRATION

REMOVING MOISTURE TO PROTECT INSULATION

Moisture is one of the most critical factors affecting transformer insulation life. Oil dehydration removes dissolved and free water from the oil to reduce the risk of insulation degradation, partial discharge and dielectric failure.



Goal: Reduce moisture content in oil and lower the relative saturation to extend insulation life and improve reliability.



WHY MOISTURE IS HARMFUL



Accelerates cellulose aging
Moisture reacts with cellulose and oil at elevated temperature, producing acids and sludge.



Reduces dielectric strength
Water lowers BDV and increases the risk of electrical failure.



Increases bubble formation
Moisture can cause gas bubbles under load changes, leading to partial discharges.



Promotes corrosion
Water with acids increases corrosion of windings and tank.



Consumes insulation life
High moisture is one of the primary drivers of insulation life consumption.



DEHYDRATION TECHNOLOGIES

Technology	How It Works	Typical Application
Vacuum Dehydration	Oil is heated under vacuum, reducing the boiling point of water and removing it as vapor.	High moisture oil, commissioning, or periodic maintenance of large transformers.
Molecular Sieve (Adsorption) Dehydration	Oil passes through molecular sieves that adsorb water molecules.	On-site dehydration, final polishing, or lower moisture maintenance.
Adsorbent Cartridge Dehydration	Oil flows through water-absorbing cartridges that remove dissolved moisture.	Continuous or offline conditioning for medium moisture levels.
Centrifuge (Separator) Dehydration	Separates free and emulsified water from oil using high-speed rotation.	Removal of free water or heavy contamination.



Note: Dehydration removes moisture from oil, but the majority of moisture resides in the cellulose insulation. Re-moistening can occur if the source is not controlled.



DEHYDRATION IMPROVES

- ✓ Breakdown voltage (BDV)
- ✓ Insulation resistance
- ✓ Relative saturation (%RS)
- ✓ Dielectric stability
- ✓ Transformer reliability and life



LIMITATIONS

- ⊗ Does not remove acids, sludge or oxidation products.
- ⊗ Does not remove dissolved gases effectively.
- ⊗ Does not remove solid particles.
- ⊗ Does not dry the paper insulation.
- ⊗ Moisture will return if the transformer continues to breathe humid air or has leaks.



WHEN AND HOW OFTEN?

- During commissioning or after major repairs
- When moisture in oil is above acceptable limits
- After transportation or long-term storage
- Periodically, depending on climate and condition

Typical frequency:

- Distribution transformers: Once every 3–10 years (or as needed)
- Power transformers: Every 2–5 years (typical)
- Generator & EHV transformers: Every 1–3 years (typical)



Dry oil is good oil — but controlling moisture at the source is even better.

Continuous moisture management provides long-term protection by continuously reducing the moisture in both oil and paper.



CONTINUOUS ONLINE MOISTURE MANAGEMENT

CONTROLLING THE SOURCE TO EXTEND TRANSFORMER LIFE

While other processes treat the oil periodically, continuous online moisture management works 24/7 to continuously remove moisture from transformer oil.

By maintaining low moisture levels in oil, it continuously shifts the oil–paper moisture equilibrium and gradually reduces moisture in the cellulose insulation — the real key to long insulation life.



Goal: Continuously control moisture migration from paper to oil and maintain a dry insulation system throughout the transformer's life.



TRAM90

High capacity system for large power and generator transformers

MMS90/TR50

Medium capacity system for substation power transformers

TR5

Compact system for small transformers and critical assets



HOW IT WORKS



1. Moisture Migration

Moisture from cellulose insulation migrates into the oil.

2. Continuous Removal

DryTrans system continuously removes moisture from the oil using advanced adsorption technology.

3. Equilibrium Shift

Oil–paper equilibrium shifts, encouraging moisture to move from paper to dry oil.

4. Dry Insulation

Over time, paper moisture reduces and insulation life is significantly extended.



This is not a one-time treatment; it is a permanent moisture control system that protects your transformer every day.



KEY BENEFITS



Continuously lowers oil moisture
Maintains oil at low moisture level at all times.



Reduces paper moisture over time
Shifts oil–paper equilibrium and dries the insulation.



Extends insulation life
Dry insulation ages significantly slower.



Improves reliability
Reduces risk of moisture-related failures, partial discharges and unplanned outages.



Works 24/7 automatically
No operator intervention; continuous protection.



Cost-effective over life
Delays or eliminates need for expensive oil dehydration treatments.

DRYTRANS CONTINUOUS MOISTURE MANAGEMENT SOLUTIONS

TRAM90



High capacity for large oil volume



Designed for large power, EHV and generator transformers



Very high moisture removal capacity



Rugged, reliable and fully automated



24/7 online protection

Recommended for: Large power transformers, generator step-up transformers and mission-critical assets.

MMS90/TR50



Medium capacity for substation transformers



Ideal for 50–200 MVA power transformers



Efficient moisture removal and equilibrium control



Compact footprint and easy integration



Continuous, maintenance-friendly operation

Recommended for: Substation power transformers and large distribution transformers.

TR5



Compact and cost-effective



Ideal for small power and distribution transformers



Reliable moisture removal for smaller oil volumes



Simple installation and operation



24/7 continuous protection

Recommended for: Small power transformers, distribution transformers and critical assets.



SELECT THE RIGHT SYSTEM FOR YOUR TRANSFORMER

All systems are designed for continuous online operation, ensuring your transformer stays dry, reliable and ready — every day.

Model	Recommended Transformer Rating (Typical)	Typical Oil Volume Capacity*	Key Application
TRAM90	> 200 MVA	Up to 90,000 liters	Large power & generator transformers, EHV networks, critical assets
MMS90/TR50	50 – 200 MVA	Up to 50,000 liters	Substation power transformers, regional networks
TR5	Up to 50 MVA	Up to 5,000 liters	Small power & distribution transformers, industrial & renewable assets

*Actual capacity depends on transformer condition, moisture ingress rate and operating temperature.





Clean oil is important. Dry oil is critical. Keeping oil dry continuously is the smartest way to extend insulation life.


ASSET MANAGEMENT PERSPECTIVE WHEN TO USE EACH OIL TREATMENT PROCESS


Every transformer ages differently. The right action depends on the condition of the oil, the insulation system and the operational environment. Use the decision guide below to select the most appropriate process.


KEY TAKEAWAYS

 Filtration removes solid contaminants and improves oil cleanliness.








 Reconditioning restores oil to acceptable operating condition by removing moisture and dissolved gases.

 Regeneration restores aged oil chemistry by removing acids and oxidation products.

 Dehydration removes moisture from oil, but most moisture resides in the paper.

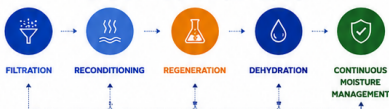
 Continuous moisture management controls moisture at the source and delays the need for expensive oil treatments.


DECISION GUIDE: MATCH THE CONDITION TO THE RIGHT PROCESS

Identified Condition	Recommended Action
 High particle count, visible contamination	Oil Filtration
 High moisture (ppm or %RS)	Oil Dehydration
 High dissolved gases (DGA), air in oil	Oil Reconditioning
 High acidity (TAN), low IFT, dark oil, sludge	Oil Regeneration
 Chronic moisture ingress, moisture rising again	Continuous Moisture Management
 After major fault, overhaul or transportation	Filtration + Reconditioning
 For long-term reliability and life extension	Continuous Moisture Management (as base strategy)





THE RIGHT PROCESS AT THE RIGHT TIME

All processes are complementary, not competing.



 Continuous moisture management helps maintain a dry, clean and chemically stable oil – reducing the frequency and severity of other treatments and extending the insulation life.

TYPICAL LIFETIME FREQUENCY (GUIDELINE ONLY)

Transformer Type	Filtration (As Needed)	Reconditioning (Dehydration + Degassing)	Regeneration (Reclamation)	Dehydration (Standalone)	Continuous Moisture Management
 < 5 MVA Distribution Transformers	Rarely (0 – 2 times)	Rarely (0 – 1 time)	Usually Never	Occasional (0 – 2 times)	Usually not justified
 5 – 50 MVA Substation Transformers	Occasional (1 – 3 times)	1 – 2 times	Possibly once (0 – 1 time)	Every 2 – 5 years (2 – 6 times)	Increasingly considered
 50 – 200 MVA Power Transformers	Several times (2 – 6 times)	2 – 4 times	1 – 2 times	Every 1 – 3 years (3 – 10 times)	Strong candidate
 > 200 MVA Generator / EHV Transformers	Multiple times (3 – 10+ times)	Several times (3 – 6+ times)	1 – 3 times	Every 1 – 2 years (5 – 15+ times)	Excellent candidate

 Note: Actual frequency depends on oil condition, transformer criticality, climate, loading, sealing effectiveness, maintenance philosophy and results of condition monitoring.

A COMPLETE STRATEGY DELIVERS LONG-TERM VALUE



 The most effective asset management approach is not choosing one process over another, but applying the right process at the right stage of the transformer's life.

COMPARING OIL TREATMENT PROCESSES

EACH PROCESS ADDRESSES DIFFERENT DEGRADATION MECHANISMS

No single process solves every problem. The table below provides a quick comparison to help utilities understand the primary impact of each oil treatment technology.



Process	Particles	Moisture	Gases	Acids/Sludge	Inhibitor Impact
Oil Filtration	✓✓✓	✗	✗	Partial	None
Oil Reconditioning	✓✓	✓	✓	Partial	Usually negligible
Oil Regeneration	✓✓	✓	✓	✓✓✓	Often removes inhibitor
Oil Dehydration	✗	✓✓✓	Partial to ✓	✗	None
Continuous Moisture Management	Partial*	✓✓✓	✗	Partial*	None

✓✓✓ = Excellent ✓✓ = Good ✓ = Moderate Partial / Partial* = Limited ✗ = No / Not a primary function

* Continuous Moisture Management may have a secondary benefit on reducing some insoluble/sludge formation over time

KEY INSIGHTS



Moisture is the root cause of most insulation problems. Dehydration and continuous moisture management directly address it.



Acids and sludge are best removed through regeneration. This process often removes inhibitor, which should be reintroduced if required.



Gases are effectively removed by reconditioning but not by filtration or dehydration.



Continuous Moisture Management is not a replacement, but a strategy that supports and extends the benefits of all other processes.

HOW TO CHOOSE THE RIGHT PROCESS

- 1 Understand the dominant degradation mechanism (moisture, oxidation, contamination, gases, etc.)
- 2 Review oil test data and operating conditions
- 3 Select the process that best addresses the primary issue
- 4 Implement continuous moisture management to sustain the improvement
- 5 Monitor trends and adjust the strategy

THE COMPLETE APPROACH FOR LONG-TERM RELIABILITY



Remove Contaminants (Filtration)



Remove Gases & Moisture (Reconditioning)



Restore Oil Chemistry (Regeneration)



Reduce Moisture (Dehydration)



Control Moisture Continuously (Continuous Moisture Management)



Achieve Long-Term Reliability & Asset Value



Use the right process for the right problem – and keep moisture under control continuously. That is the key to extending transformer life and maximizing asset value.

REFERENCES & RESOURCES

TECHNICAL STANDARDS, GUIDES & PUBLICATIONS

The following industry standards and technical resources provide authoritative guidance on transformer oil testing, maintenance processes and moisture management.

	IEC 60422	Mineral insulating oils in electrical equipment – Supervision and maintenance guidance.
	IEC 60567	Mineral oil-filled electrical equipment in service – Guidance on the interpretation of dissolved and free gases analysis.
	IEC 60814	Insulating liquids – Determination of water by the coulometric Karl Fischer titration method.
	IEC 60156	Insulating liquids – Determination of the breakdown voltage at power frequency.
	IEC 60247	Measurement of relative permittivity, dielectric dissipation factor ($\tan \delta$) and d.c. resistivity of insulating liquids.
	ASTM D3487	Standard test method for acid number of insulating oils by potentiometric titration.
	ASTM D1533	Standard test method for water in insulating liquids by Coulometric Karl Fischer titration.
	ASTM D3612	Standard test method for analysis of gases dissolved in electrical insulating oil by gas chromatography.
	ASTM D971	Interfacial tension of oil against water by the ring method.
	CIGRE Technical Brochures	CIGRE TB 445, TB 436, TB 773 – Transformer maintenance, DGA interpretation and moisture in insulation.



FINAL THOUGHT

Transformer insulation life is not extended by chance — it is extended by:

- Understanding the true condition
- Choosing the right process
- Applying it at the right time
- Controlling moisture *continuously*

When moisture is under control, reliability, performance and asset value follow.

“ Manage moisture at the source. Extend life with confidence. ”

WHY UTILITIES CHOOSE DRYTRANS



Specialized Expertise
Focused exclusively on dry oil and moisture management solutions.



Proven Technology
Advanced adsorption and dehydration technologies for superior results.



Complete Solutions
From portable units to high-capacity systems for all transformer types.



Measurable Results
Lower moisture, better oil quality, extended insulation life and reduced risk.



Global Support
Reliable technical support and service wherever you operate.



Trusted by Utilities
Deployed in power systems worldwide across all climate conditions.



LET'S EXTEND YOUR TRANSFORMER LIFE TOGETHER

Talk to our experts to design the right moisture management strategy for your assets.



Learn more about our solutions and products
www.drytrans.com



DryTrans is a technology-driven company specializing in dry oil and continuous moisture management solutions for transformers and critical electrical assets.



Our mission is simple:
Keep oil dry. Keep assets reliable.
Extend transformer life.



We combine engineering expertise, advanced technology and a deep understanding of insulation science to deliver lasting value.



With DryTrans, you don't just treat oil — you protect the future of your assets.



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