drytrans

Moisture Under Control.
Reliability Assured.

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

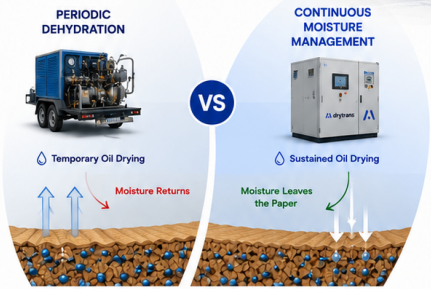
Periodic Dehydration vs Continuous Moisture Management

Understanding the Difference Between Temporary Moisture Reduction and Long-Term Insulation Drying

Moisture is the primary driver of insulation aging and transformer failure. While periodic dehydration removes moisture from the oil, it does not address the true source of moisture—the paper insulation. Because of oil–paper equilibrium, moisture will naturally migrate from the paper back into the oil, causing moisture rebound.

Continuous moisture management takes a different approach. By keeping the oil consistently dry, the equilibrium is continuously shifted, driving moisture out of the paper and enabling true, long-term insulation drying.

This paper explains the science behind both approaches and why continuous moisture management is the key to long-term transformer reliability.



True Insulation Drying
Continuously shifts equilibrium to remove moisture from paper.

Higher Reliability
Reduces failure risk and improves asset performance.

Extended Asset Life
Slows insulation aging and extends transformer life.

Sustainable Operation
Lower risk, lower emissions, greater stewardship.

AVACO Solutions FZC
P.O. Box 18672, SAIF Zone
Sharjah, United Arab Emirates
vishal@drytrans.com
+971-50-6790417
www.drytrans.com

drytrans

drytrans

Moisture Under Control.
Reliability Assured.

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

Executive Summary

Why This Paper Matters

Utilities and industries have relied on periodic dehydration for decades to remove moisture from transformer oil. While these activities can effectively dry the oil, experience has shown that moisture returns—sometimes quickly. The reason is simple: most of the moisture resides in the paper insulation, not in the oil.

After dehydration, a moisture gradient is created. Moisture naturally migrates from the paper into the dry oil until a new oil–paper equilibrium is re-established. This process, known as moisture rebound, is not a failure of the equipment—it is a natural consequence of oil–paper equilibrium.

Continuous Moisture Management (CMM) takes a different approach. By keeping the oil consistently dry over time, the equilibrium is continuously shifted, driving moisture out of the paper and enabling true, long-term insulation drying.

This paper explains the fundamental differences between these two approaches and why continuous moisture management is the key to long-term transformer reliability.

Moisture rebound after dehydration is inevitable. Only continuous moisture management can maintain a low moisture level and gradually dry the paper insulation over time.

Figure 1: Periodic Dehydration vs Continuous Moisture Management

PERIODIC DEHYDRATION		VS		CONTINUOUS MOISTURE MANAGEMENT
Temporary Oil Drying Removes moisture from oil at a point in time, but oil becomes wet again.	Oil Moisture Removal			**Sustained Oil Drying** Continuously removes moisture from oil and keeps it consistently low.
Moisture Rebound Occurs Moisture migrates from paper back into the oil until equilibrium is restored.	Moisture Rebound			**Minimizes Moisture Rebound** Equilibrium is continuously shifted, reducing moisture migration.
Intermittent Protection No protection between dehydration cycles; moisture can rise again.	Protection Between Cycles			**Continuous Protection** Provides ongoing protection by maintaining low oil moisture at all times.
Limited Impact on Paper Drying Paper moisture is only slightly reduced, with limited long-term drying.	Impact on Paper Drying			**Promotes Paper Drying** Drives moisture out of the paper gradually, achieving true insulation drying.
Short-Term Benefit Provides temporary improvement, not a long-term solution.	Long-Term Outcome			**Long-Term Reliability** Sustained low moisture, improved reliability, and extended asset life.

Key Takeaway

Periodic dehydration treats the symptom. Continuous moisture management **addresses the cause and delivers long-term insulation health.**

AVACO Solutions FZC
P.O. Box 18672, SAIF Zone
Sharjah, United Arab Emirates
vishal@drytrans.com
+971-50-6790417
www.drytrans.com

drytrans

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

Understanding Transformer Moisture

Where Moisture Resides and Why It Matters

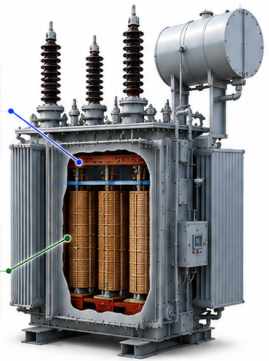
Moisture exists in both the oil and the paper insulation of a power transformer, but not in equal amounts. The vast majority of moisture—typically more than 95%—resides in the cellulose paper, while less than 5% is in the oil under normal operating conditions.

Paper has a high affinity for water. It absorbs moisture from the oil until equilibrium is reached at a given temperature. As long as the oil is saturated or near saturation, the paper remains wet.

Because paper holds most of the moisture, any effective moisture management strategy must focus on removing moisture from the paper, not just the oil.

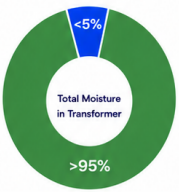
Understanding where moisture resides is the foundation for understanding why periodic dehydration is temporary, while continuous moisture management achieves long-term drying.

Figure 2: Transformer Moisture Distribution



More than 95% of the moisture in a transformer is in the paper insulation. Effective moisture control must focus on drying the paper, not just the oil.

Moisture Location in the Transformer



Paper Moisture
>95%
Absorbed in cellulose paper insulation

Oil Moisture
<5%
Dissolved in oil

The paper is the primary moisture reservoir and the key to long-term insulation health.

Why This Matters

- Oil can be dried quickly. Paper dries very slowly.
- Moisture continually migrates from the paper into the oil until a new equilibrium is reached.
- Oil–paper equilibrium governs moisture behavior in the transformer.
- Managing moisture effectively requires a strategy that continuously removes moisture from the oil to dry the paper.

Key Takeaway

Since more than 95% of the moisture resides in the paper, strategies that only dry the oil provide temporary relief. Long-term insulation drying requires continuous moisture removal to shift the equilibrium and dry the paper.

AVACO Solutions FZC
P.O. Box 18672, SAIF Zone
Sharjah, United Arab Emirates

vishal@drytrans.com | +971-50-6790417 | www.drytrans.com

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

What Is Periodic Dehydration?

The Traditional Approach to Removing Moisture from Transformer Oil

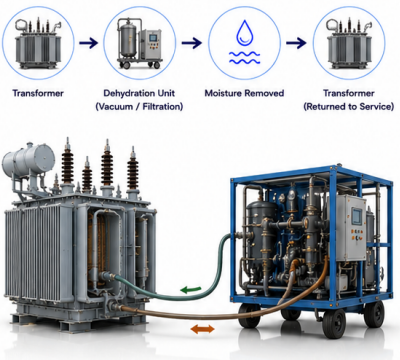
Periodic dehydration is the most widely used method for removing moisture from transformer oil. The goal is to reduce the moisture content in the oil to an acceptable level using external filtration and vacuum dehydration equipment.

This process is typically performed offline, meaning the transformer is taken out of service or isolated for the duration of the treatment.

Common Methods

- **Vacuum Dehydration:** Uses vacuum to lower the boiling point of water, enabling faster removal.
- **Hot Oil Circulation:** Oil is heated and circulated through a dehydrator to remove moisture.
- **Adsorbent Filtration:** Removes both water and dissolved gases using adsorbent materials.
- **Mobile Dehydration Units:** Portable systems deployed on-site for offline treatment.

Figure 3: Typical Periodic Dehydration Process



Periodic dehydration is effective at removing free and dissolved moisture from oil, but it does not remove moisture from the paper insulation.

Key Characteristics

Intermittent Process
Performed occasionally based on schedule, alarms, or maintenance needs.

Usually Offline
Transformer is taken out of service or isolated for treatment.

Focuses on Oil
Primarily removes moisture from oil, not from the paper insulation.

Short-Term Impact
Provides temporary improvement in oil moisture levels.

Cost & Downtime
Involves equipment cost, labor, and outage or reduced availability.

What It Achieves — and What It Doesn't

What It Achieves	What It Doesn't Achieve
✓ Removes free and dissolved moisture from oil	✗ Does not remove moisture from paper insulation
✓ Improves oil dielectric strength and insulation performance (short term)	✗ Does not change the oil–paper equilibrium
✓ Reduces risk of moisture-related oil breakdown	✗ Moisture will return to oil after treatment
✓ Restores oil to a lower moisture level	✗ Does not provide continuous protection

Periodic dehydration provides temporary relief by drying the oil, but the paper remains wet. The equilibrium will restore over time, and moisture will return to the oil.

Key Takeaway

Periodic dehydration removes moisture from the oil—but not from the source.
To achieve long-term insulation drying, the equilibrium must be shifted and maintained. This requires a continuous approach to moisture management.

AVACO Solutions FZC
P.O. Box 18672, SAIF Zone
Sharjah, United Arab Emirates
vishal@drytrans.com
+971-50-6790417
www.drytrans.com

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

What Happens After Dehydration?

Why Moisture Returns

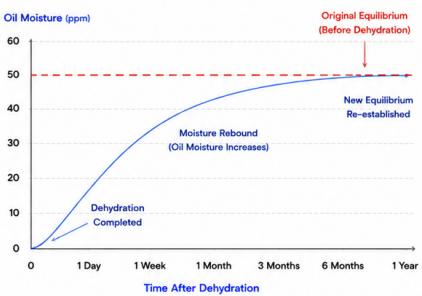
After periodic dehydration, the oil moisture level drops to a low value. However, the paper insulation remains wet because dehydration primarily removes free and dissolved moisture from the oil—not the moisture absorbed in the paper.

A moisture gradient is created between the wet paper and the dry oil. Driven by this gradient, moisture naturally migrates from the paper into the oil until a new oil–paper equilibrium is reached.

This process—known as moisture rebound—begins immediately after dehydration and continues until equilibrium is restored.

Therefore, the benefit of periodic dehydration is temporary unless the paper is also dried.

Figure 4: Moisture Rebound Curve



Moisture rebound is a natural process driven by oil–paper equilibrium. It is not a failure of the equipment; it is the physics of moisture migration.

Key Observations

- Immediately after dehydration, oil moisture is very low.
- Moisture migrates from the wet paper into the dry oil.
- Oil moisture increases until a new equilibrium is reached.
- The higher the paper moisture and temperature, the faster the rebound.
- Rebound can occur in days, weeks, or months depending on conditions.

Factors That Influence Moisture Rebound

- Initial paper moisture content
- Operating temperature
- Oil temperature
- Transformer design and paper mass
- Oil circulation and cooling
- Ambient humidity and ingress rate

Implications

- Oil moisture will not remain low after periodic dehydration.
- Moisture will continue to migrate from the paper.
- The paper remains wet; insulation aging continues.
- Repeat dehydration is required, leading to higher cost and risk.
- Long-term insulation drying requires a different approach.

Key Takeaway

Periodic dehydration removes moisture from the oil, but moisture rebound is inevitable because the paper remains wet. To achieve long-term insulation drying, the equilibrium must be continuously shifted by keeping the oil consistently dry.

AVACO Solutions FZC
P.O. Box 18672, SAIF Zone
Sharjah, United Arab Emirates
vishal@drytrans.com
+971-50-6790417
www.drytrans.com

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

Understanding Moisture Rebound

The Science Behind Moisture Migration and Equilibrium Restoration

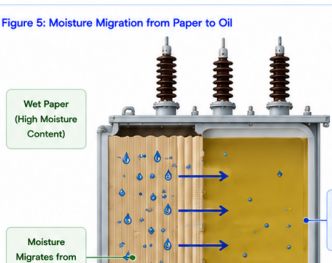
After dehydration, the paper insulation remains wet and contains the majority of the moisture. Because of the moisture concentration gradient between the wet paper and the dry oil, moisture naturally migrates from the paper into the oil.

This migration continues until a new oil–paper equilibrium is established at the prevailing temperature.

Moisture rebound is not a failure of the equipment or the drying process; it is the natural behavior of moisture in a hygroscopic insulation system.

To achieve long-term drying of the paper insulation, the equilibrium must be continuously shifted by maintaining the oil in a consistently dry condition.

Figure 5: Moisture Migration from Paper to Oil



Driven by the moisture concentration gradient: moisture moves from high concentration (paper) to low concentration (oil) until equilibrium is reached.

Figure 6: Equilibrium Restoration Process

1. After Dehydration
- Oil moisture is low
- Paper remains wet
- Large moisture gradient exists

2. Moisture Migration
- Moisture migrates from paper into oil
- Oil moisture increases
- Gradient decreases

3. Approaching Equilibrium
- Migration rate slows down
- Gradient is small
- System approaches new equilibrium

4. New Equilibrium Re-established
- New oil–paper equilibrium is reached
- Moisture migration stops
- Rebound complete

Equilibrium is a dynamic process. Any change in temperature, load or moisture ingress can trigger a new migration cycle.

Key Drivers

Temperature (Higher temp = faster migration)

Paper Moisture Content (Higher content = more rebound)

Oil Temperature (Affects oil's moisture holding capacity)

System Conditions (Load, cooling, and ambient humidity)

The Key Insight

Moisture rebound will continue as long as the oil is allowed to become wetter.

Sustained insulation drying requires keeping the oil consistently dry:

- Maintains the equilibrium shift
- Drives moisture out of the paper
- Prevents moisture rebound
- Improves insulation life and reliability
- Provides continuous protection

AVACO Solutions FZC
P.O. Box 18672, SAIF Zone
Sharjah, United Arab Emirates

vishal@drytrans.com | +971-50-6790417 | www.drytrans.com

drytrans

Moisture Under Control.
Reliability Assured.

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

What Is Continuous Moisture Management?

A Proactive Approach to Insulation Drying

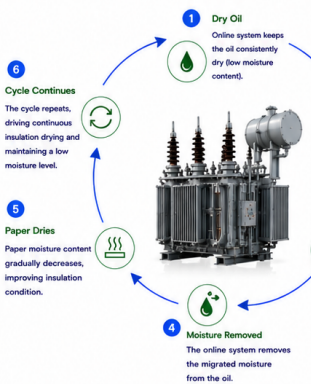
Continuous Moisture Management (CMM) is a proactive strategy that continuously removes moisture from the oil while the transformer remains in service.

By maintaining the oil in a consistently dry condition, the oil–paper equilibrium is continuously shifted. This causes moisture to migrate from the paper into the oil, where it is removed by the online system.

Over time, this leads to a gradual and sustained reduction of moisture in the paper insulation—achieving true insulation drying.

Unlike periodic dehydration, CMM does not just remove moisture from the oil; it drives moisture out of the paper.

Figure 7: Continuous Moisture Management Cycle



Continuous moisture management maintains the equilibrium shift, causing the paper to continuously release moisture until it reaches a lower, healthier moisture level.

How It Works

- An online moisture management system is connected to the transformer.
- The system continuously removes moisture from the oil.
- The oil remains dry, maintaining a low moisture level.
- Moisture migrates from the paper into the oil.
- The removed moisture is expelled from the system.
- The paper insulation gradually dries, improving reliability and extending asset life.

Key Benefits

- Dries the paper insulation (not just the oil)
- Minimizes moisture rebound
- Operates online (no outage required)
- Improves reliability and reduces risk
- Extends transformer insulation life
- Supports sustainability and asset stewardship

Key Characteristics

- Continuous operation 24/7, 365 days
- Maintains consistently low oil moisture
- Drives moisture out of the paper
- Provides ongoing protection and measurable improvement
- Automated and reliable performance
- Supports long-term insulation health and asset value

Key Takeaway

Continuous Moisture Management is the only proven approach to achieve long-term insulation drying and maintain a low moisture level. It shifts the focus from temporary moisture removal to permanent moisture control.

AVACO Solutions FZC
P.O. Box 18672, SAIF Zone
Sharjah, United Arab Emirates
vishal@drytrans.com
+971-50-6790417
www.drytrans.com

drytrans

drytrans

Moisture Under Control.
Reliability Assured.

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

Periodic Dehydration vs Continuous Moisture Management

Understanding the Key Differences

While periodic dehydration provides temporary moisture reduction in the oil, Continuous Moisture Management (CMM) offers long-term insulation drying by continuously shifting and maintaining the oil–paper equilibrium.

The table below highlights the fundamental differences between these two approaches.

The ultimate goal is not just to remove moisture from the oil, but to dry the paper insulation and keep it dry. CMM achieves this; periodic dehydration does not.

PERIODIC DEHYDRATION

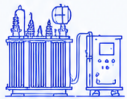
Temporary Relief

Reduces oil moisture periodically

VS

CONTINUOUS MOISTURE MANAGEMENT

Long-Term Solution



Continuously removes moisture and dries the insulation

PARAMETER	PERIODIC DEHYDRATION	CONTINUOUS MOISTURE MANAGEMENT (CMM)
Removes Moisture from Oil	Yes, during treatment	Yes, continuously
Removes Moisture from Paper	Limited – paper remains wet	Excellent – paper is gradually dried
Operates Online	Usually No – offline process	Yes – fully online
Moisture Rebound	High – moisture returns after treatment	Low – equilibrium shift is maintained
Long-Term Insulation Drying	Limited – requires repeated treatments	High – continuous drying over time
Continuous Protection	No – protection gap between treatments	Yes – continuous protection against moisture ingress
Impact on Insulation Life	Short-term improvement	Significant long-term life extension
Total Cost of Ownership	Higher over time due to repeat treatments & outages	Lower over time through continuous protection & life extension
Sustainability	Higher environmental impact (oil handling & waste)	Lower environmental impact (no oil processing, less waste)

Key Takeaway

Periodic dehydration treats the symptom.
Continuous Moisture Management addresses the root cause.
For true insulation health and long-term reliability, Continuous Moisture Management is the solution.

AVACO Solutions FZC
P.O. Box 18672, SAIF Zone
Sharjah, United Arab Emirates
vishal@drytrans.com
+971-50-6790417
www.drytrans.com

drytrans

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

The Asset Management Perspective

Why Continuous Moisture Management Delivers Long-Term Value

Transformers are long-life assets that operate in demanding environments. Moisture is the most common hidden threat to insulation health and reliability.

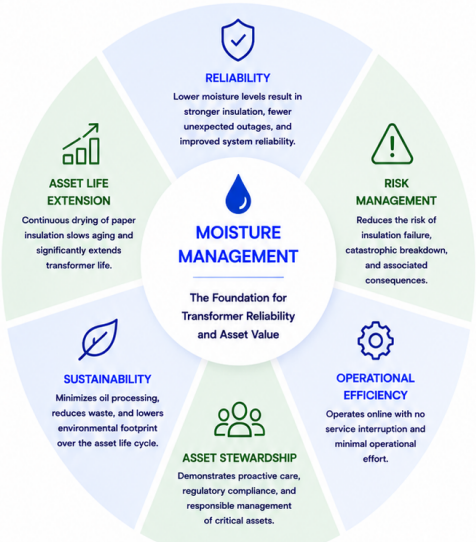
Periodic dehydration provides temporary relief, but only Continuous Moisture Management (CMM) delivers sustained insulation drying, lower risk, and long-term asset value.

By maintaining the oil in a consistently dry condition, CMM shifts the oil–paper equilibrium and enables the paper to continuously release moisture—extending insulation life and improving performance.

The Bottom Line

Moisture management is not just a maintenance activity—it is an asset management strategy that directly improves reliability, reduces risk, and maximizes the return on transformer investment.

Figure 9: Benefits of Continuous Moisture Management



Key Enablers of Success

Understand Moisture Behavior
Know the oil–paper equilibrium and the factors that influence moisture migration.

Monitor Continuously
Use data and trends to understand the moisture trend and insulation condition.

Manage Proactively
Implement continuous moisture management to control the root cause—moisture.

Improve Decisions
Make informed decisions that improve reliability and optimize maintenance.

Maximize Value
Extend asset life, reduce costs, and improve overall return on investment.

Continuous Moisture Management is the key to achieving reliable, efficient, and sustainable transformer operation.
It is not an expense—it is an investment in the long-term health and value of critical assets.

AVACO Solutions FZC
P.O. Box 18672, SAIF Zone
Sharjah, United Arab Emirates
vishal@drytrans.com
+971-50-6790417
www.drytrans.com

WHITE PAPER | Moisture Intelligence for Smarter Transformer Decisions

Conclusion

Moisture Control is Transformer Life Control

Moisture is the root cause of insulation degradation in power transformers. While periodic dehydration provides temporary relief, only Continuous Moisture Management addresses the real challenge—maintaining a consistently dry insulation system.

By shifting the oil–paper equilibrium and continuously removing migrated moisture, CMM enables true insulation drying, reduces risk, extends asset life, and improves reliability.

The future of transformer asset management is proactive, data-driven, and moisture-smart.

> When moisture is under control, reliability is assured, performance is sustained, and value is maximized.

Continuous Moisture Management is not just the solution—it is the strategic advantage.

Key Takeaways

Moisture is the Primary Driver
Moisture is the #1 factor that influences insulation aging, reliability, and failure risk.

Testing is Only the First Step
Comprehensive testing across four domains is essential—but actionable insights matter most.

Trend Over Snapshot
Regular testing under different conditions helps understand insulation behavior and real risk.

Equilibrium Matters
Moisture migration will continue until the oil–paper equilibrium is shifted and restored.

Continuous Dries the Paper
Only Continuous Moisture Management can dry the paper insulation and maintain it dry.

Long-Term Value Creation
CMM improves reliability, extends asset life, reduces costs, and maximizes return on investment.

Take Control of Moisture. Take Control of Reliability.

Partner with DryTrans to implement proven, online moisture management solutions for your critical transformers.

Let's Build a Drier, More Reliable Grid—Together.

vishal@drytrans.com
www.drytrans.com
+971-50-6790417

Visit our website