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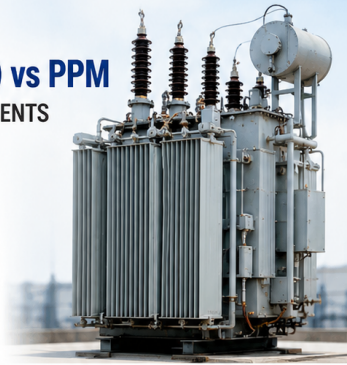
RELATIVE SATURATION (%RS) vs PPM

UNDERSTANDING MOISTURE MEASUREMENTS IN TRANSFORMER OIL



WHY MOISTURE MATTERS

Moisture is one of the most important factors affecting transformer insulation life and reliability.

- Accelerates cellulose aging
- Reduces dielectric strength
- Increases dielectric losses
- Promotes bubble formation during overloads
- Increases partial discharge risk
- Reduces transformer reliability

WHAT DOES PPM MEAN?

PPM (Parts Per Million) measures the amount of water dissolved in transformer oil.

10 ppm = 10 mg water per kg oil
20 ppm = 20 mg water per kg oil

PPM answers only one question:

➔ **How much water is dissolved in the oil?**

PPM DOES NOT directly indicate:

- Moisture stress
- Insulation condition
- Free water risk
- Moisture equilibrium with paper
- Transformer drying condition

WHAT IS RELATIVE SATURATION (%RS)?

Relative Saturation indicates how close the oil is to its moisture saturation limit at the current temperature.

$$RS\ (\%) = \frac{\text{Water Content in Oil}}{\text{Water Saturation Limit at Current Temperature}} \times 100$$

Relative Saturation is often considered a better indication of moisture risk because it accounts for temperature effects.

MOISTURE RISK INTERPRETATION

RELATIVE SATURATION (%RS)	<10%	10–20%	20–30%	30–50%	50–70%	>70%
CONDITION	Very Dry	Dry	Normal	Elevated Moisture	High Moisture Risk	Potential Free Water Risk

(Interpretation based on IEC and industry practice)

EXAMPLE

Transformer Oil

At 20°C
- Moisture = 15 ppm
- Saturation Limit = 30 ppm

Relative Saturation
15 ÷ 30 × 100 = **50%**

➔

At 60°C
- Moisture = 15 ppm
- Saturation Limit ≈ 200 ppm

Relative Saturation
15 ÷ 200 × 100 = **7.5%**

Same PPM. Completely different moisture condition.

KEY MESSAGE

PPM changes with **temperature.**

Relative Saturation reflects actual **moisture stress.**

For transformer reliability, **stress is usually more important than quantity.**

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WHY RELATIVE SATURATION IS MORE USEFUL THAN PPM

1. SAME PPM – DIFFERENT RISK

PPM alone can be misleading because it does not consider temperature. Relative Saturation shows the real moisture stress.

TRANSFORMER A (COOL CONDITIONS)		VS	TRANSFORMER B (HOT CONDITIONS)	
Moisture (PPM)	15 ppm		Moisture (PPM)	15 ppm
Oil Temperature	20 °C		Oil Temperature	70 °C
Saturation Limit	~30 ppm		Saturation Limit	~200 ppm
Relative Saturation (%RS)	**~50%**		**Relative Saturation (%RS)**	**~7%**

Oil is carrying 50% of its moisture capacity. Transformer is much closer to moisture related issues.

Same moisture (15 ppm) but only 7% of moisture capacity. Transformer is in a very dry condition.

Same PPM. Completely different moisture condition and risk.

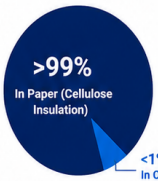
2. DIFFERENT OILS – DIFFERENT INTERPRETATION

Water solubility varies significantly between insulating fluids. PPM values cannot be compared across different fluid types.

FLUID TYPE	RELATIVE WATER SOLUBILITY	EXAMPLE: 50 PPM MOISTURE
Mineral Oil	Low	May indicate **WET** condition
Synthetic Ester	High	May indicate **NORMAL** condition
Natural Ester	Very High	May indicate **VERY DRY** condition

Always interpret moisture based on fluid type, temperature and Relative Saturation.

3. MOISTURE ACTUALLY LIVES IN THE PAPER



More than **99%** of moisture is typically stored in **cellulose insulation.**

Less than **1%** of moisture is dissolved in the oil.

Oil acts as a moisture transport medium.

Paper insulation acts as the moisture reservoir.

Therefore, monitoring Relative Saturation helps us understand the moisture condition of the entire insulation system – not just the oil.

4. WHY ONLINE MONITORING USES %RS

Modern online moisture sensors measure:

Moisture (PPM) + **Oil Temperature** + **Relative Saturation (%RS)**

Relative Saturation provides:

- Better indication of dielectric risk
- Better trend analysis over time
- Better seasonal comparison
- Better comparison between transformers
- Better understanding of moisture migration
- Better estimation of paper moisture

5. WHAT SHOULD ENGINEERS TREND?

For effective moisture management and informed decision making, monitor the following parameters.

RELATIVE SATURATION (%RS)	OIL TEMPERATURE	MOISTURE TREND	ESTIMATED PAPER MOISTURE	LOAD & THERMAL CONDITIONS
Primary indicator of moisture stress	Affects saturation and moisture solubility	Shows the direction of moisture movement	Indicates actual insulation moisture condition	Determine insulation stress and moisture migration

IMPORTANT

Use PPM as supporting information.

DO NOT use PPM alone to assess transformer dryness or risk.

FINAL TAKEAWAY

PPM tells us: **"How much water is dissolved in the oil."**

Relative Saturation tells us: "How close the transformer is to moisture-related risk."

For transformer insulation assessment, **Relative Saturation (%RS)** is usually **the more meaningful parameter.**

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REFERENCES, STANDARDS & TECHNICAL GUIDANCE

INTERNATIONAL STANDARDS

IEC 60422
Mineral insulating oils in electrical equipment – Supervision and maintenance guidance
Provides guidance on Relative Saturation, moisture limits, oil condition assessment and moisture interpretation.

IEC 60814
Insulating liquids – Determination of water content – Karl Fischer titration method
Reference laboratory method for the determination of water content in insulating liquids.

IEEE C57.106™
Guide for Acceptance and Maintenance of Insulating Oil in Equipment
Provides moisture interpretation guidance and transformer oil maintenance recommendations.

CIGRÉ PUBLICATIONS

CIGRÉ TB 741
Moisture Measurement and Assessment in Transformer Insulation
Comprehensive guidance on moisture measurement techniques and interpretation.

CIGRÉ TB 349
Moisture Equilibrium and Moisture Assessment in Power Transformers
Explains oil–paper moisture equilibrium, moisture migration and estimation methods.

CIGRÉ TB 761
Condition Assessment of Power Transformers
Includes moisture related condition assessment methodologies and best practices.

KEY TECHNICAL PUBLICATIONS

T. V. Oommen
Moisture Equilibrium in Paper–Oil Insulation Systems
One of the most widely referenced papers explaining oil–paper moisture equilibrium, moisture migration and estimation methods.

Michael Koch
Research on Moisture Diagnostics in Transformers
Research on dielectric response methods, moisture estimation, online moisture diagnostics and interpretation uncertainty.

Stefan Tenbohlen
Research on Transformer Diagnostics
Research on moisture diagnostics, dielectric response analysis and transformer insulation assessment.

IMPORTANT TECHNICAL CONSIDERATIONS

- PPM values are strongly temperature dependent.
- Relative Saturation (%RS) is generally more suitable for operational risk assessment.
- Moisture equilibrium charts provide estimates, not exact values.
- Moisture migration between oil and paper is dynamic and continuous.
- Transformer loading and temperature must always be considered during interpretation.
- Moisture should be evaluated using trends rather than single measurements.

TECHNICAL CONCLUSION

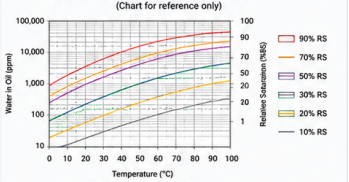
PPM is a concentration measurement.
It tells us how much water is dissolved in the oil.

Relative Saturation is a risk indicator.
It tells us how close the transformer is to moisture-related risk.

For transformer moisture assessment, condition monitoring and moisture management programs, **Relative Saturation (%RS)** provides a more meaningful representation of insulation moisture stress and operational risk.

REFERENCE MOISTURE CHART

Typical Moisture Equilibrium in Mineral Oil / Paper System
(Chart for reference only)



Source: IEC 60422 / Transformer Moisture Chart Reference [1]

REMEMBER:

PPM tells you:
"How much water is dissolved in the oil."

Relative Saturation tells you:
"How close the transformer is to moisture-related risk."

For transformer reliability, manage moisture. Don't just measure it.

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