Phantom Moisture-Evaluation and Migration

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Responsible for the material testing laboratory within Siemens transformers. Main topics of interest: testing of insulating fluids, insulating and conductive materials. Member of Cigre D1 „Materials for electrotechnical applications“ and IEC TC 10. Leader of 2 WG within Cigre D1 D1.30 „Oxidation stability of insulating fluids“, D1.52 „Capacitive sensors for moisture determination“.

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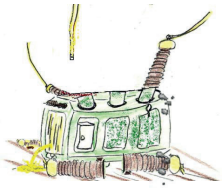
Ivanka.hoehlein-atanasova@siemens.com



Content

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- Impact of Moisture
- Sources of Moisture
- Moisture Equilibrium and Migration
- Measurement Methods
- Evaluation of Moisture
- Action against Moisture

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Impact of Moisture – immediate risk of breakdown

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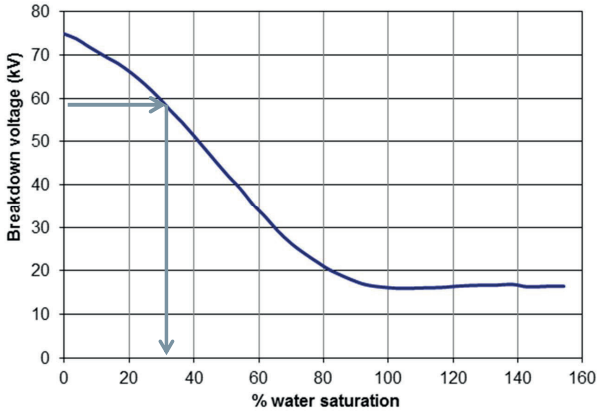
Reduction of Dielectric Strength – direct dependence of breakdown strength with moisture – immediate risk of a breakdown



Impact of Moisture – accelerated ageing

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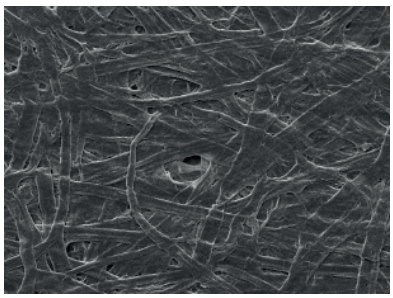
STRUCTURE OF INSULATION PAPER



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Impact of Moisture – accelerated ageing

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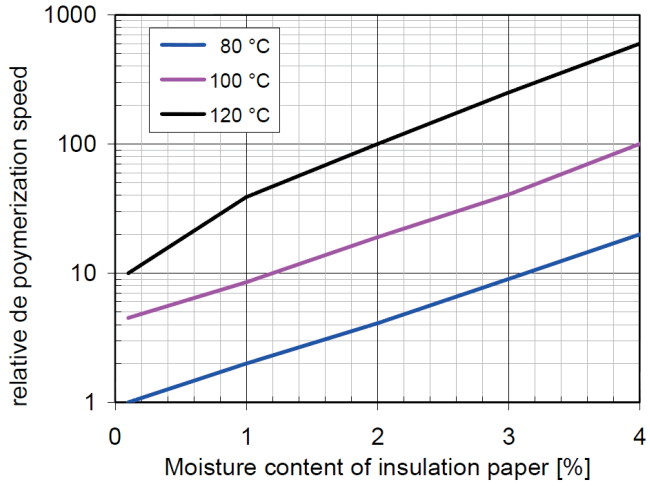
Accelerated Ageing



Impact of Moisture – accelerated ageing

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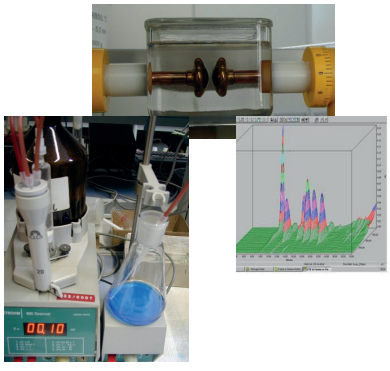
The presence of moisture in transformers influences directly the oil parameters, especially:

Breakdown voltage

Furanes

Acidity



as well as
the DP-Profiles in a transformer

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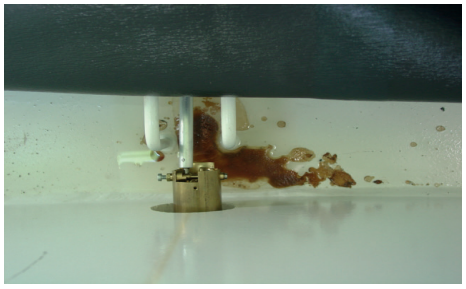
Where Does Moisture Come From?
External Sources

Not maintained dehumidifiers



Rupture in a rubber bag

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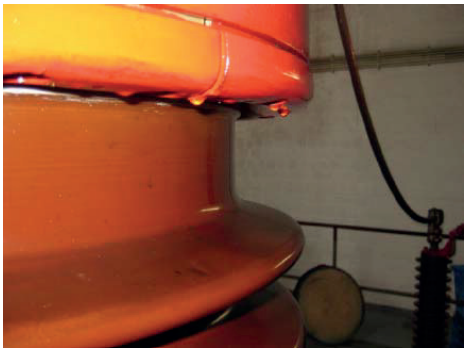
Where Does Moisture Come From?
External Sources

Untight metal bellow



leakages

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Where Does Moisture Come From?
Internal Sources

Ageing of Oil and Solid Insulation

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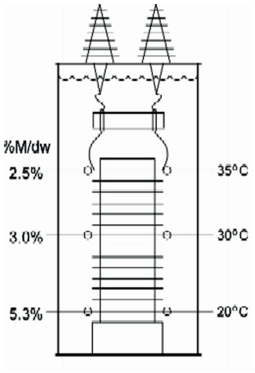
Distribution of Moisture Between Solid and Liquid Insulation

Humidity distribution between oil and paper

Temperature (°C)	Water in oil (parts)	Water in paper (parts)
20	1	3000
40	1	1000
60	1	300



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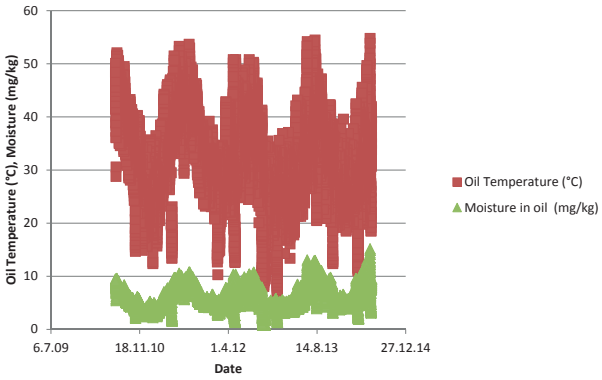
Distribution of Moisture Between Solid and Liquid Insulation – Temperature Influence



Transformer 20 MVA, 65 kV, manufacturing year 2007. This case shows the seasonal dependence of water content, since the oil temperature will be influenced by the ambient temperature in ONAN mode.

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Dependence Between Humidity in Oil and Breakdown Voltage

ATTENTION: RESULTS ARE STRONGLY DEPENDENT ON TEMPERATURE AND OIL AGEING CONDITION

	05.05.2005	02.12.2003	12.08.2003
Temp. (°C)	79	14	45
Ud (kV/2,5 mm)	13	70	45
H20 (mg/kg)	48	10	20

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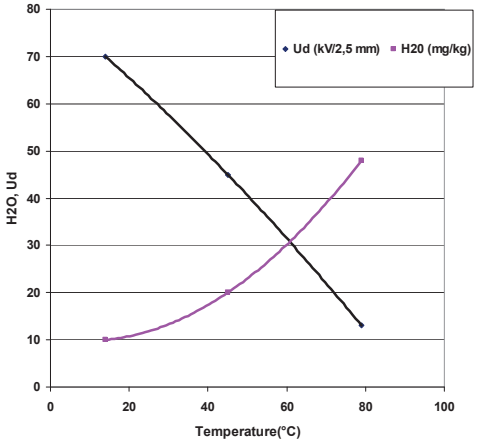
Dependence Between Humidity in Oil and Breakdown Voltage

46 MVA, 30 kV, Manufacturing year 1970



SAMPLING AT SERVICE TEMPERATURES

IS NECESSARY TO EVALUATE HUMIDITY

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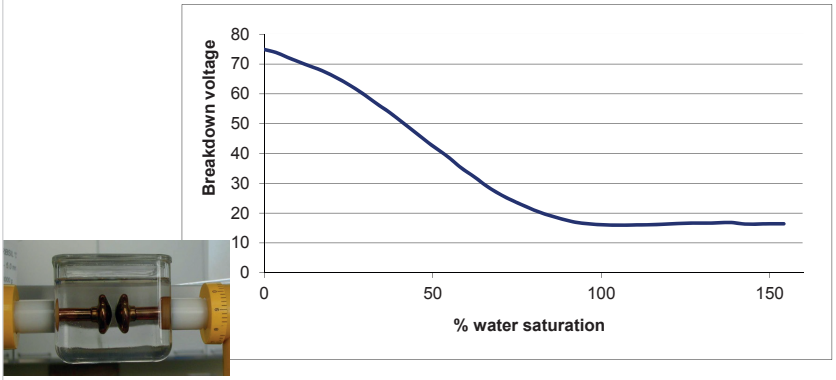
Dependence of the breakdown voltage from % water saturation in oil



IEC 60156

Dependence of the breakdown voltage from % water saturation in oil

I. Fonfana, V. Wasserberg, H. Borsi, E. Gockenbach, Challenge of Mixed Insulating Liquids for Use in High-Voltage Transformers, Part 1: Investigations of Mixed Liquids, IEEE Electrical Insulation Magazine, 2002, Vol. 18, Nr. 3, 18-25

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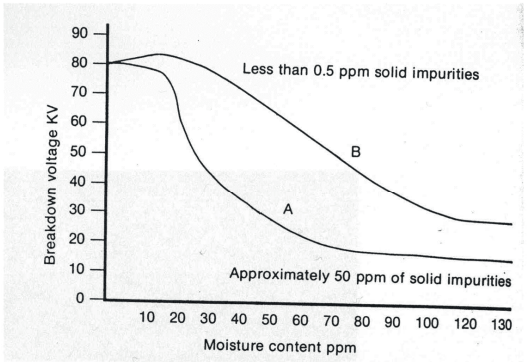
Dependence of the breakdown voltage from humidity and particle content



Dependence of the breakdown voltage from humidity and particle content

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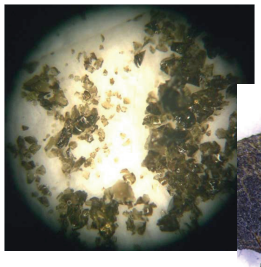
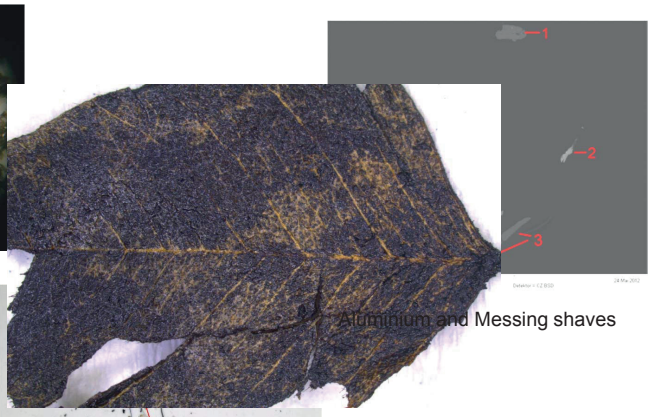
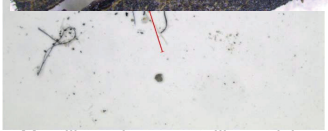
Particles in Oil



Blasting grit



Aluminium and Messing shaves



Metallic and non metallic particles

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How to Measure Moisture?

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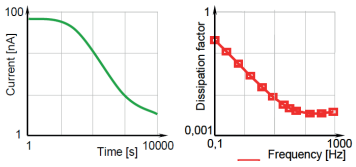
CIGRE – WORK:
Comparison between Karl-Fischer results and capacitive sensors

Capacitive sensors – Relative Humidity

Karl Fischer – Absolute Humidity

Dielectric Response



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Absolte Humidity Values (mg/kg) or Relative Humidity? That is the question.

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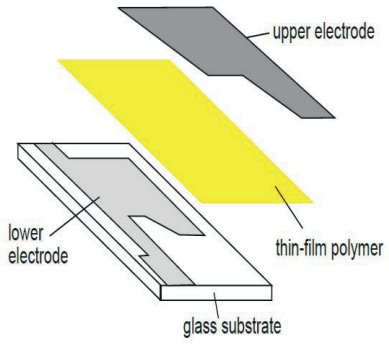
Thin film capacitive sensor



Unit = % saturation =

$$= \frac{\text{dissolved amount of humidity at a certain temperature}}{\text{max. amount of water at this temperature}} * 100$$

Karl-Fischer

Unit = mg/kg (ppm)

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Evaluating water in oil and insulation

Property	Category [a]	Recommended action limits			Recommended action [b, c]	Notes
		Good	Fair	Poor		
Colour and appearance	All	Clear and without visible contamination		Dark and/or turbid	As dictated by other tests	Dark colour is a symptom of chemical contamination or ageing. Turbidity is a symptom of high water content
Breakdown voltage (kV)	O, A, D	> 60	50 to 60	< 50	Good: Continue normal sampling. Fair: More frequent sampling. Check other parameters, e.g. water, particle content and perhaps DDF/resistivity and acidity. Poor: Recondition the oil (see 11.2) or, alternatively, if more economical because other tests indicate severe ageing, replace (see Clause 12) or reclaim (see 11.3) the oil combined with subsequent drying procedures	
	B, E	> 50	40 to 50	< 40		
	C	> 40	30 to 40	< 30		
	F	< 30 kV for OLTC in star-point application. < 40 kV for OLTC in delta or line-end application				
	G			< 30		
Water content (mg/kg at transformer operating temperature)	O, A	< 15	15 to 20	> 20	Good: Continue normal sampling. Fair: More frequent sampling. Check other parameters e.g. breakdown voltage, particle content and perhaps DDF/resistivity and acidity. Poor: Check source of water, recondition the oil (see 11.2) or, alternatively, if more economical because other tests indicate severe ageing, replace (see Clause 12) or reclaim (see 11.3) the oil combined with subsequent drying procedures, although regard should be taken of the quantity of water that will still be retained in the solid insulation	The values of water content shall be always regarded together with the values for breakdown voltage. In case of a suspicion of a moisture problem, sampling at different equipment temperatures is recommended. In case of switching equipment without paper insulation (Category F), the values of breakdown voltage are of overriding importance. The listed limit values represent 90 % statistical values and are valid for transformer operating temperatures. The equilibrium between solid and liquid insulation under 40 °C is not reliable and for heavy loaded transformers with oil temperature over 70 °C an implementation of the correction procedure described in Annex A may be useful.
	B, D	< 20	20 to 30	> 30		
	C, E	< 30	30 to 40	> 40		
	F	Action necessity > 40				
	G	Not a routine test				

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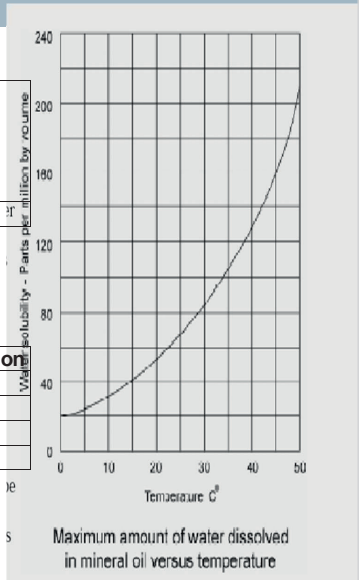
Evaluating water in oil and insulation

% Saturation in oil at the sampling temperature > 20°C	Rating > 170 kV	170 kV >R > 72,5 kV	R < 72 kV
	< 20	< 25	< 45

Table 4. Recommended Saturation Levels

% Saturation water in oil	Condition of Cellulosic Insulation
0 - 5	Dry Insulation
6 - 20	Moderate wet
21 – 30	Wet
> 30	Extremely wet

Table 5. Guidelines for Interpreting Data Expressed in Percent Saturation [IEC 60422, IEEE 62: 1995]



Maximum amount of water dissolved in mineral oil versus temperature

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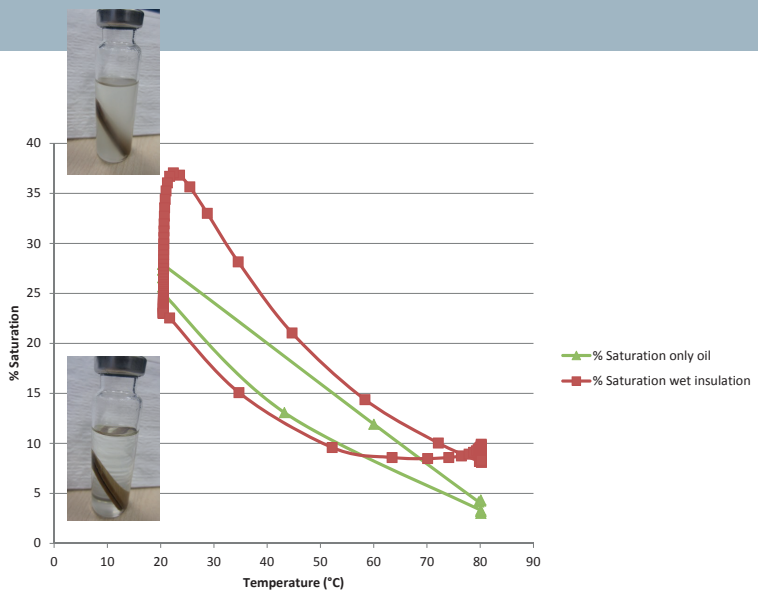
What Does % Saturation Tell Us?



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WHAT IS THE PHYSICS BEHIND?

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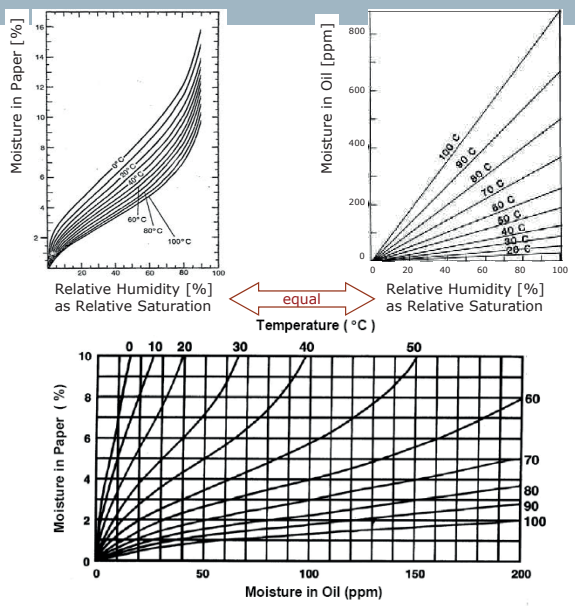
What Are the Humidity Curves?



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Restrictions of the Humidity Curves

- **EQUAL SOLUBILITY OF WATER IN NEW AND AGED OILS.**

BUT AGED OILS CAN SOLVE UP TO 3 TIMES MORE WATER THAN NEW ONES.

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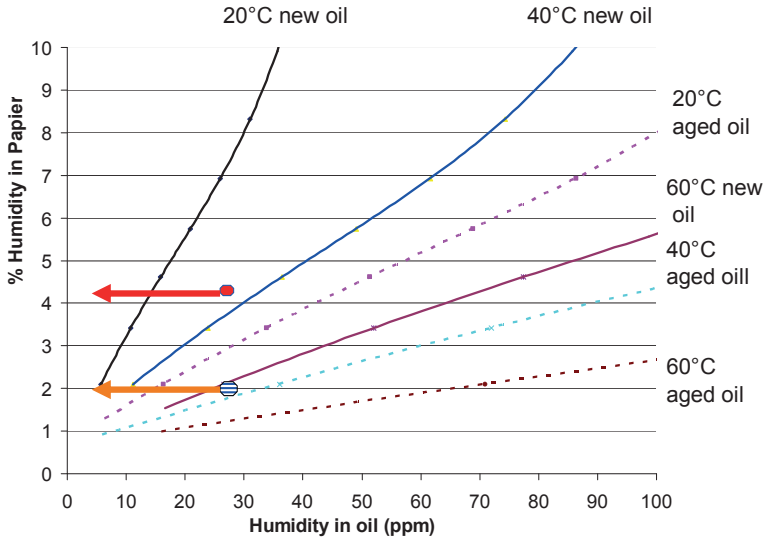
Solubility of Water in New and Aged Oils is not the Same



Ommen curves for a new and aged oil (dashed lines)

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Restrictions of the Humidity Curves

- **EQUILIBRIUM BETWEEN OIL AND SOLID INSULATION**

IN REAL TRANSFORMERS IS THIS CASE RARE

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Different Kind of Solid Insulation, Different Diffusion Coefficents

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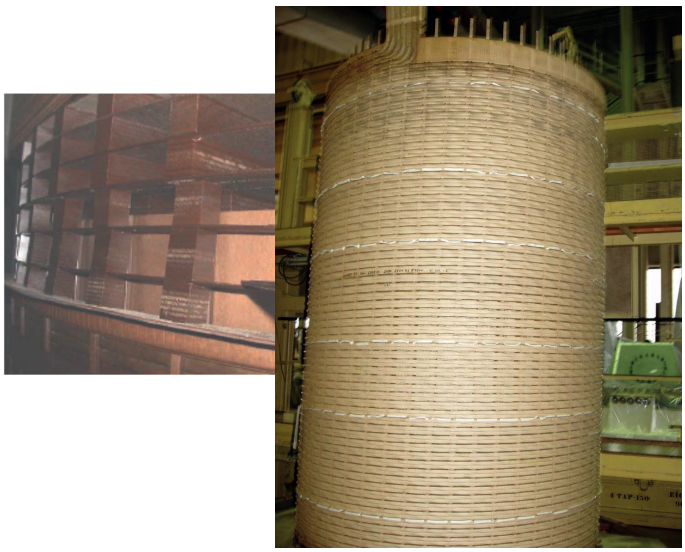

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Restrictions of the Humidity Curves

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- **THE DIFFUSION CONSTANTS ARE LOW, I. E. ONLY THIN INSULATION IS CONSIDERED**

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Diffusion Coefficients

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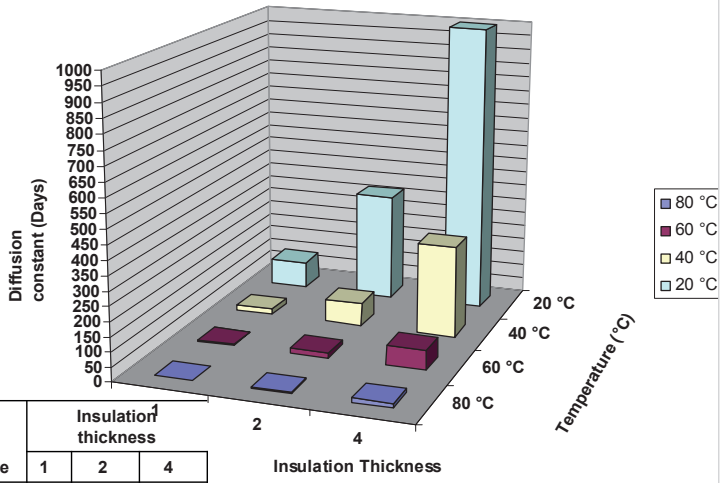

Temperature	Insulation thickness 1	2	4
80 ° C	0,9	3,6	14
60 ° C	4,2	17	67
40 ° C	20	79	317
20 ° C	93	373	1493

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Corrective Actions and Maintenance Procedures

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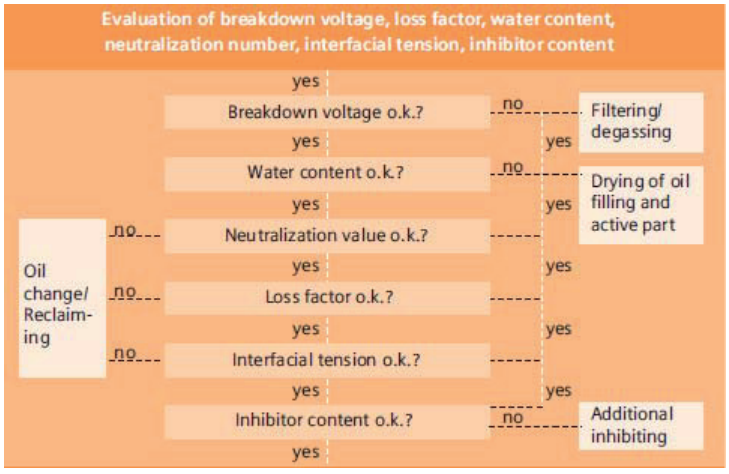

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VapourPhase Drying in the Factory

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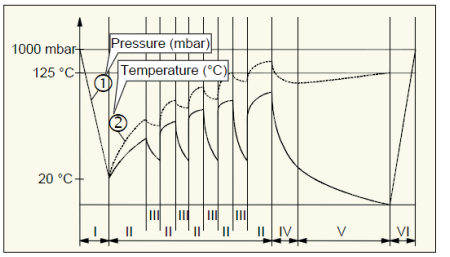

I Preparation phase
II Heating phase
III Intermediate pressure reduction phase
IV Pressure reduction phase
V Fine vacuum phase
VI Ventilation phase

① Pressure in autoclave
② Transformer temperature

Drying On-Site (Equipment out of Service)

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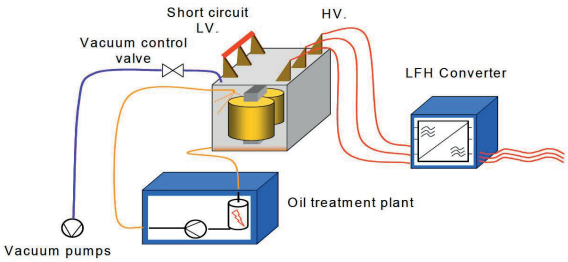

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Drying On-Site

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In practice there are several points of view, regarding drying.

The best way of drying is not always the first choice and this is due to a number of considerations.

A rapid solution to prevent the loss of oil dielectric strength

Removal from service impossible or not desirable

Drying On-Site

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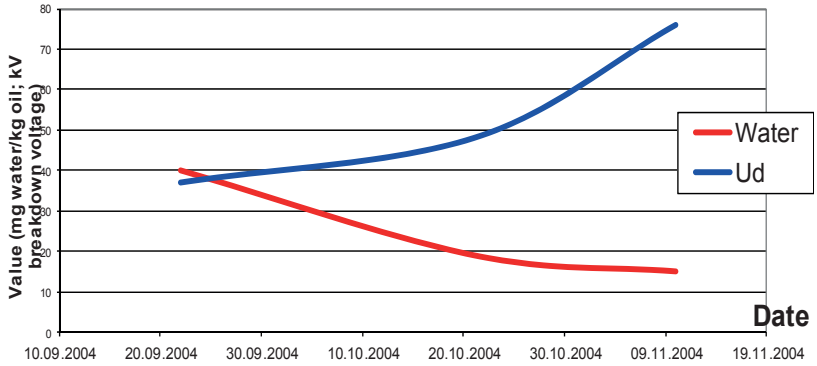
In such cases an on-line drying equipment, e.g. molsieve drying can be preferential to assure a stable condition.



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Drying On-Site

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Conclusion

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- Water solubility in oil ist strongly dependent on the temperature, therefore sampling temperature must always be recorded
- Humidity and Breakdown voltage are dependent. In case of moistue evaluation both together with the sampling temperature must be considered. These data are only indicative at service temperatures.
- % Saturation in case of on-line monitoring is an invaluable tool for evaluating moisture in the insulating system.
- All Remedial measures (maintenance methods) have merits and drawbacks, depending on the transformer condition.The necessary maintenance procedures must be a reasonable quintessence of condition, aims, possibilities and risk.

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