WEBINAR

Hidden Risks: Moisture in Cellulose Insulation Explained

June 26th | 16:00 CEST | 10:00 EST

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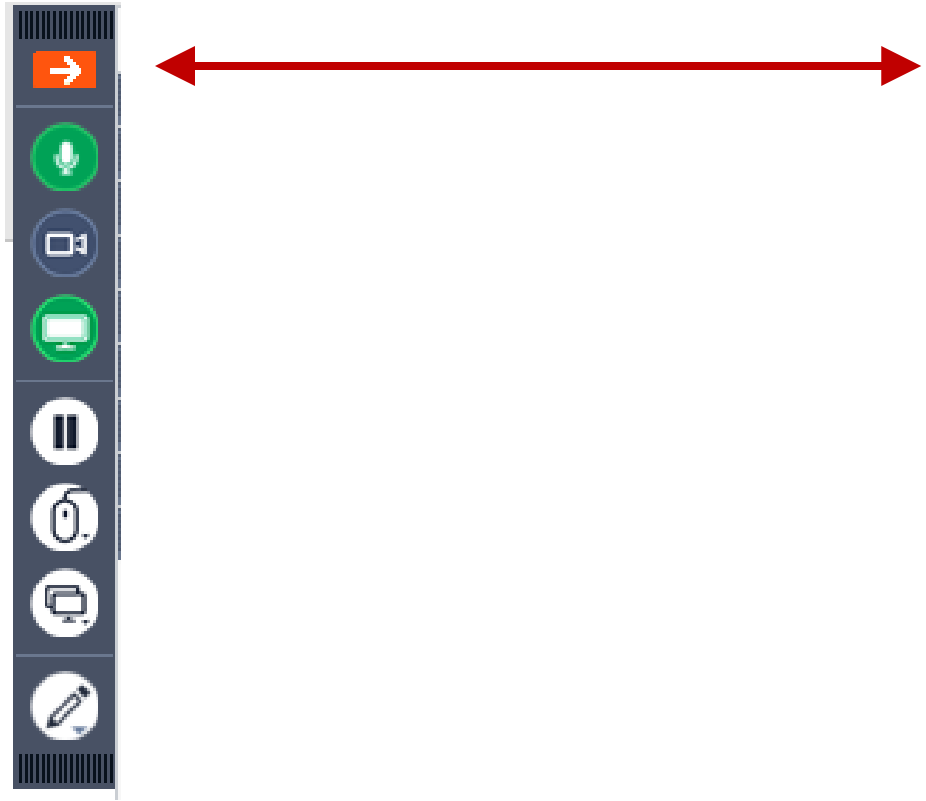
HOW TO ASK A QUESTION?

Minimized GoToWebinar panel

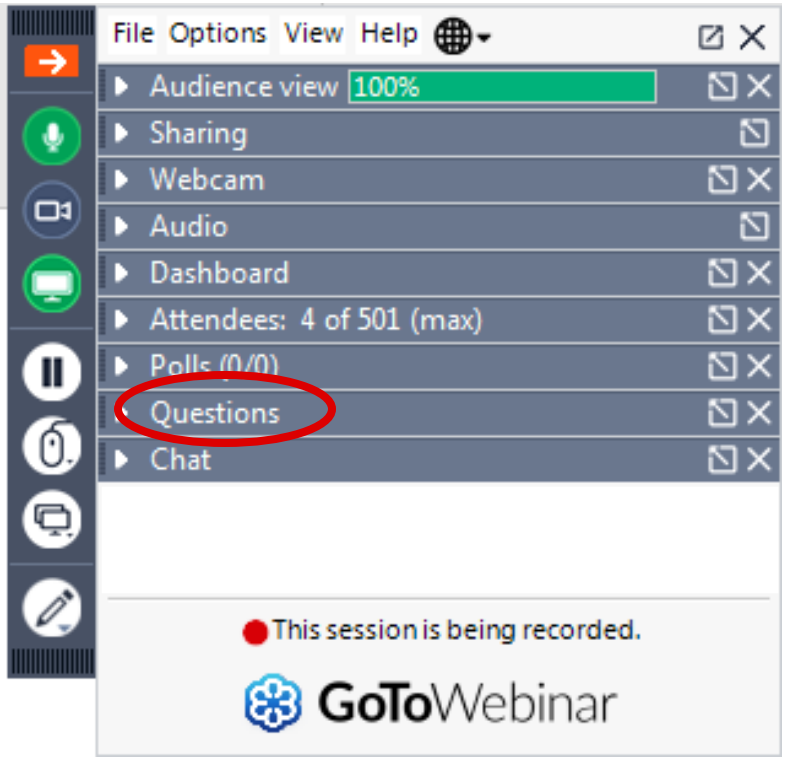
→ Click arrow to enlarge



Enlarged GoToWebinar panel

→ Expand the field Questions

→ Type your question and send to Organizers or to All



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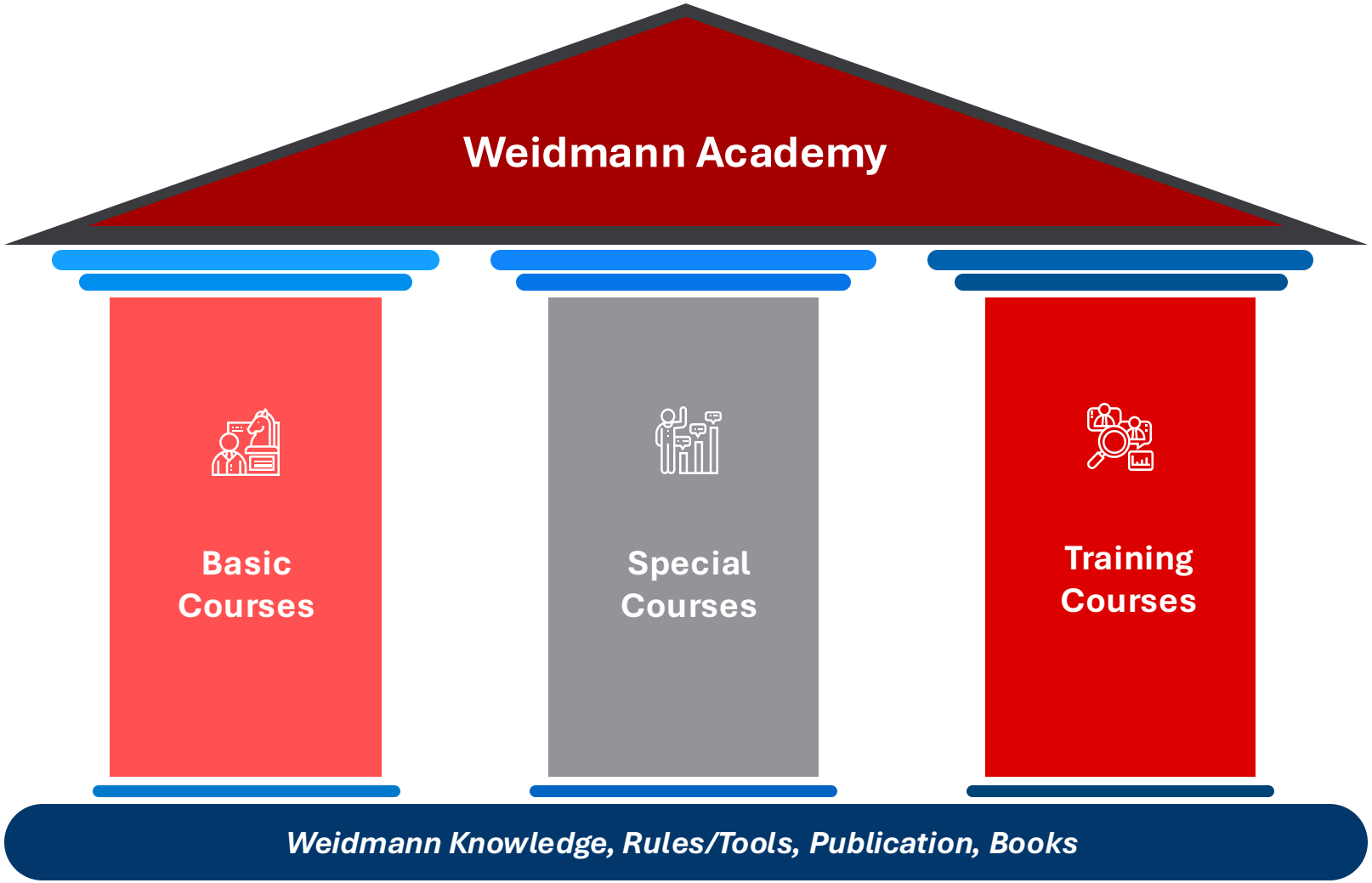
WEIDMANN ACADEMY

HIDDEN RISKS: MOISTURE IN CELLULOSE INSULATION

WEIDMANN ACADEMY

OUR INTENTION IS TO SHARE KNOWLEDGE!



AGENDA

01 Water and cellulose

02 Moisture absorption

03 Consequences of water absorption

04 Protection from water absorption

05 Lifetime expectancy

AGENDA

01

Water and cellulose

WATER AND CELLULOSE

CELLULOSE-BASED INSULATION MATERIALS

PAPER

- Insulation paper LD, MD, HD
- Diamond Printed Paper DPP
- Crepe paper
- Calendered crepe paper
- TU paper

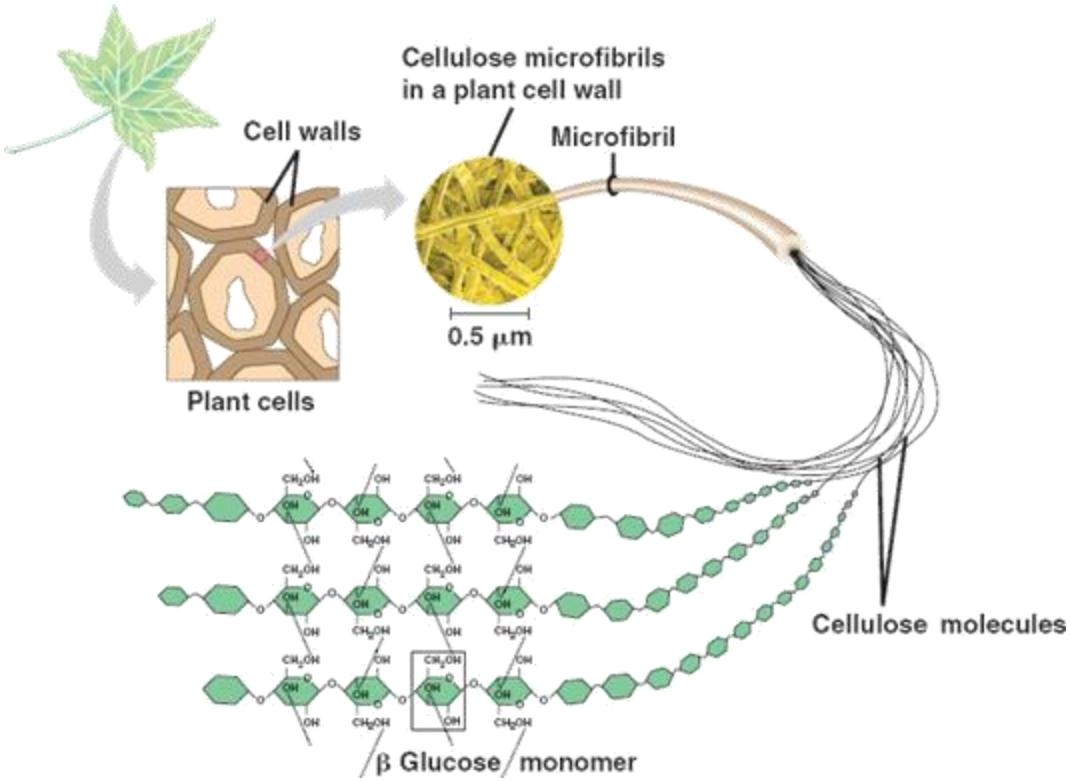
BOARD

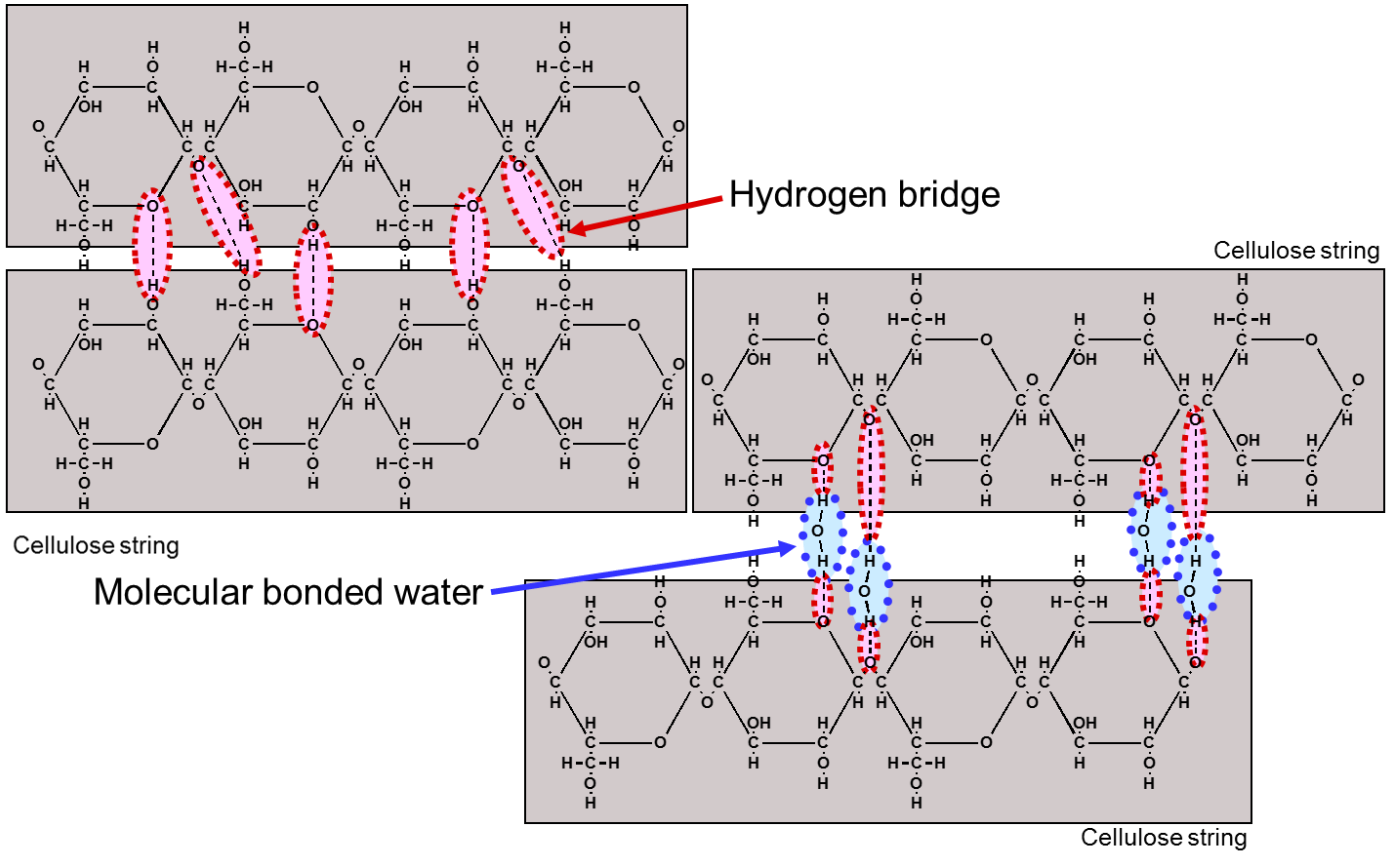
- Transformerboard
- Laminated board
- Components

WATER AND CELLULOSE

WHERE IS THE WATER?

Due to the high number of hydroxyl-groups, the cellulose molecule is very hydroscopic; meaning, these groups attract water molecules. In reality – all cellulose-based materials (wood, paper, plywood, clothes, etc.) always have water inside.





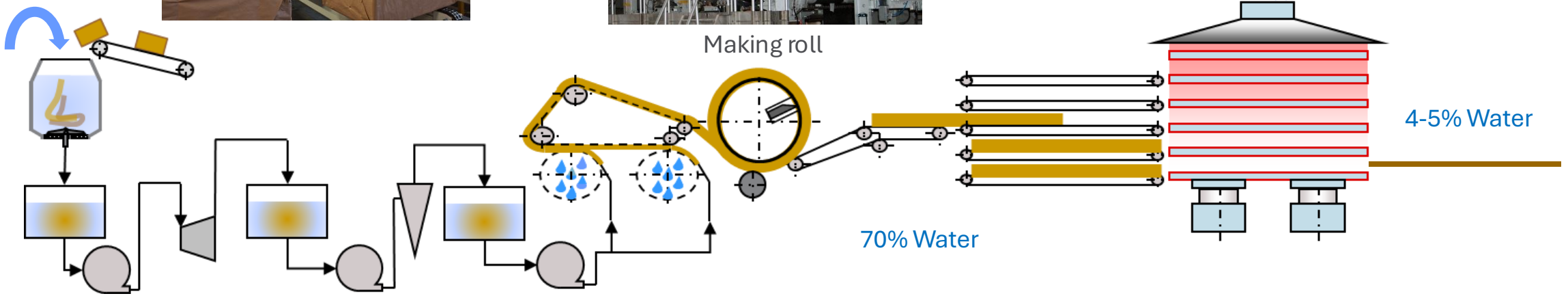
WATER AND CELLULOSE

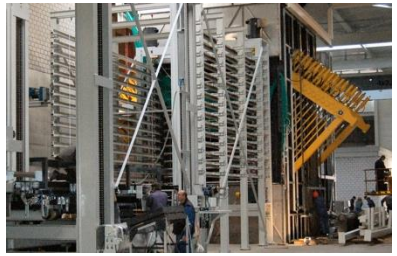
PRODUCTION OF TRANSFORMERBOARD

Pulper

95% Water

Making roll





WATER AND CELLULOSE

REQUIREMENTS AND SUBSTANCES BALANCE

Water

Cellulose

For production process of paper or board manufacturing, we need 97–99% of water and only 1–3% of fibers.
Typical paper and board (which we are consuming usually) consist of 95% fibers and 5% water (approximately).
For insulation properties, paper or board must have as little water as possible inside – almost ZERO.
But remember, cellulose itself is strongly hydrophilic – meaning it easily and lovingly absorbs water!!!

AGENDA

01 Water and cellulose

02 **Moisture absorption**

MOISTURE ABSORPTION

RELEVANT QUESTIONS FOR CELLULOSE-BASED INSULATION MATERIALS

1. How is water coming into cellulose insulation material?
2. How can we measure the water content of cellulose insulation?
3. How much water is absorbed?
4. How fast is water absorbed?
5. How fast is water removed from cellulose insulation material?
6. How does the water content influence geometry, mechanical, and electrical properties of cellulose insulation?

MOISTURE ABSORPTION

HOW IS WATER COMING INTO CELLULOSE INSULATION MATERIAL?

- **Adsorption** to the surface of the material from air

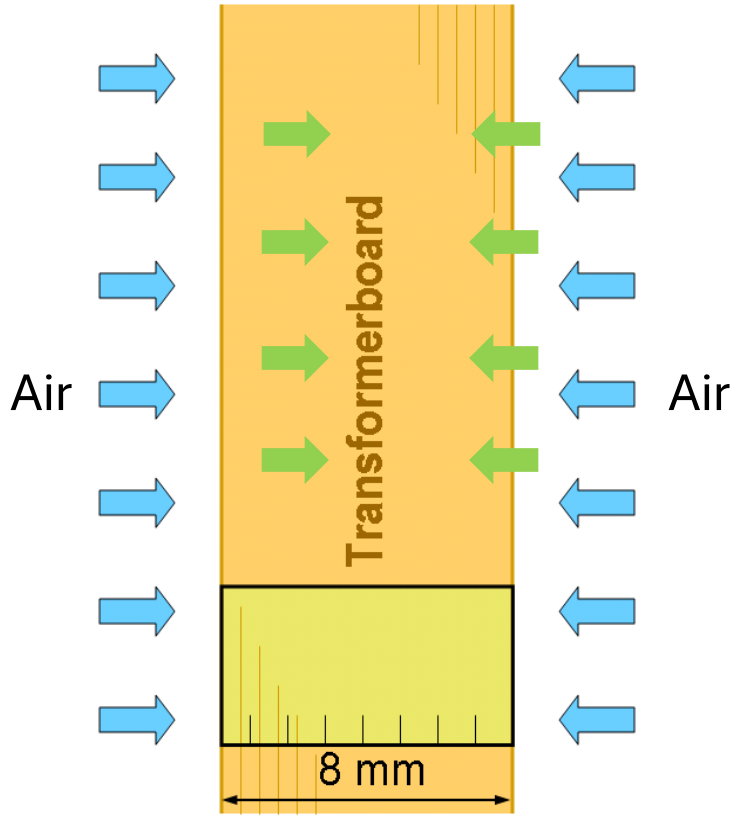
  Governed by:

  - Ambient conditions

- **Diffusion** within the bulk of the material

  Governed by:

  - Temperature
  - Pressure
  - Impregnation

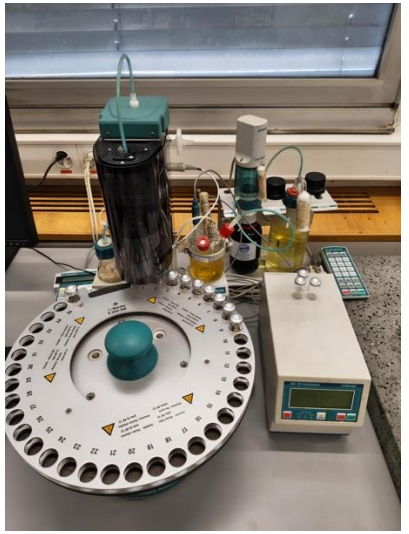


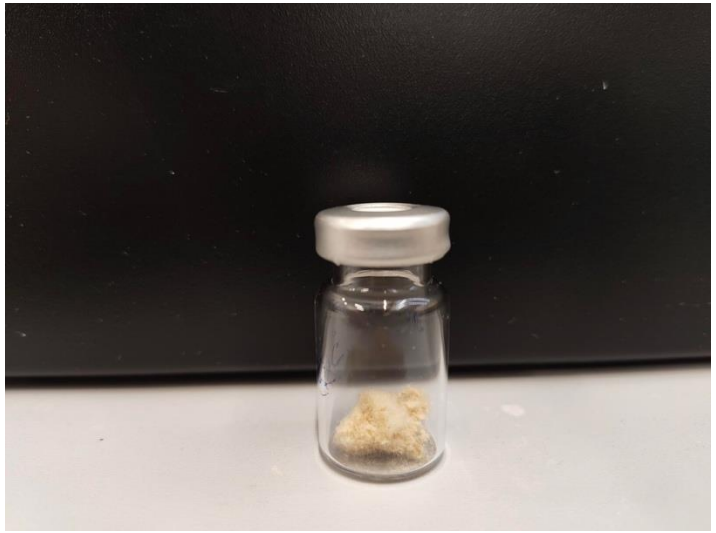
MOISTURE ABSORPTION

HOW CAN WE MEASURE THE WATER CONTENT OF CELLULOSE INSULATION?

- **Oven drying** according to IEC 60641-2
  - Global value
  - Combination of forced air circulation and vacuum

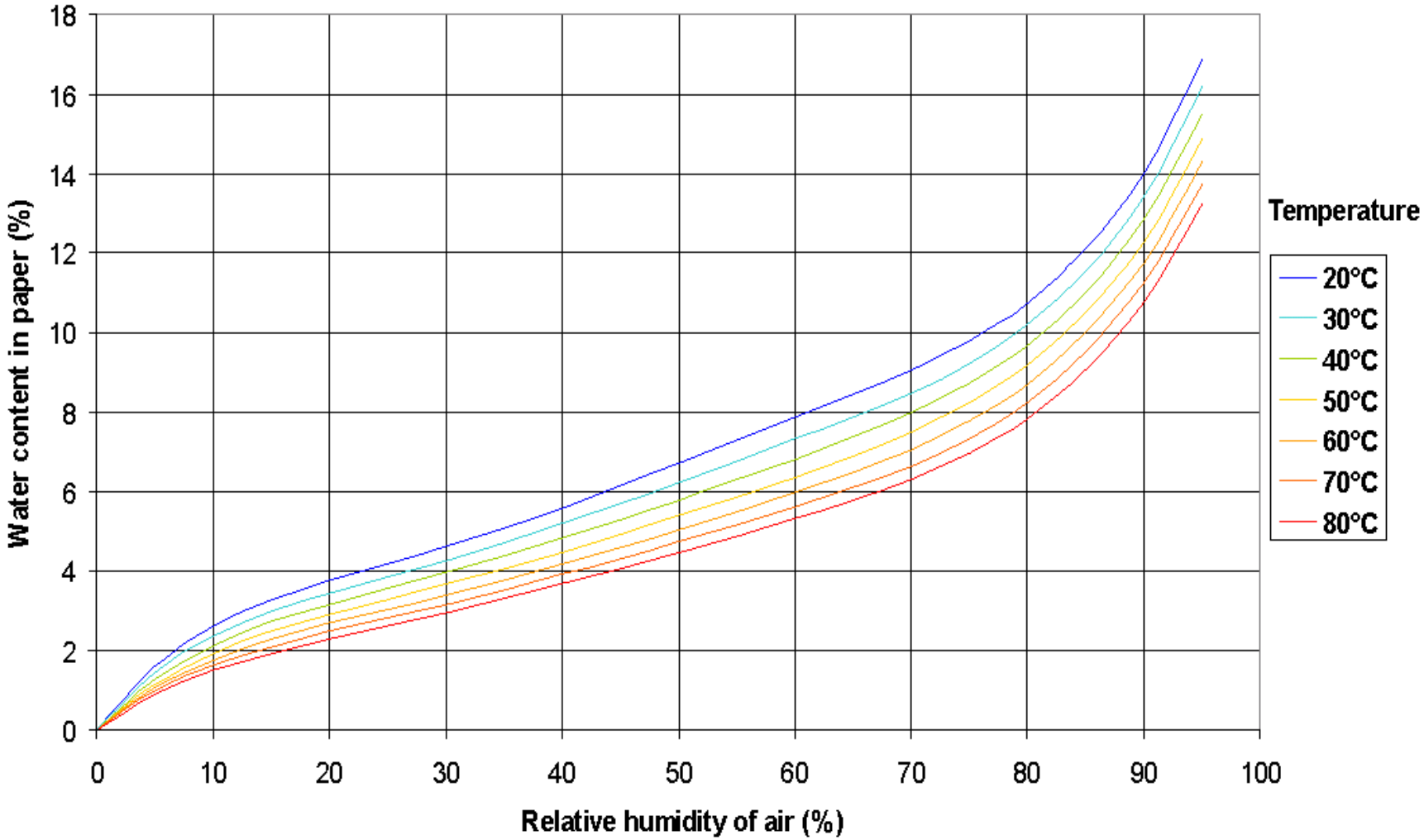
- **Karl Fischer titration** according to IEC 60814
  - Local value
  - Highly sensitive sample generation
  - Heating up the sample to release water for measurement





MOISTURE ABSORPTION

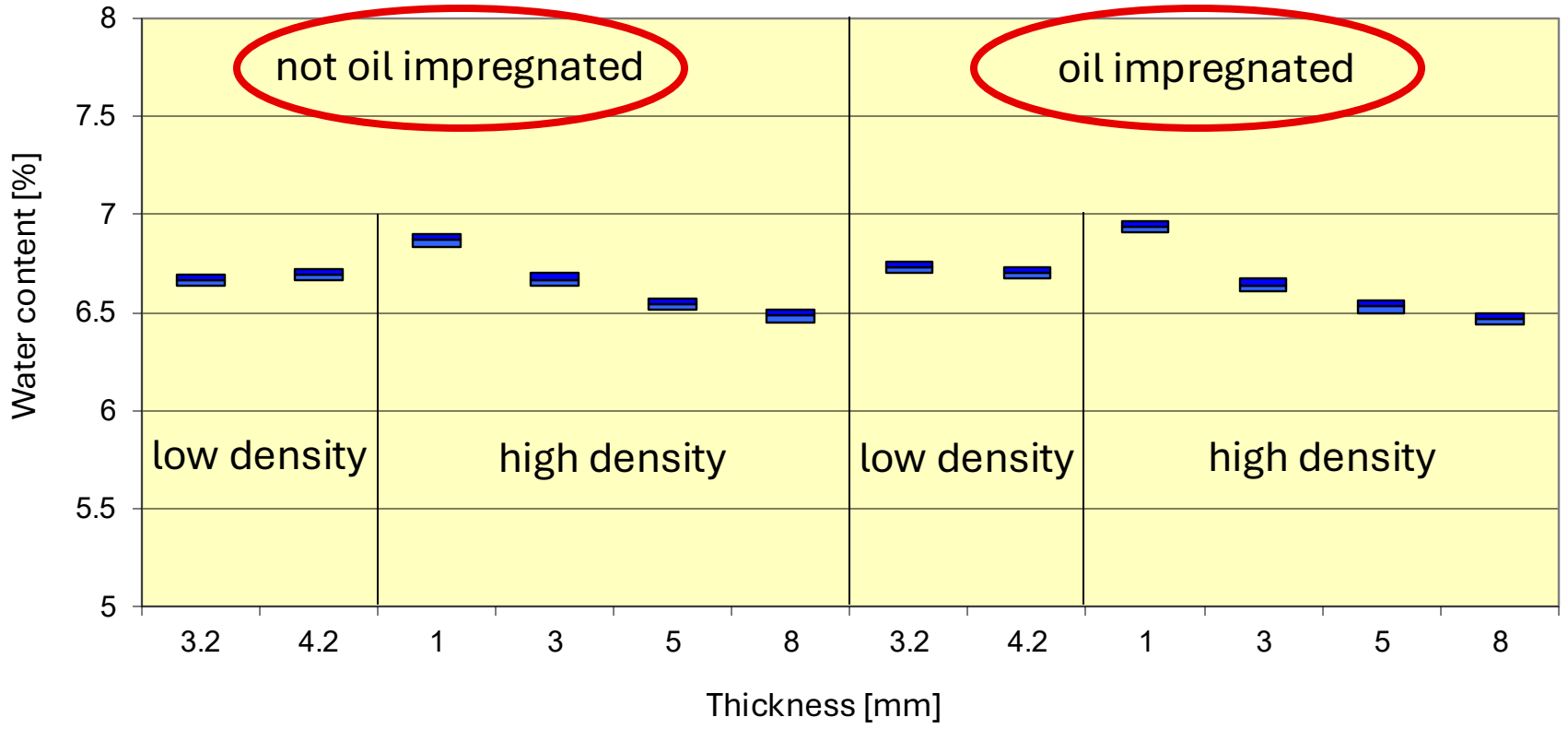
HOW MUCH WATER IS ABSORBED?



MOISTURE ABSORPTION

HOW MUCH WATER IS ABSORBED?

MOISTURE EQUILIBRIUM OF TRANSFORMERBOARD AT 23°C AND 50% RH CONDITIONED



MOISTURE ABSORPTION

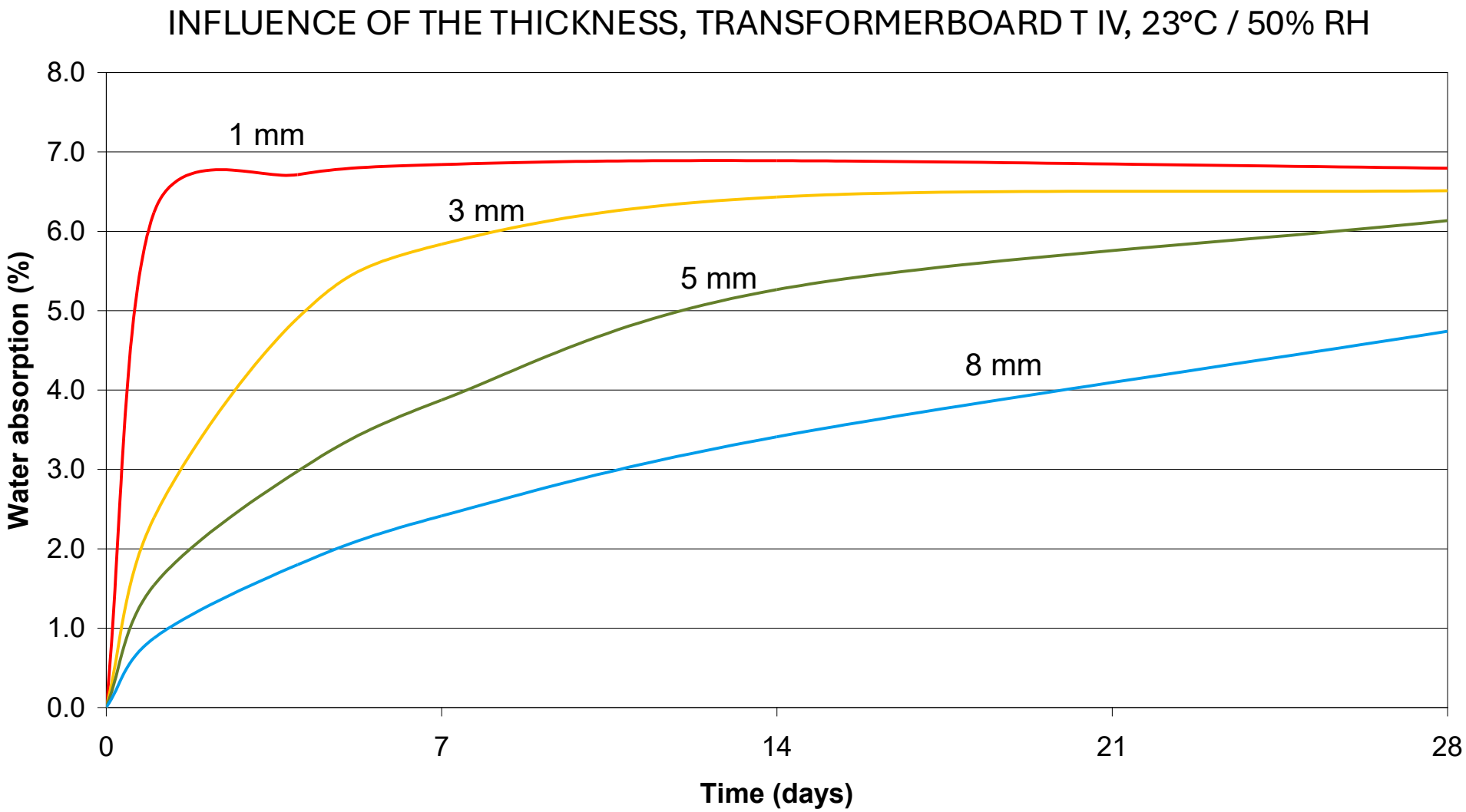
HOW FAST IS WATER ABSORBED?

The **velocity / rate** of water absorption is governed by:

1. The thickness of the board / paper
2. The density of the board / paper
3. Temperature
4. Oil impregnation (without / with oil)
5. Presence of glue lines
6. Relative humidity

MOISTURE ABSORPTION

HOW FAST IS WATER ABSORBED?



MOISTURE ABSORPTION

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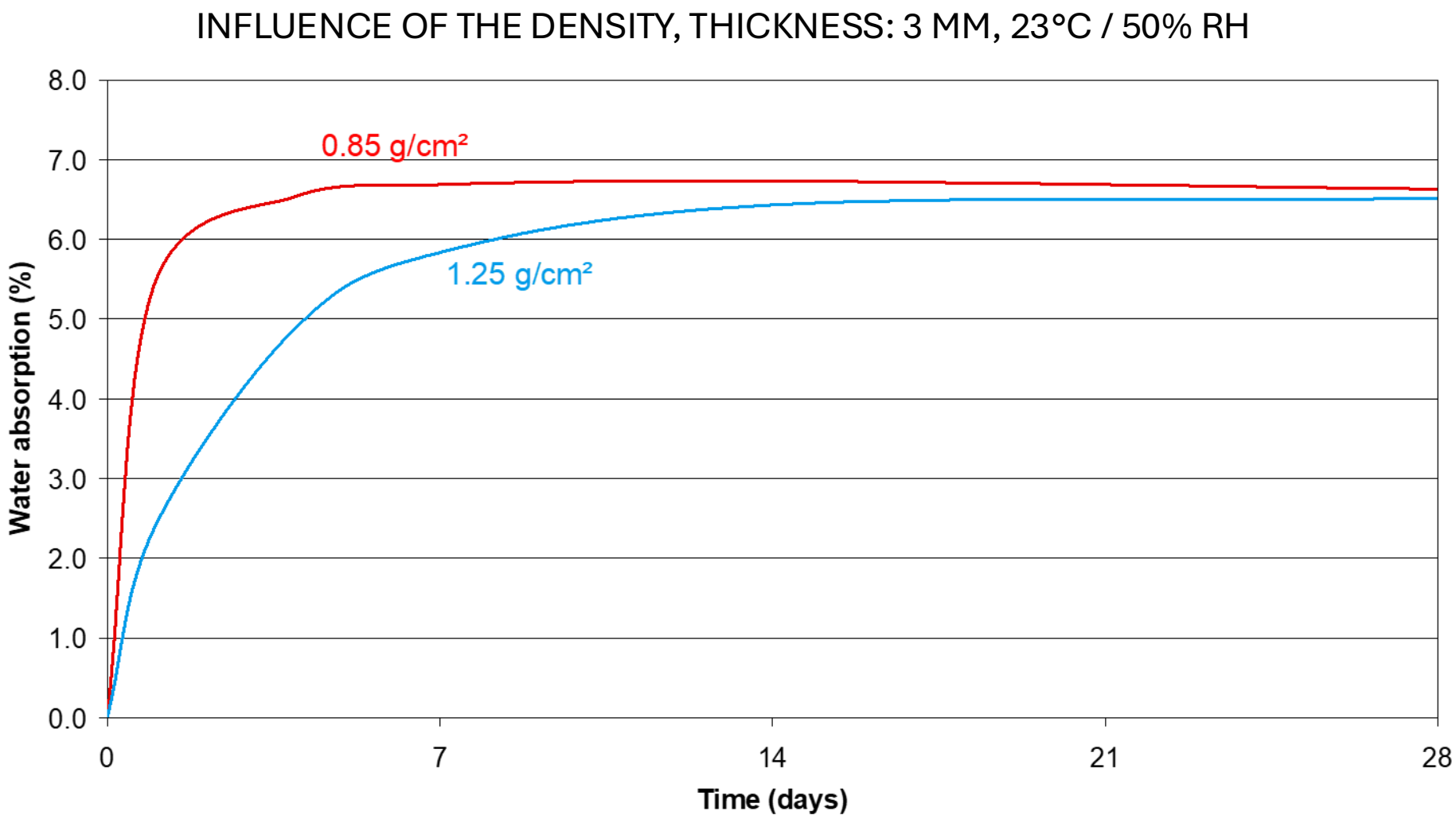

MOISTURE ABSORPTION

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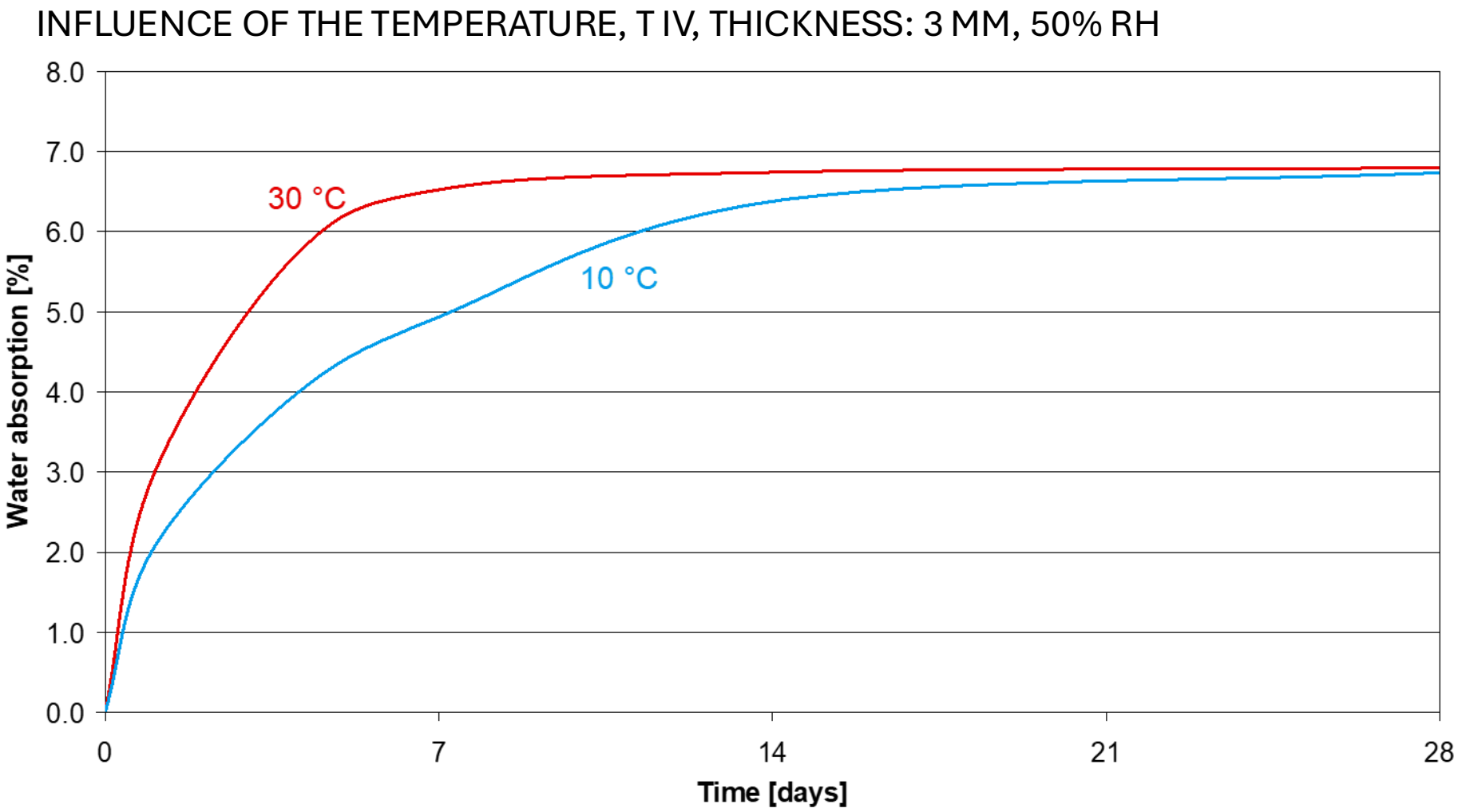
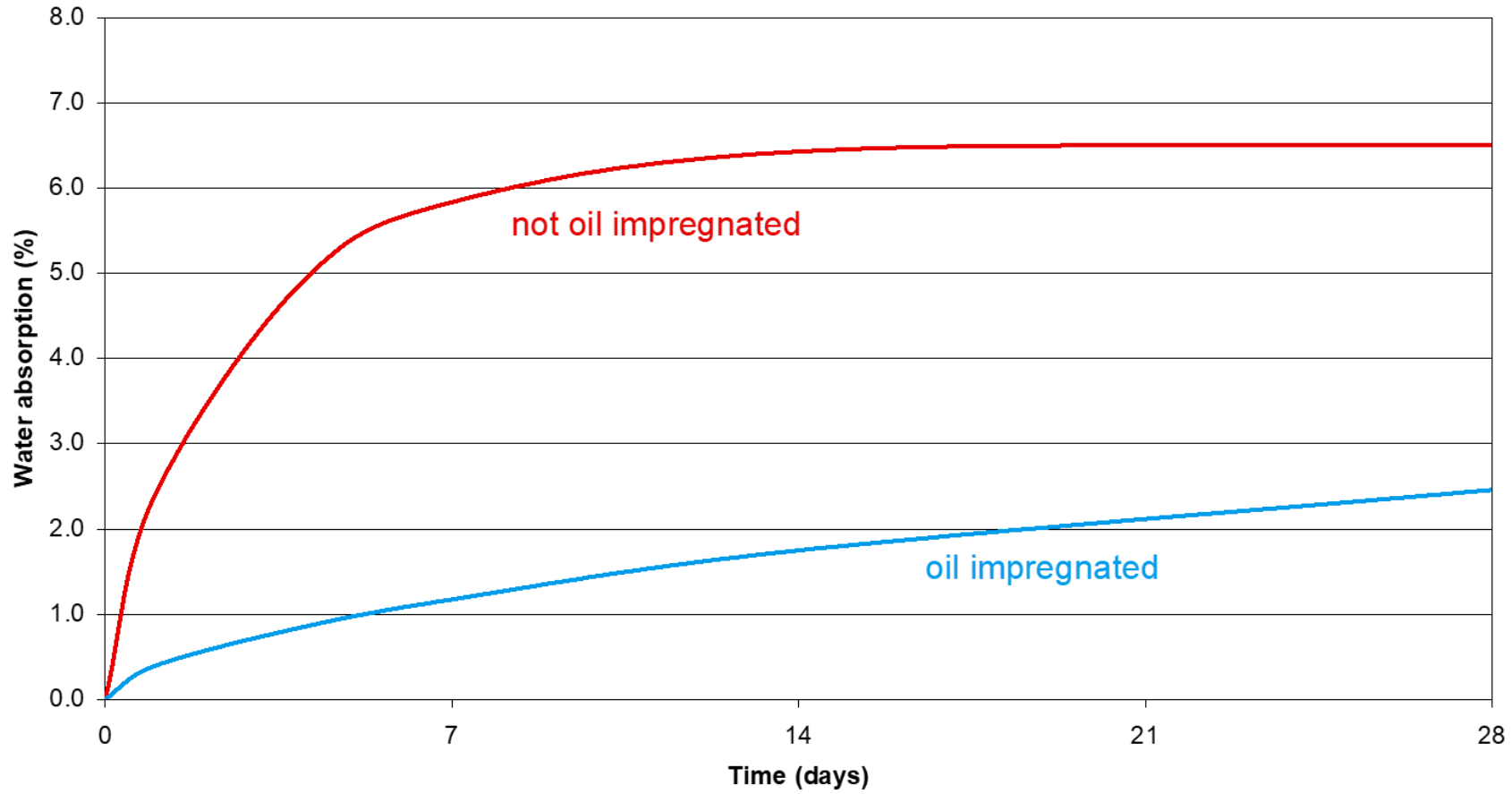


MOISTURE ABSORPTION

HOW FAST IS WATER ABSORBED?

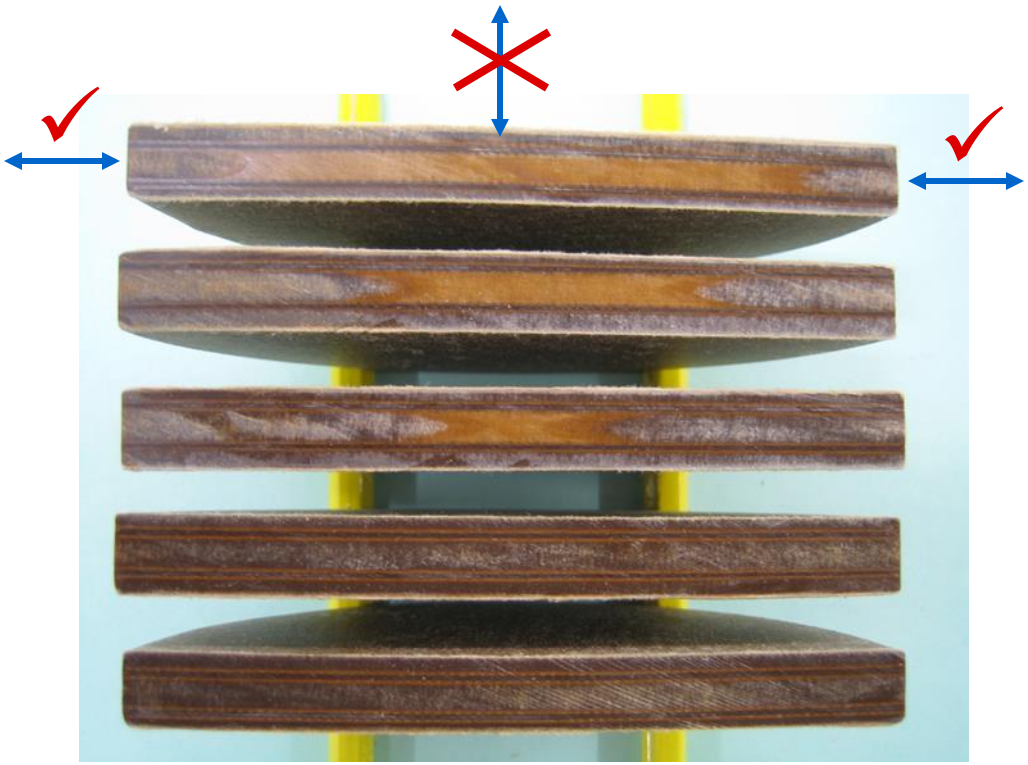
INFLUENCE OF THE OIL, T IV, THICKNESS: 3 MM, 25°C / 50% RH

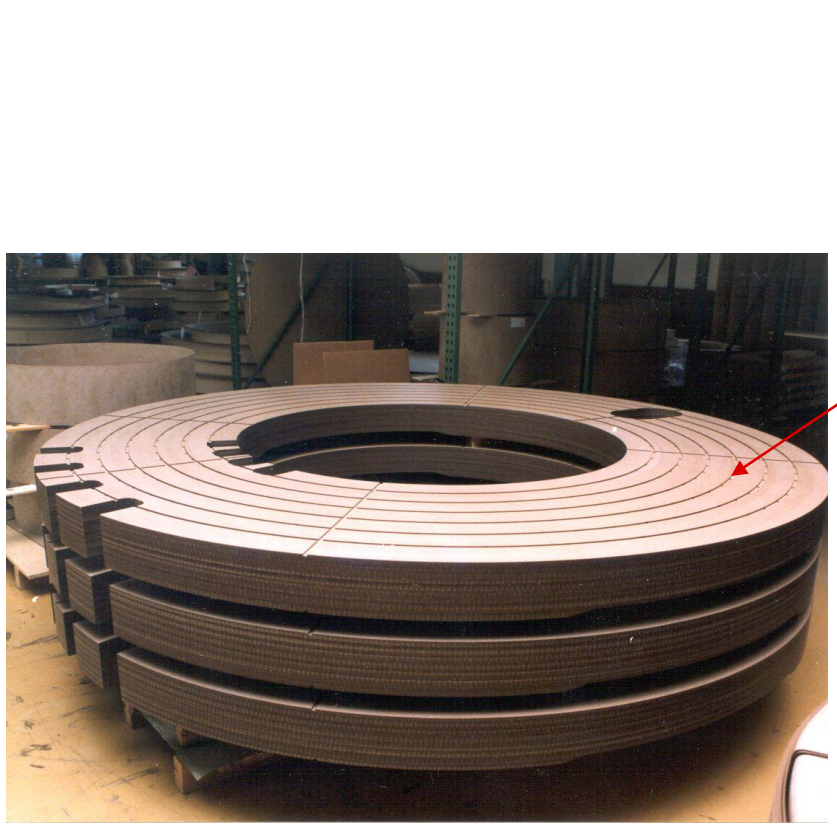


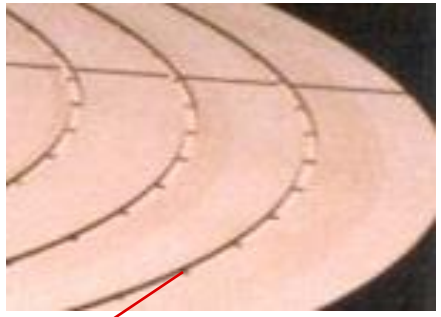
MOISTURE ABSORPTION

MUCH MORE COMPLICATED FOR LAMINATED BOARD

Glue lines act like barriers. Neither water nor oil can penetrate.
Thus, laminated pressboard products are equipped with drying and impregnation holes.





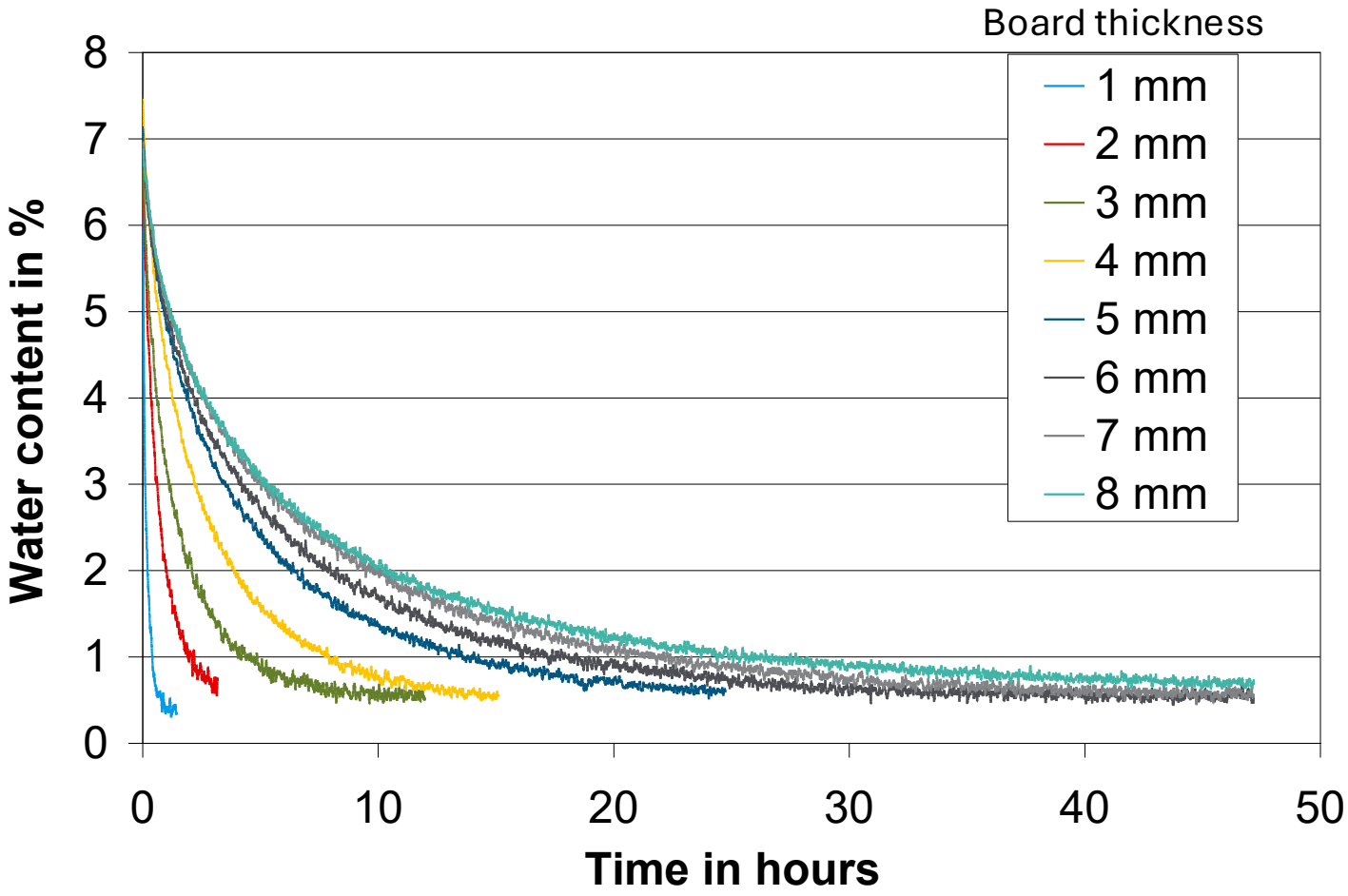


Clamping rings

MOISTURE ABSORPTION

HOW FAST CAN WATER BE REMOVED FROM TRANSFORMERBOARD

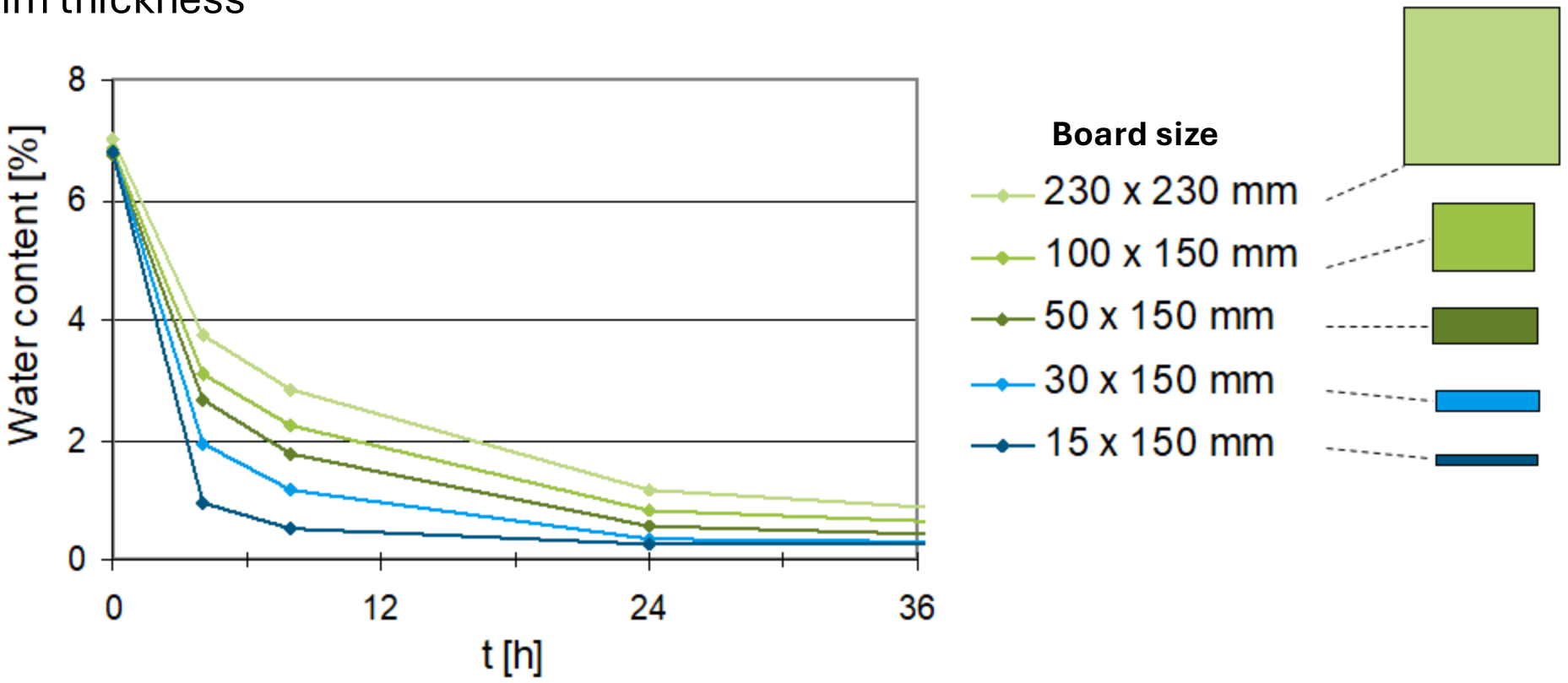
Method: hot air drying (105 °C), with forced air circulation
Sample: TIV, 200 x 200 mm



MOISTURE ABSORPTION

HOW FAST CAN WATER BE REMOVED FROM TRANSFORMERBOARD

Method: hot air drying (105°C), with forced air circulation
Sample: TIV, 8 mm thickness

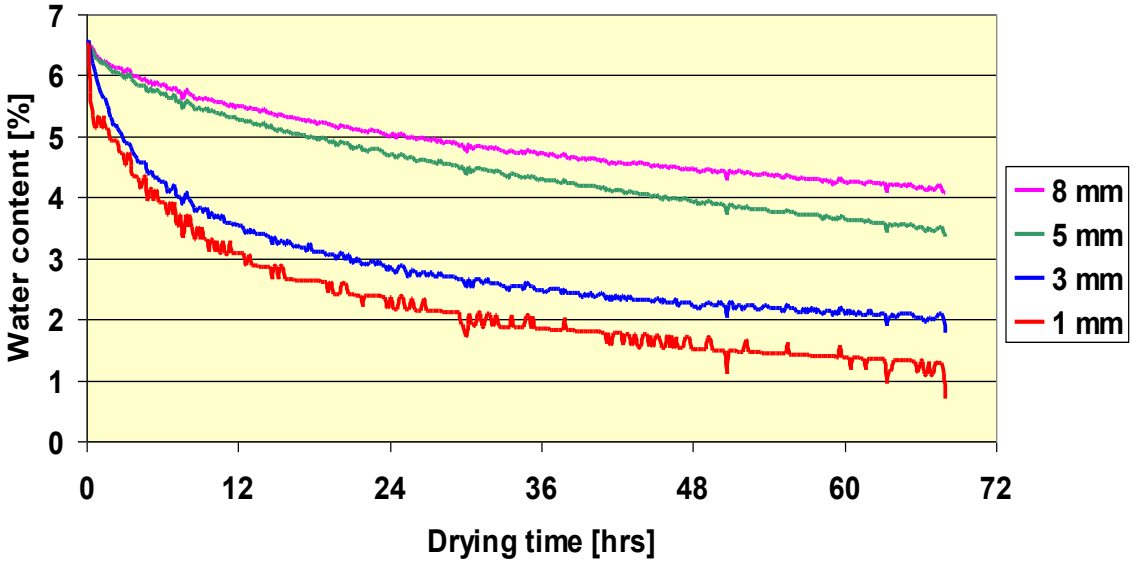


MOISTURE ABSORPTION

HOW FAST CAN WATER BE REMOVED FROM TRANSFORMERBOARD

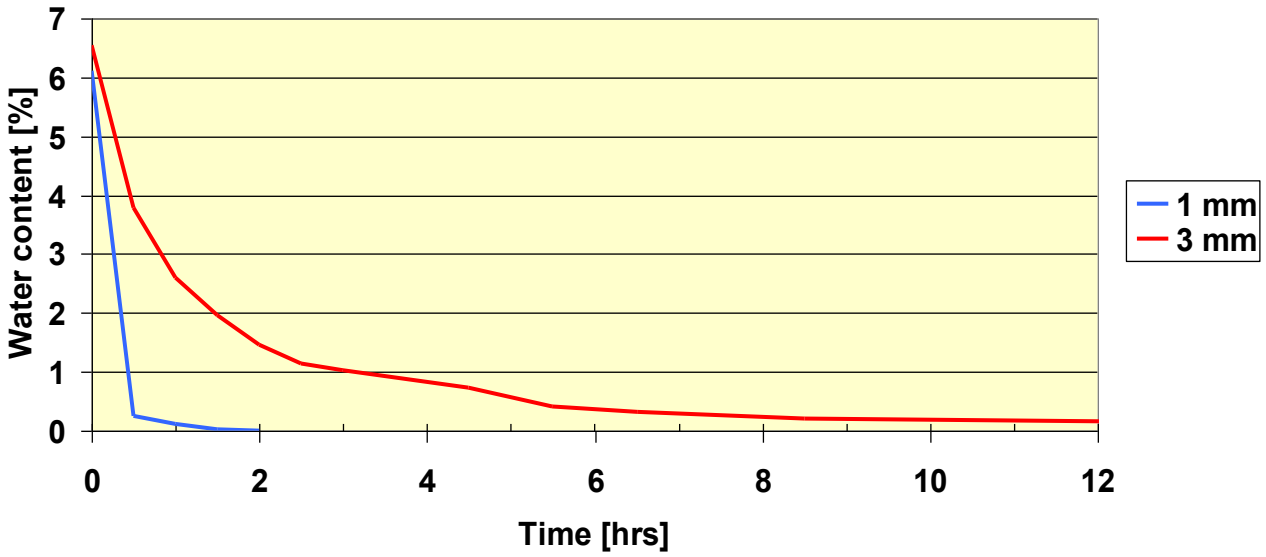
Drying of non impregnated Transformerboard TIV

Temperature: 23°C; Pressure: 0.5 mbar



Drying of non impregnatede Transformerboard T IV

Temperature: 105°C; Pressure: 1 mbar



AGENDA

01 Water and cellulose

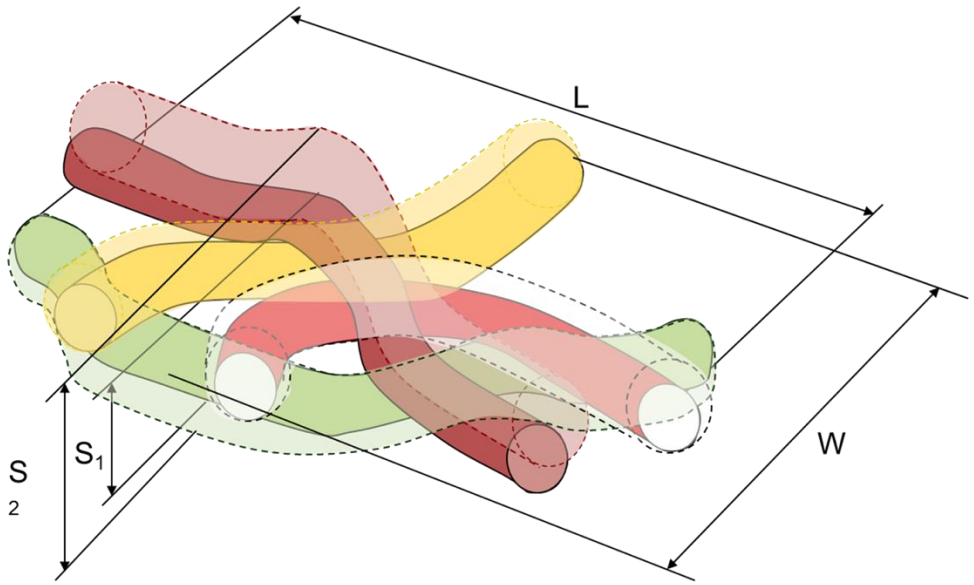
02 Moisture absorption

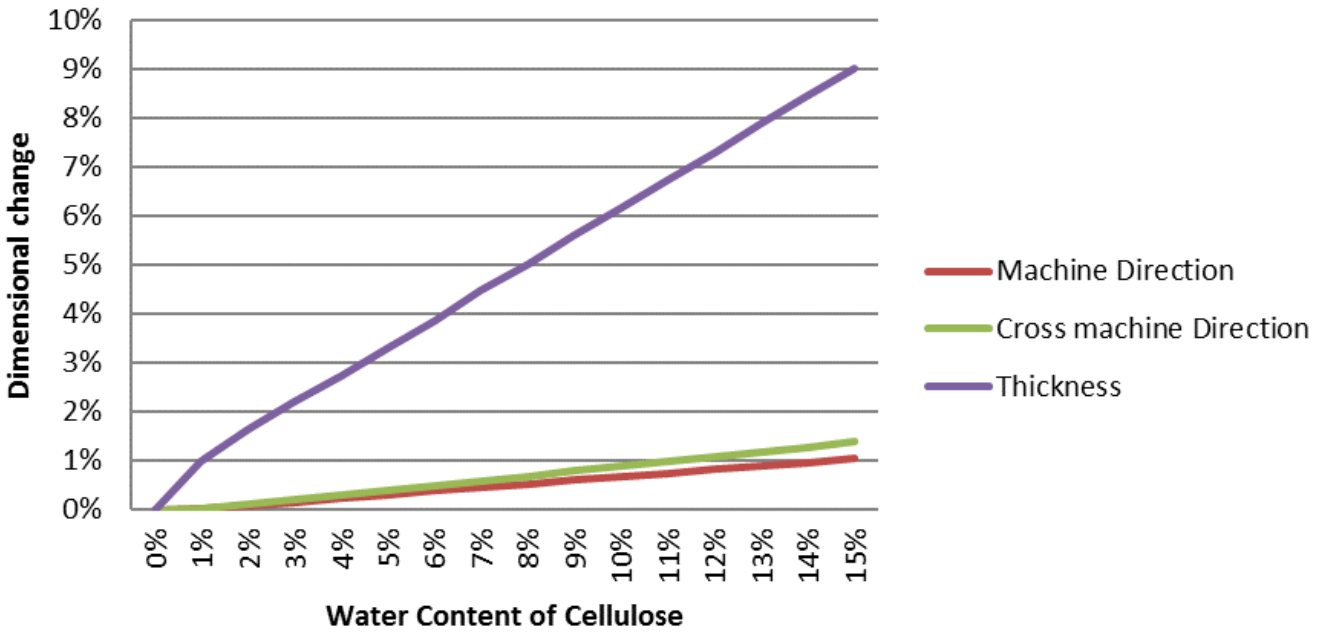
03 **Consequences of water absorption**

CONSEQUENCES OF MOISTURE ABSORPTION

SHRINKAGE AND SWELLING

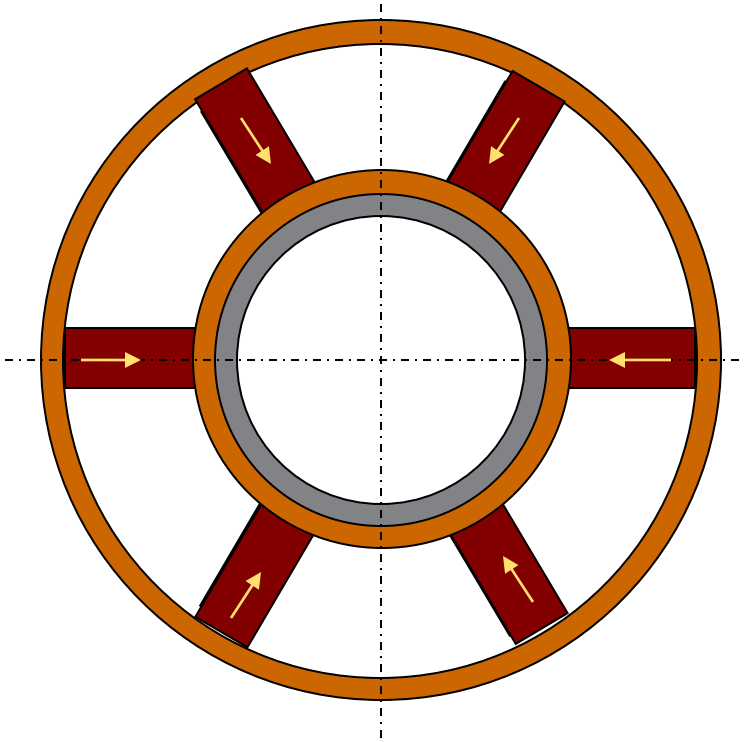
- Water absorption leads to a swelling of the material. Rule of the thumb: 6% water absorption leads to a growth of 0.4% in length and 4% in thickness.
- Shrinkage and swelling is not a completely reversible process. Several cycles of shrinkage and swelling leads to a small net shrinkage





CONSEQUENCES OF MOISTURE ABSORPTION

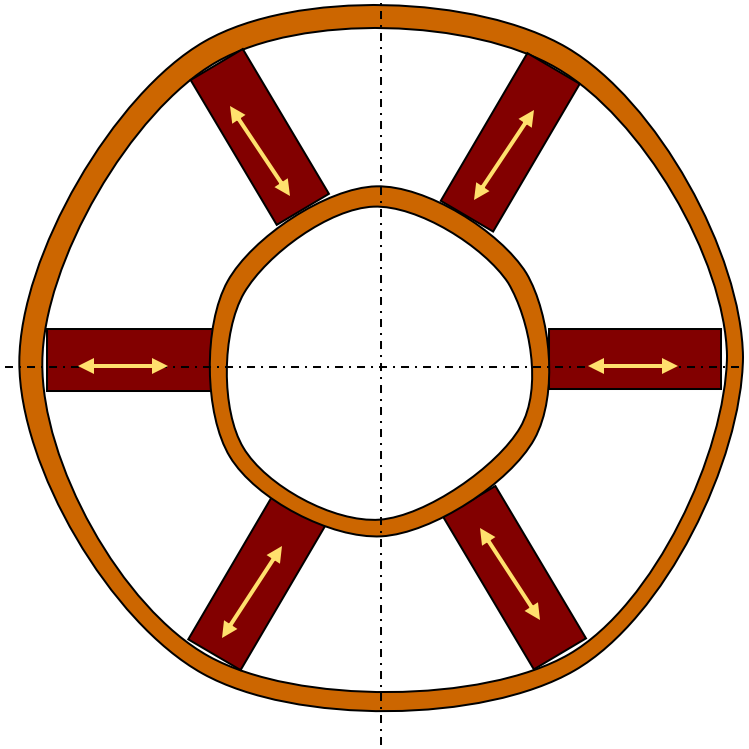
HOW DOES THE WATER CONTENT INFLUENCE THE GEOMETRY OF A PART?



- Metallic solid core
- Spacing elements and a barrier
- Assembled in e.g., 20°C and 50%rH, parts contain 6% water
- Drying in oven after assembly
- Barrier becomes loose
  - Spacers shrink ≈ 3%
  - ID of barrier shrinks ≈ 0.4%
  → gap ≈ 2.6% * h_{Spacer}

CONSEQUENCES OF MOISTURE ABSORPTION

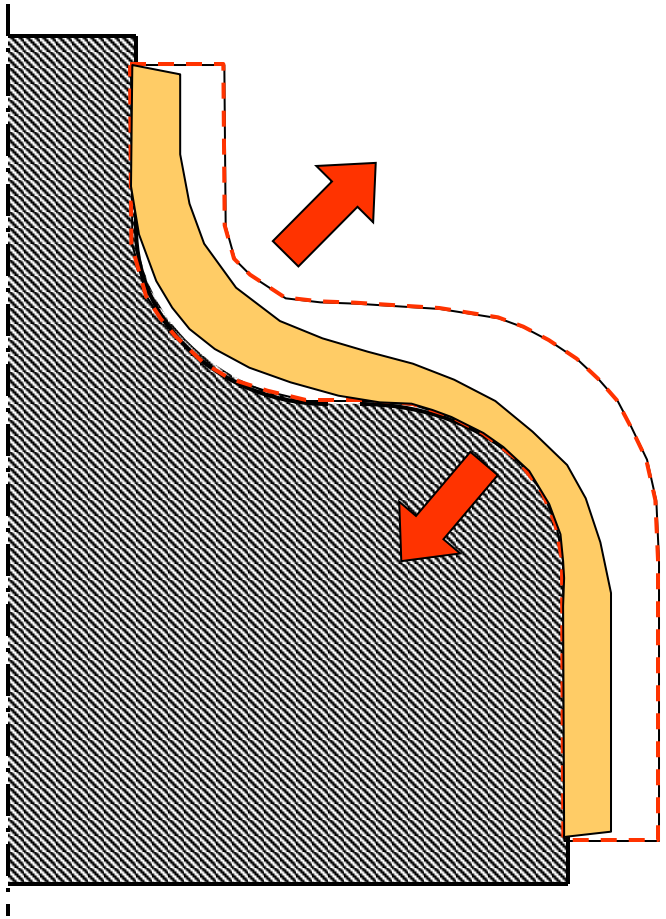
HOW DOES THE WATER CONTENT INFLUENCE THE GEOMETRY OF A PART?



- No metallic core
- Spacers and 2 concentric tubes
- Oven dried parts assembled; parts contain <1% water
- Exposure to humidity 20°C/50%rH
- Both tubes are deformed
  - Spacers grow ≈ 3%
  - circumference of barrier grows ≈ 0.4%

CONSEQUENCES OF MOISTURE ABSORPTION

HOW DOES THE WATER CONTENT INFLUENCE THE GEOMETRY OF A PART?

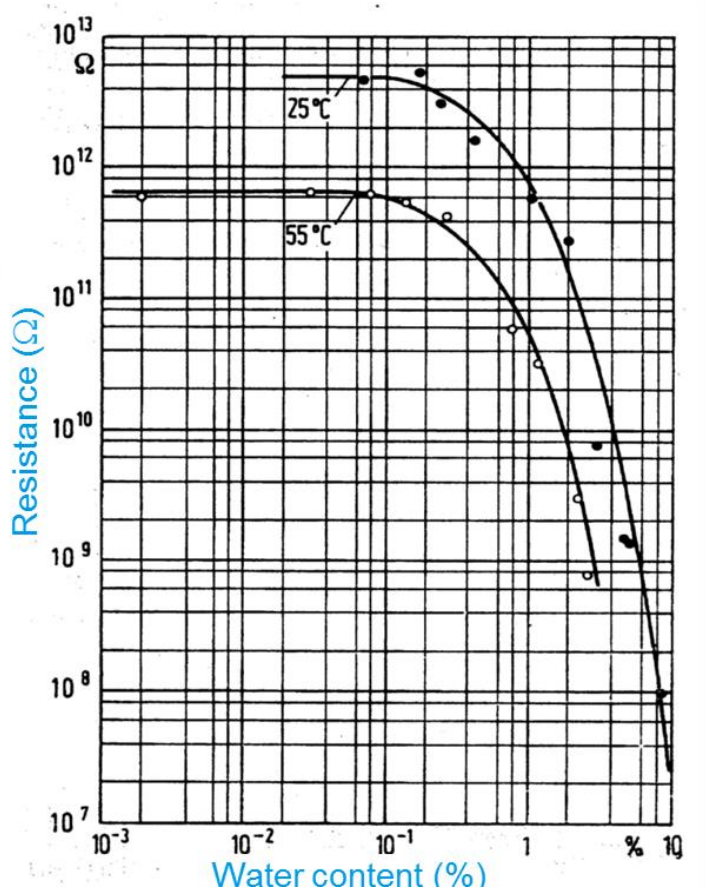


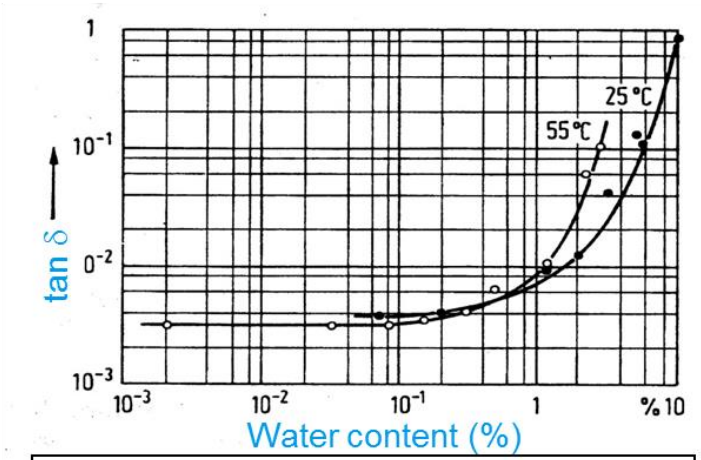
Shrinking of material during the molding process:

In tendency, the material shrinks off concave parts and is pressed to convex parts.

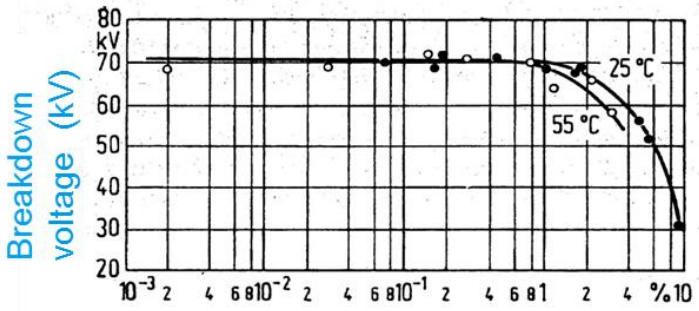
CONSEQUENCES OF MOISTURE ABSORPTION

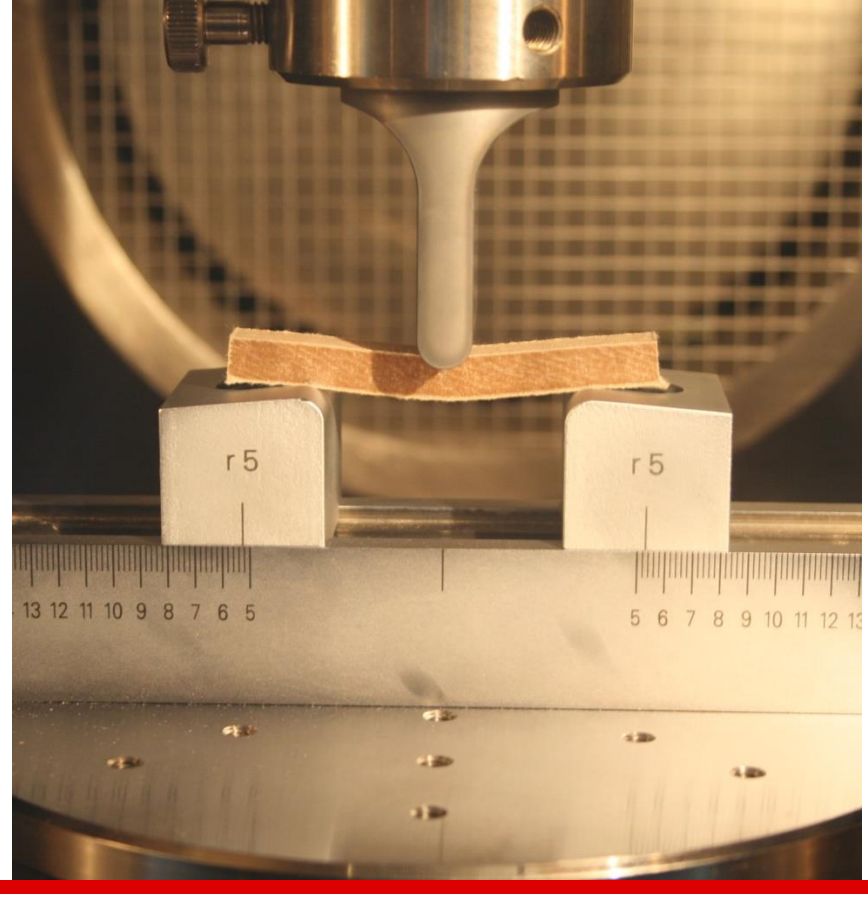
LOOSING OF INSULATION PROPERTIES





Oil impregnated paper





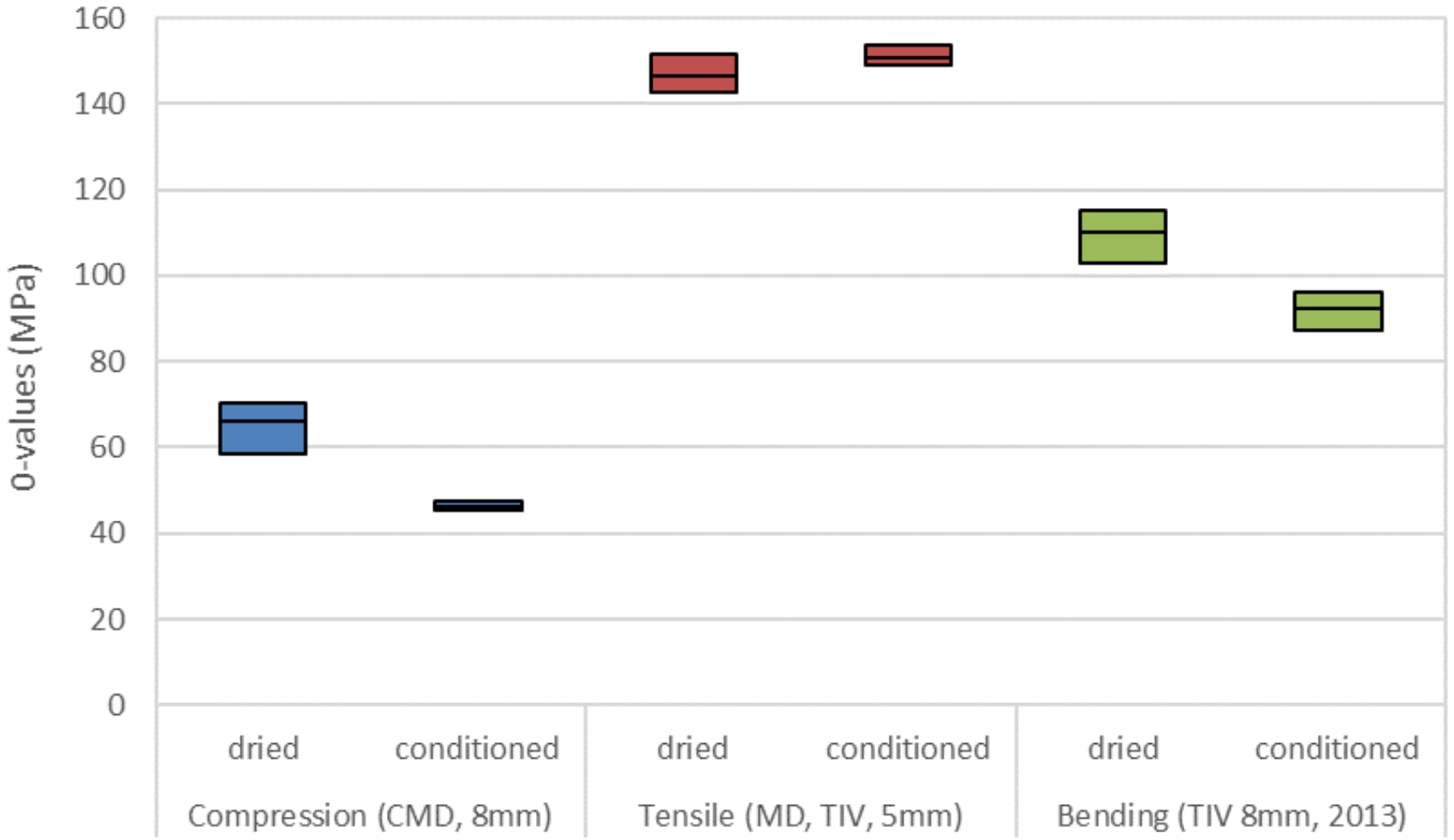
- Compression

- Tensile strength

- Bending strength

CONSEQUENCES OF MOISTURE ABSORPTION

HOW DOES THE WATER CONTENT INFLUENCE MECHANICAL PROPERTIES?



Tested at 23.5°C

CONSEQUENCES OF MOISTURE ABSORPTION

SUMMARY AND CONCLUSION

- Water in cellulose-based materials is associated with changes in its geometrical dimensions.
- Water in cellulose-based materials is associated with changes in its mechanical properties.
- Water in cellulose-based materials is associated with changes in its electrical properties.

AGENDA

01 Water and cellulose

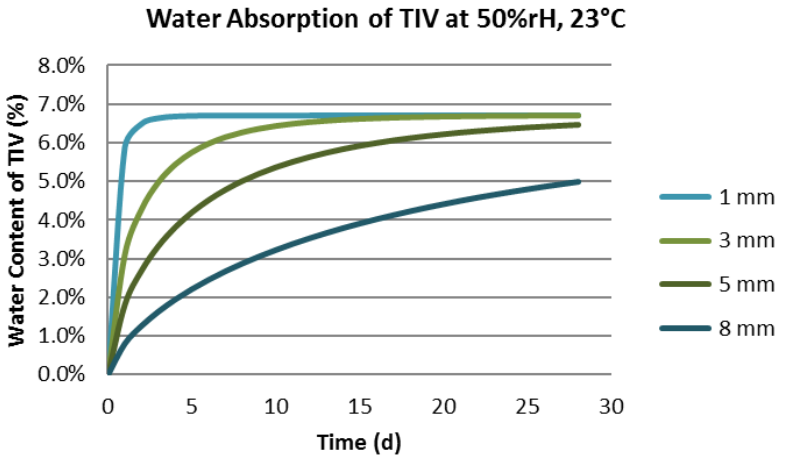
02 Moisture absorption

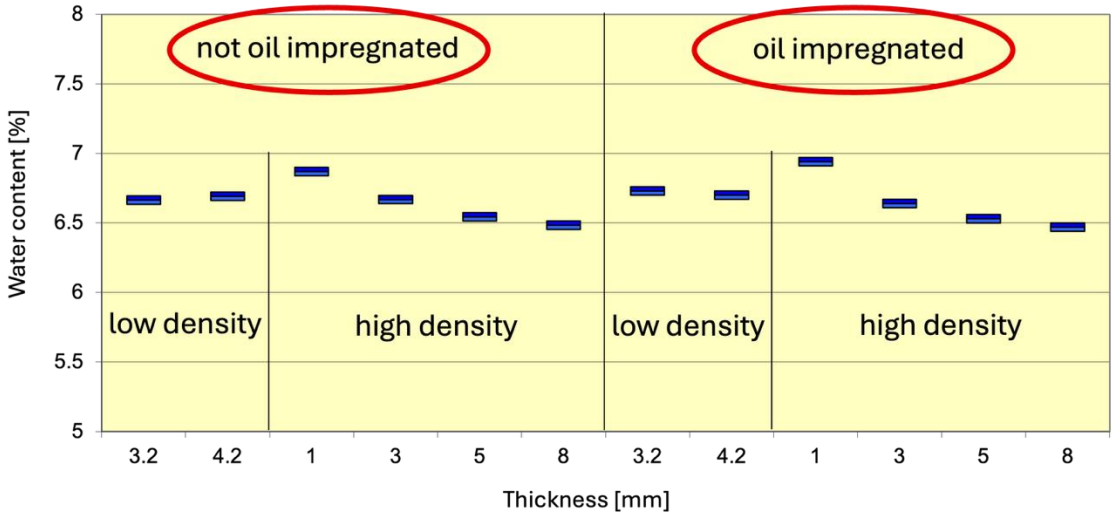
03 Consequences of water absorption

04 **Protection from water absorption**

PROTECTION FROM MOISTURE ABSORPTION

ABSORPTION RULES. JUST A QUESTION OF TIME.

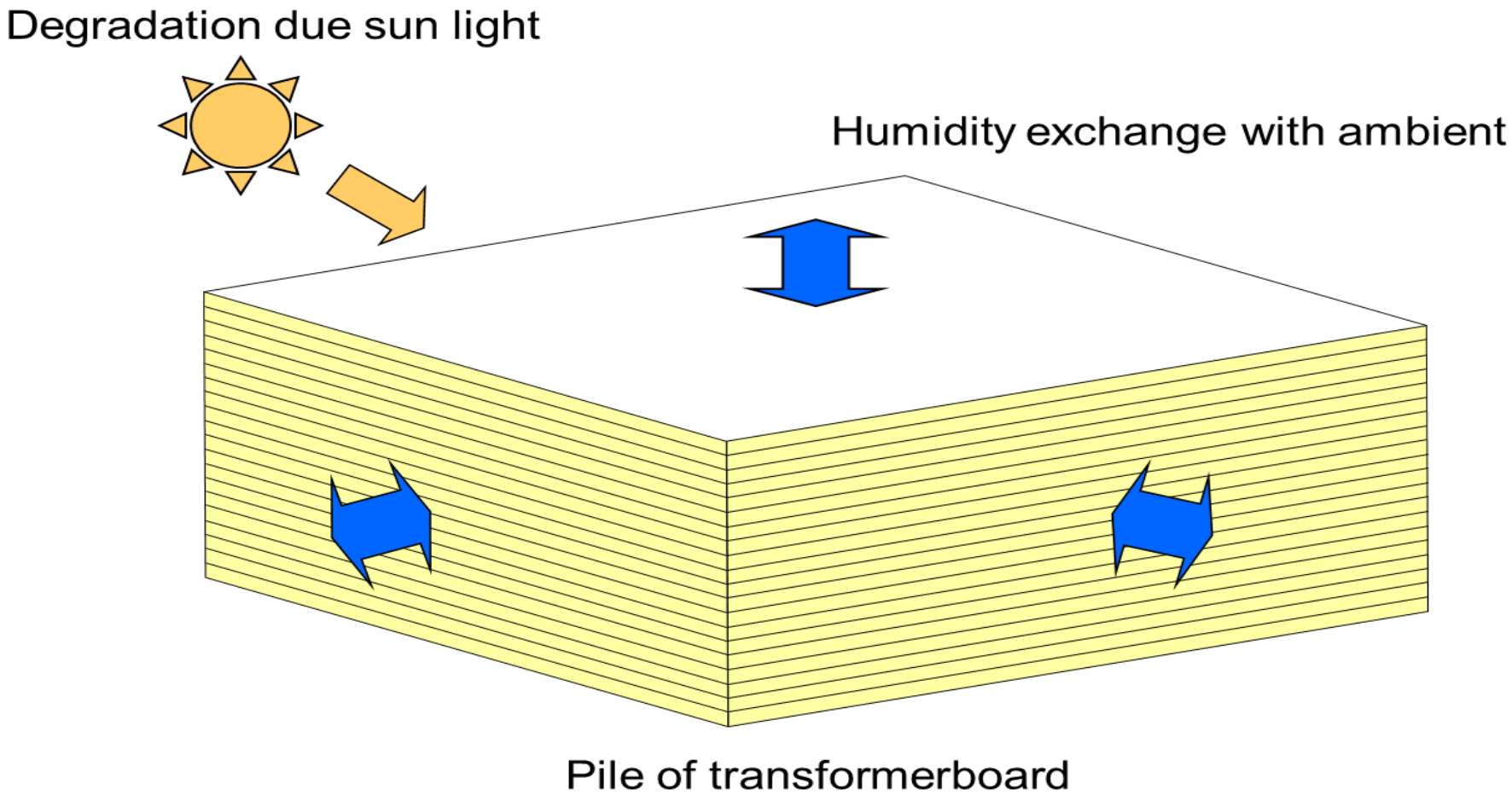




- Absorption and desorption of water by cellulose molecules – are natural processes.
- Depends on ambient conditions – equilibrium will be different.
- Absorption or drying needs time.
- Thinner board absorbs water faster than thick board.
- Low density board absorbs water faster than high density materials.
- Geometry matters: water is more easily absorbed from the edges (x/y) than through the sieve structure (z).
- Temperature matters: absorption occurs faster at a higher temperature, but it will not absorb more water.
- Almost the same “rules” are valid for drying.

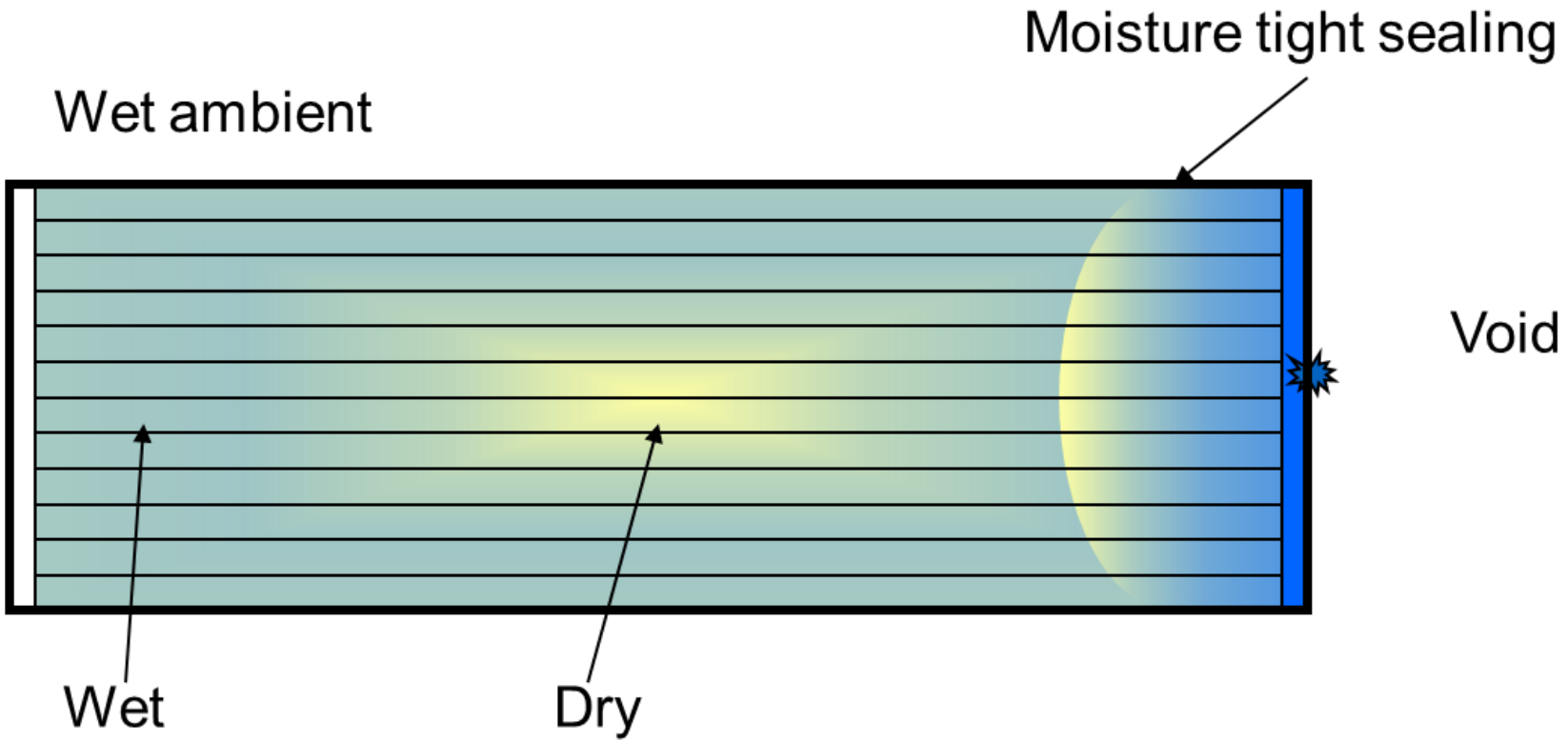
PROTECTION FROM MOISTURE ABSORPTION

AMBIENT CONDITION INFLUENCES



PROTECTION FROM MOISTURE ABSORPTION

MOISTURE DISTRIBUTION



Unequal moisture distribution leads
to dimension differences and/or mechanical tension

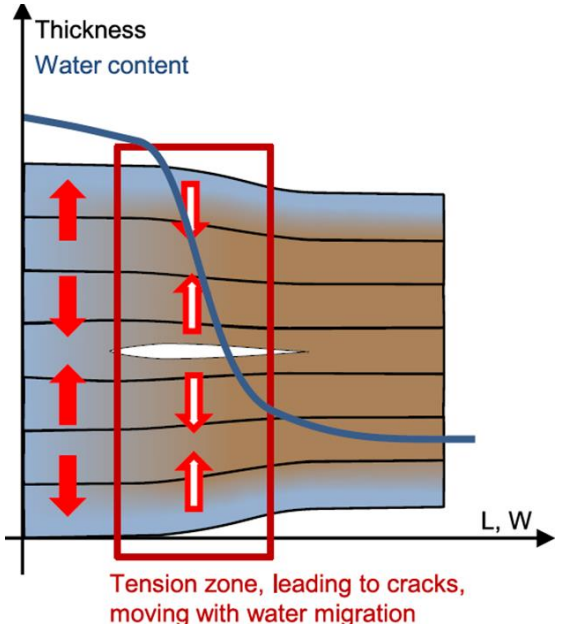
PROTECTION FROM MOISTURE ABSORPTION

REALITY AND HEADACHE

Warped material causes many troubles e.g., to produce precise components such as:

- Cylinders
- Strips and spacers
- Shields
- Washers

Thick laminated material, kept for a long time on stock bears the risk of invisible, internal cracks!
Water is absorbed at the cutting edge depending on the equilibrium to the ambient conditions.
The material is swelling in the saturated area.
These cracks are dangerous as they are not detectable from outside!



PROTECTION FROM MOISTURE ABSORPTION

PROPER PACKAGING MUST HAVE

Polyethylene film effectively slows water absorption. Two layers protect better than one.

Desiccant (silica gel) slows down / prevents water absorption as long as it is able to absorb water.

Oil impregnation does not reduce the mass of water absorbed – it only slows down the dimensional change over proportionally.

PROTECTION FROM MOISTURE ABSORPTION

PROPER STORING MUST HAVE

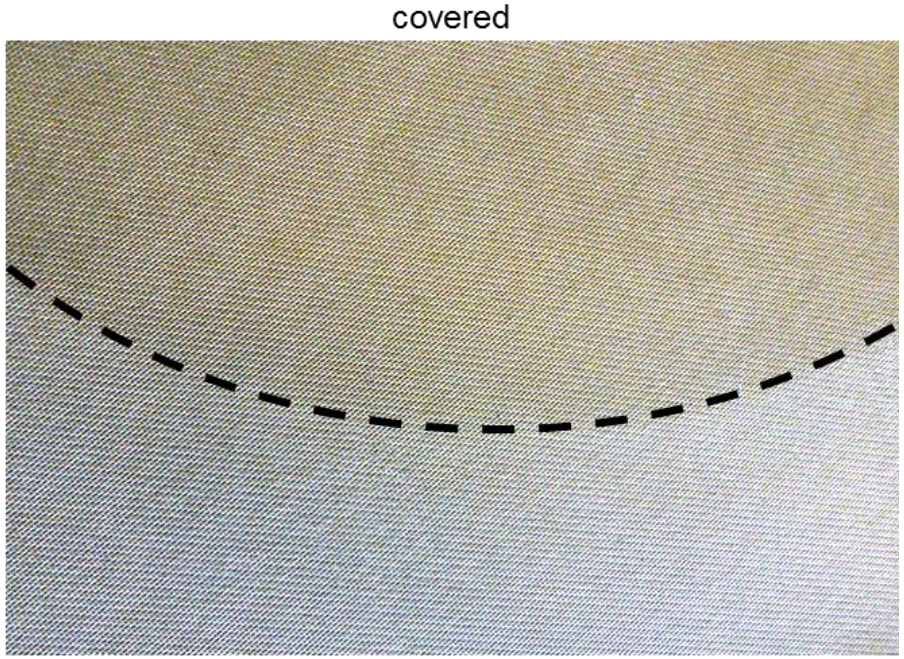
Dry – Cool – Dark – simple rules for proper storage location.

Store materials in original packaging – simple request to avoid further headache.

Avoid direct sunlight – prevent bleach out and loss of DP at surface.

Do not store near radiators or underneath overhead heaters

Protect from ventilation, i.e., do not store near open doors and windows



AGENDA

01 Water and cellulose

02 Moisture absorption and diffusion

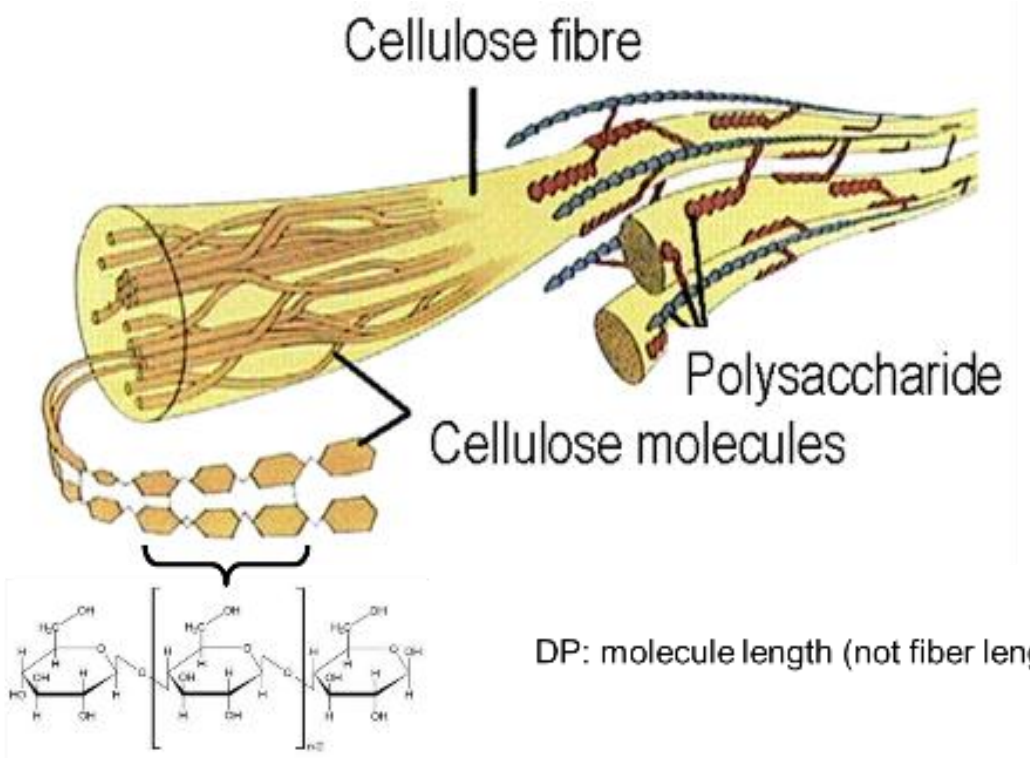
03 Consequences of water absorption

04 Protection from water absorption

05 **Lifetime expectancy**

LIFETIME EXPECTANCY

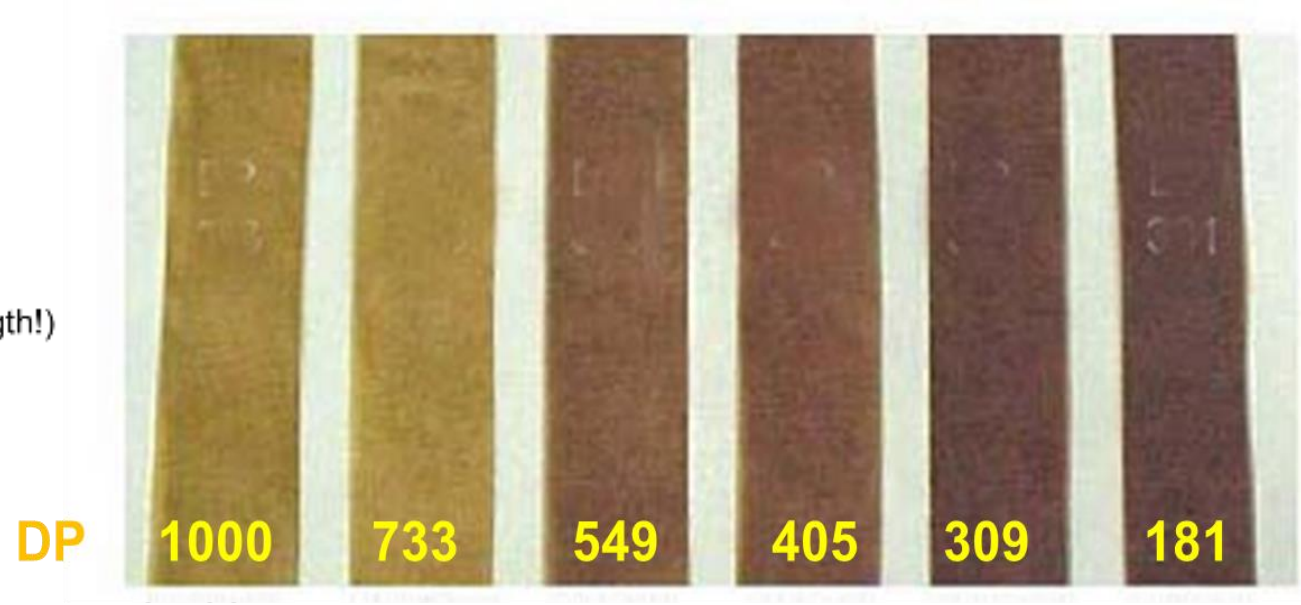
DEGREE OF POLYMERIZATION (DP VALUE)



The degree of polymerization (DP) is a measure of the length of the molecule (not the length of the fiber!)

DP value – can be determined by a variety of methods, usually evaluating the viscosity of the cellulose solution.

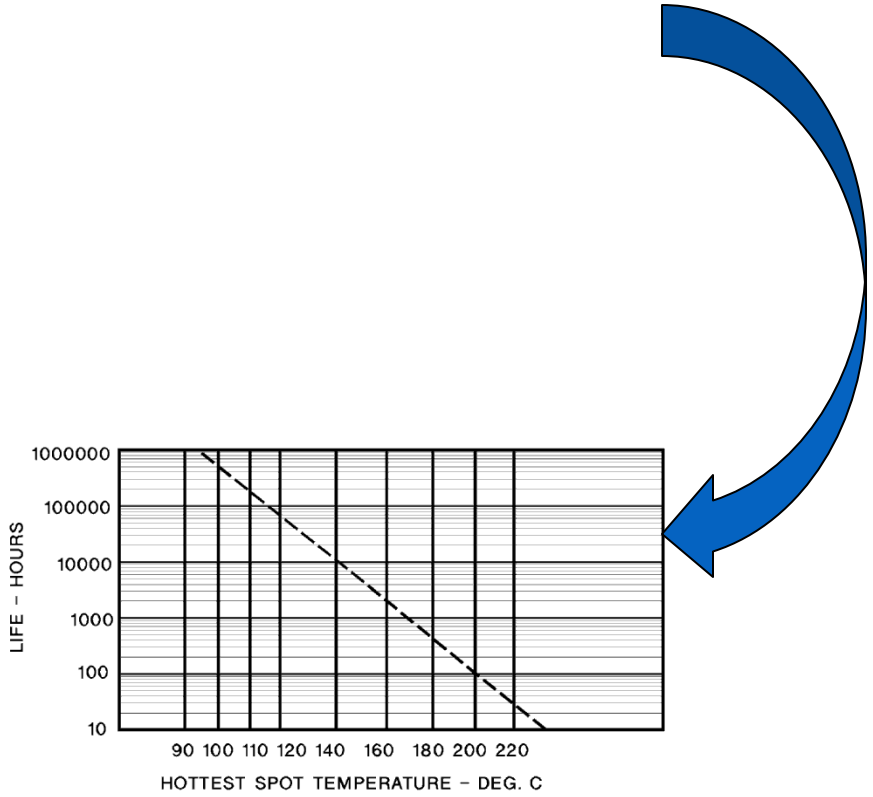
The degree of polymerization always decreases, CANNOT be increased.



LIFETIME EXPECTANCY

TEMPERATURE INFLUENCE

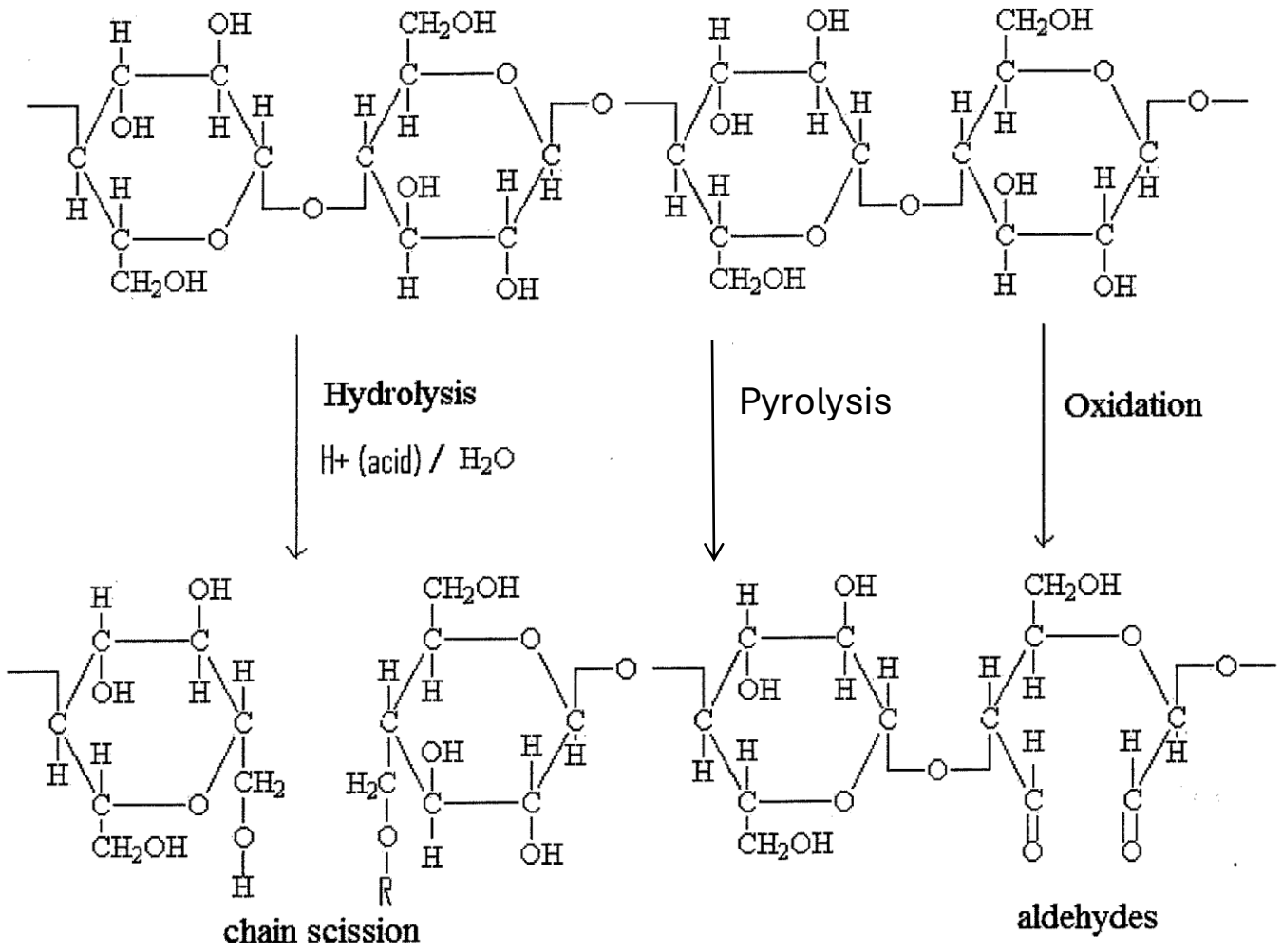
Arrhenius equation



Svante Arrhenius 1859 – 1927
Swedish chemist
Nobel prize winner 1903
Kinetics, electrolytic dissociation, meteorology (greenhouse effect), physiology, cosmology

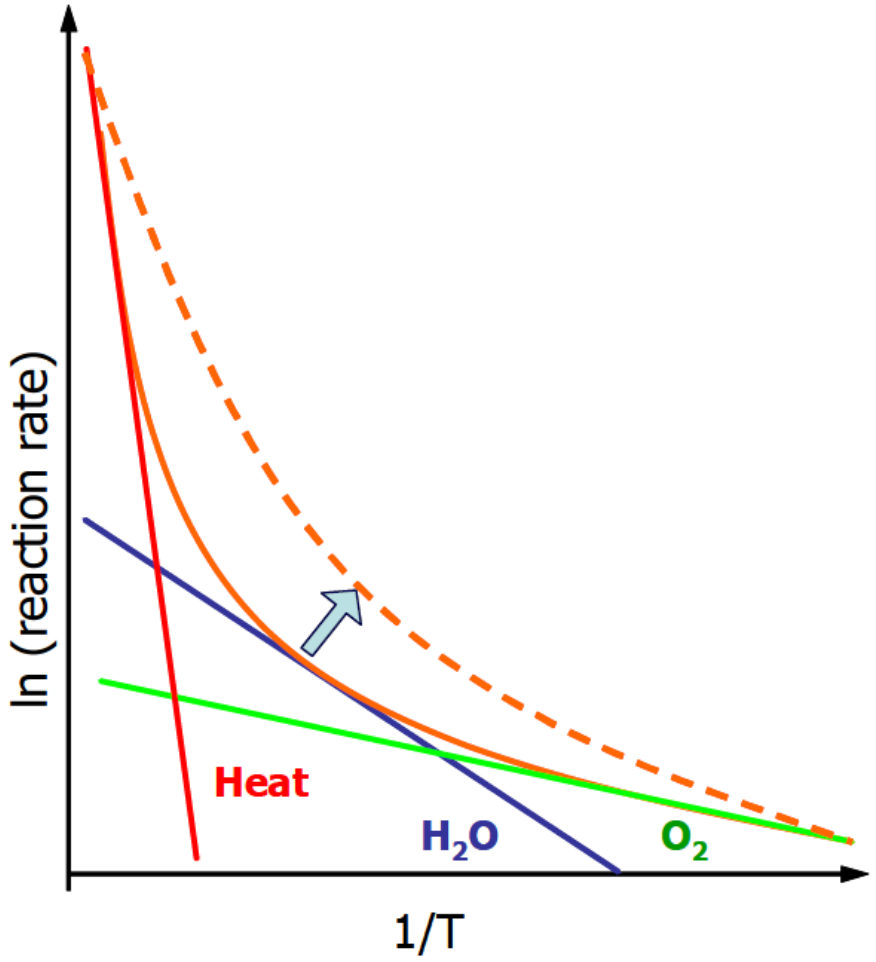
LIFETIME EXPECTANCY

PAPER AGING MECHANISMS



LIFETIME EXPECTANCY

AGEING MECHANISMS



[Cigré Brochure 323, 2007]

- Oxidation
- Hydrolysis
- Pyrolysis (> 140 °C)

LIFETIME EXPECTANCY

DRYING AND AGING

WATERY TRANSFORMERBOARD (>30%)

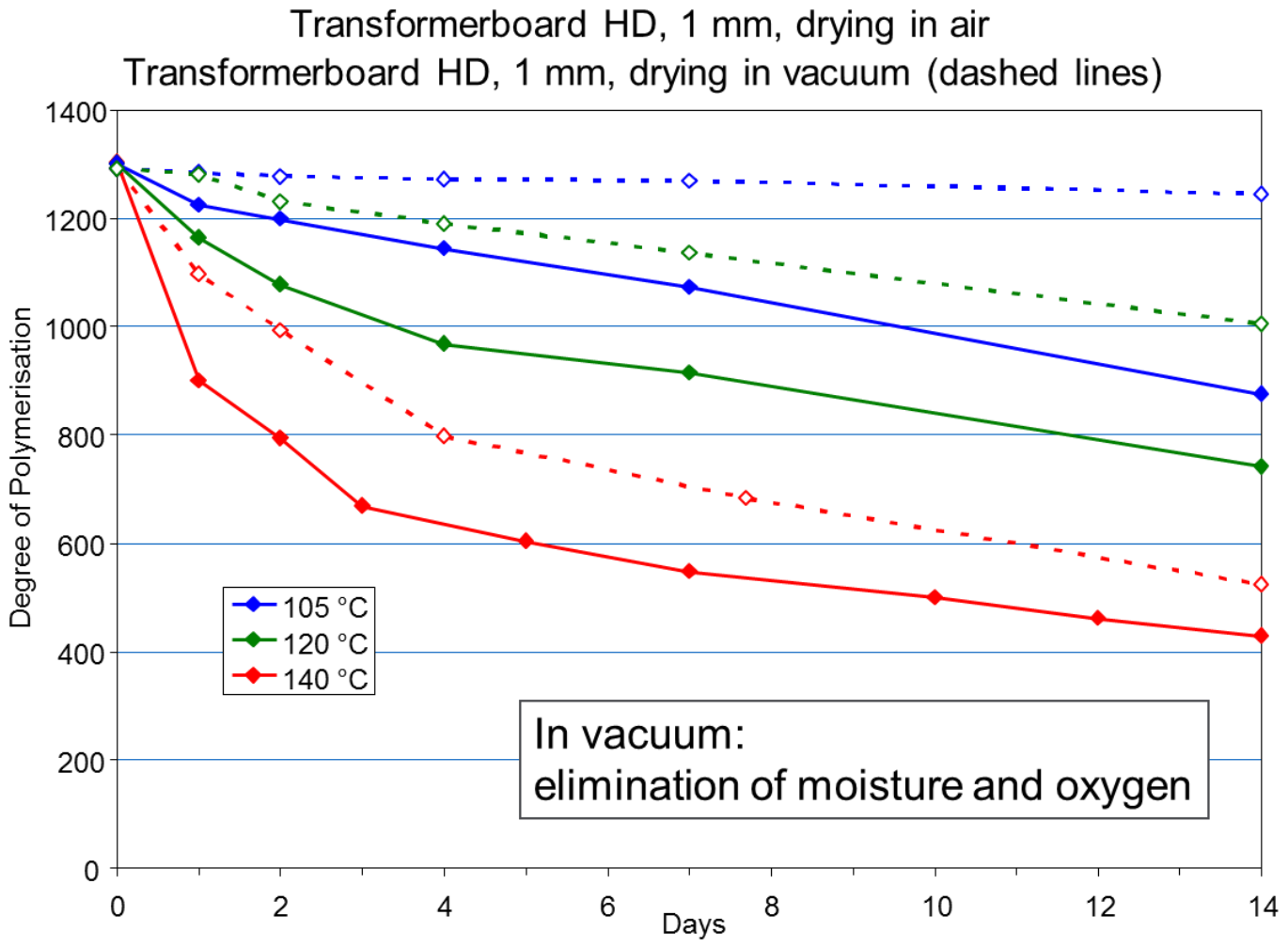
removing of ***free*** water, no degradation

WET TRANSFORMERBOARD

removing of ***bounded*** water / humidity, degradation, oxidation

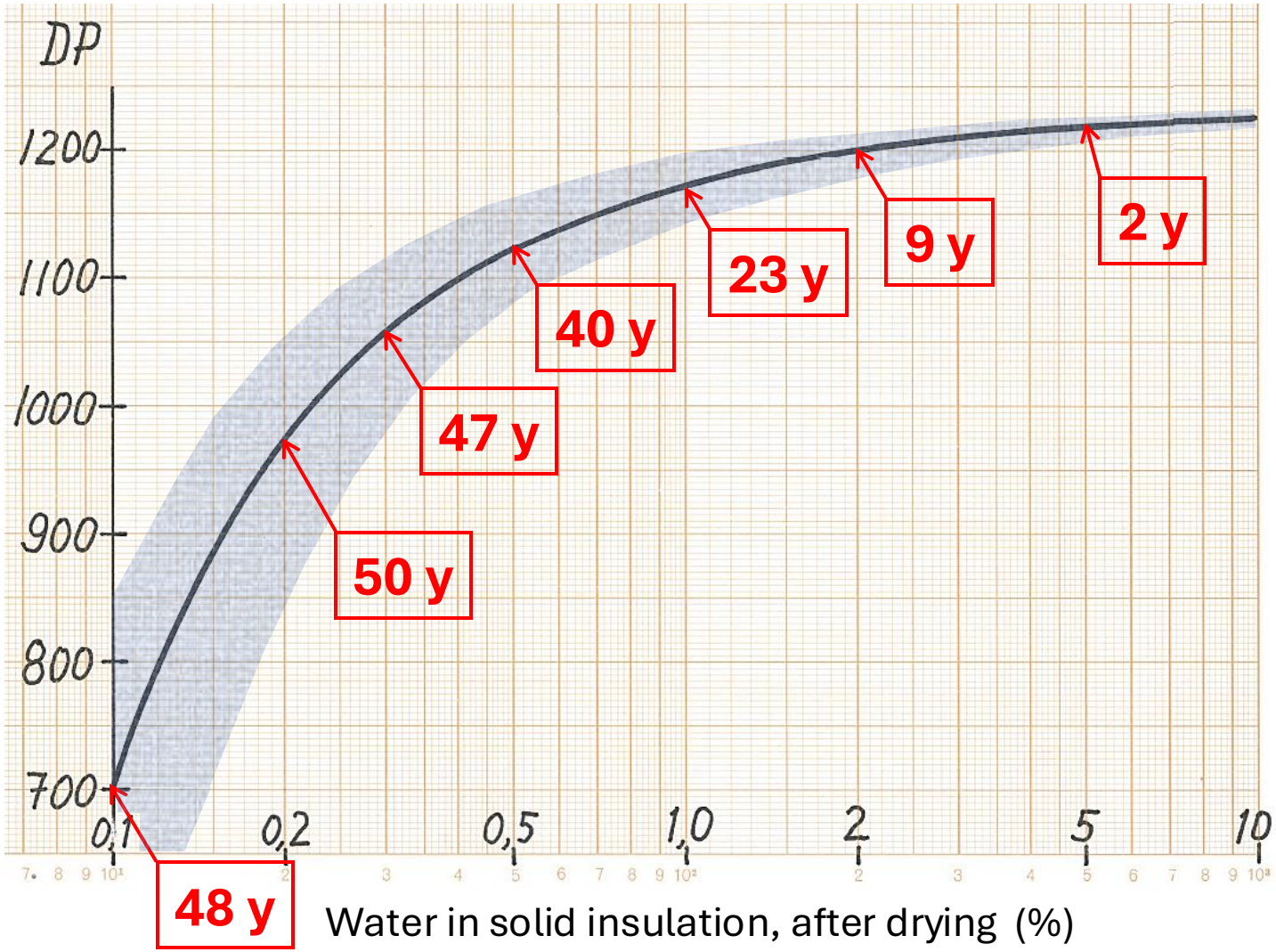
DRY TRANSFORMERBOARD

degradation, oxidation



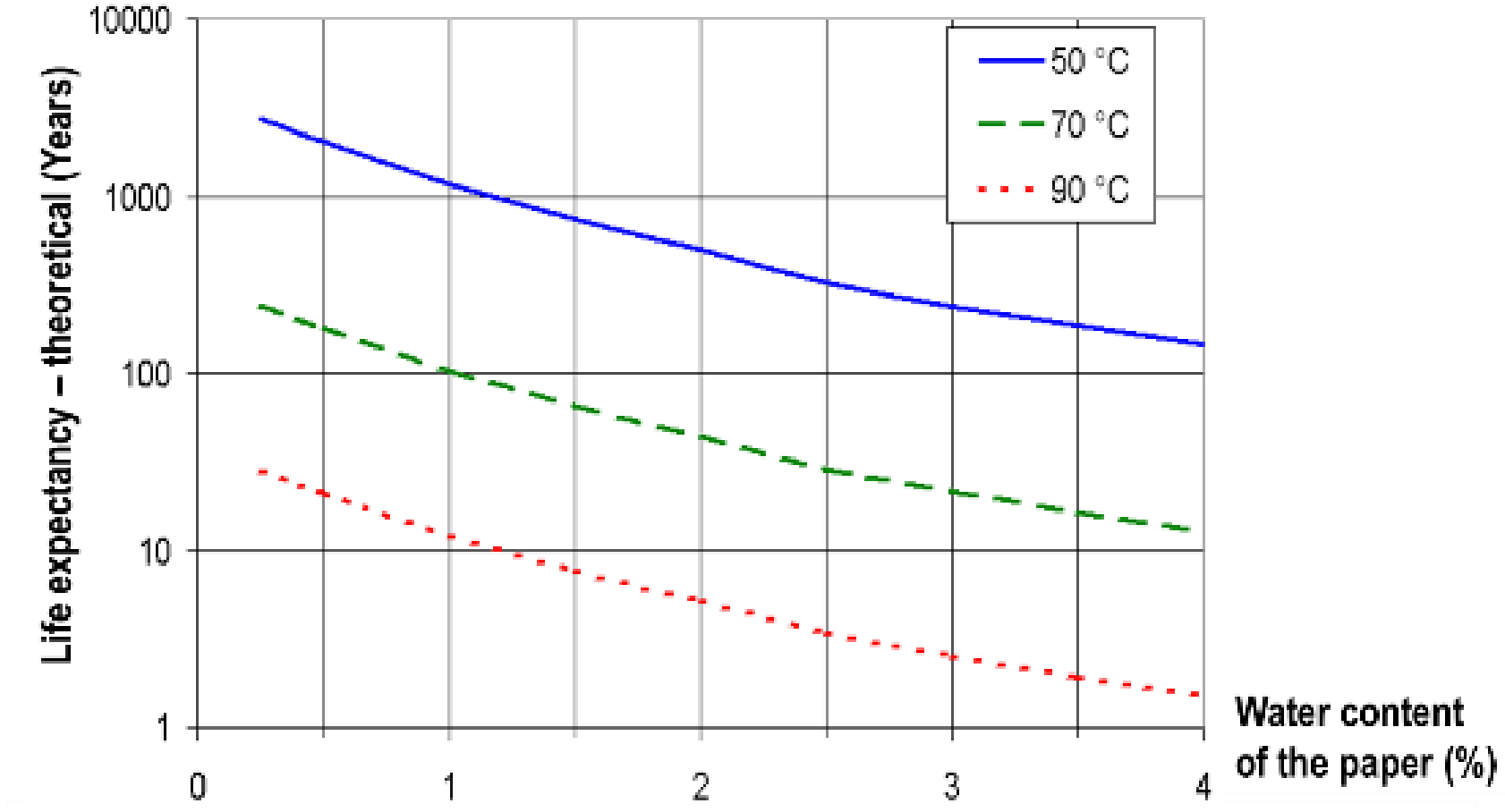
LIFETIME EXPECTANCY

DP VS MOISTURE CONTENT

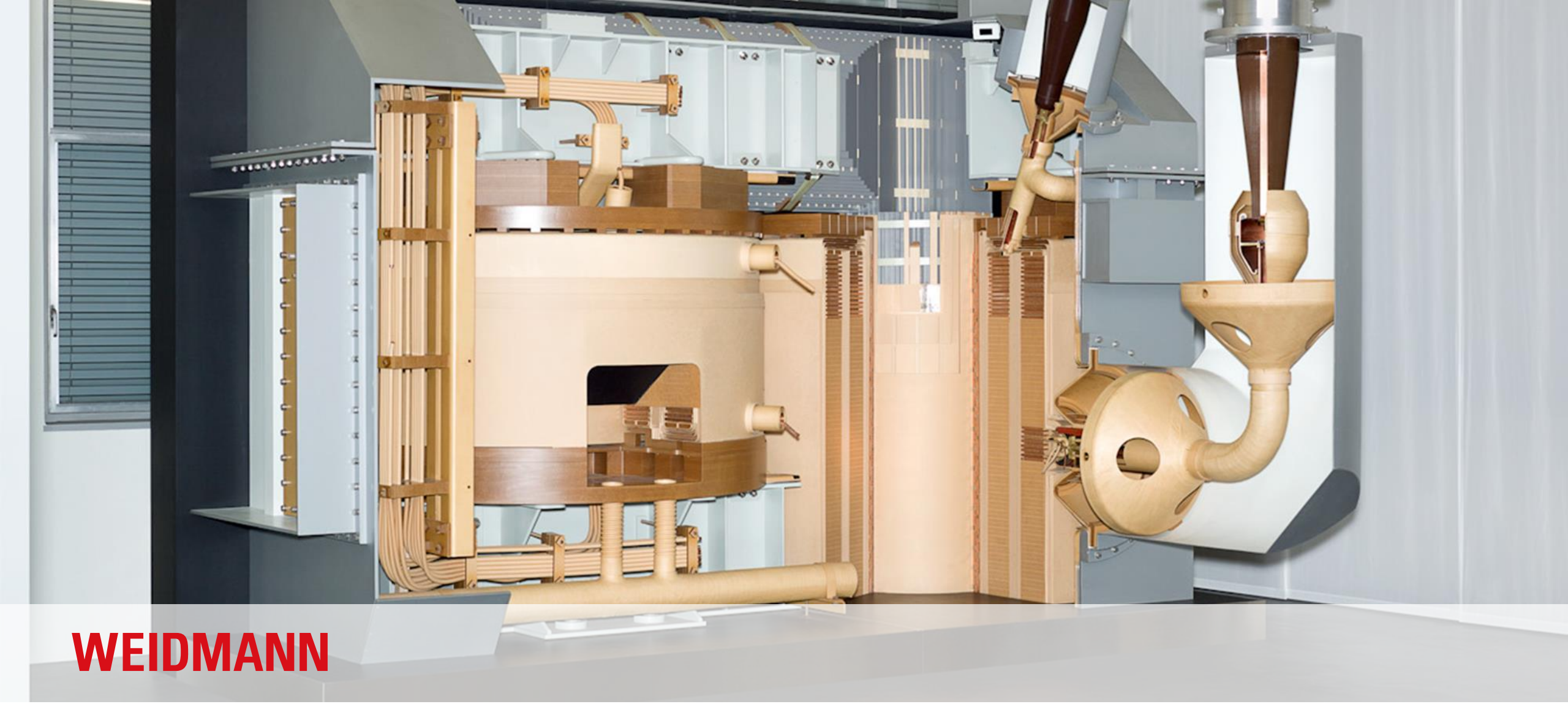


LIFETIME EXPECTANCY

AGING SPEED AT DIFFERENT MOISTURE CONTENT



Water and heat reduce the life expectancy significantly! Keep your transformer cool and dry!



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THANK YOU FOR YOUR ATTENTION!

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2. Ch. Krause, H.P. Gasser, T. Prevost, “Water Absorption of Cellulosic Insulating Materials used in Power Transformers,” ICSD, pp. 289–293, Winchester, 2007.

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