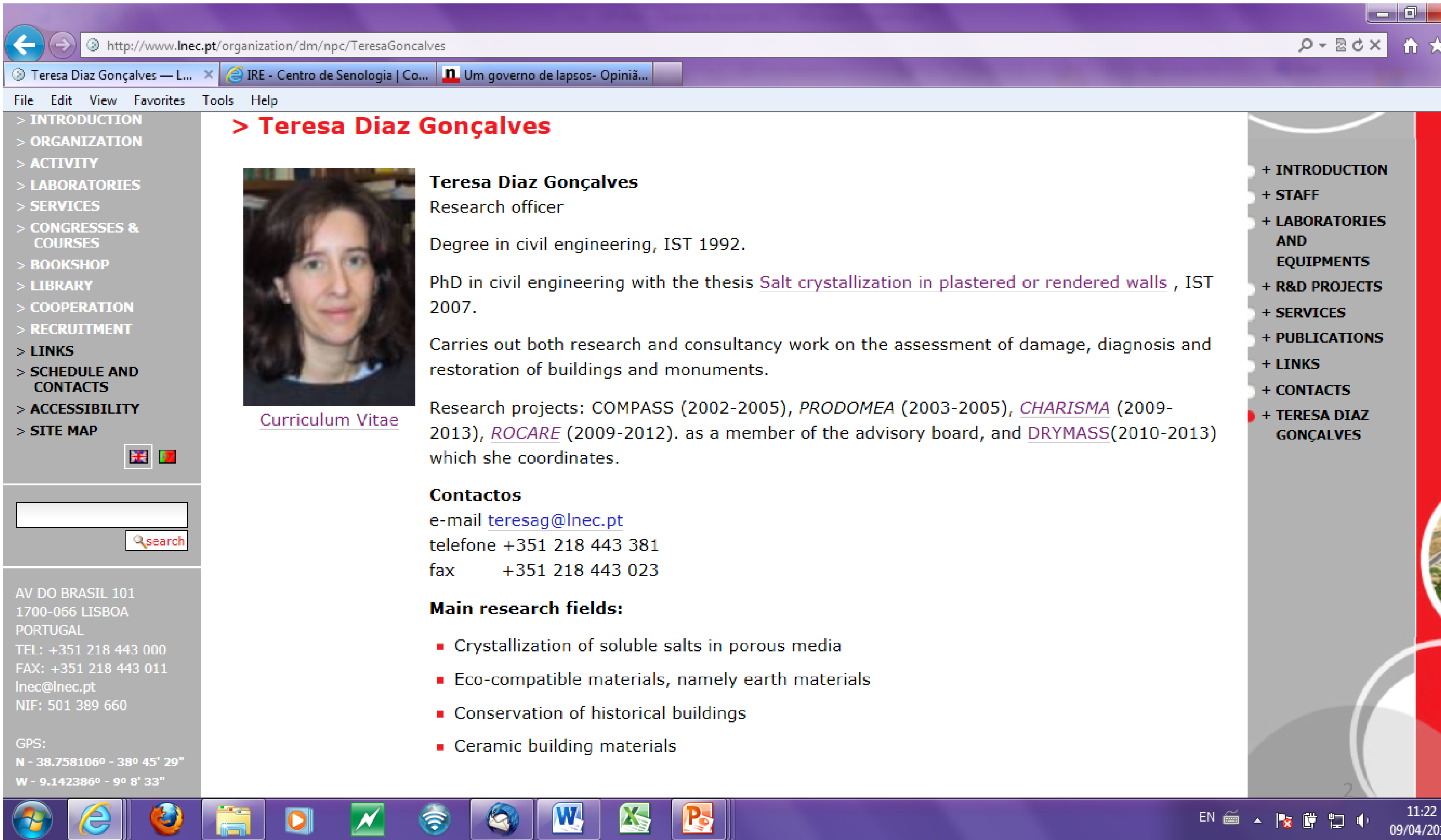
Drying of porous materials

Teresa Diaz Gonçalves

Drying of porous materials



> Teresa Diaz Gonçalves

Teresa Diaz Gonçalves
Research officer

Degree in civil engineering, IST 1992.

PhD in civil engineering with the thesis Salt crystallization in plastered or rendered walls , IST 2007.

Carries out both research and consultancy work on the assessment of damage, diagnosis and restoration of buildings and monuments.

Research projects: COMPASS (2002-2005), *PRODOMEA* (2003-2005), *CHARISMA* (2009-2013), *ROCARE* (2009-2012). as a member of the advisory board, and DRYMASS(2010-2013) which she coordinates.

Curriculum Vitae

Contactos
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telefone +351 218 443 381
fax +351 218 443 023

Main research fields:

- Crystallization of soluble salts in porous media
- Eco-compatible materials, namely earth materials
- Conservation of historical buildings
- Ceramic building materials

Drying of porous materials - Introduction

- stone
- ceramics
- mortars
- earth materials

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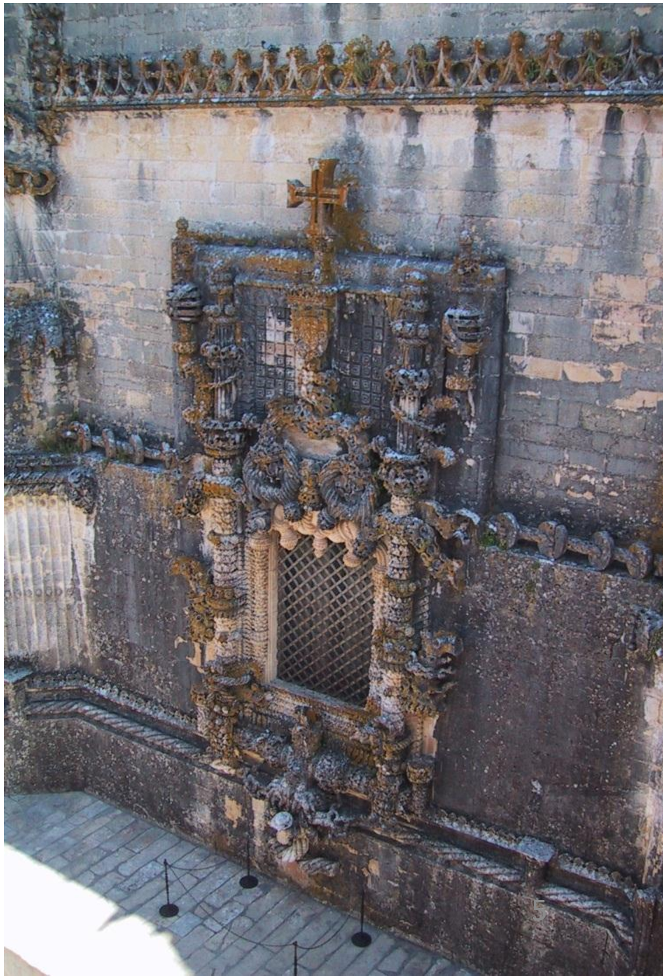
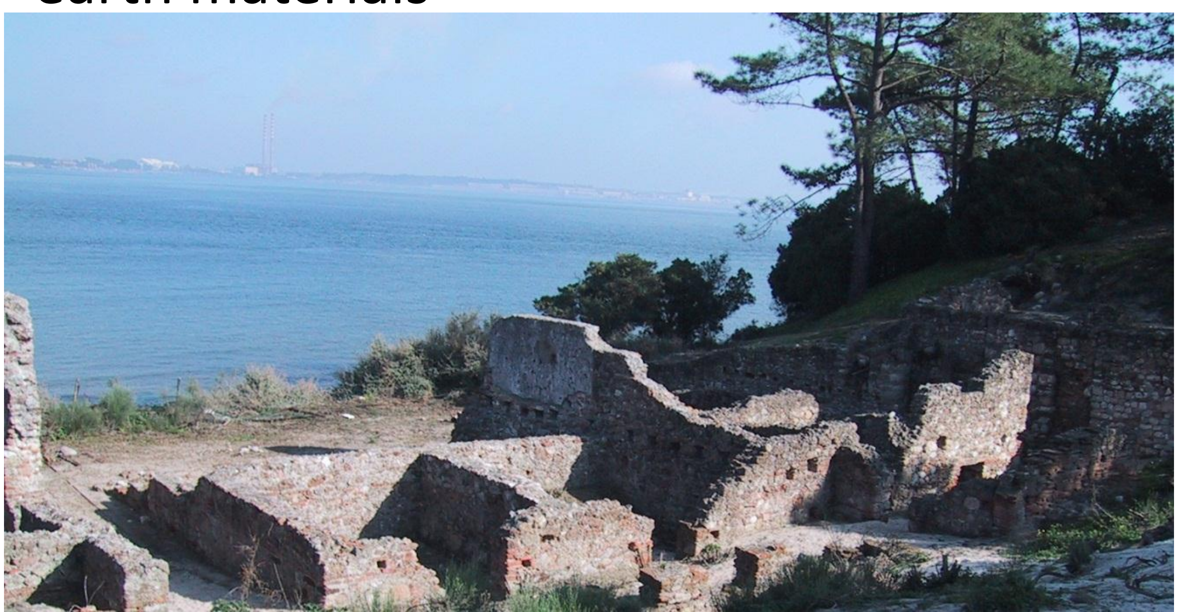
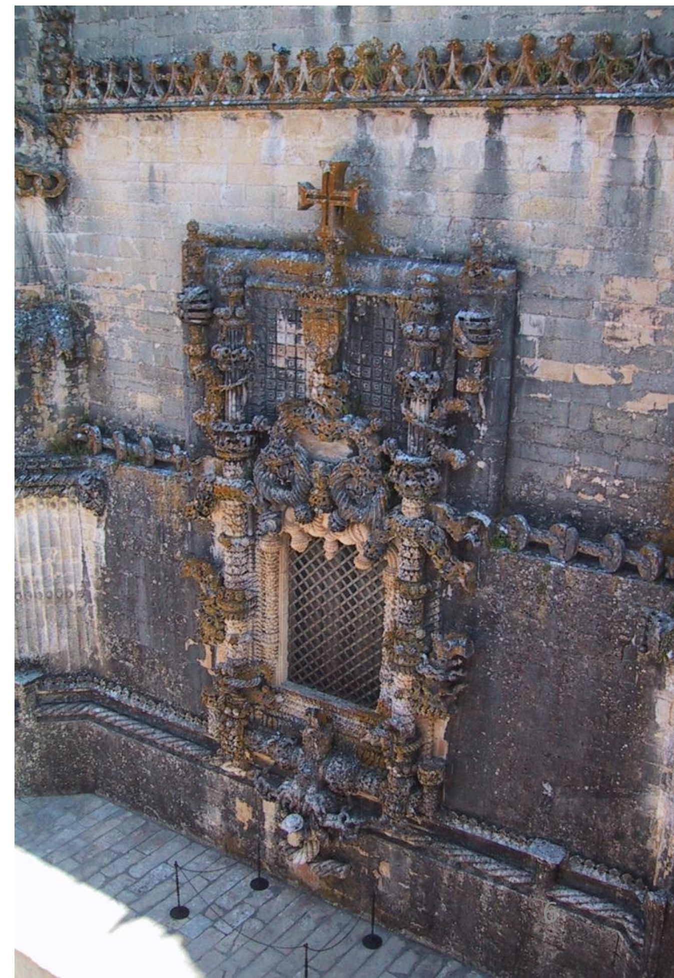


Drying of porous materials - Introduction

porous materials: contain a network of interconnected voids, through which water (liquid and vapour) can migrate

- stone
- ceramics
- mortars
- earth materials





Drying of porous materials - Introduction

drying: process by which water leaves the porous material

why is it important?

Drying of porous materials - Introduction

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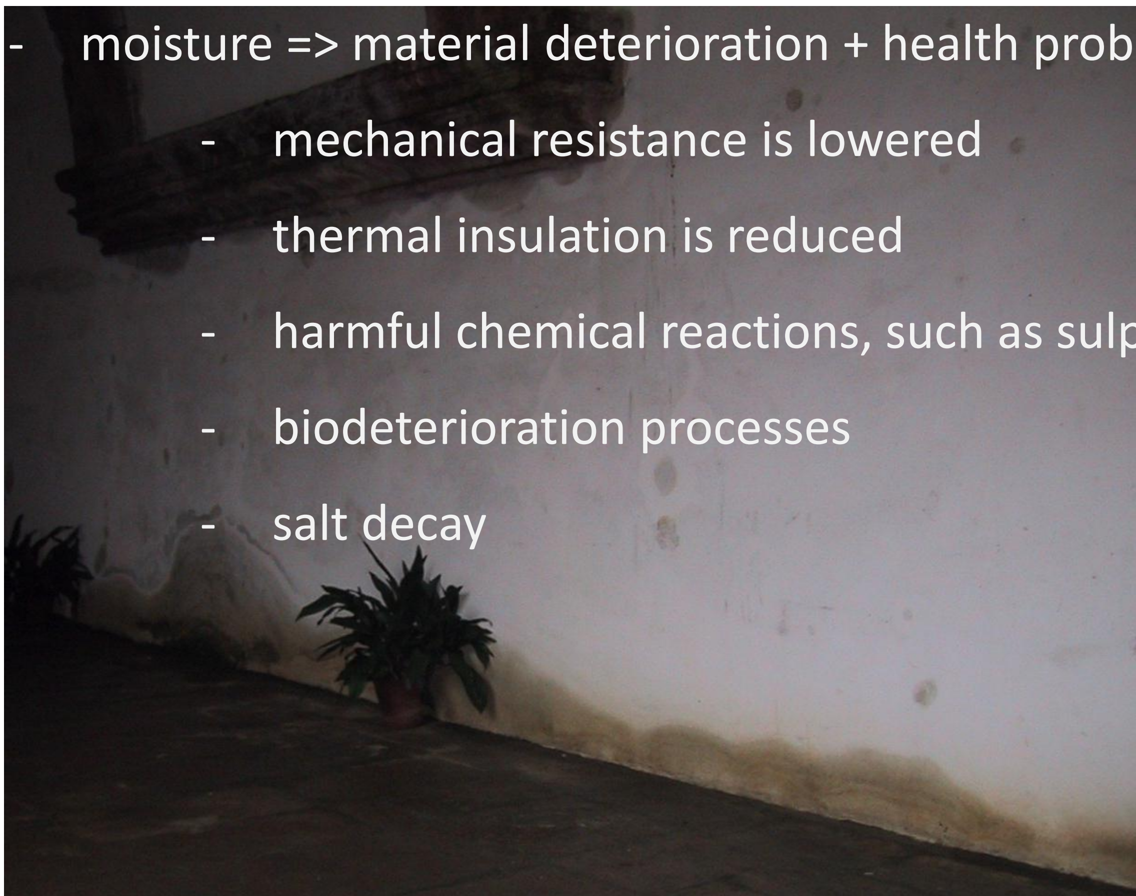
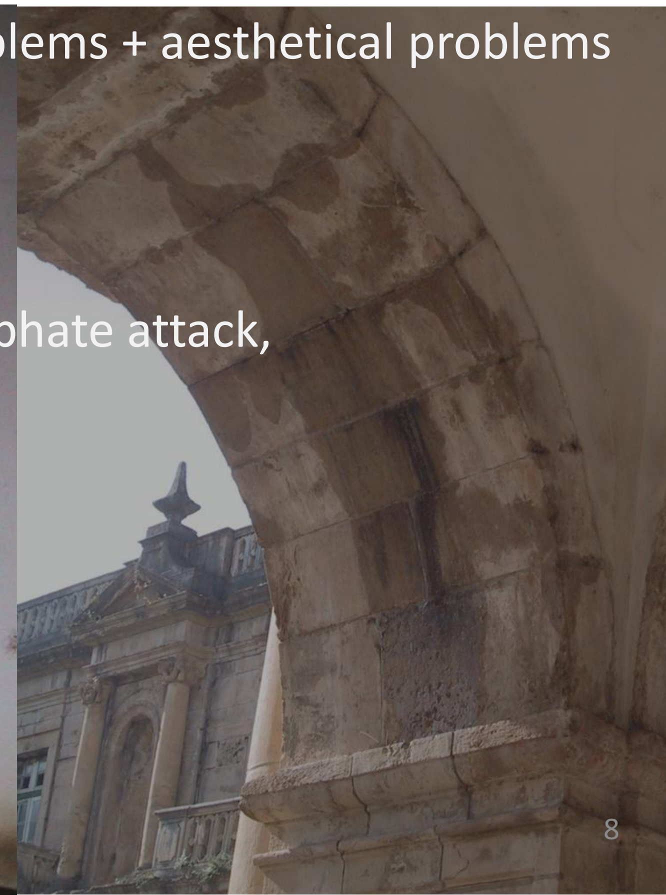

- moisture => material deterioration + health problems + aesthetical problems
    - mechanical resistance is lowered
    - thermal insulation is reduced
    - harmful chemical reactions, such as sulphate attack,
    - biodeterioration processes
    - salt decay

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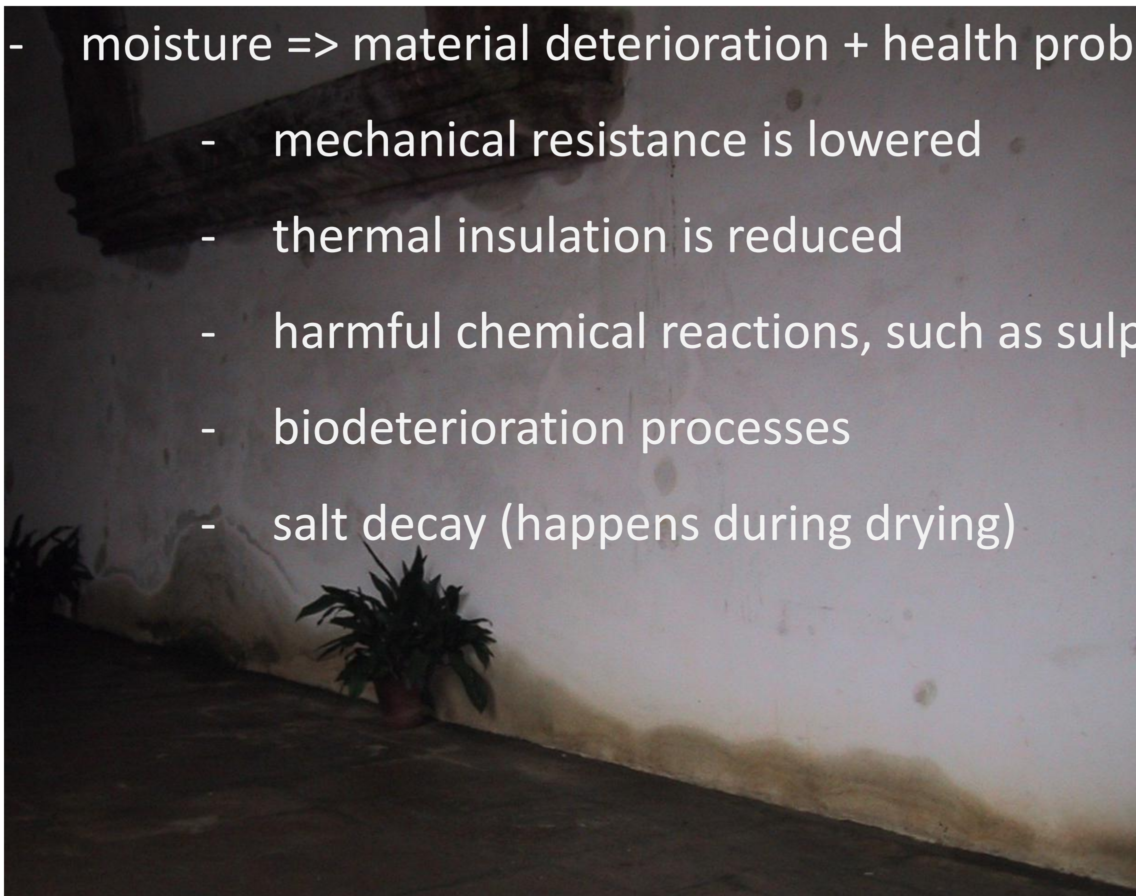
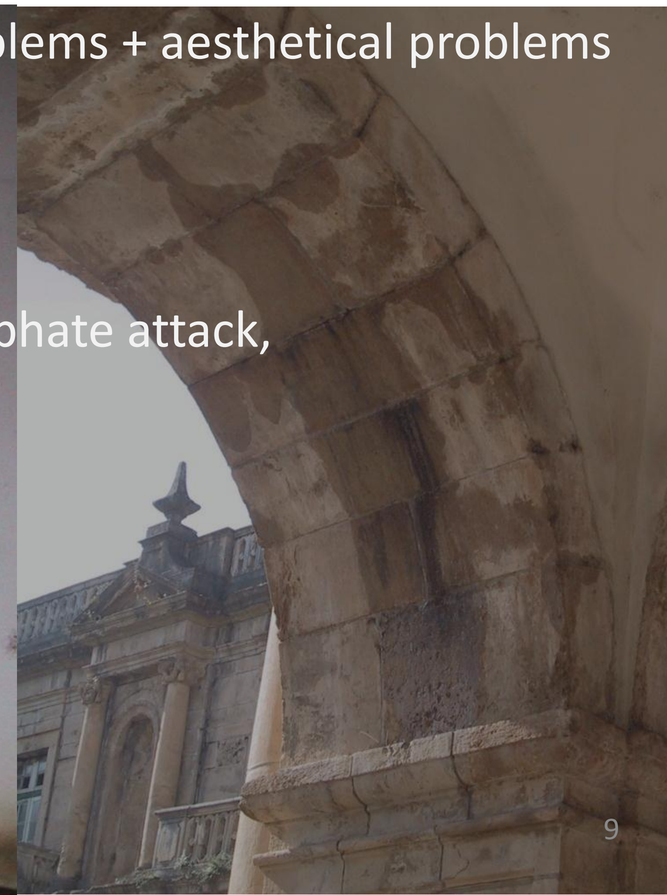

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Drying of porous materials - Introduction

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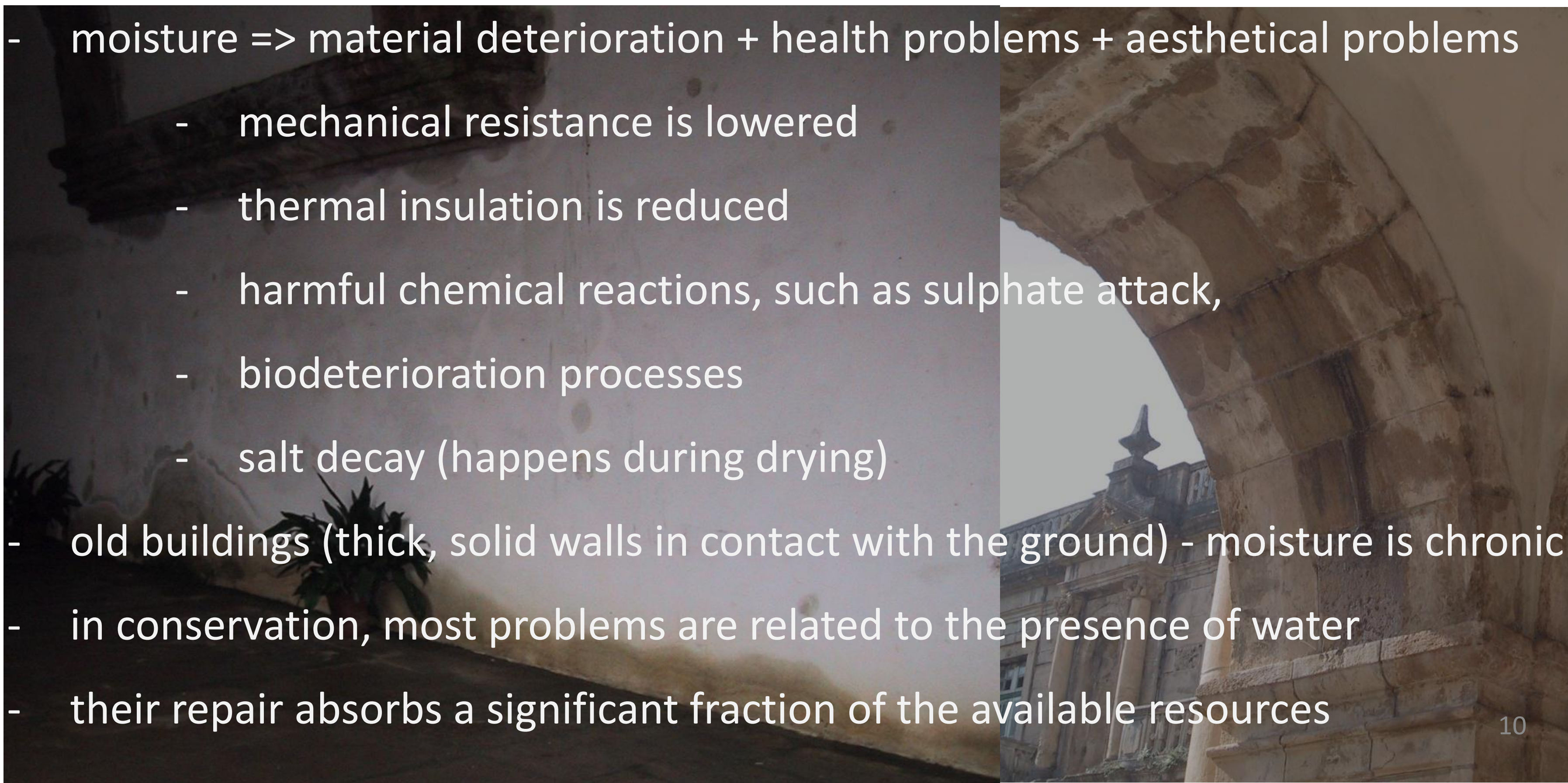

- moisture => material deterioration + health problems + aesthetical problems
    - mechanical resistance is lowered
    - thermal insulation is reduced
    - harmful chemical reactions, such as sulphate attack,
    - biodeterioration processes
    - salt decay (happens during drying)
- old buildings (thick, solid walls in contact with the ground) - moisture is chronic
- in conservation, most problems are related to the presence of water
- their repair absorbs a significant fraction of the available resources

Drying of porous materials
Lecture contents

- Introduction
- The two-stage model
- NMR animation of drying with pure water
- Drying tests
    - The evaporation curve
    - The drying index
- Slower drying: causes and effects
- Influence of soluble salts on drying + NMR animation
- Influence of paint layers on drying + NMR results
- Influence of hydrophobic treatments on drying + results

… including 3D effects

Drying of porous materials – The two-stage model

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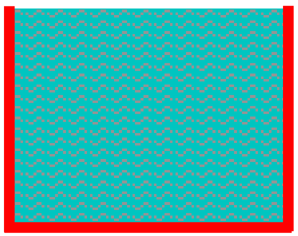
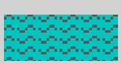
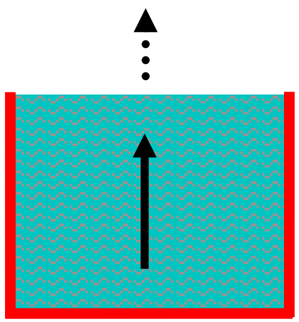




Liquid continuity / wet material

Drying of porous materials – The two-stage model



Stage I

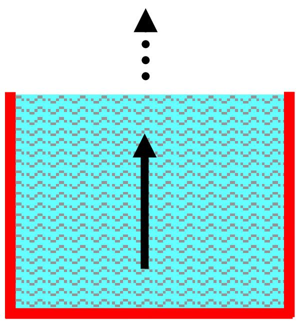
- Liquid continuity across the sample
- Evaporation front at the surface
- Drying rate is constant

wet surface

Two flows:

- liquid flow *interior→surface*
- vapour flow *surface→exterior*
- systems (constantly) tend to equilibrium
- equilibrium => liquid flow=vapour flow

Drying of porous materials – The two-stage model



Stage I

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wet surface

Moisture content decreases uniformly across the sample …

Liquid continuity / wet material

Liquid discontinuity / dry material

Liquid transport

Vapour transport

Sealant

Drying of porous materials – The two-stage model

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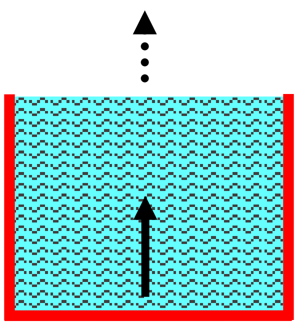

Stage II

- Decrease of the moisture content => lower liquid flow

Liquid continuity / wet material

Liquid discontinuity / dry material

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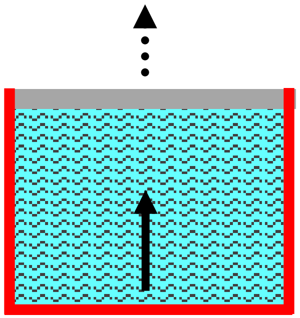
Drying of porous materials – The two-stage model



Stage II

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- Liquid continuity across the sample
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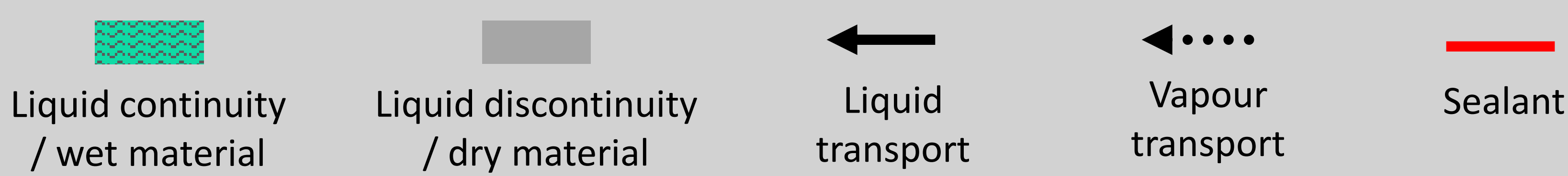
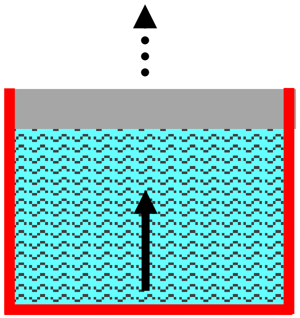
- Decrease of the moisture content => lower liquid flow
- Evaporation front recedes into the material

because the flows tend to equalize …



Drying of porous materials – The two-stage model



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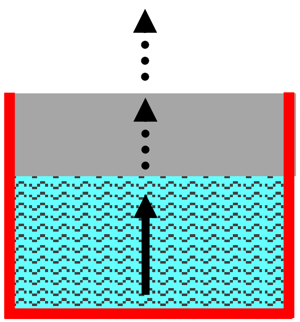

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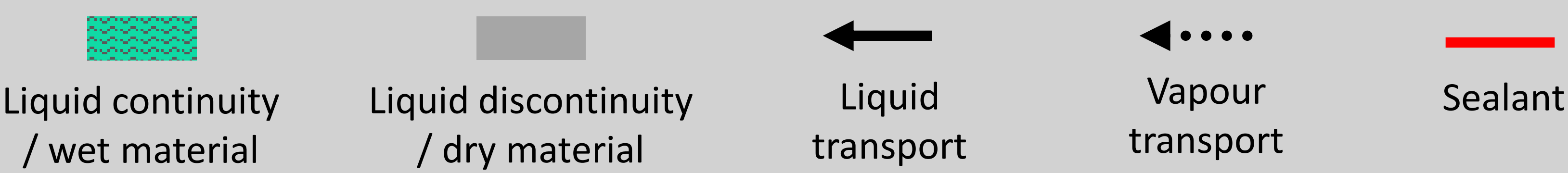

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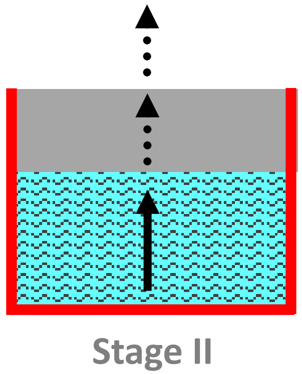

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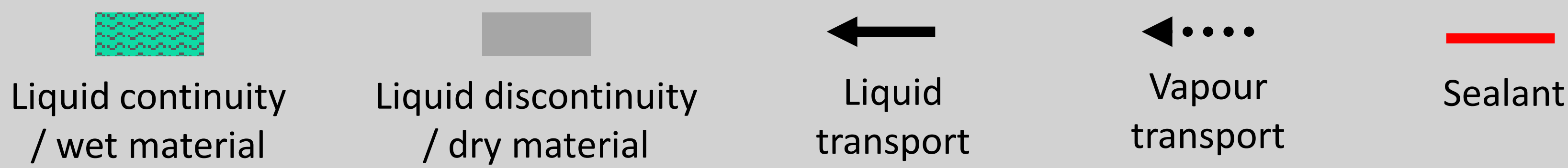

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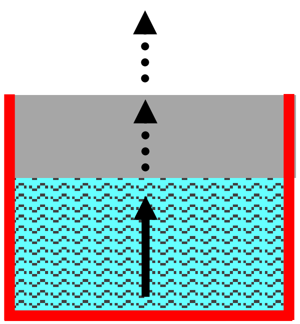

Stage II

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<u>Stage II</u>

- Decrease of the moisture content => lower liquid flow
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dry surface

Liquid continuity / wet material

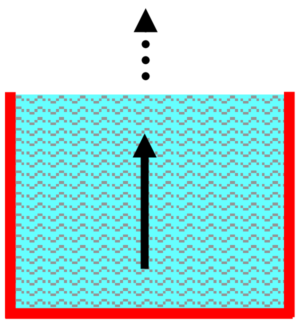
Liquid discontinuity / dry material

Liquid transport

Vapour transport

Sealant

Drying of porous materials – The two-stage model



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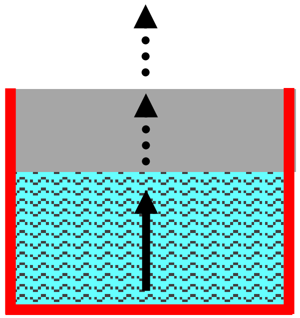

Stage II

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- Decrease of the moisture content => lower liquid flow
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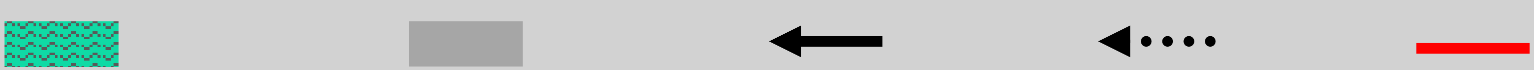
dry surface



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Liquid discontinuity / dry material

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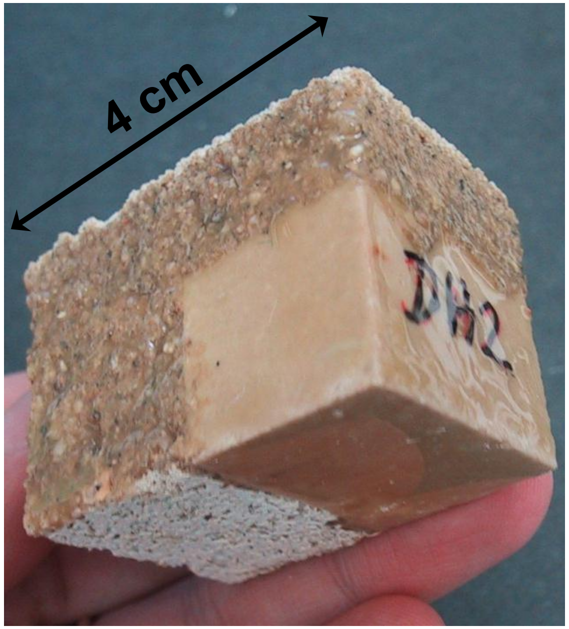
Drying of porous materials – NMR animation of drying



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Drying of porous materials – NMR animation of drying

Side view

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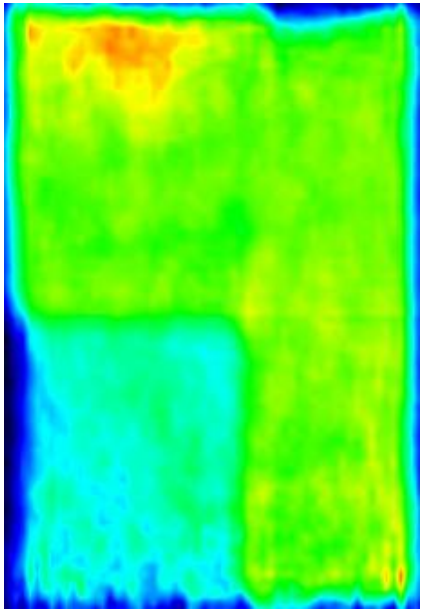

NMR image of the saturated specimen

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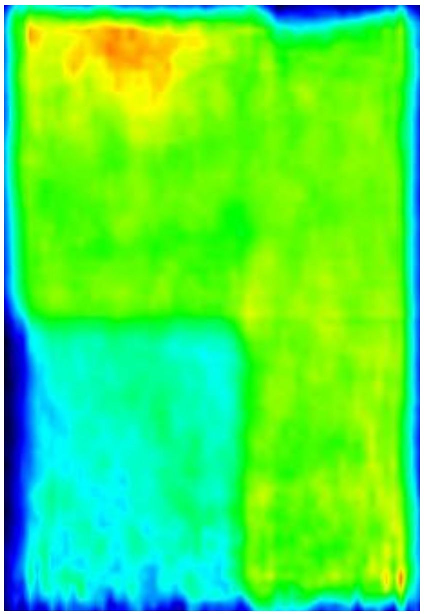
Drying of porous materials – NMR animation of drying



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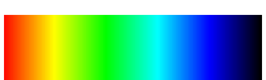
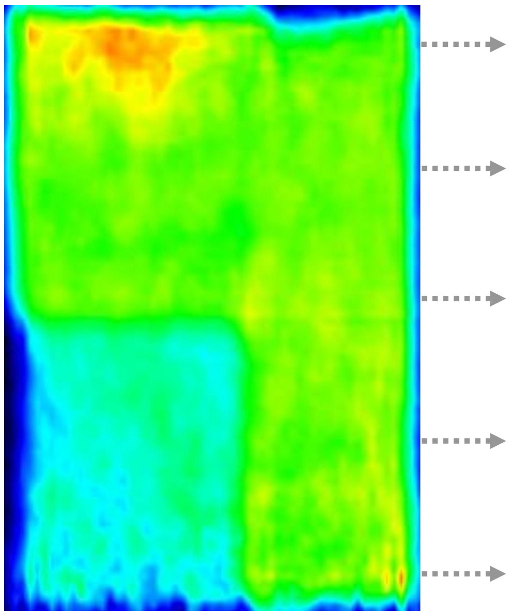
dry surface

248 kg/m³  0 kg/m³

Drying of porous materials – NMR animation of drying

18°C - 0% RH



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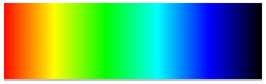
248 kg/m³  0 kg/m³

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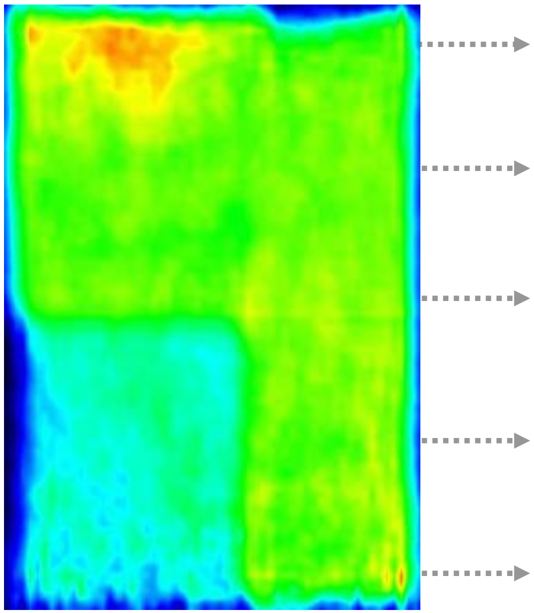

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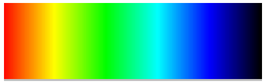
248 kg/m³  0 kg/m³

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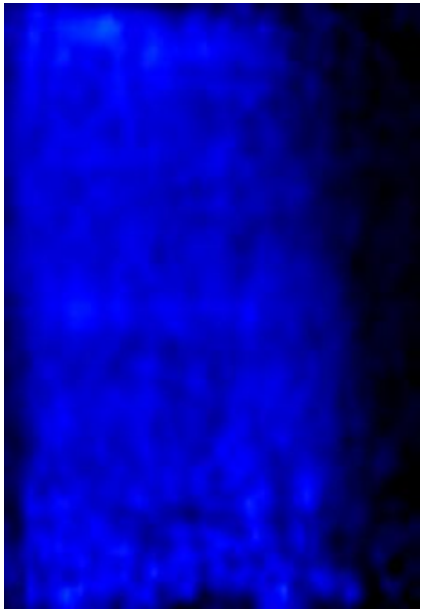
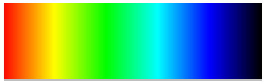


20h – final state

248 kg/m³



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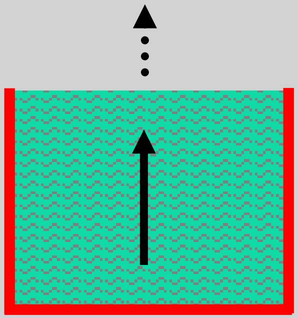
Drying of porous materials – Drying tests



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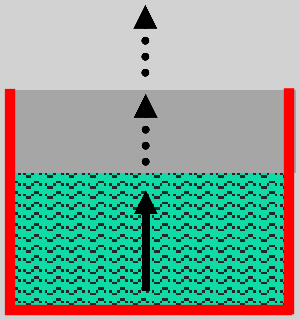

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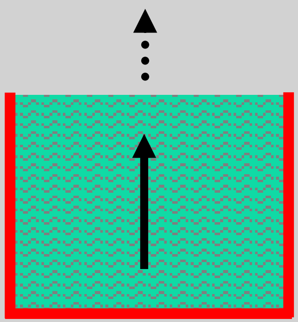

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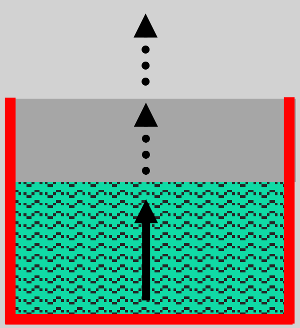
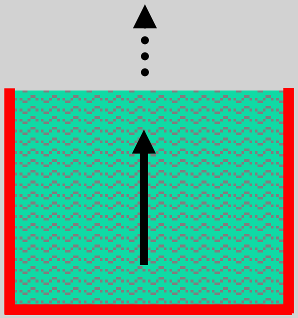


Stage II

RILEM TC 25-PEM (1980) Materials and Structures 13, 204–207

Drying of porous materials – Drying tests



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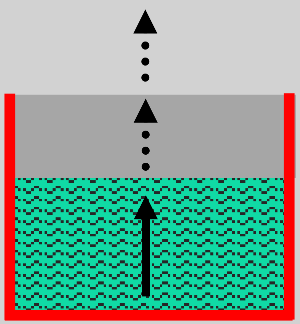
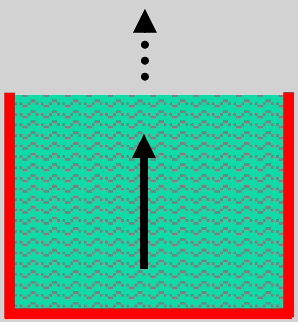


Stage II

RILEM TC 25-PEM (1980) Materials and Structures 13, 204–207

Specimens
- laterally sealed with epoxy
- put in partial or total immersion
- removed and bottom sealed with film
- let dry in certain environment
- periodical weighting => m_i

Drying of porous materials – Drying tests



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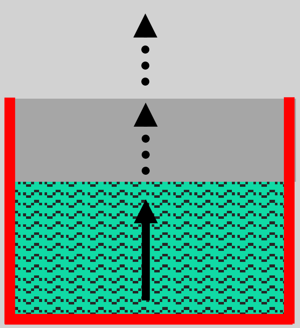

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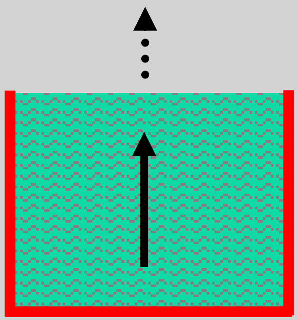

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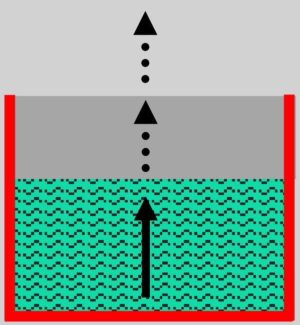

Stage II

- Measure the "evaporation curve"

RILEM TC 25-PEM (1980) Materials and Structures 13, 204–207

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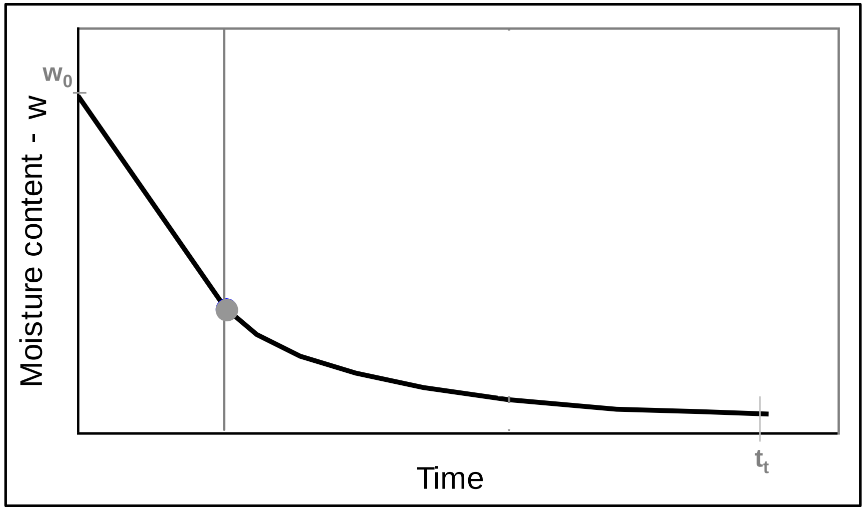

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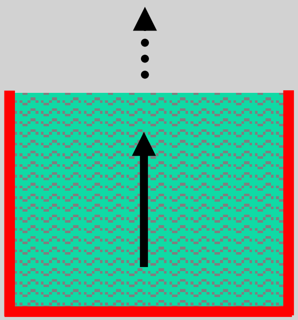

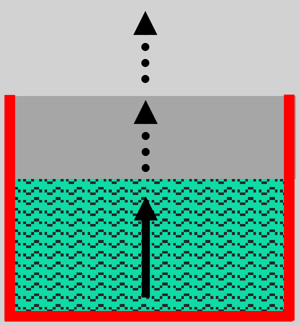

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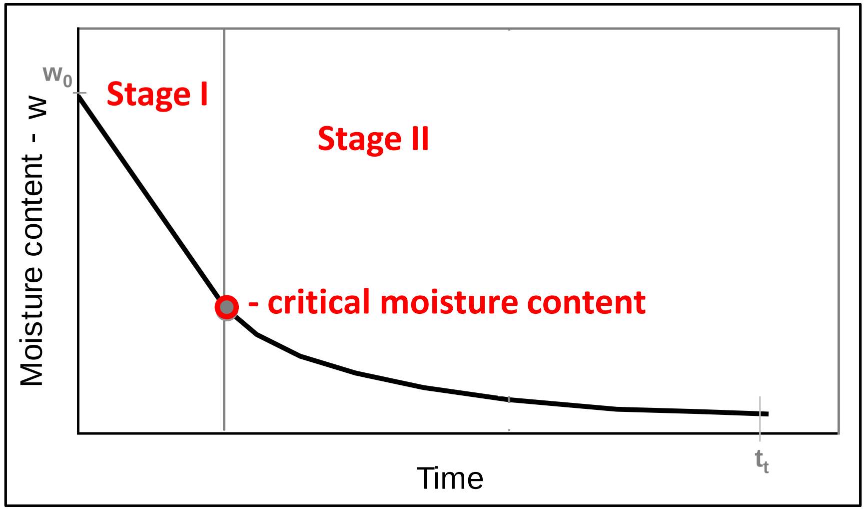
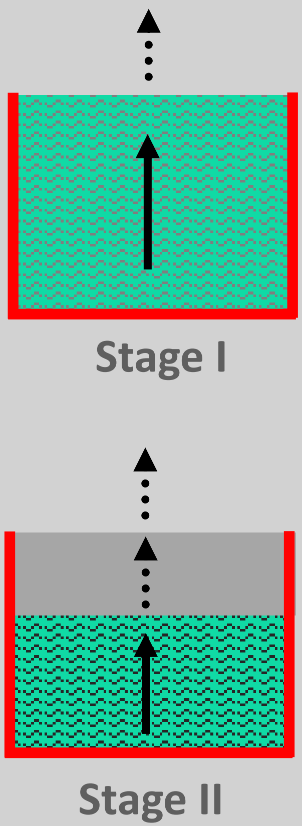


Drying of porous materials – Drying tests



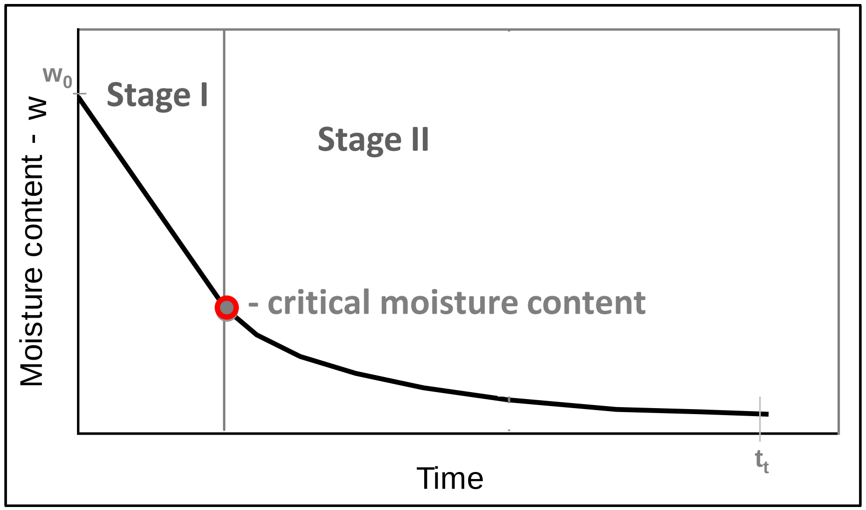
- Measure the "evaporation curve"

  RILEM TC 25-PEM (1980) Materials and Structures 13, 204–207

- Calculate the "drying index"

  Commissione Normal, (1991) Misura dell'indice di asciugamento (drying index). Roma: CNR/ICR. Normal 29/88

  DI translates the drying curve into a single quantitative parameter



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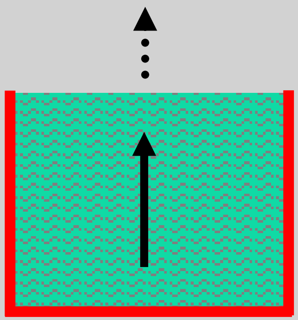
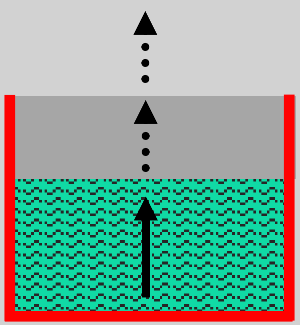
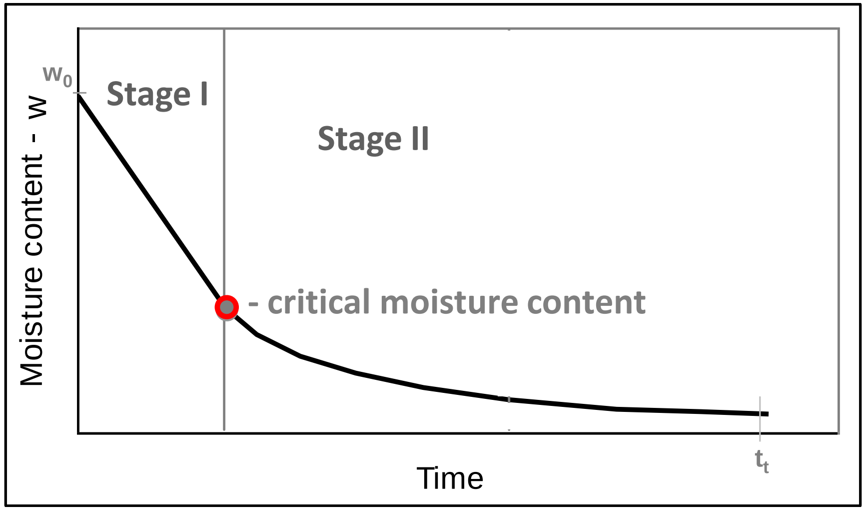
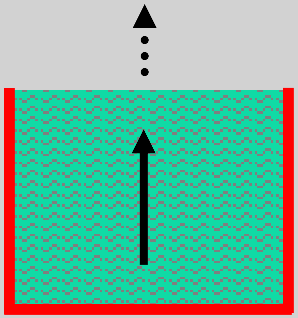

Stage I


Stage II

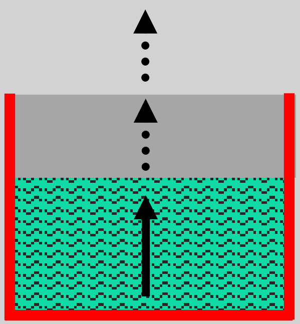
$$DI = \frac{\int_{t_0}^{t_i} f(w_i)\,dt}{w_0 t_i}$$



Drying of porous materials – Drying tests



Stage I



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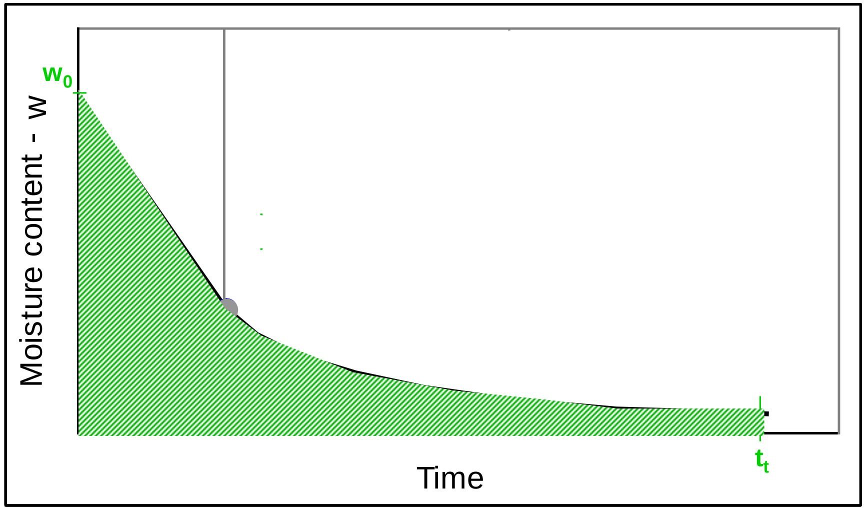
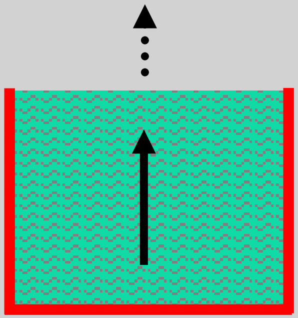
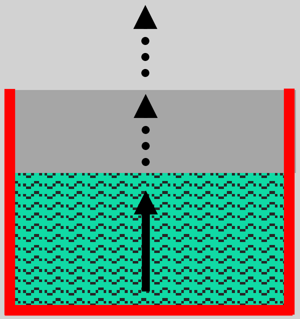


Drying of porous materials – Drying tests



Stage I



Stage II

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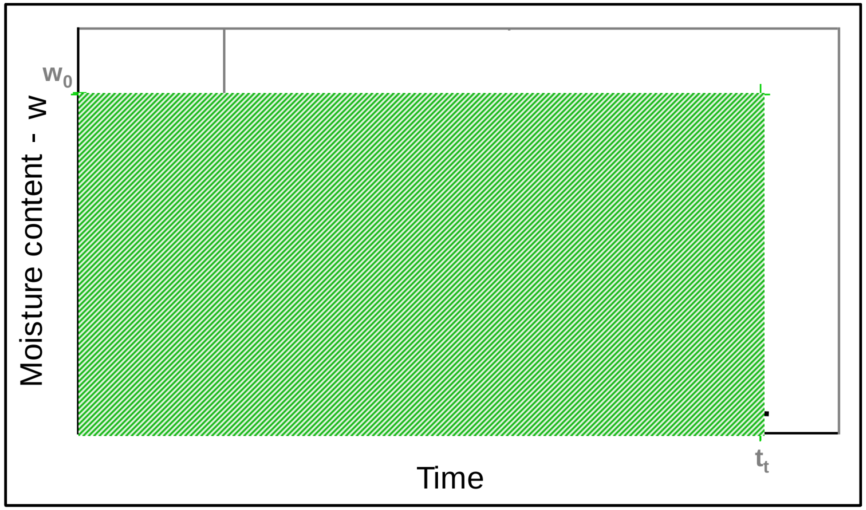
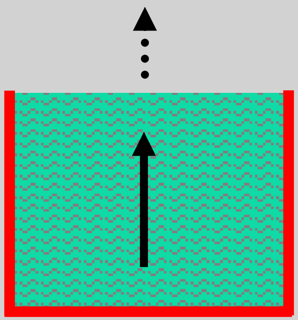
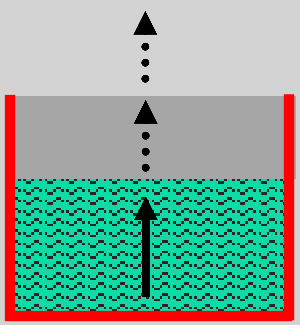


Drying of porous materials – Drying tests



Stage I



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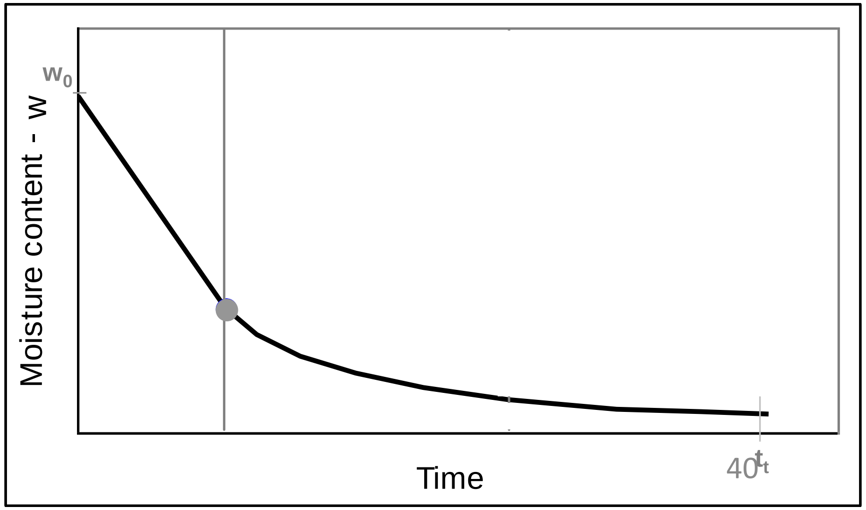
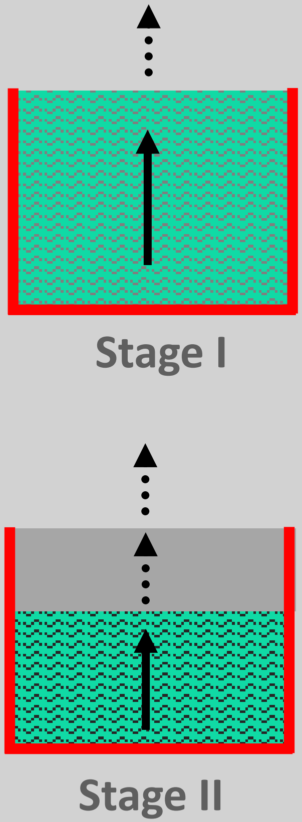


Drying of porous materials – Drying tests



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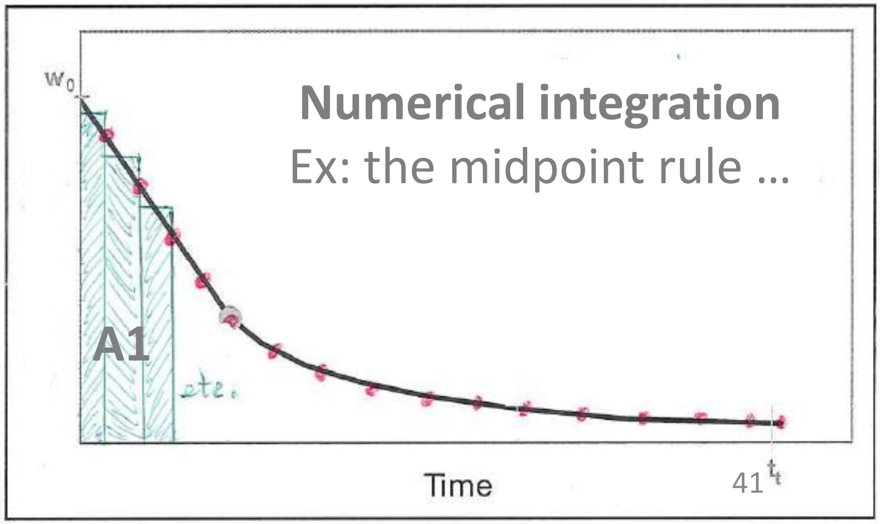

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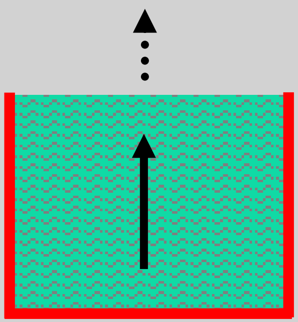

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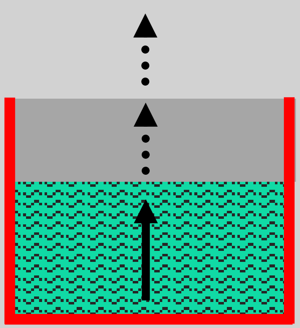

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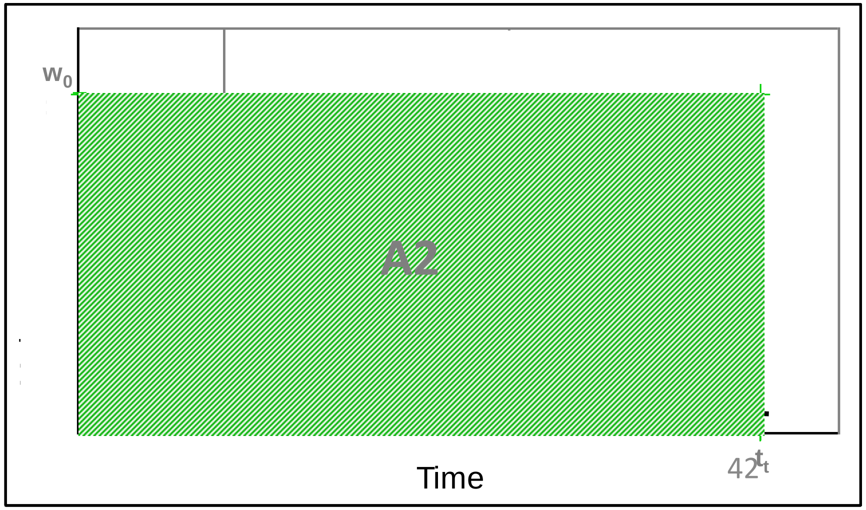
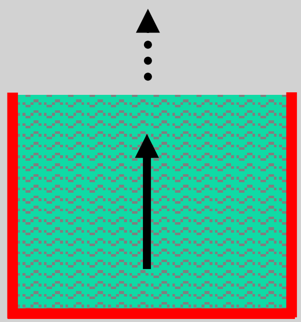
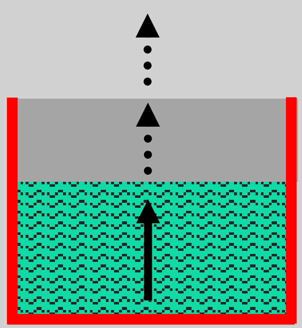


Drying of porous materials – Drying tests



Stage I



Stage II

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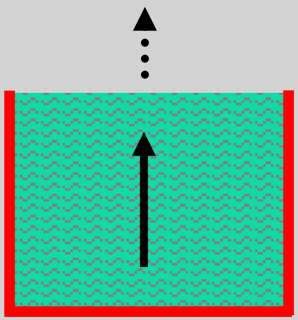
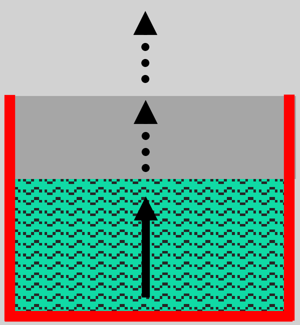
Compare the behaviour/effect of different:

- materials
- environmental conditions (T, RH, air velocity, etc.)
- paints, hydrophobic treatments , consolidants, etc.
- type and concentration of salt
- etc.

Drying of porous materials – Slower drying



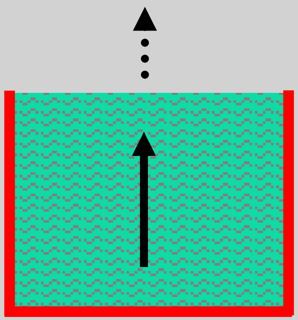
Stage I



Stage II

Drying of porous materials – Slower drying

=> longer stage I + higher DI



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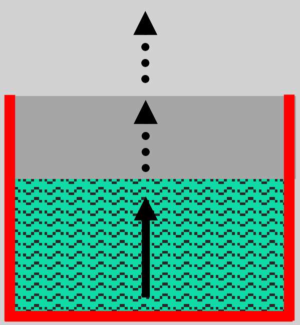

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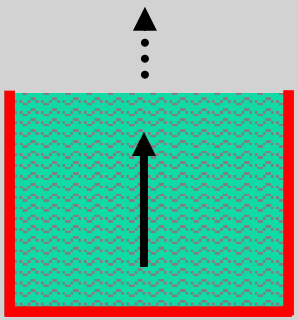

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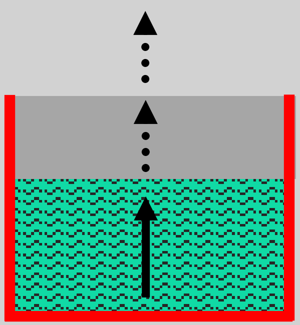

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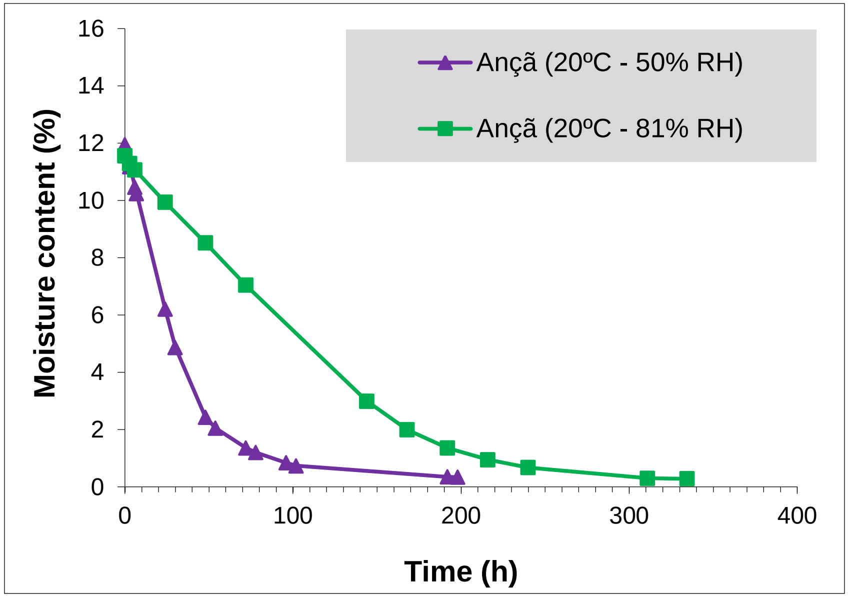

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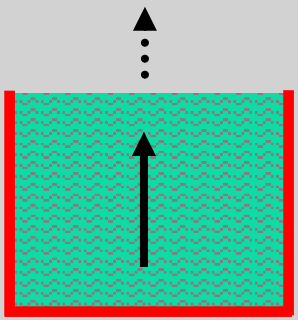

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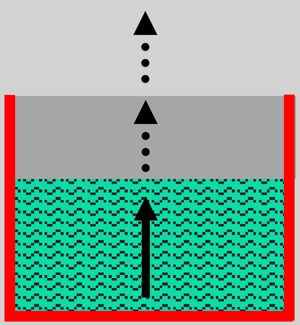

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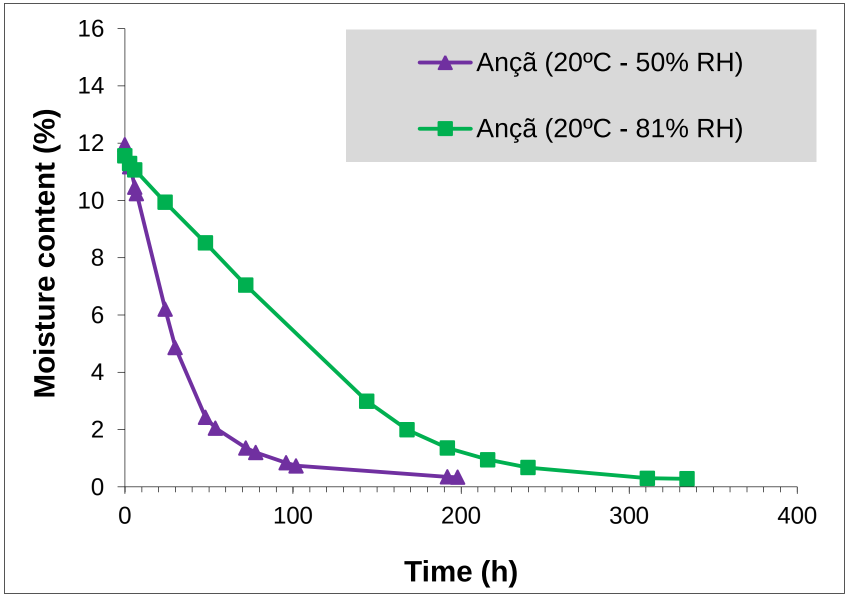
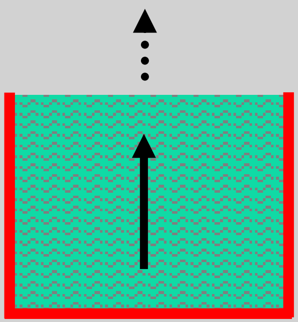


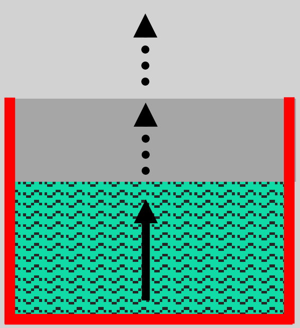
Possible causes:

- Environmental conditions: higher RH, lower T, etc.

Drying of porous materials – Slower drying



Stage I



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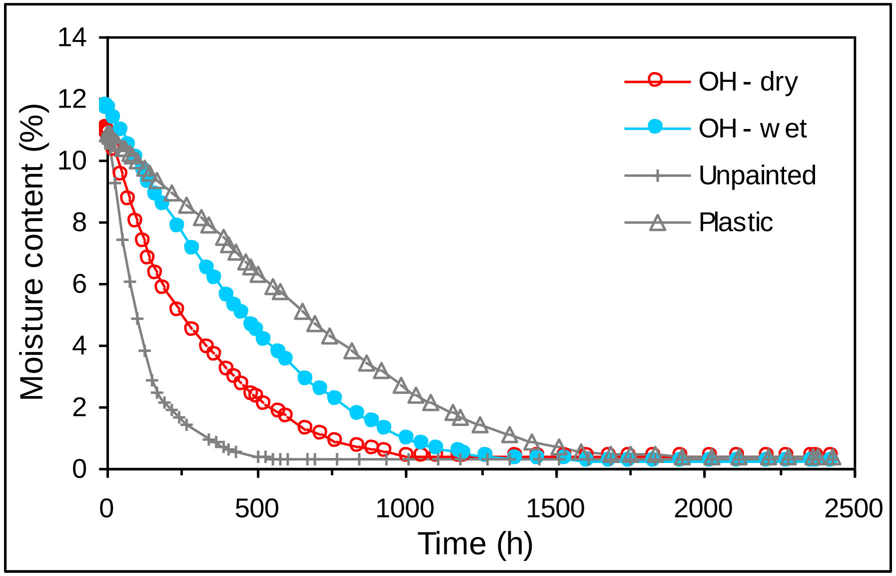
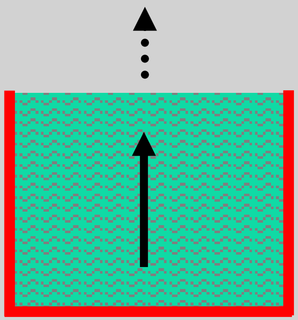


Possible causes:

- Environmental conditions: higher RH, lower T, etc.
- Evaporation blocking layers (paints…)

Drying of porous materials – Slower drying



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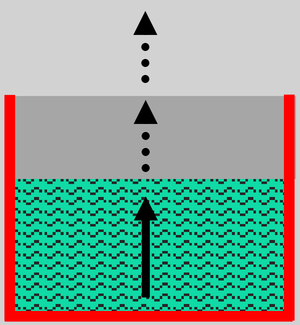

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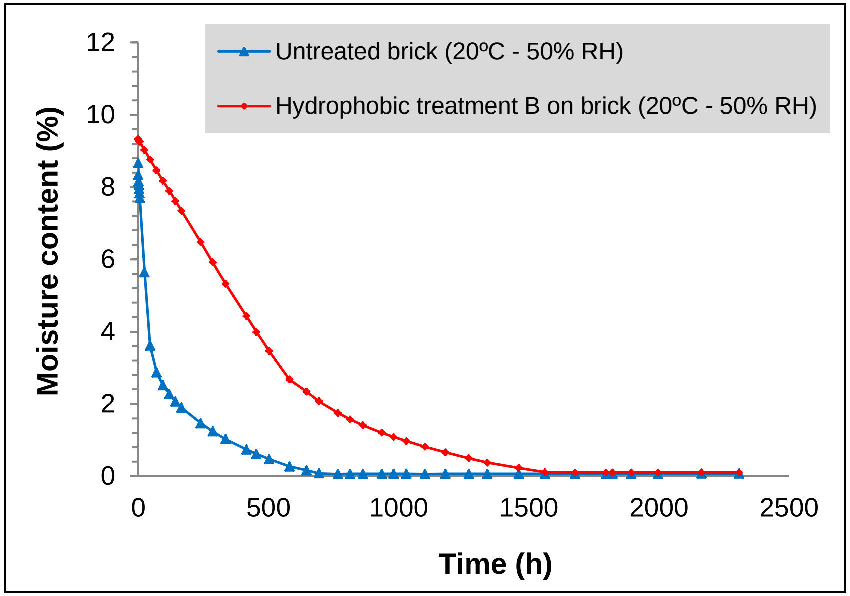
=> longer stage I + higher DI



Possible causes:

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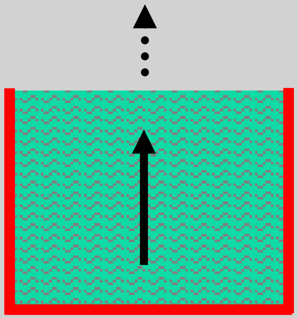
- Evaporation blocking layers (paints…)
- Hydrophobic treatments

Drying of porous materials – Slower drying



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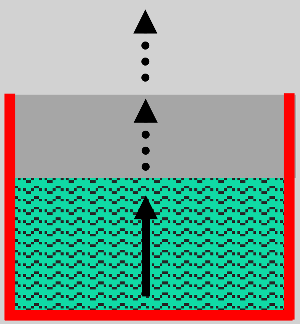

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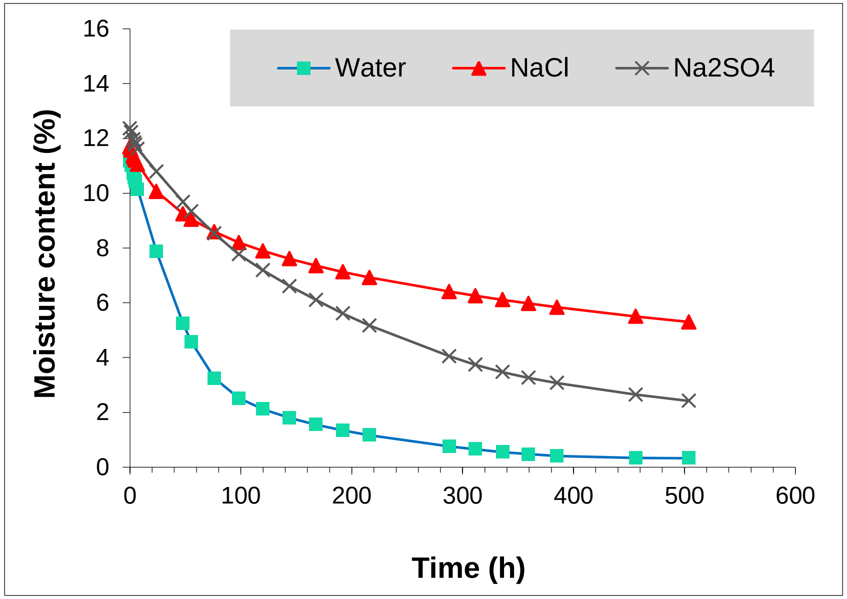


Possible causes:

- Environmental conditions: higher RH, lower T, etc.
- Evaporation blocking layers (paints…)
- Hydrophobic treatments
- Salts …

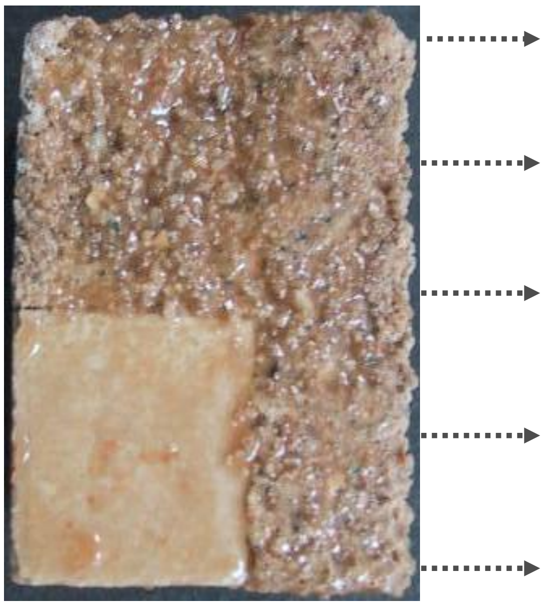
Drying of porous materials – Influence of soluble salts


Castelo de Terena, Évora, 2002

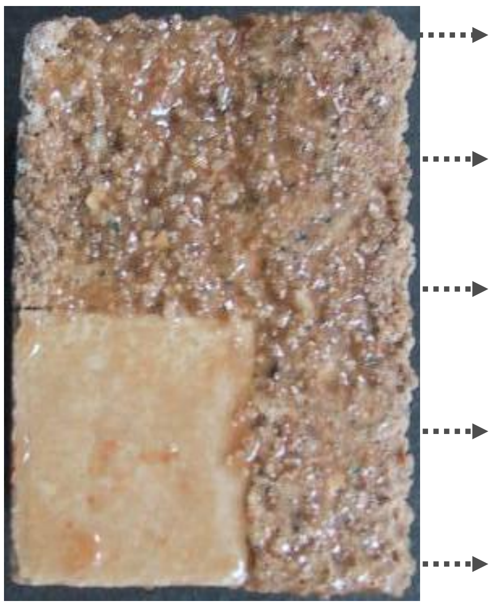

Igreja de Sta. Cruz, Coimbra, 2002

Drying of porous materials – Influence of soluble salts

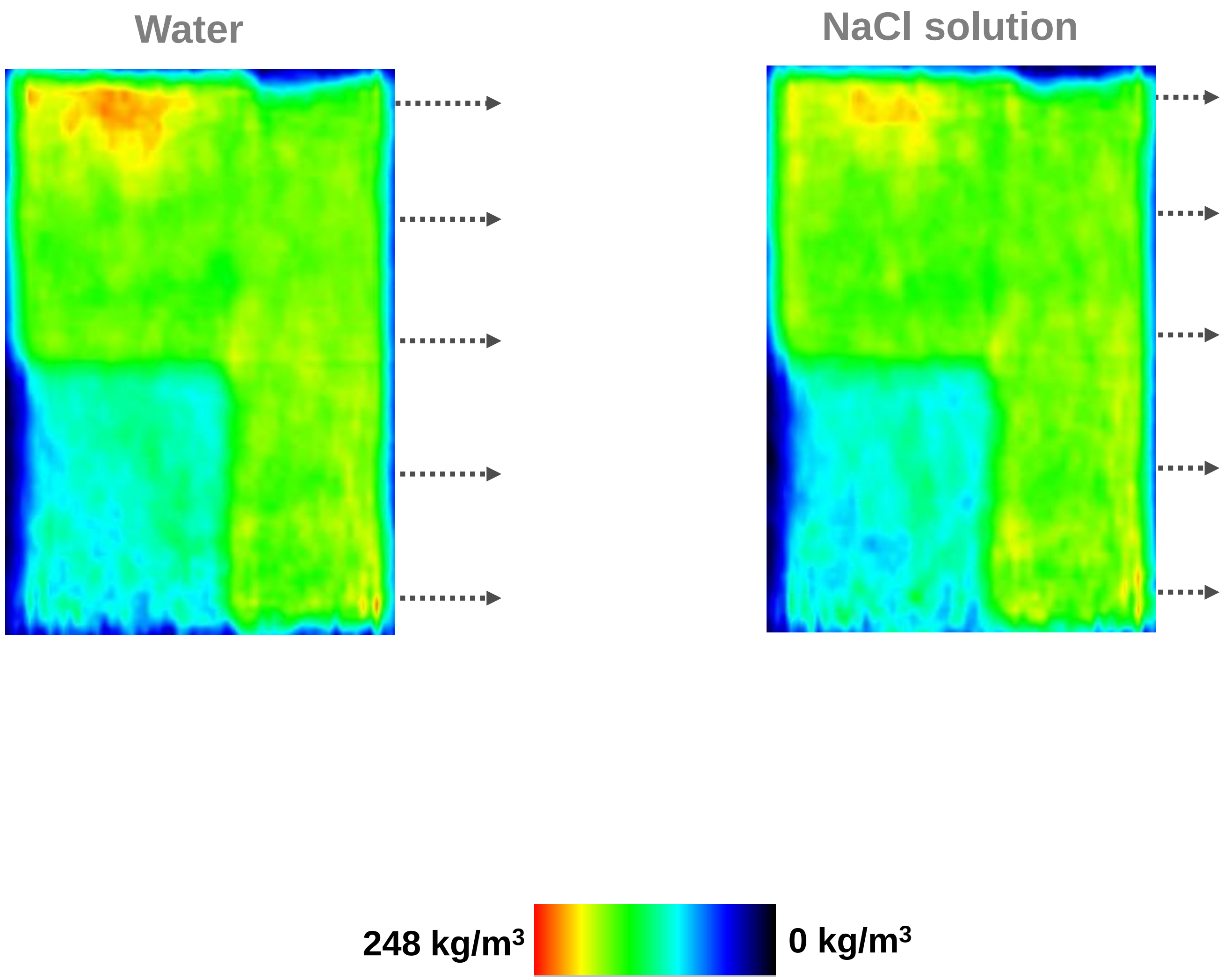
Water



NaCl solution

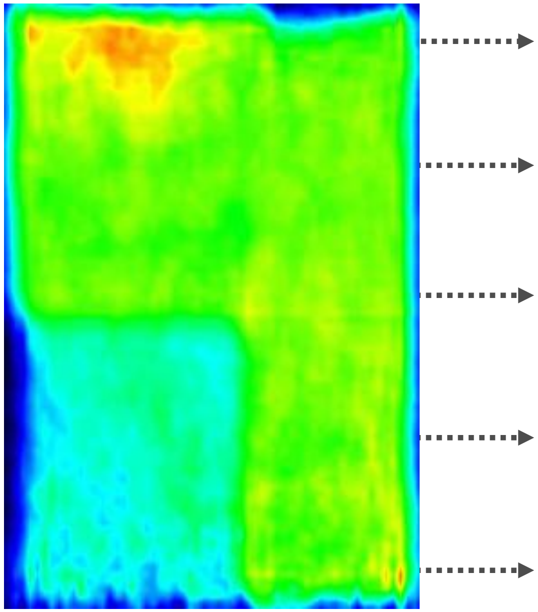


Drying of porous materials – Influence of soluble salts



Drying of porous materials – Influence of soluble salts

Water



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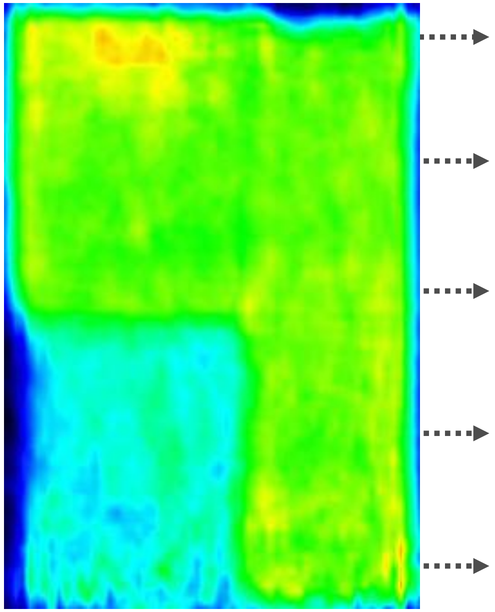
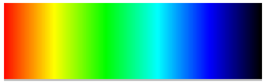
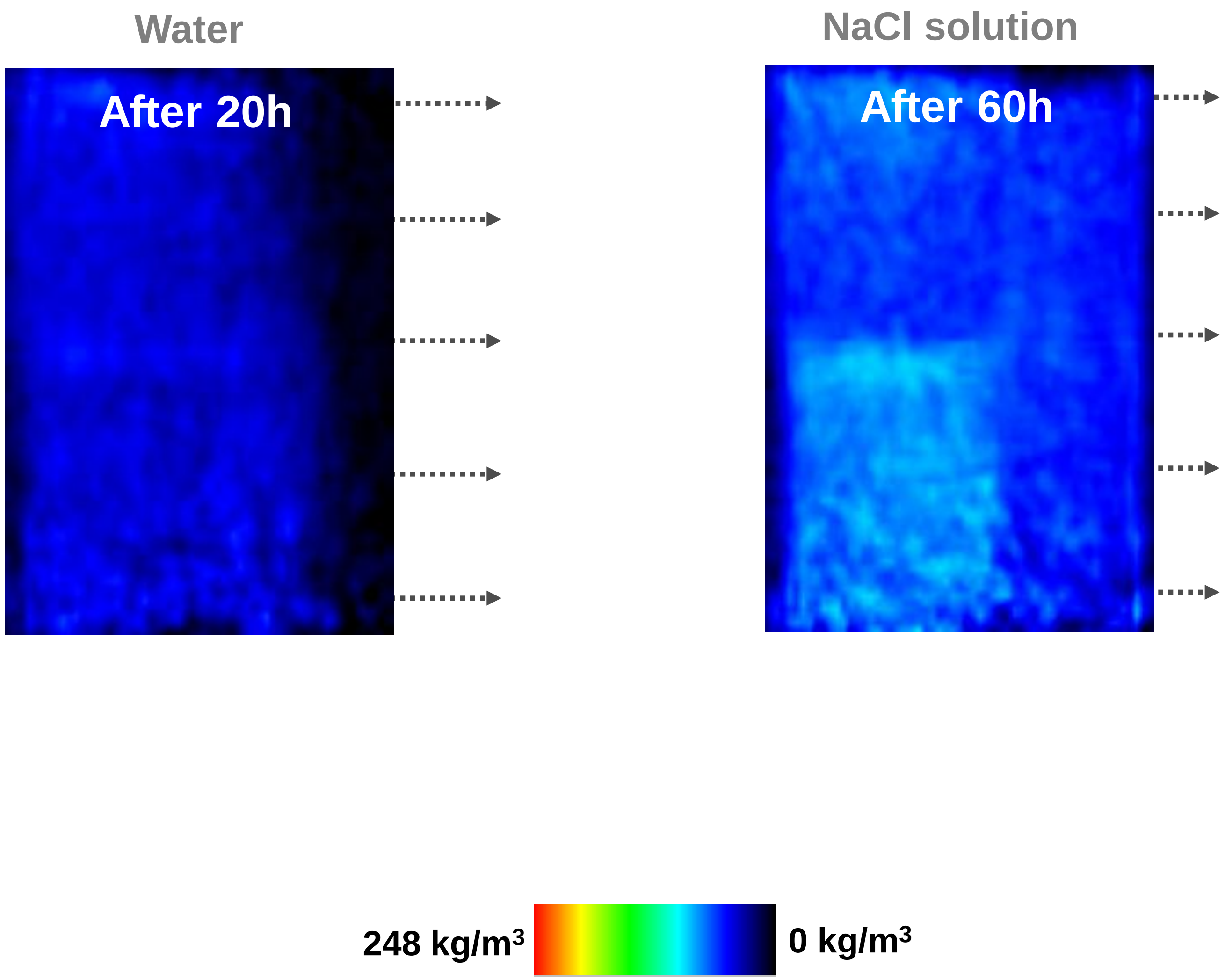


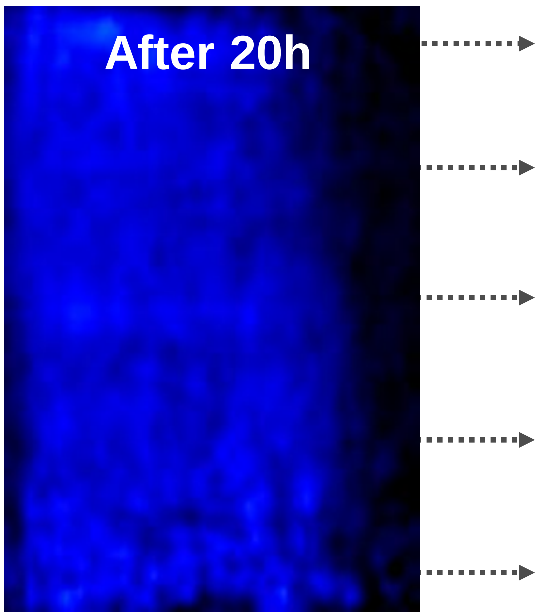
248 kg/m³  0 kg/m³

Drying of porous materials – Influence of soluble salts

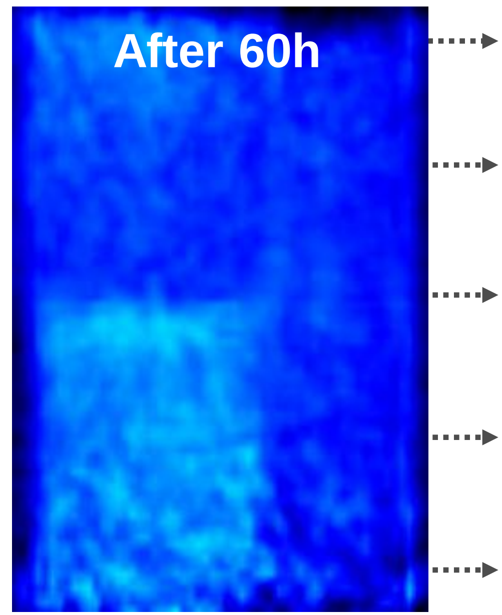


Drying of porous materials – Influence of soluble salts

Water

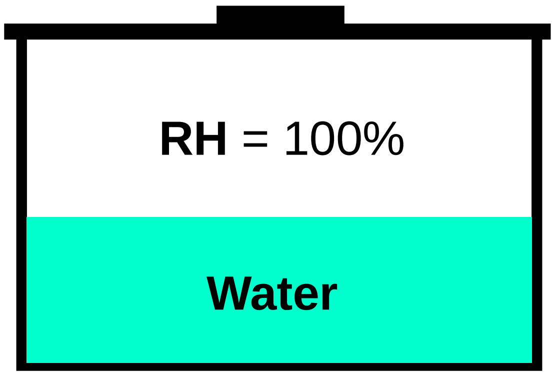


NaCl solution



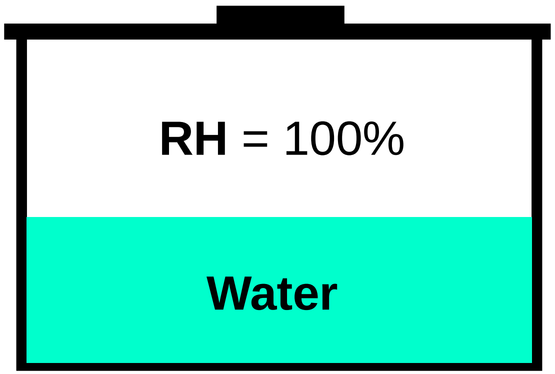
- Drying is sower
- Stage I is longer => surface is wet at lower moisture contents

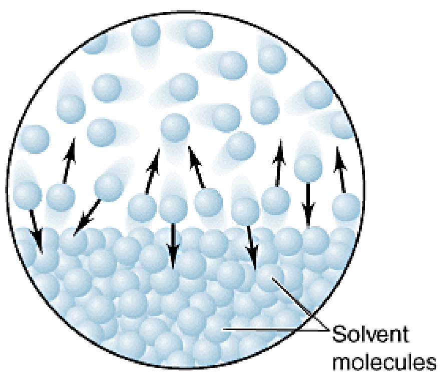
Drying of porous materials – Influence of soluble salts



Drying of porous materials – Influence of soluble salts

state of dynamic equilibrium …

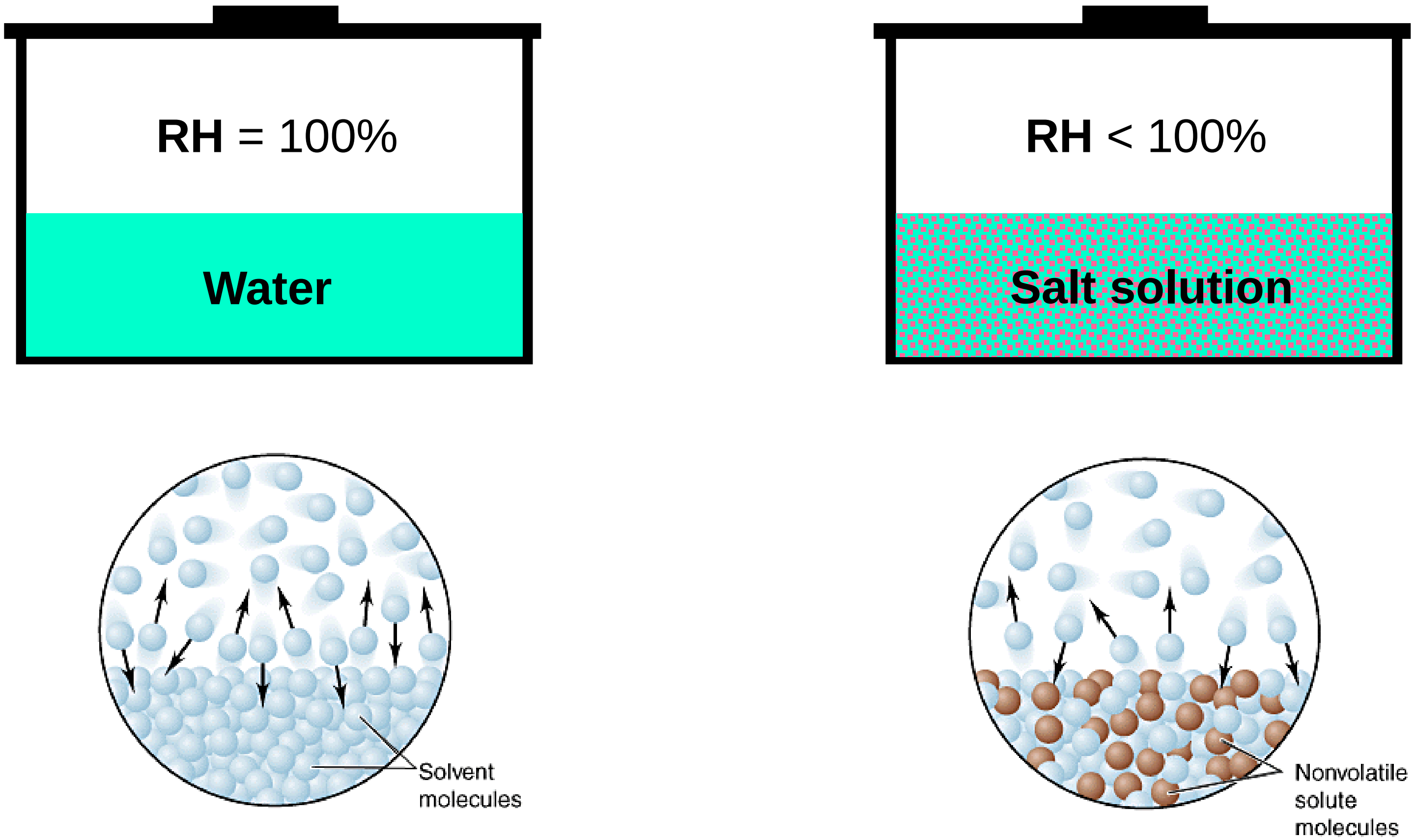




http://www.chem.ufl.edu/~itl/4411/lectures/lec_i.html

Drying of porous materials – Influence of soluble salts

state of dynamic equilibrium …



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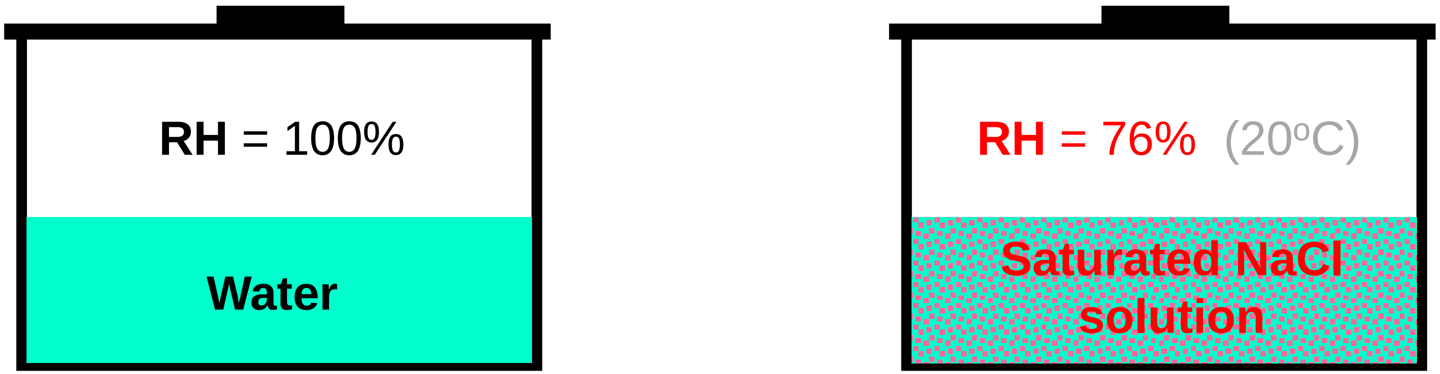
Drying of porous materials – Influence of soluble salts



Relative equilibrium humidity (RHeq)…

Drying of porous materials – Influence of soluble salts

Consequences in terms of drying behaviour ?

20ºC

0% RH

Drying of porous materials – Influence of soluble salts

20ºC
0% RH

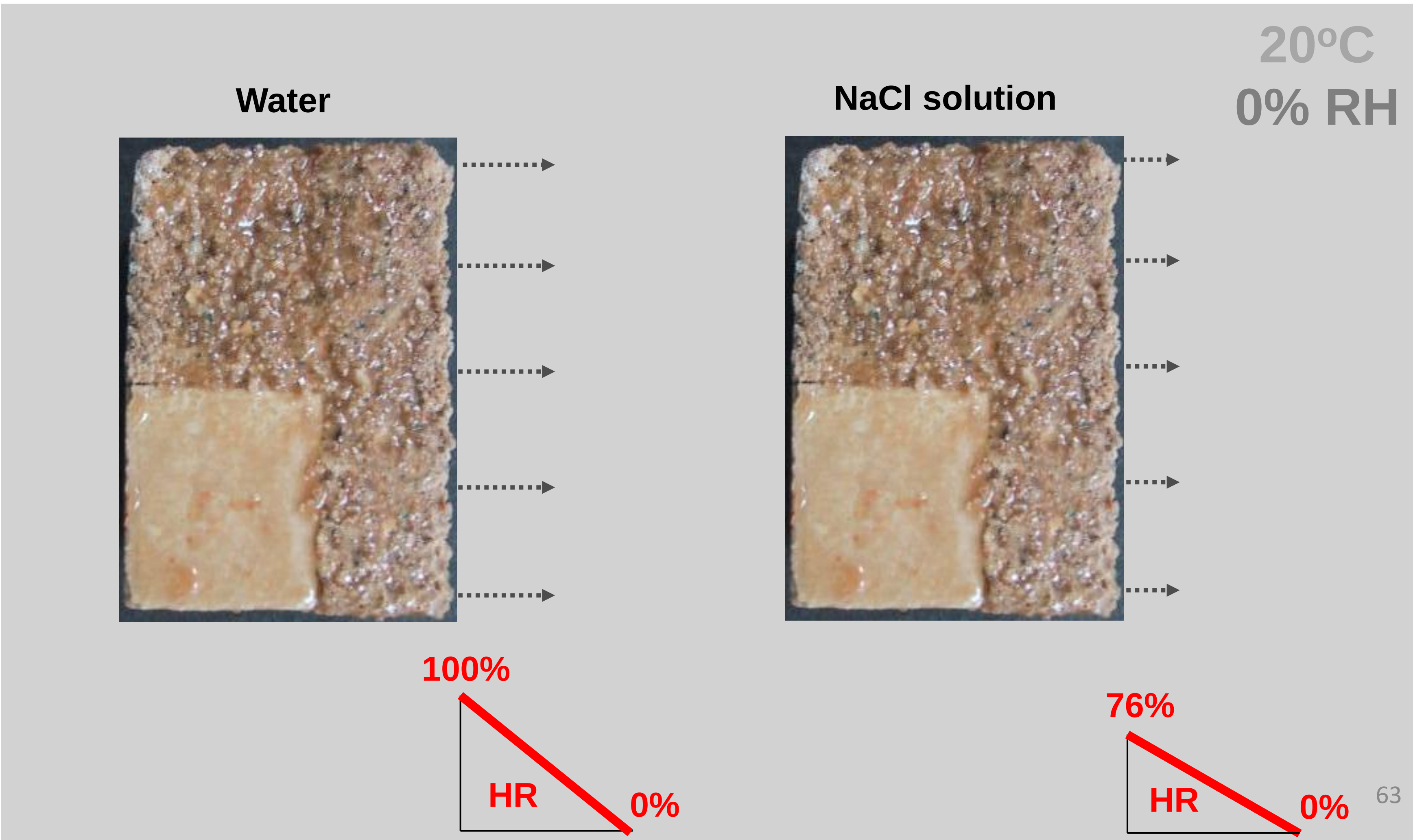
Water

100%

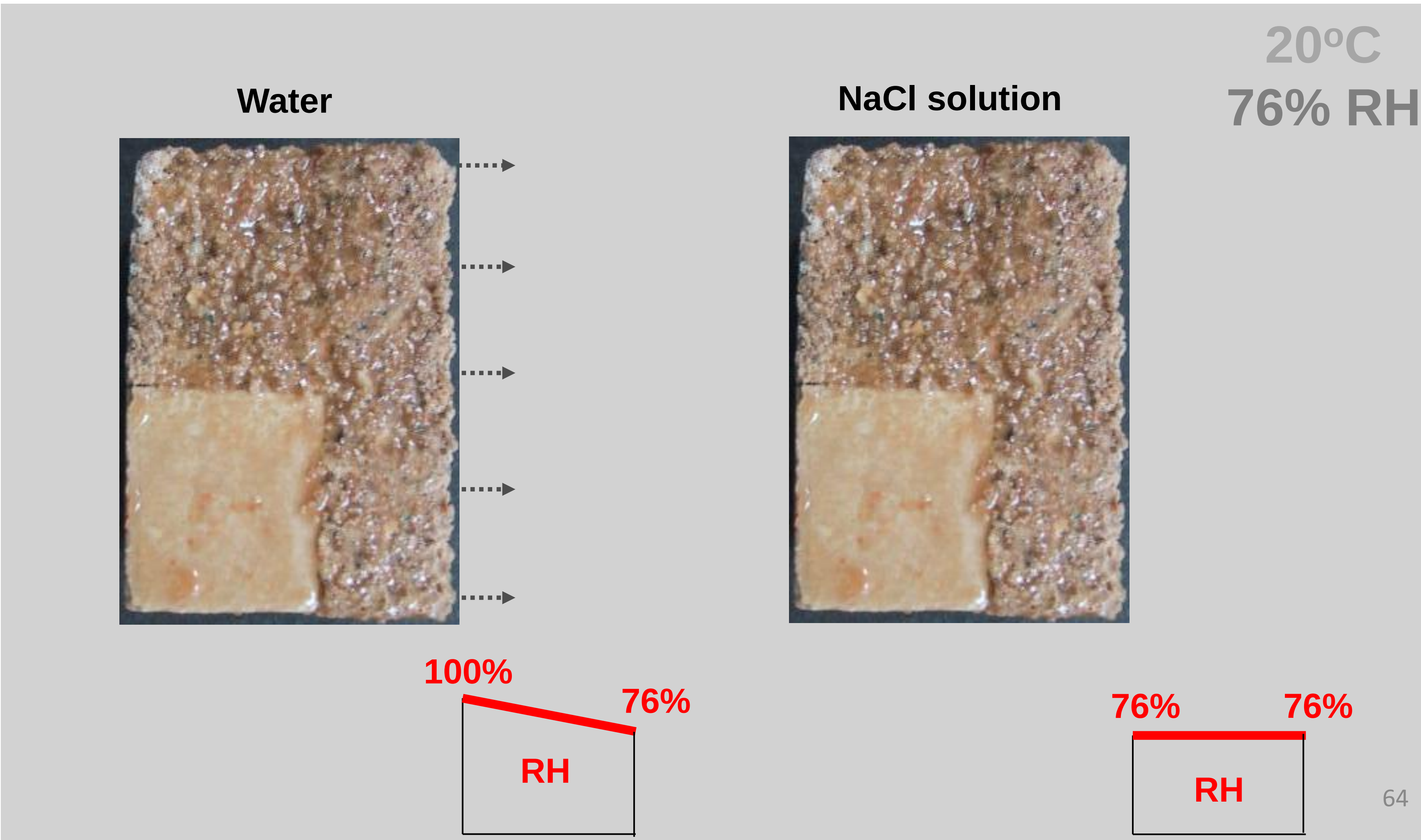
NaCl solution

76%

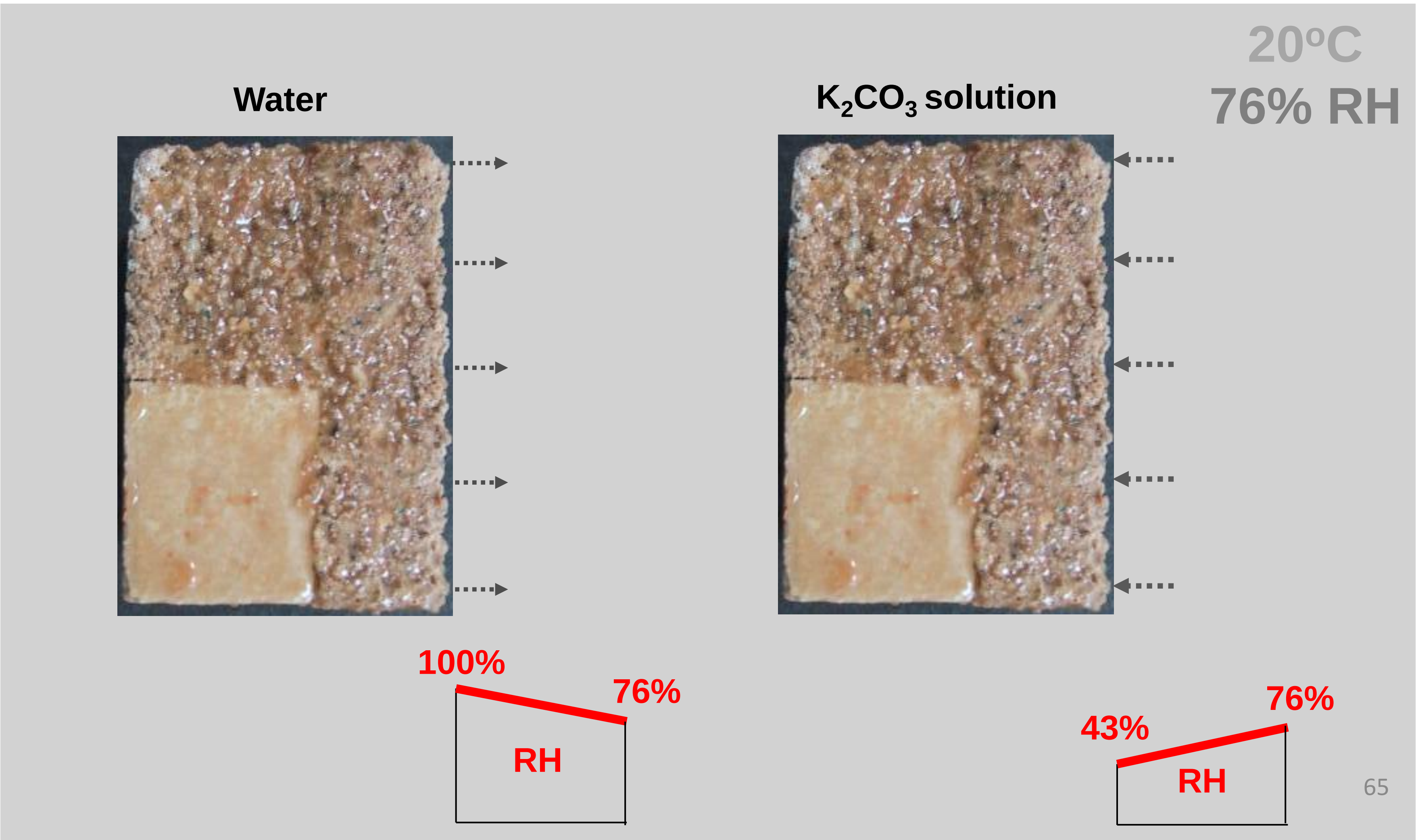
Drying of porous materials – Influence of soluble salts



Drying of porous materials – Influence of soluble salts



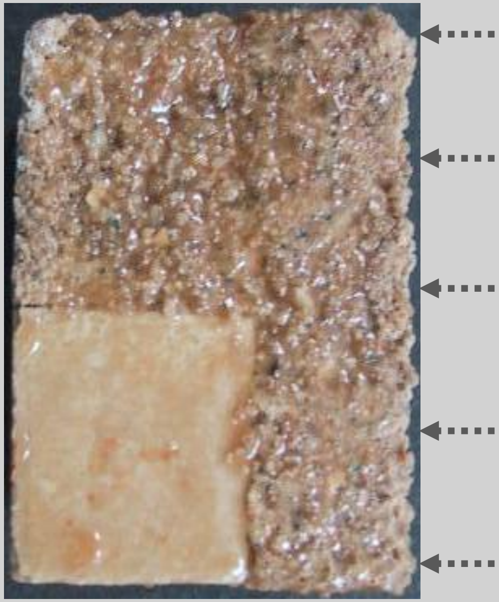
Drying of porous materials – Influence of soluble salts

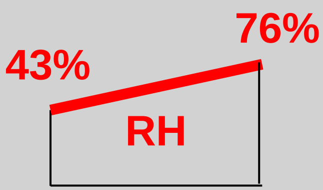


Drying of porous materials – Influence of soluble salts

20ºC
76% RH

K_2CO_3 solution

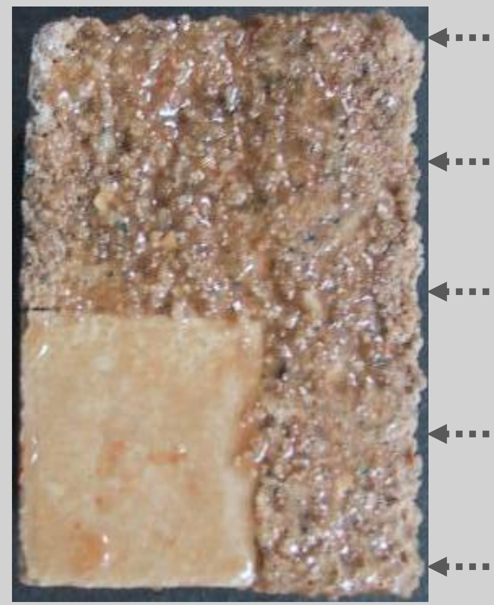




Drying of porous materials – Influence of soluble salts

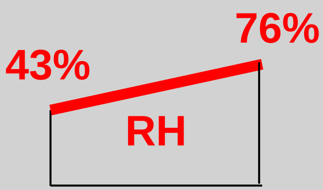
20ºC
76% RH

K_2CO_3 solution



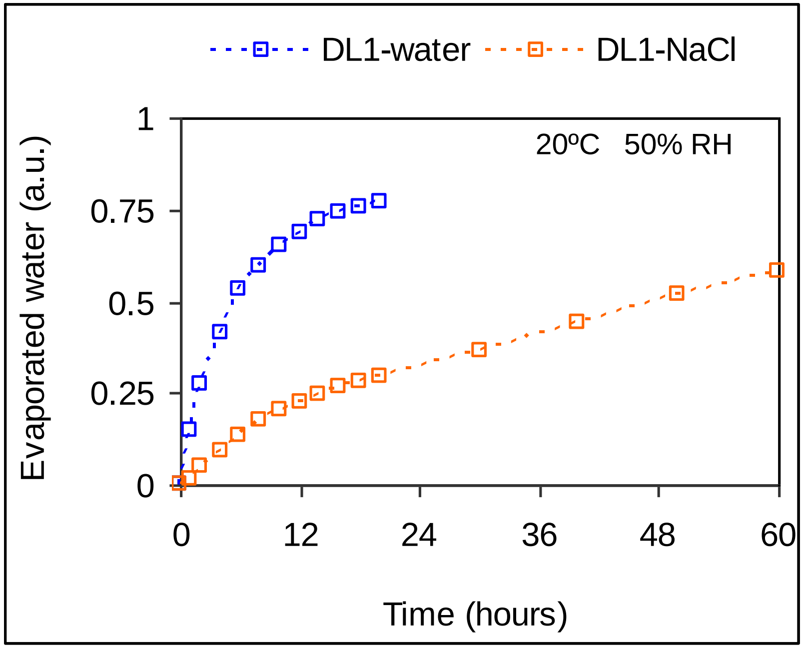
Hygroscopic absorption of moisture from the air

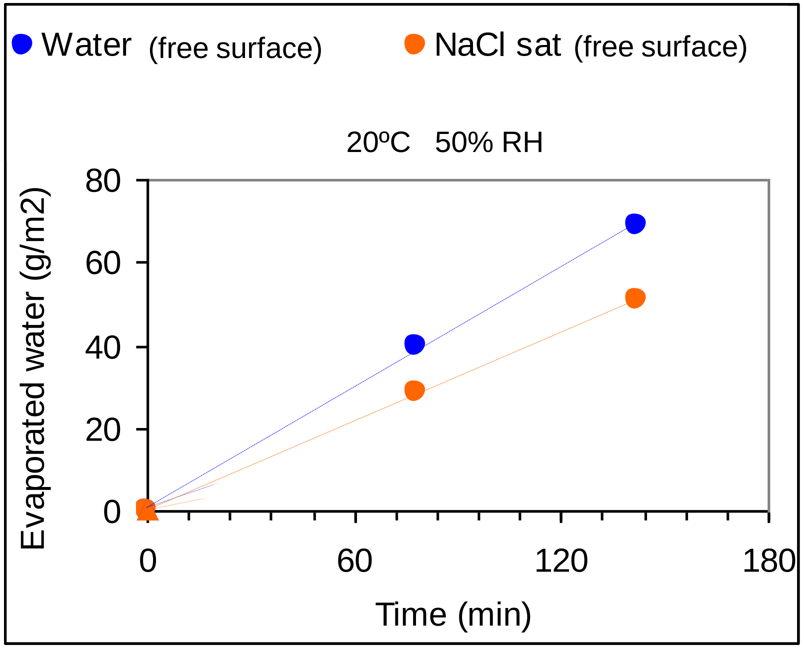
RH_{eq} **< RH air**



Drying of porous materials – Influence of soluble salts

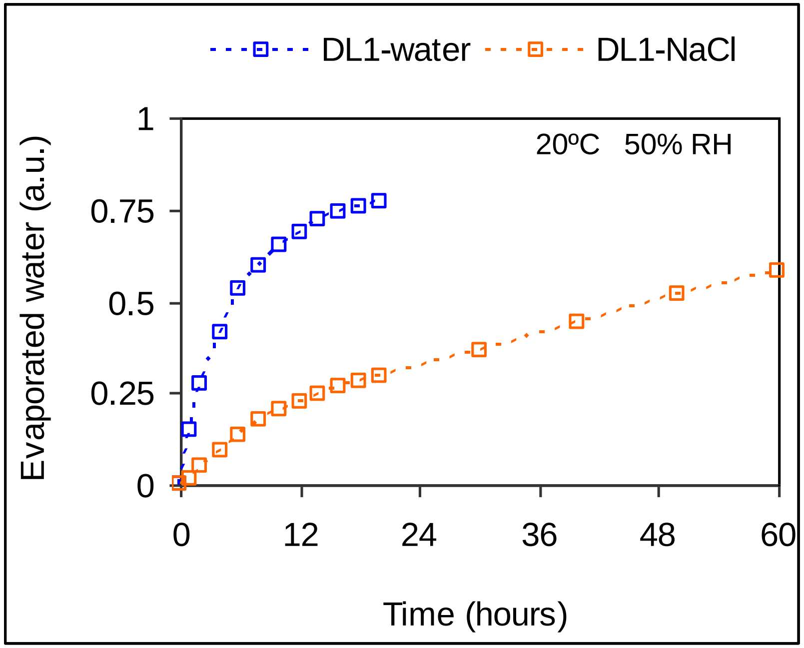
- The vapour pressure gradient can not fully explain the huge differences in drying rate

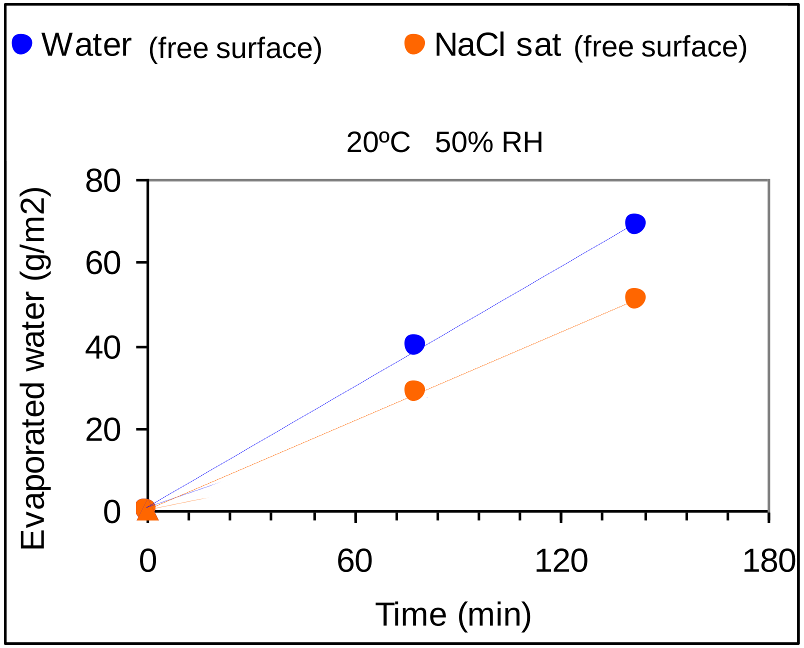




Drying of porous materials – Influence of soluble salts

- The vapour pressure gradient can not fully explain the huge differences in drying rate
- Blocking of the pores by salt crystals …





Drying of porous materials – Three-dimensional effects

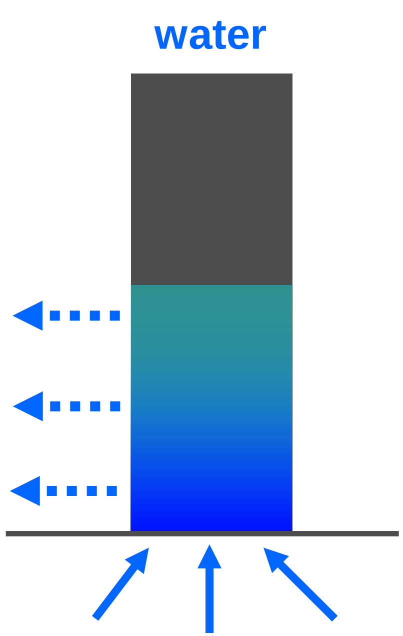
Drying of porous materials – Three-dimensional effects

In walls with rising damp…

Drying of porous materials – Three-dimensional effects

In walls with rising damp…

… the liquid tends to rise up to where the vapour flow through the surface of the wall is equal to the liquid flow that penetrates through the base of the wall



Drying of porous materials – Three-dimensional effects

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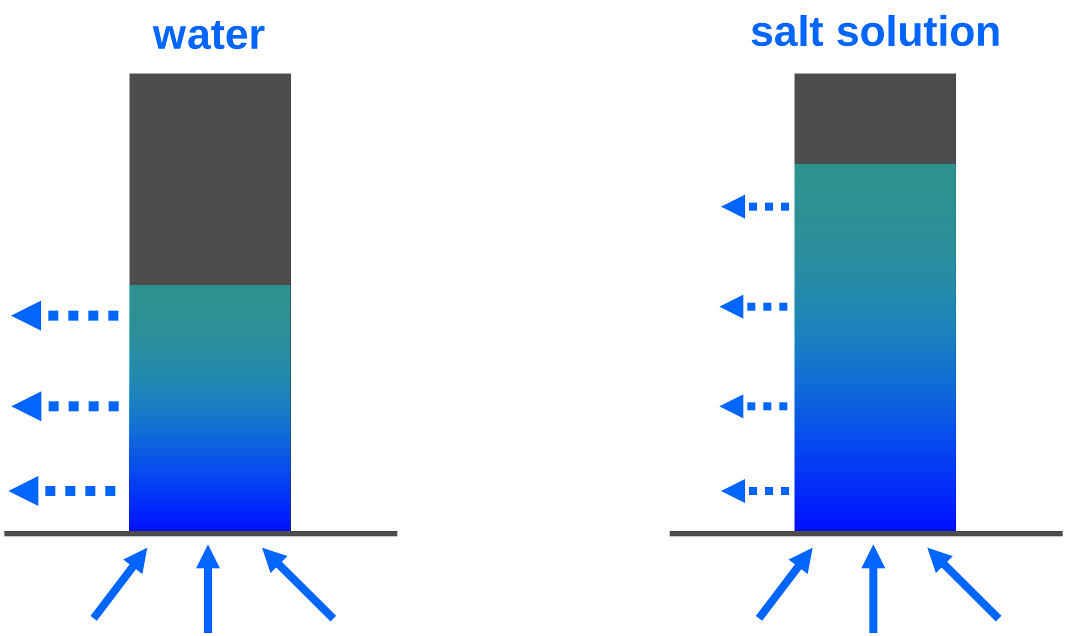
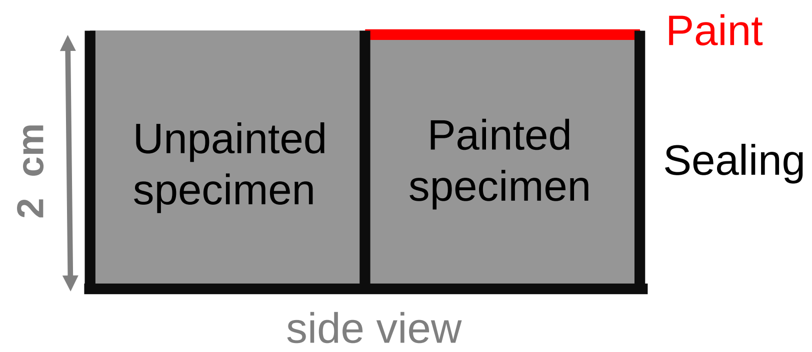
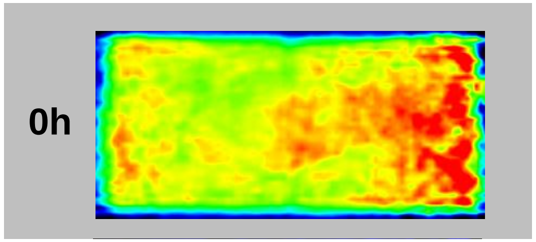


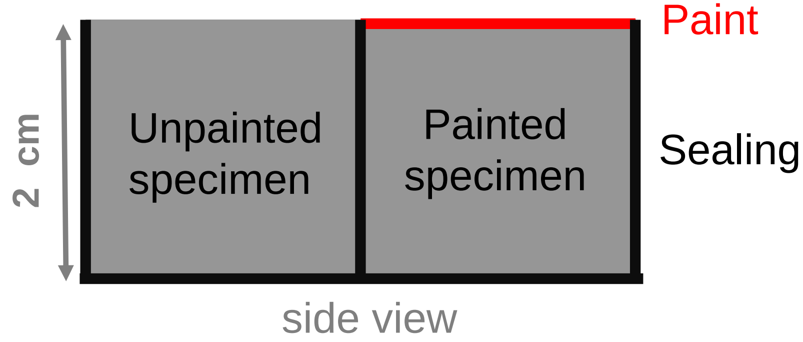
Drying of porous materials – Influence of paints

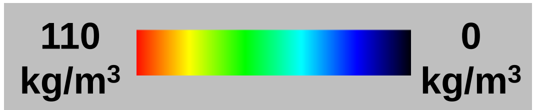
Drying of porous materials – Influence of paints



Drying of porous materials – Influence of paints

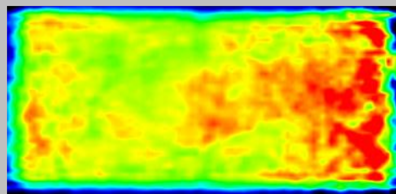


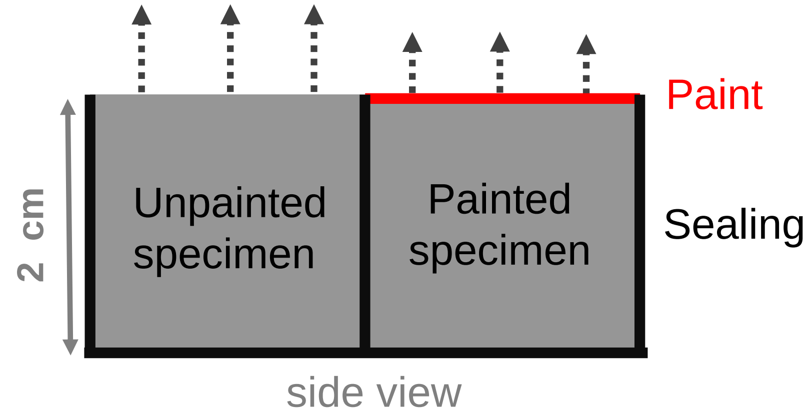




Drying of porous materials – Influence of paints

0h

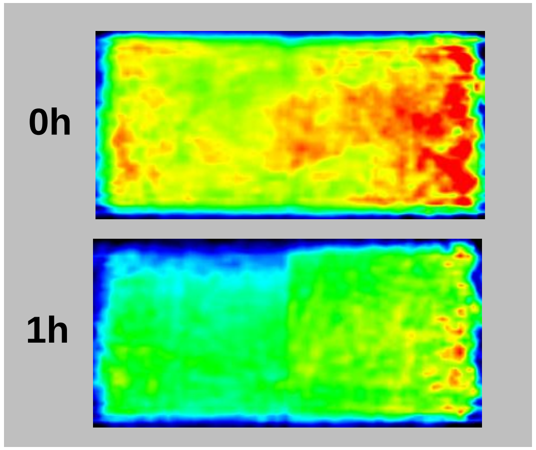


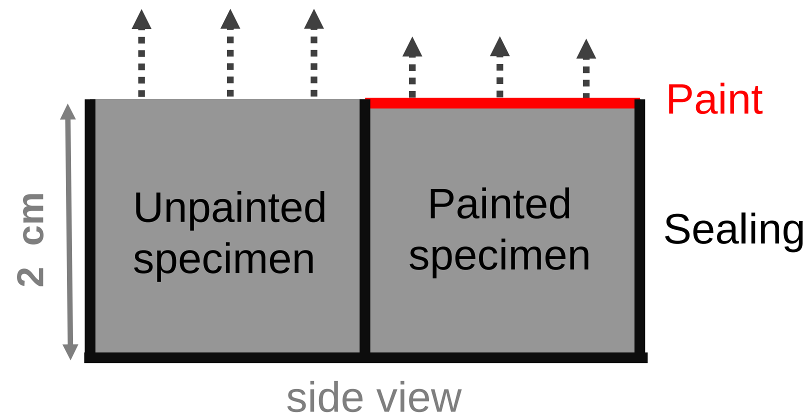


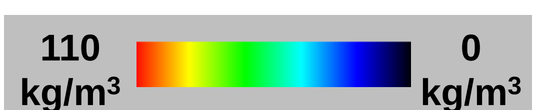
110 kg/m³

0 kg/m³

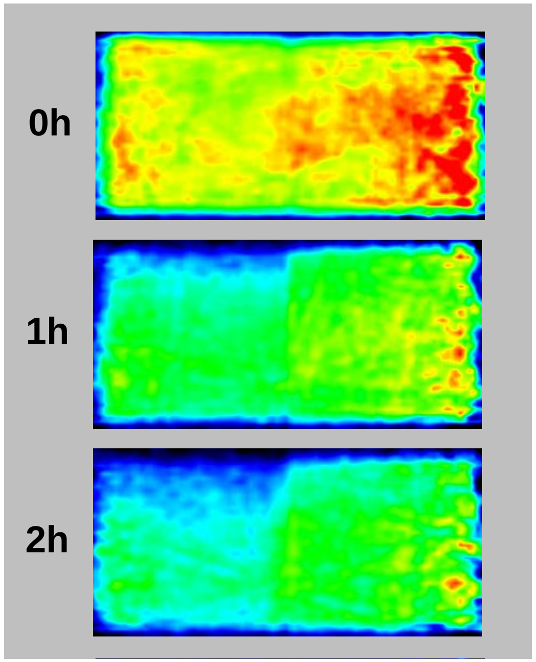
Drying of porous materials – Influence of paints

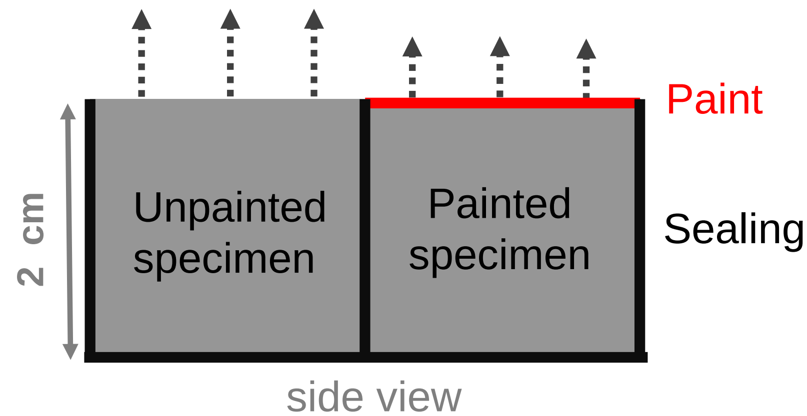


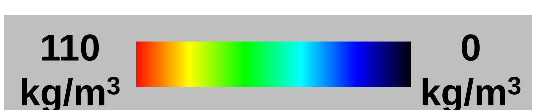




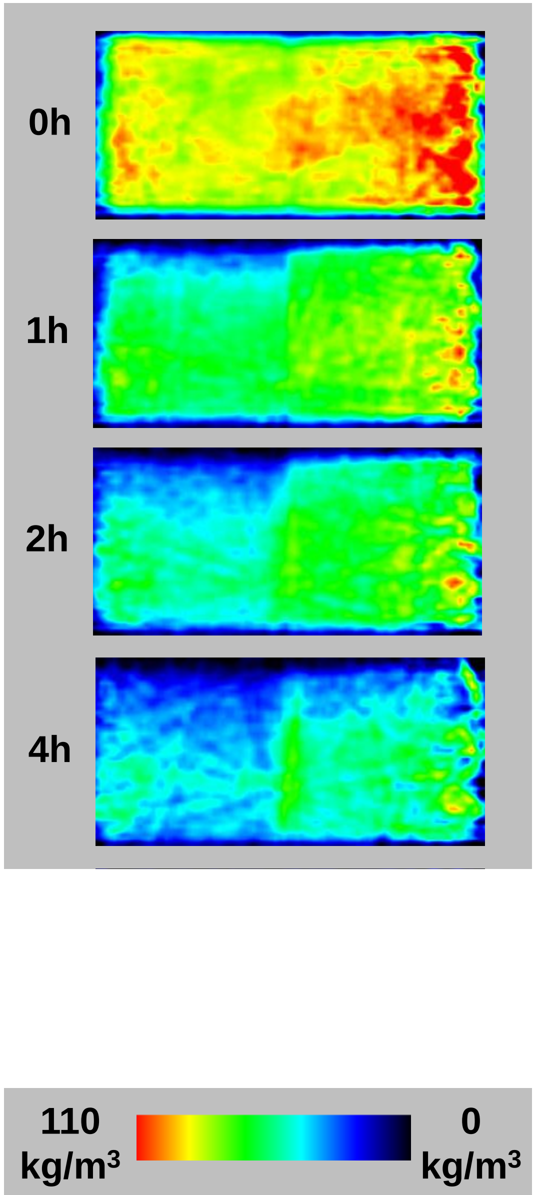
Drying of porous materials – Influence of paints

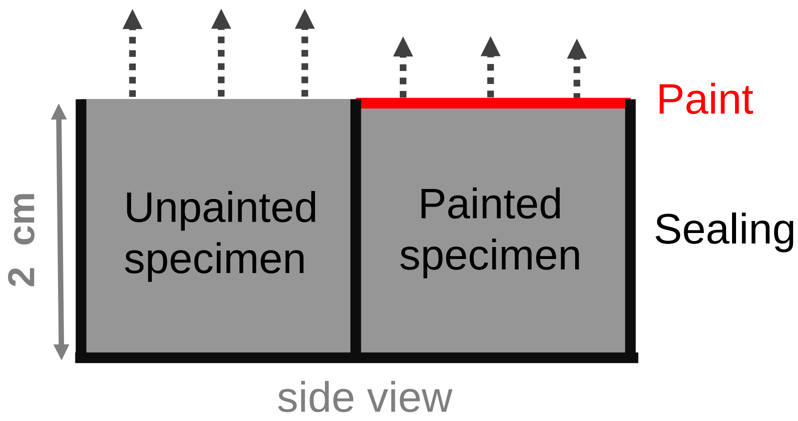




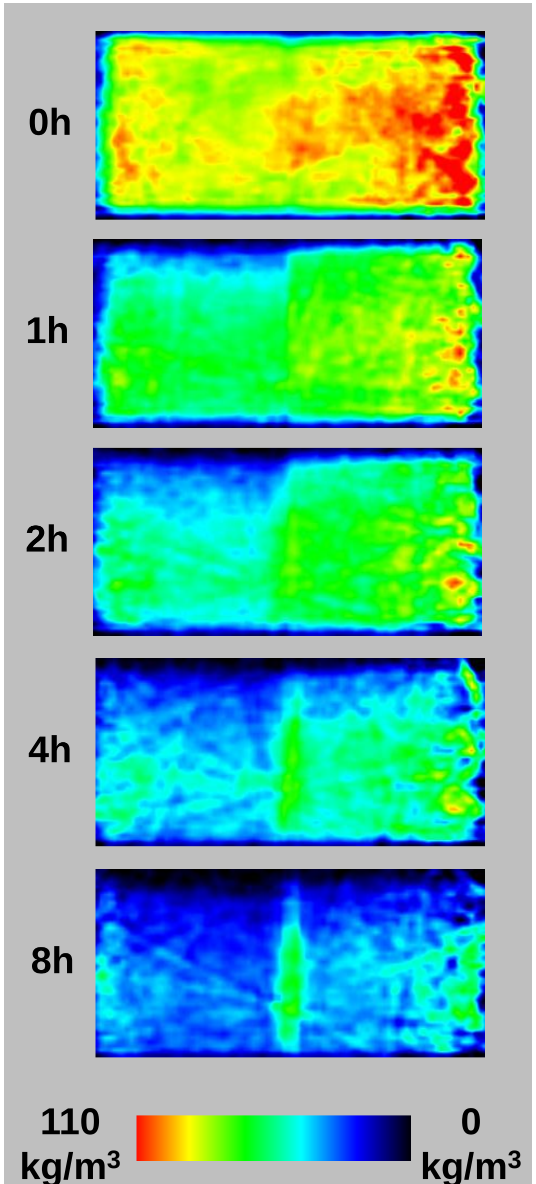


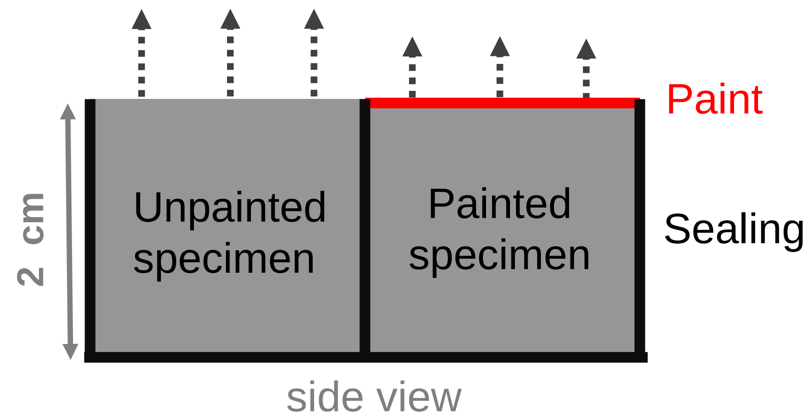
Drying of porous materials – Influence of paints





Drying of porous materials – Influence of paints





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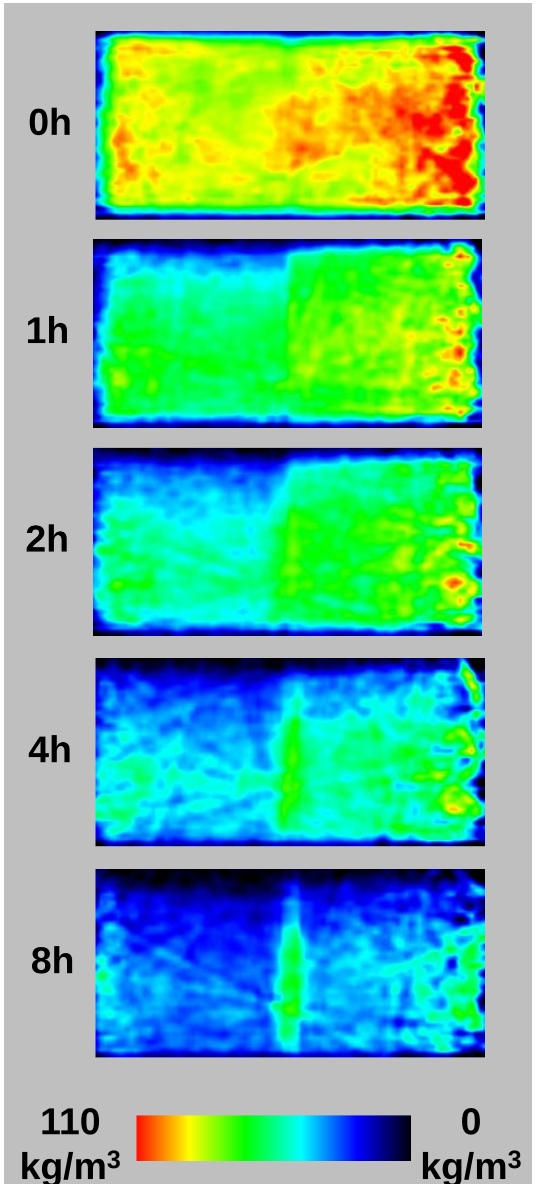
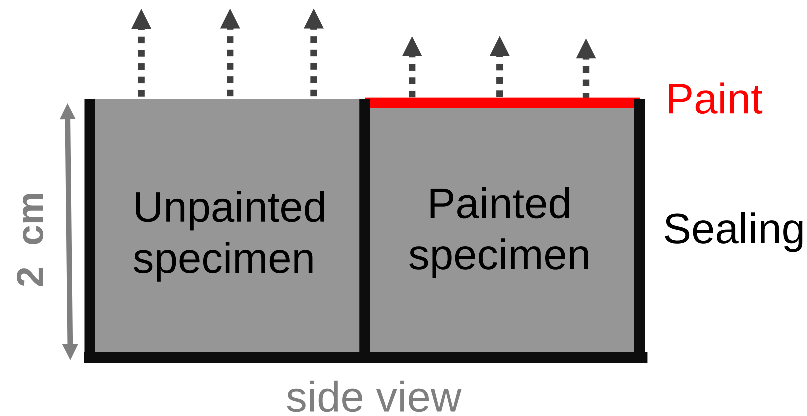




With the paint:

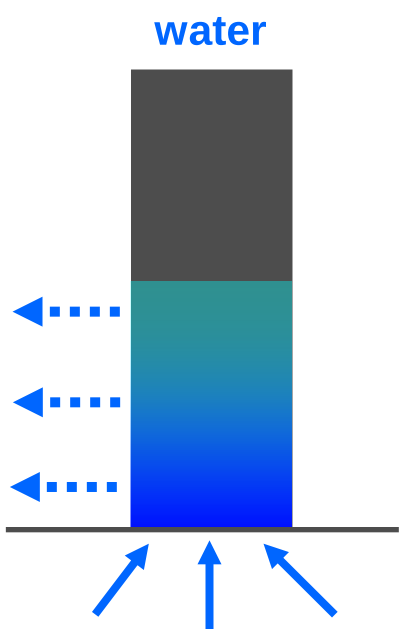
- Drying is slower
- Stage I is longer

=> surface stays wet longer / at lower moisture contents

Drying of porous materials – Three-dimensional effects

In walls with rising damp…

… the liquid tends to rise up to where the vapour flow through the surface of the wall is equal to the liquid flow that penetrates through the base of the wall



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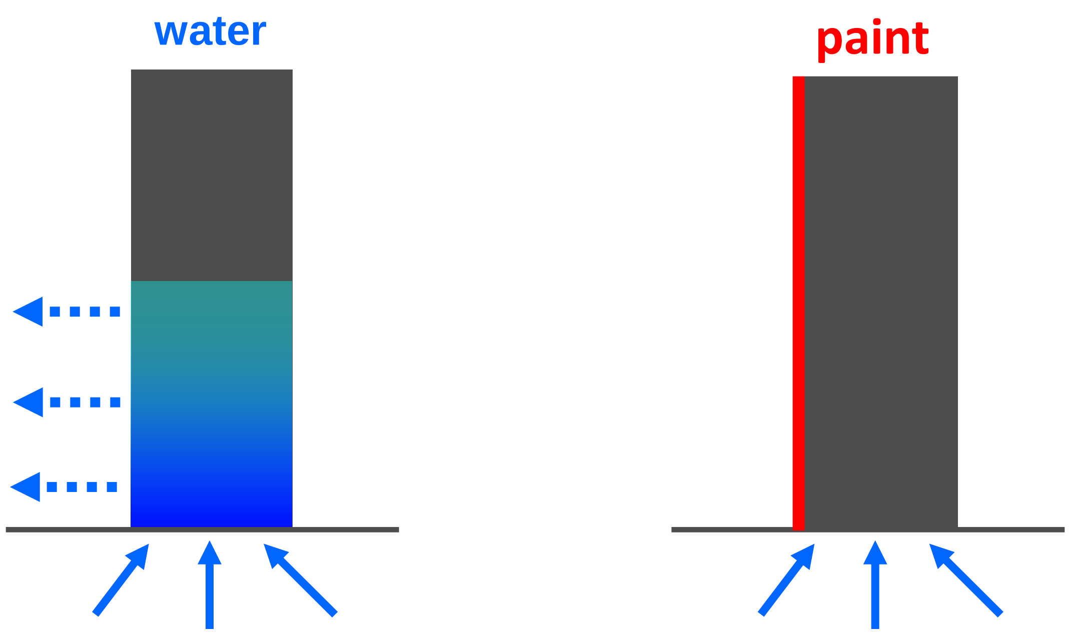

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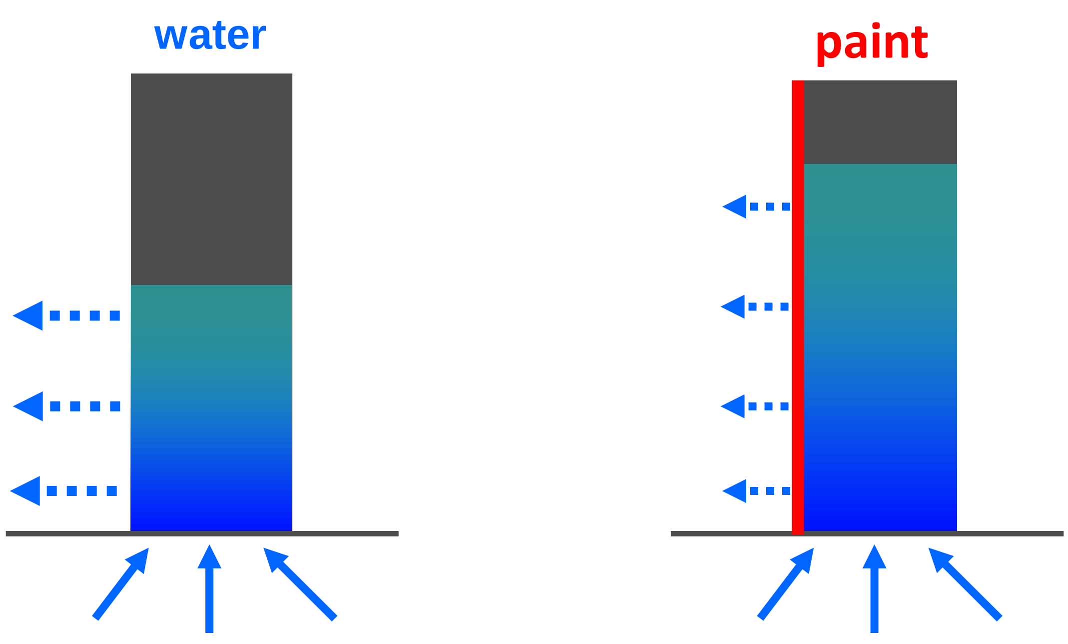

Drying of porous materials – Influence of water repellents

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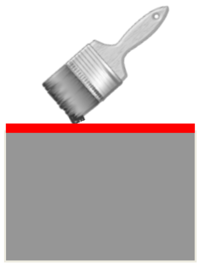
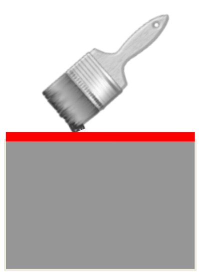


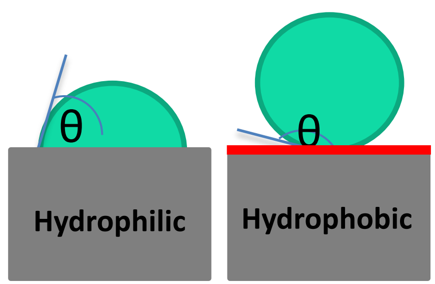
- Colourless liquid
- Applied by brushing or spray

Drying of porous materials – Influence of water repellents

Water repellent treatments are used to:

• Reduce the capillary suction of the material



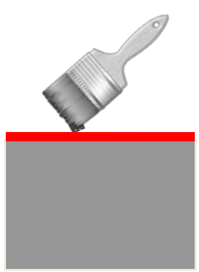


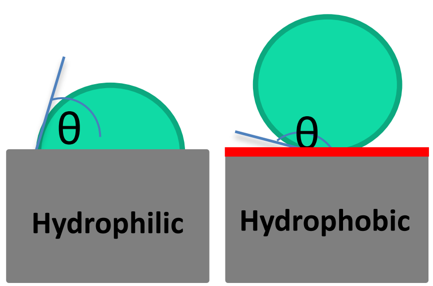
- Colourless liquid
- Applied by brushing or spray

Drying of porous materials – Influence of water repellents

Water repellent treatments are used to:

- Reduce the capillary suction of the material
- Protection of facades
    - prevent the ingress of moisture
    - prevent staining and moisture-related
    - deterioration of the surface

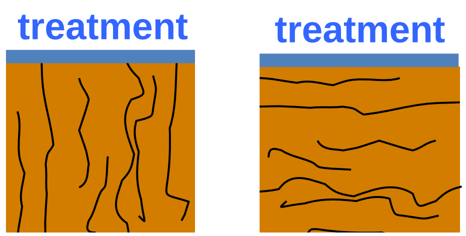


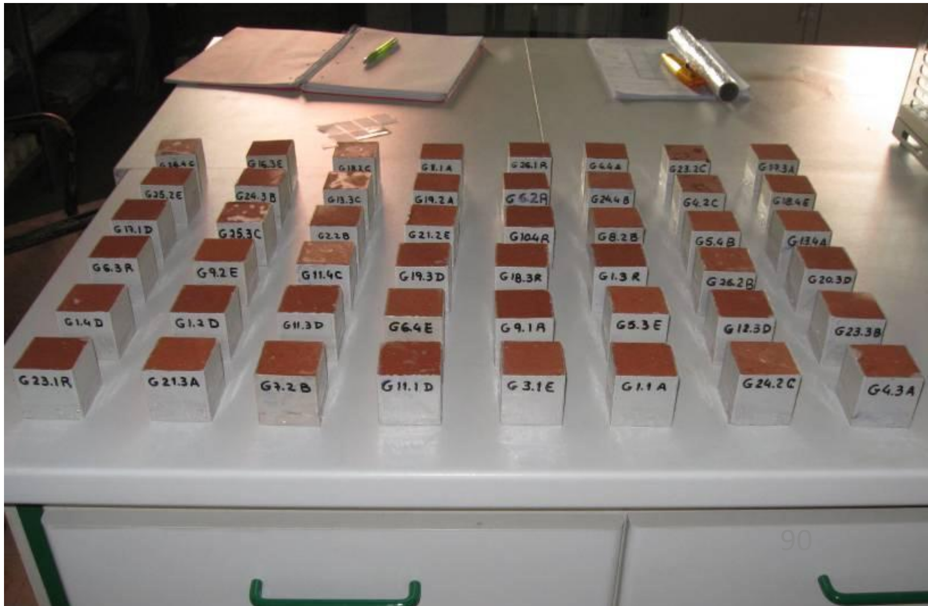


- Colourless liquid
- Applied by brushing or spray

Drying of porous materials – Influence of water repellents

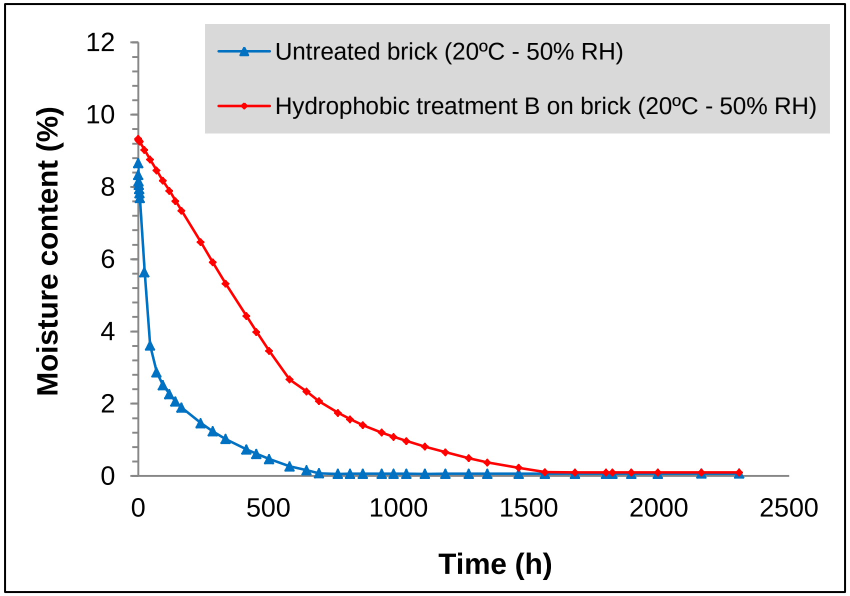
- Five silicone-based treatments
- Acquired in the market
- Applied on cubic brick specimens
- Consumption respected the thresholds
- Drying tests (20°C – 50% RH)

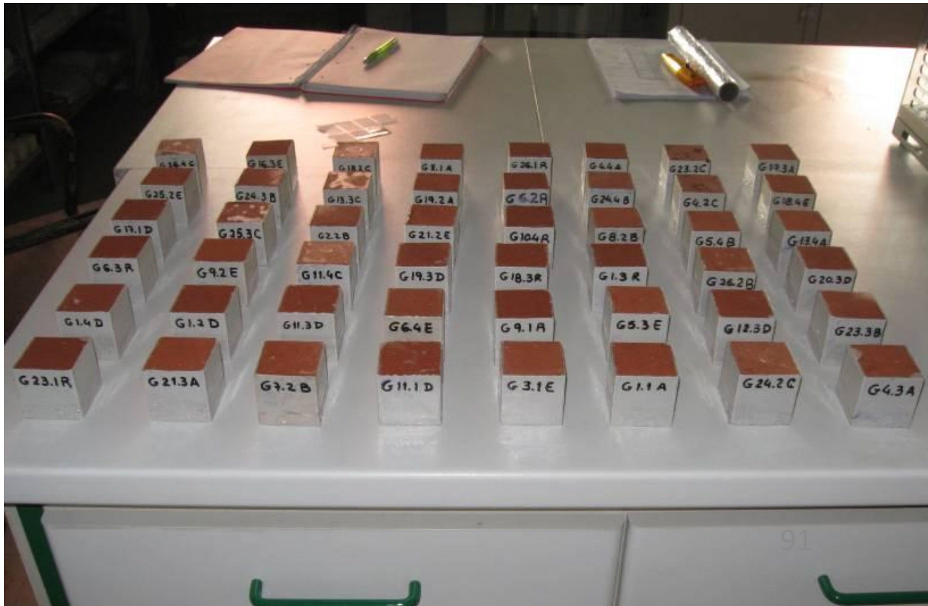




Drying of porous materials – Influence of water repellents

- Five silicone-based treatments
- Acquired in the market
- Applied on cubic brick specimens
- Consumption respected the thresholds
- Drying tests (20ºC – 50% RH)
- Slower drying





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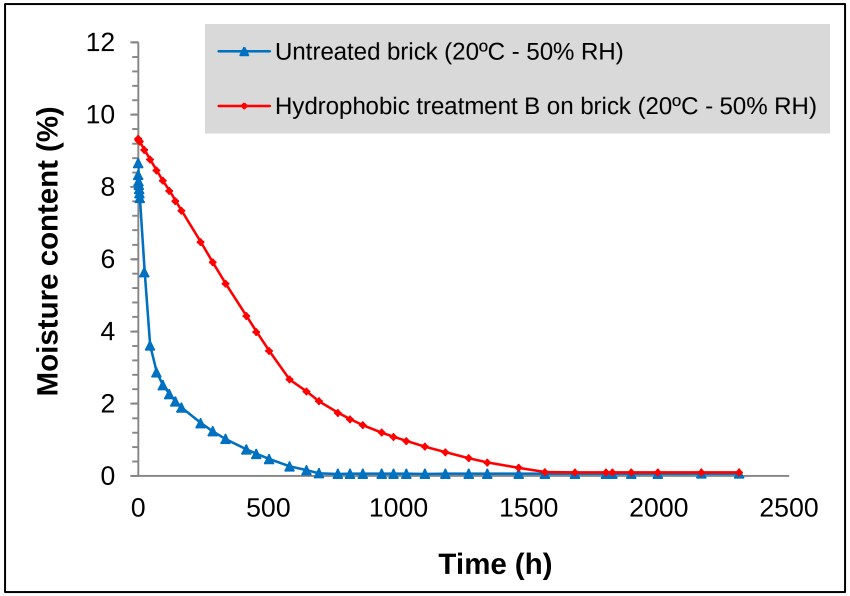
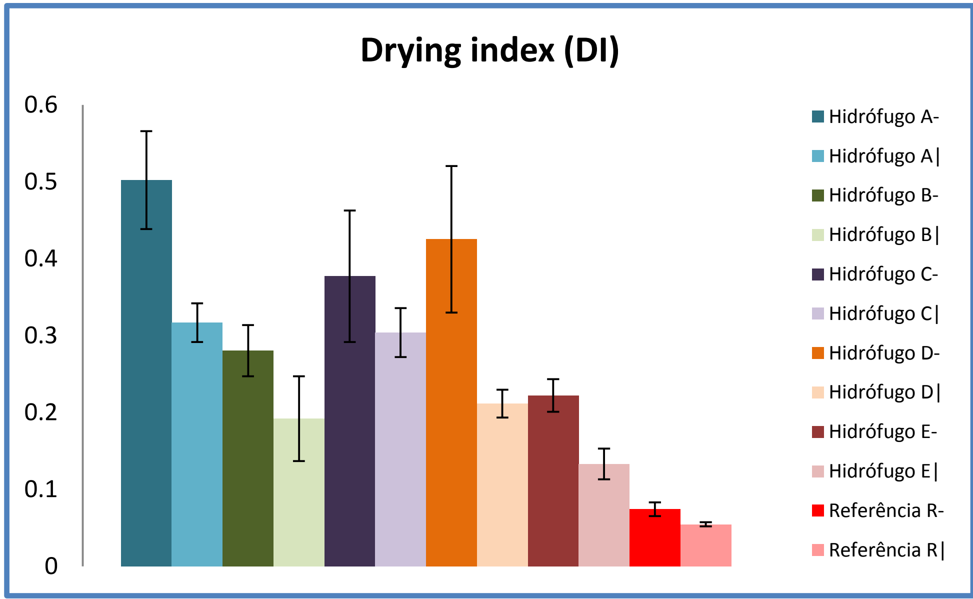
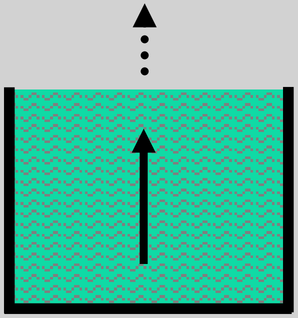
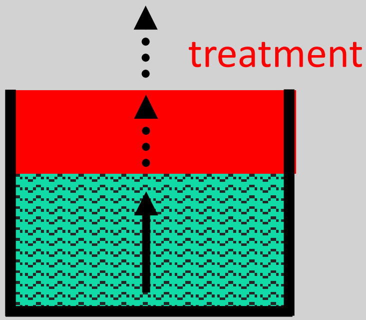




Drying of porous materials – Influence of water repellents

- Five silicone-based treatments
- Acquired in the market
- Applied on cubic brick specimens
- Consumption respected the thresholds
- Drying tests (20ºC – 50% RH)
- Slower drying: because there is no stage I…





Drying of porous materials – Three-dimensional effects

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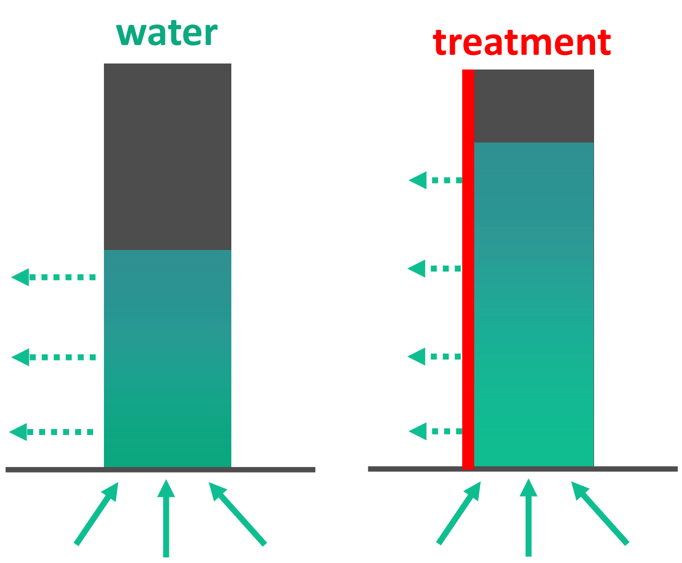

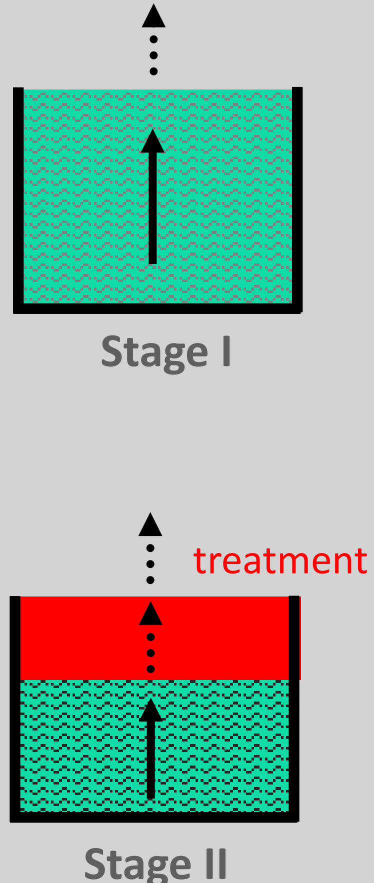

Drying of porous materials
Lecture contents

- Introduction
- The two-stage model
- NMR animation of drying with pure water
- Drying tests
    - The evaporation curve
    - The drying index
- Slower drying: causes and effects
- Influence of soluble salts on drying + NMR animation
- Influence of paint layers on drying + NMR results
- Influence of hydrophobic treatments on drying + results

… including 3D effects

Drying of porous materials

THANK YOU…