Modelling of drying phenomena in concrete with recycled aggregates

Master's thesis presented to obtain the degree of Master of Science (MSc) in Civil Engineering

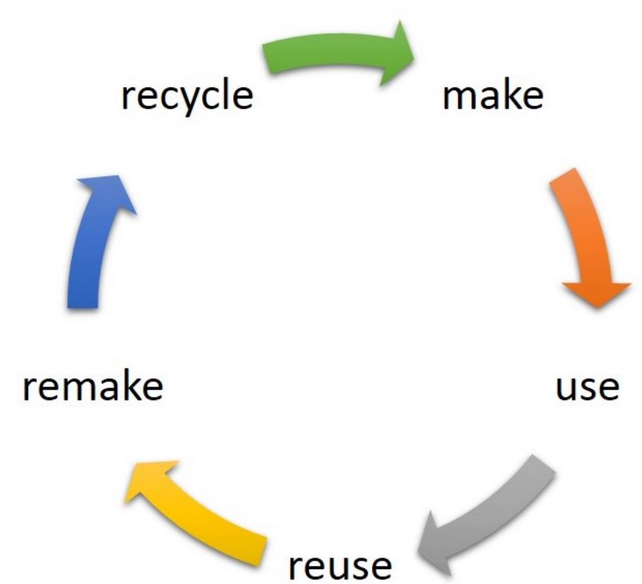
Arthur FANARA - 25 June 2020

Promotors: L. COURARD and F. COLLIN - Academic Year 2019-2020

Purpose of this thesis

- Concrete: 1 billion tons/year in EU
- Natural Aggregates (NA): 2.8 billion tons (all uses) in EU (2017)
- C&D Waste: 374 million tons in EU (2016) (30% total)

→ Recycled Concrete Aggregates = NA + Residual cement paste

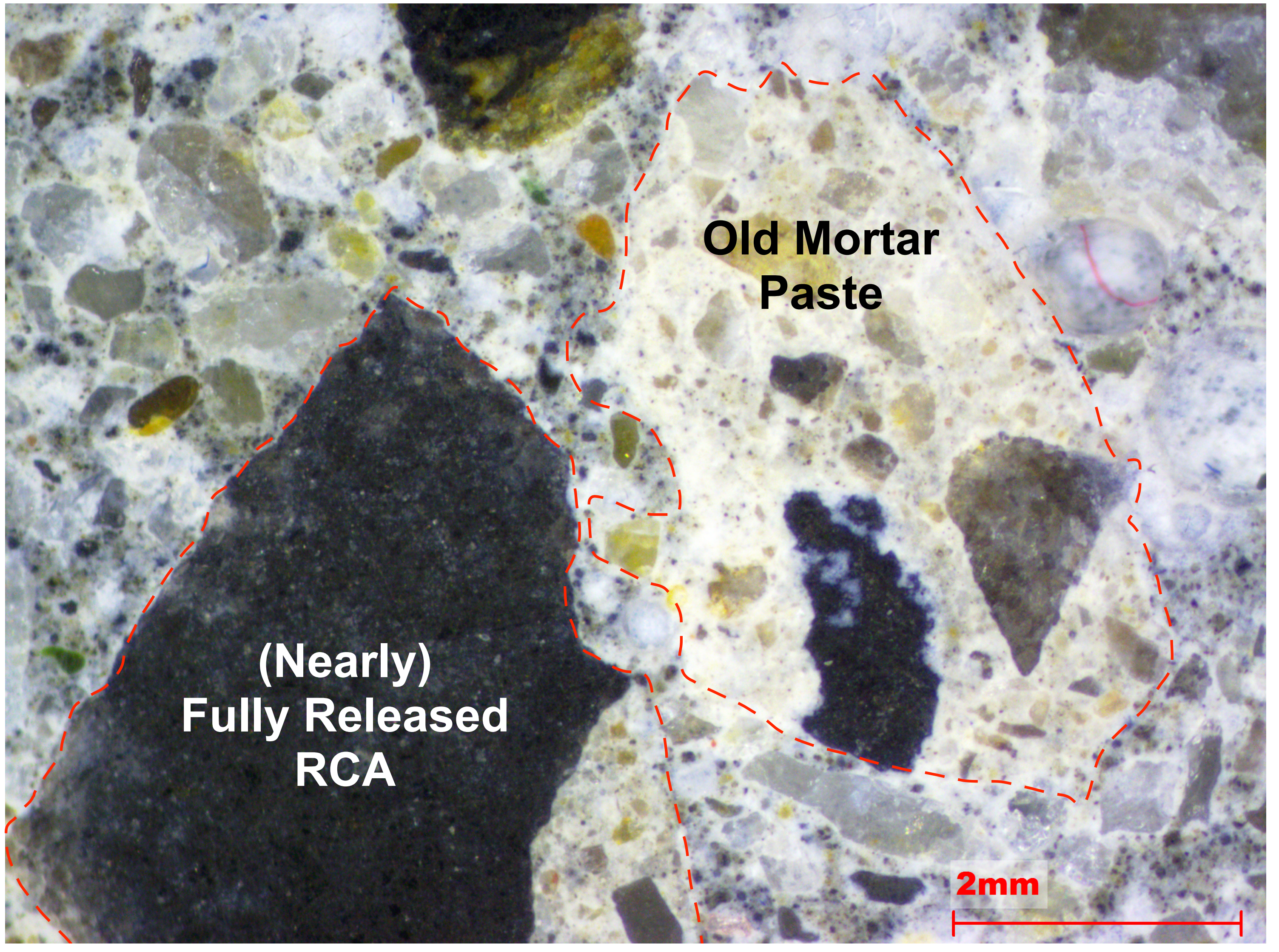


From [Wikipedia, 2020a]

Purpose of this thesis

- RCA: increased porosity and water absorption

- Water is the cause of many degradations processes because it favours ions penetration



Purpose of this thesis

Is the use of Recycled Concrete Aggregates (RCA) inside concrete affecting its **durability** from a point of view of **water transfers**?

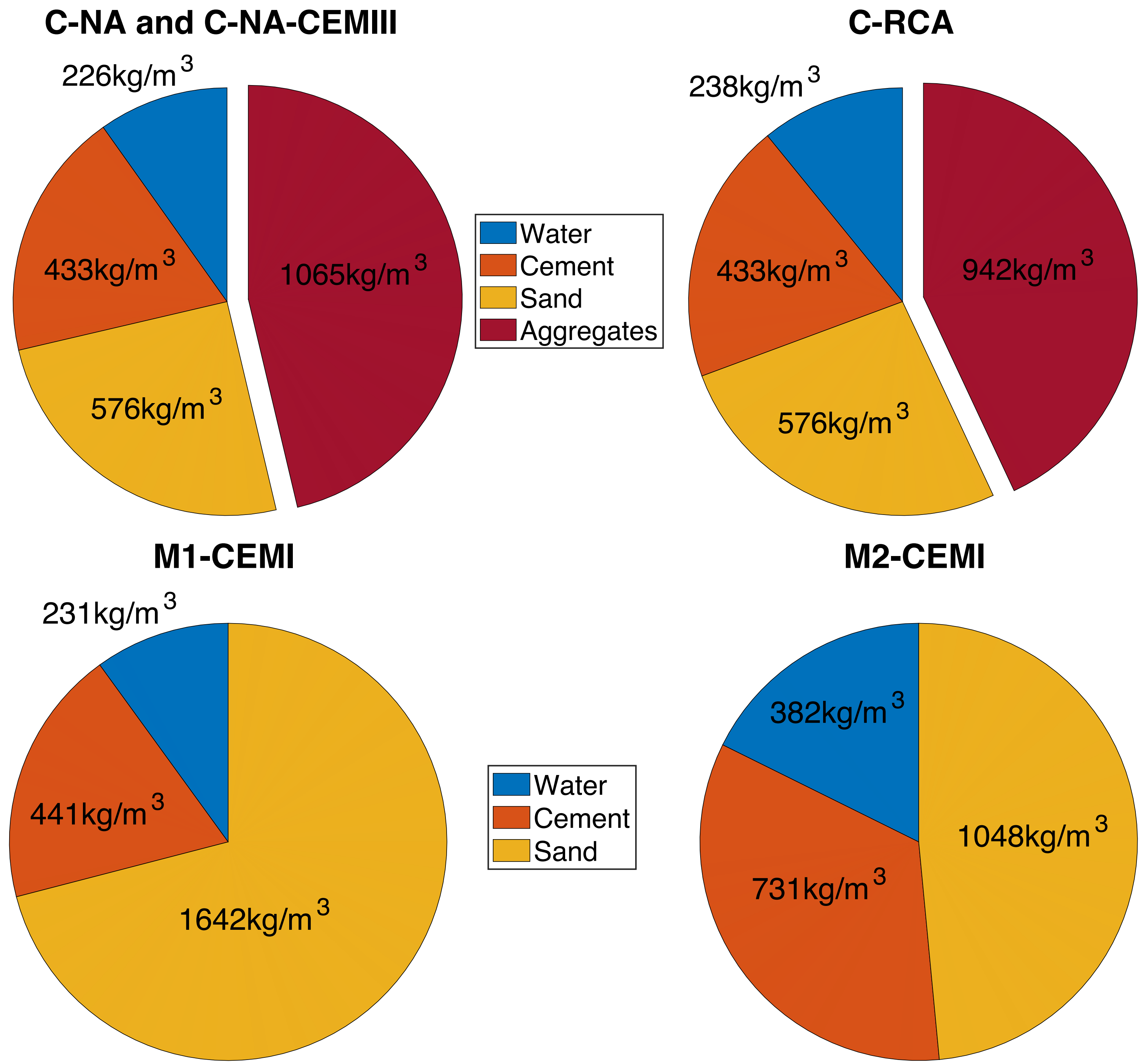
→ Modelling of water flows inside concrete

→ Parameters obtained through several experiments

Experimentation

Compositions

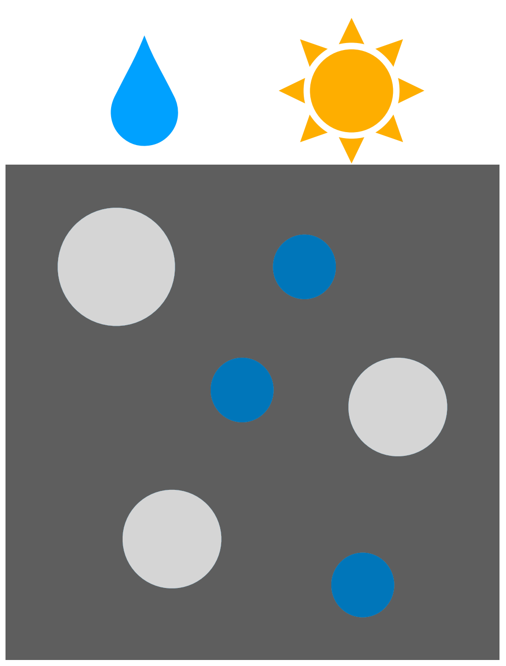
- **C-NA**: NA with CEM I (Dreux-Gorisse)
- C-NA-CEMIII: NA with CEM III (Dreux-Gorisse)
- **C-RCA**: RCA with CEM I (Constant volume)
- M1-CEMI: Mortar with CEM I (Dreux-Gorisse)
- M2-CEMI: Mortar with CEM I (C.E.M.)



Experimentation

Experiments & Concrete’s properties

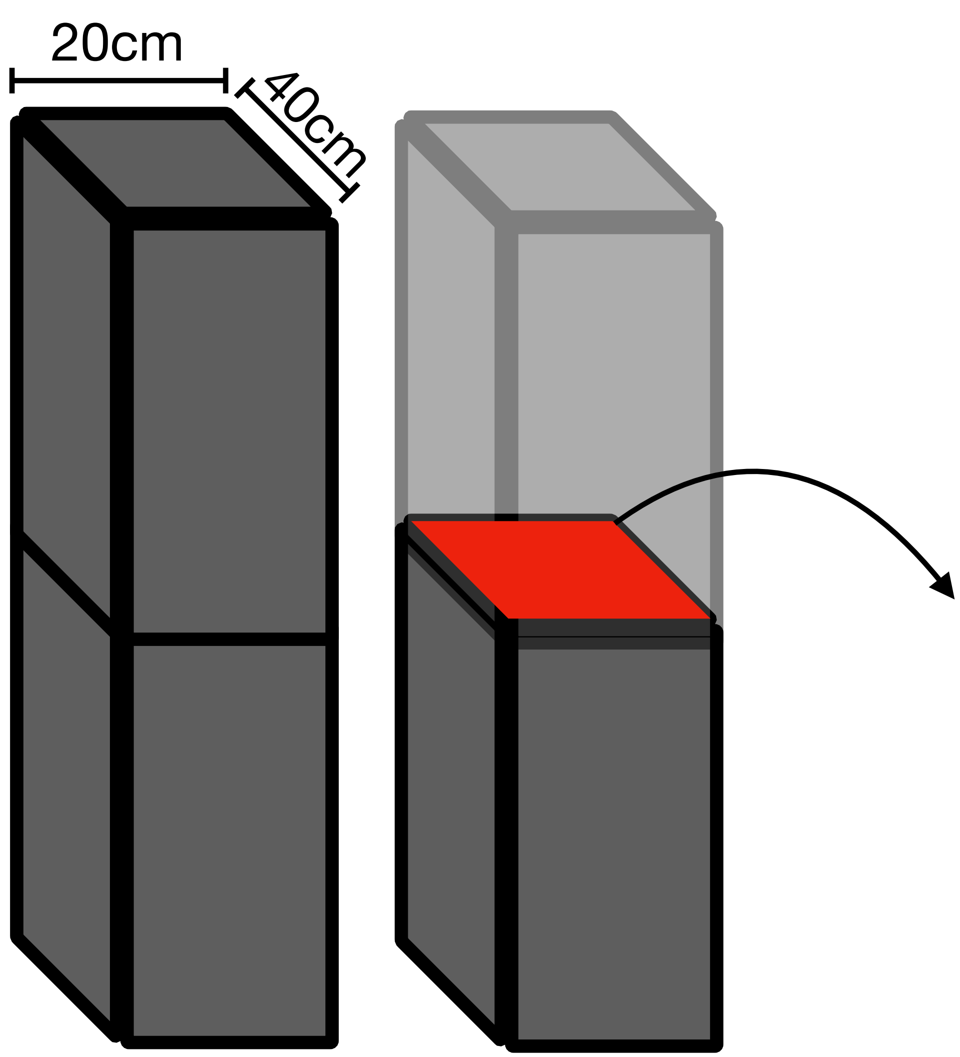
- Water Absorption Immersion → Densities and porosity
- Water permeability → Intrinsic permeability
- Static (De)Sorption → WRC and Van Genuchten’s model
- DVS → WRC and Van Genuchten’s model (only mortars)
- Convective drying → Mass and heat transfer coefficients
  → Validation of the model
- Carbonation → Carbonation depth

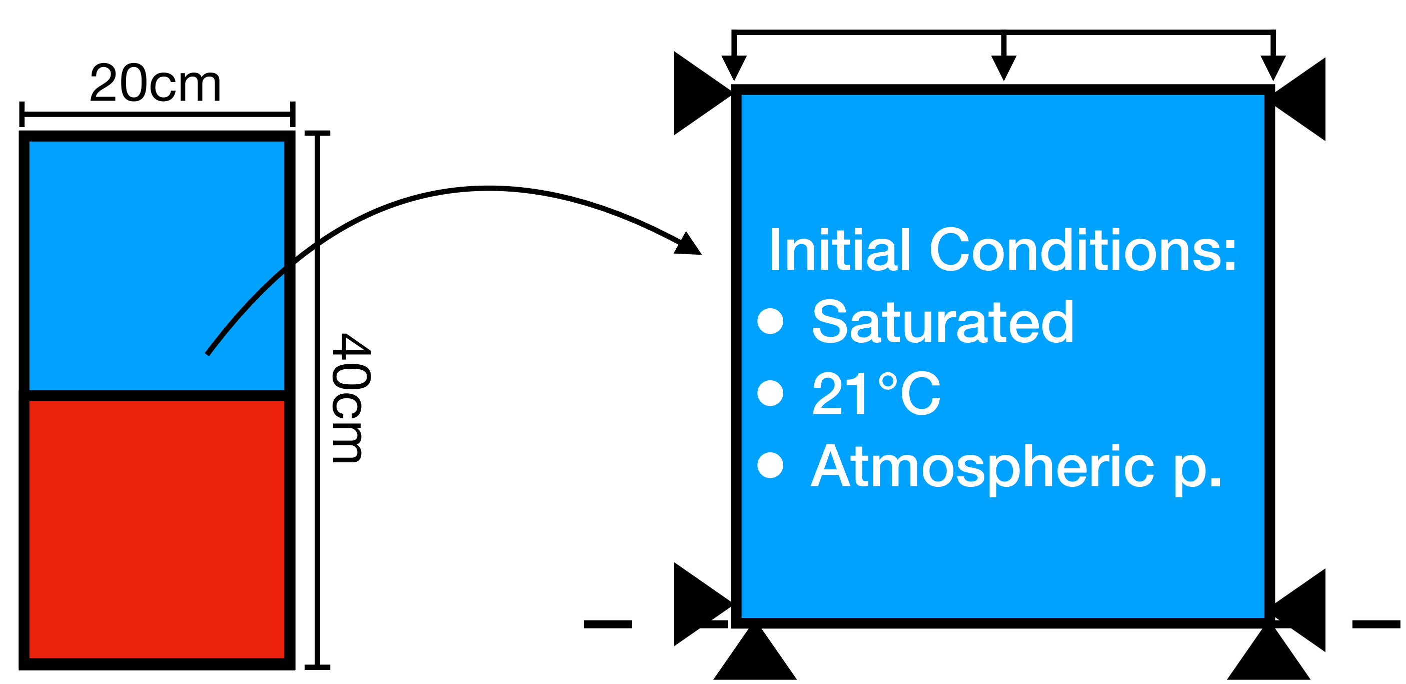


Application

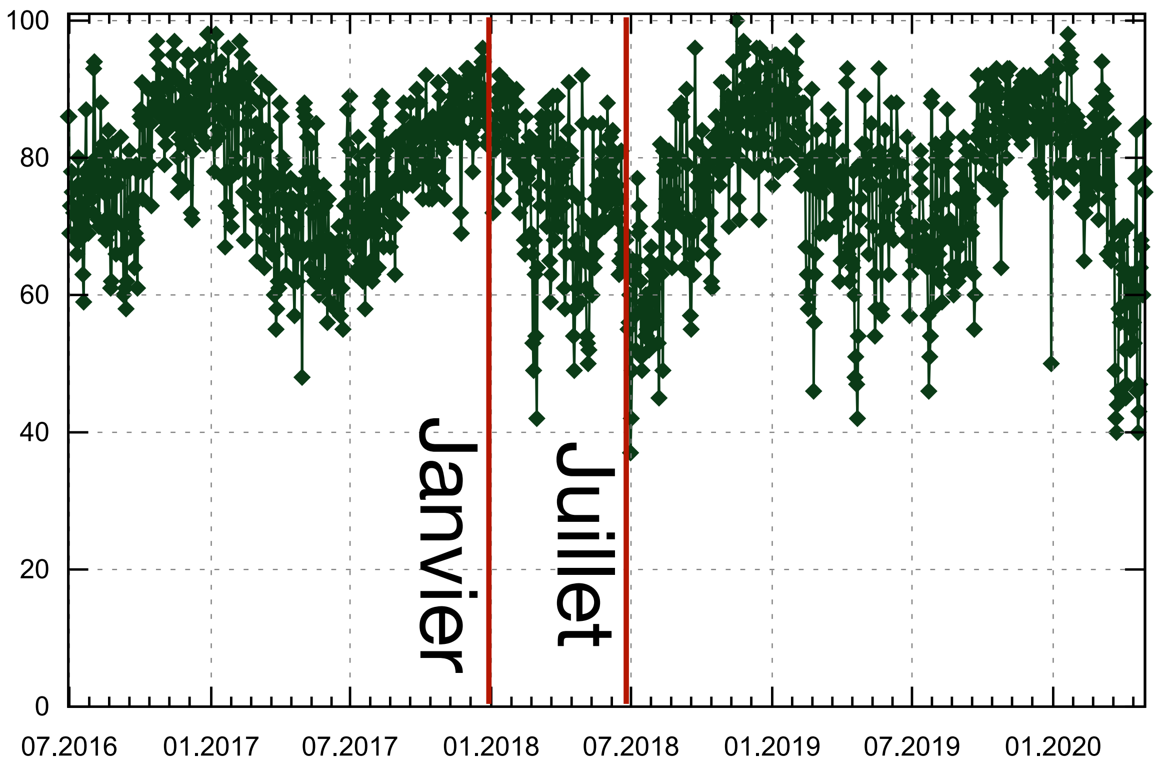
Mesh & Applied conditions

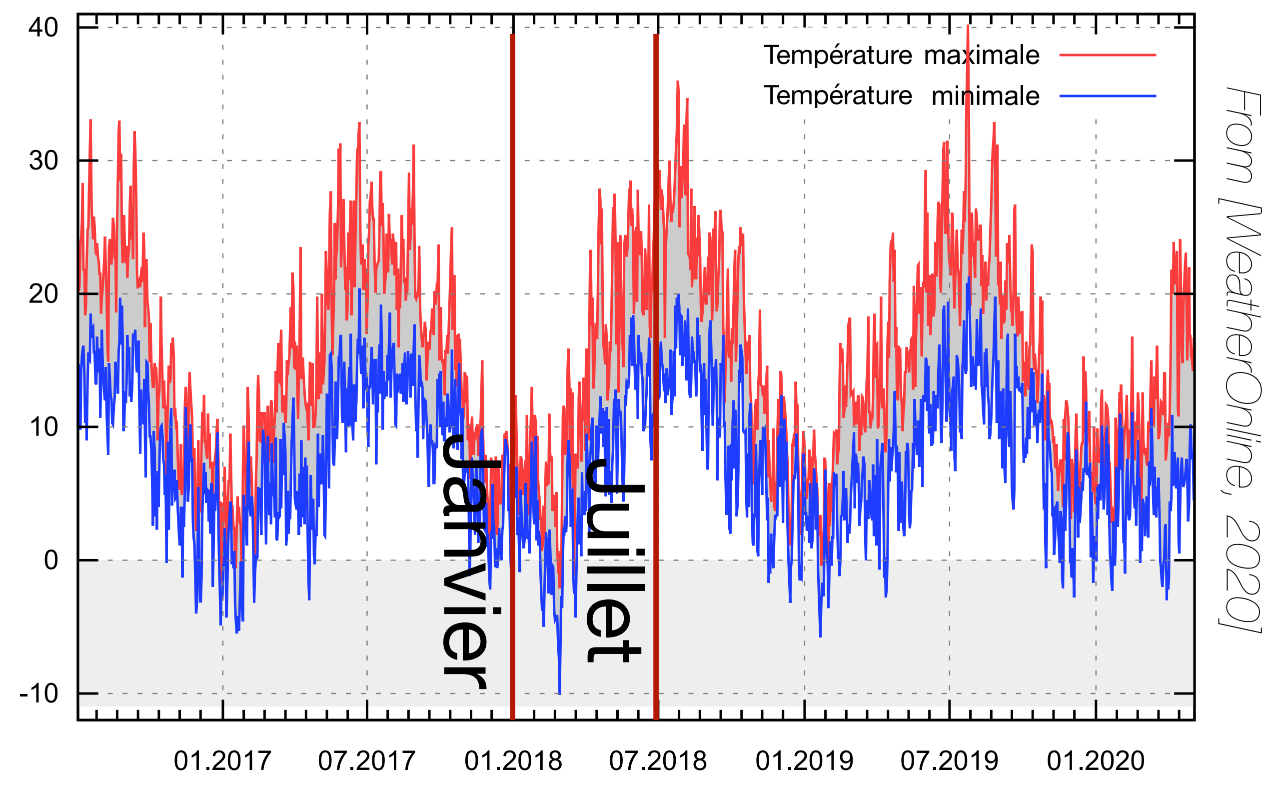
From [Wikipedia, 2020c]





Application
Applied conditions





$RH \in [40; 95]\,\%$ $T \in [-5; 25]$°C

- January: 95% of RH for a temperature of -5°C
- July: 40% of RH for a temperature of 25°C

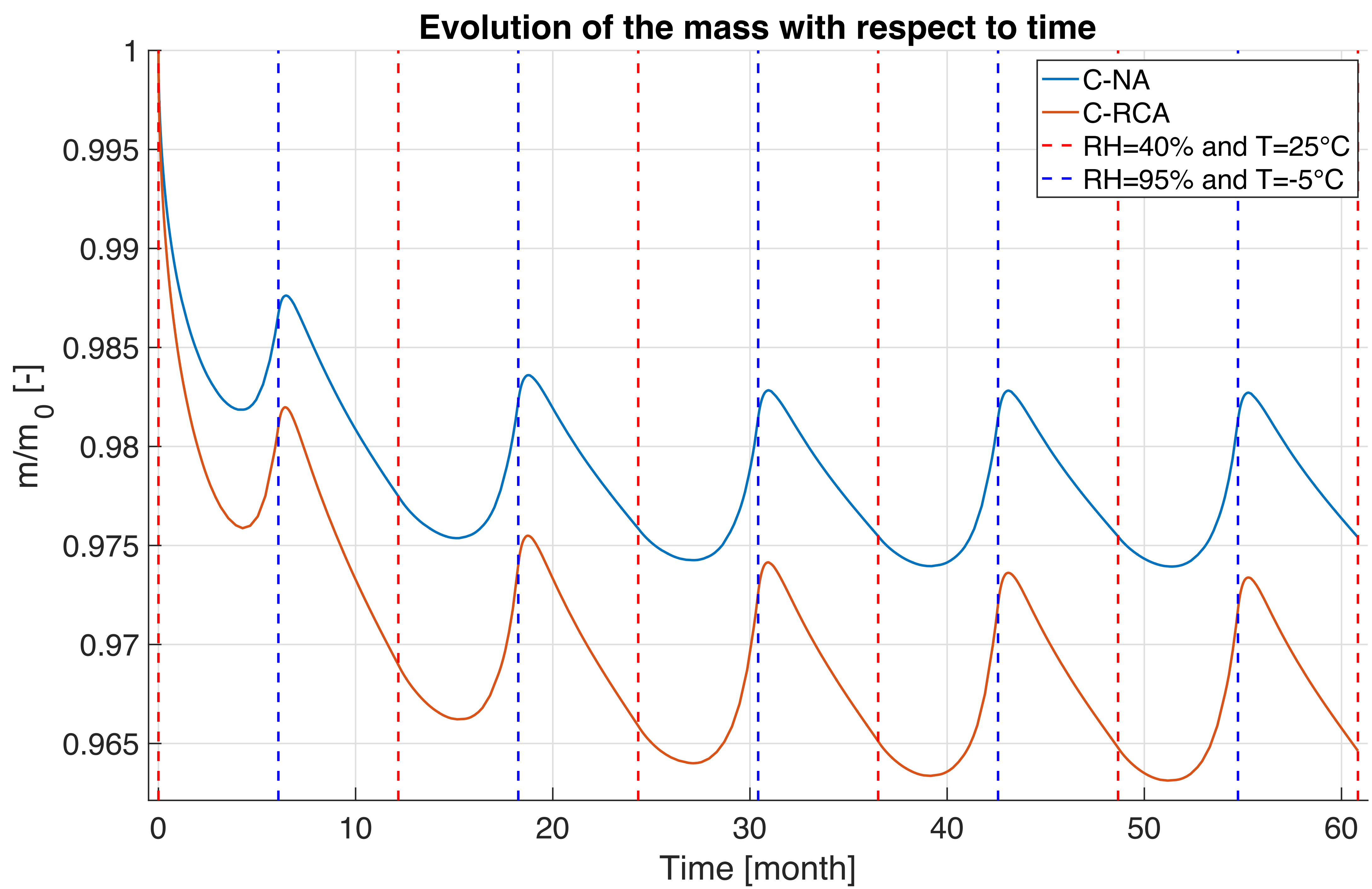
Application

Parameters

Parameter	C-NA	C-RCA	Experimental source
Density of the solid grains (ρ_s) [$\mathrm{kg/m^3}$]	2630	2557	Water Absorption Immersion
Concrete's intrinsic permeability (k_{int}) [$\mathrm{m^2}$]	7.68E-20	1.04E-19	Water Permeability
Concrete porosity (n) [-]	0.156	0.205	Water Absorption Immersion
Van Genuchten's model parameter (m_{vG}) [-]	0.32	0.31	Static Desorption
Van Genuchten's model parameter (n_{vG}) [-]	1.47	1.44	Static Desorption
Air entry pressure (α_{vG}) [MPa]	23.4	19.88	Static Desorption
Minimal concrete's relative permeability [-]	1E-4	1E-4	-
Seepage penalty coefficient (K) [$\mathrm{m/s.Pa}$]	0	0	-
Mass transfer coefficient (α) [$\mathrm{m/s}$]	0.0236	0.0236	(from expertise)
Heat transfer coefficient (β) [$\mathrm{W/m^2.K}$]	31.42	31.42	(from expertise)

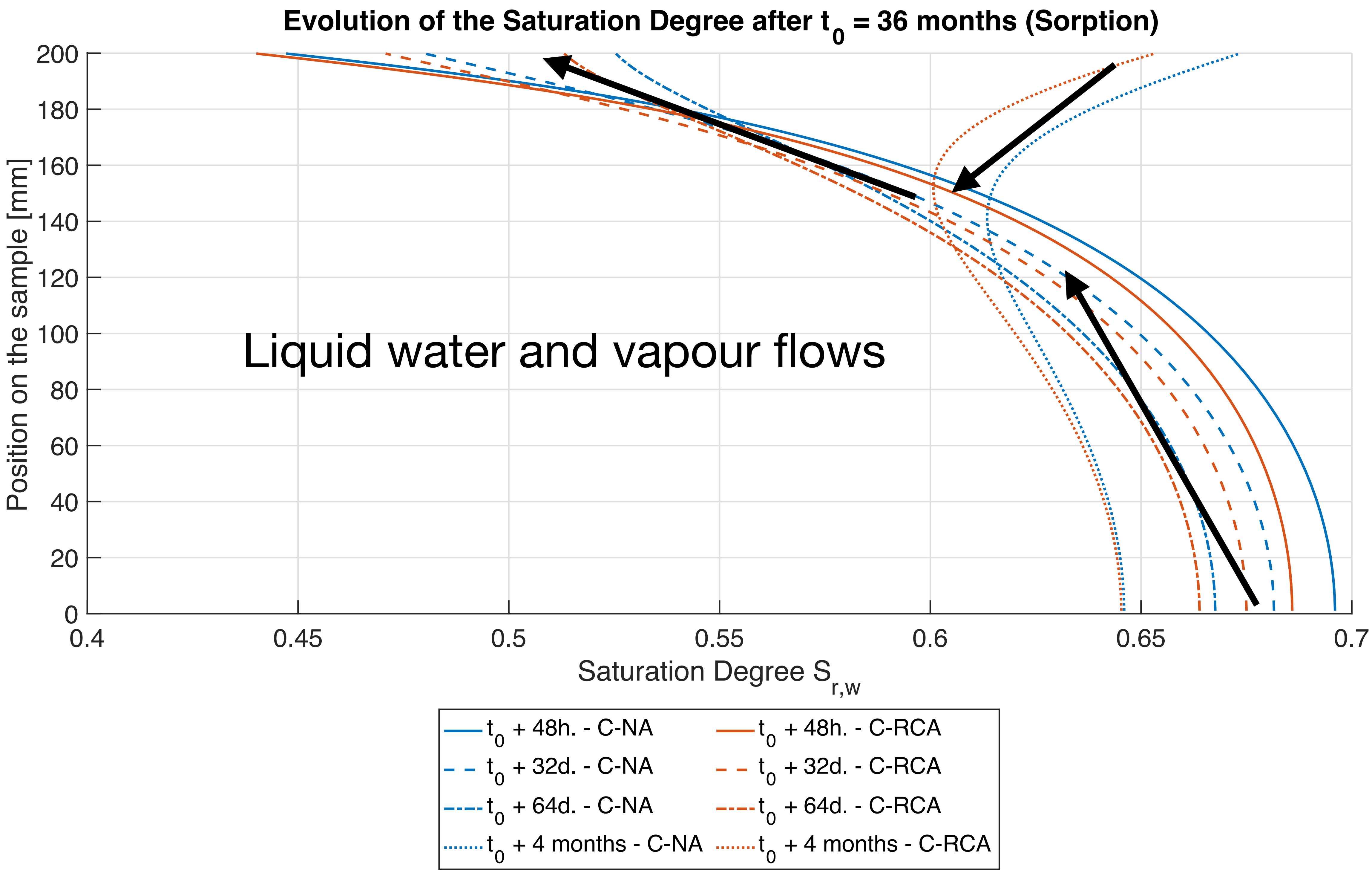
- Parameters for the modelling obtained from experimentations
- Main differences: Permeability, Porosity and WRC

Application
Results



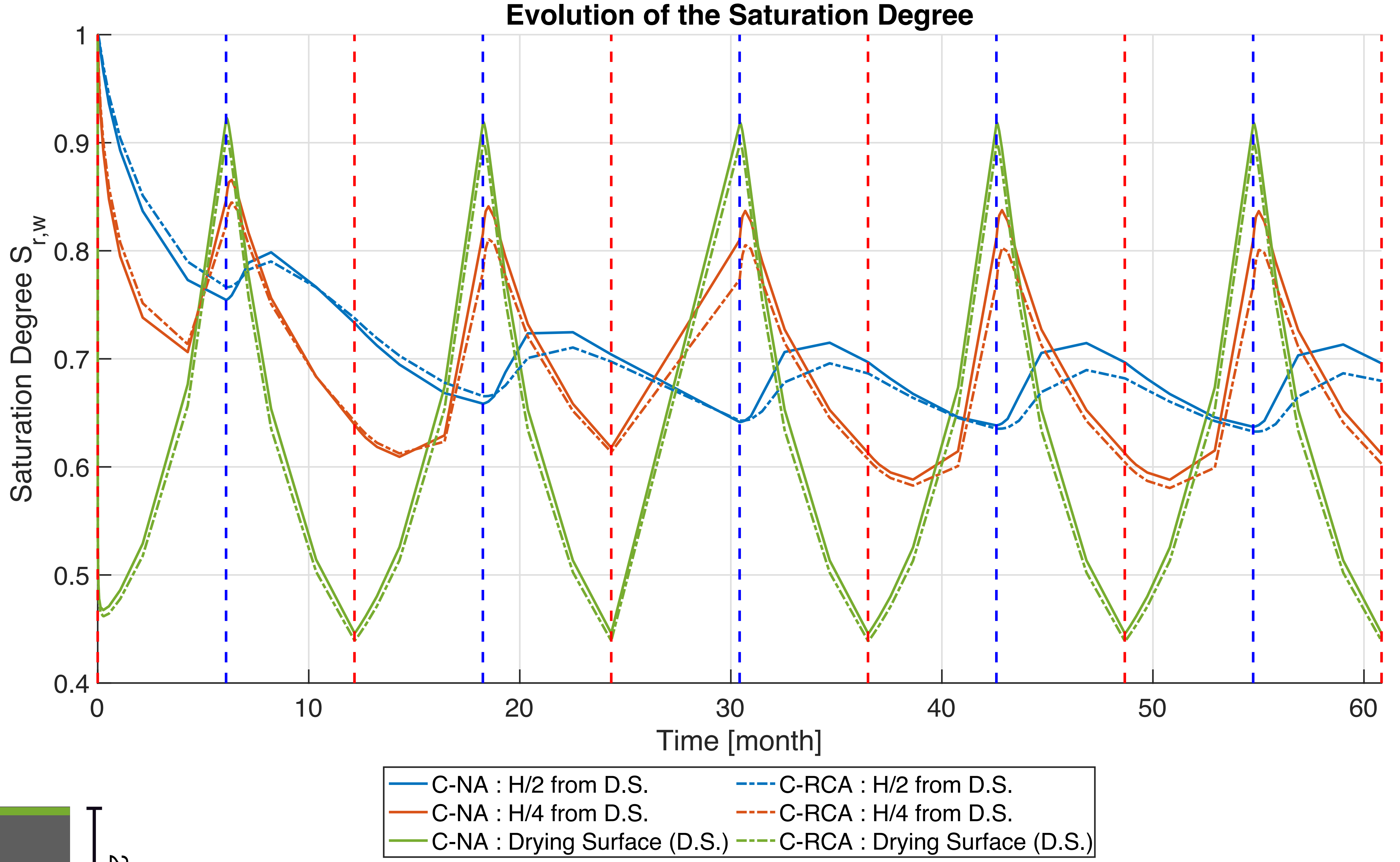
Application

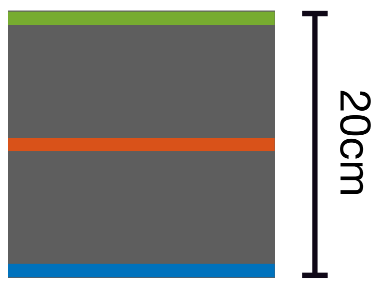
Results



Application

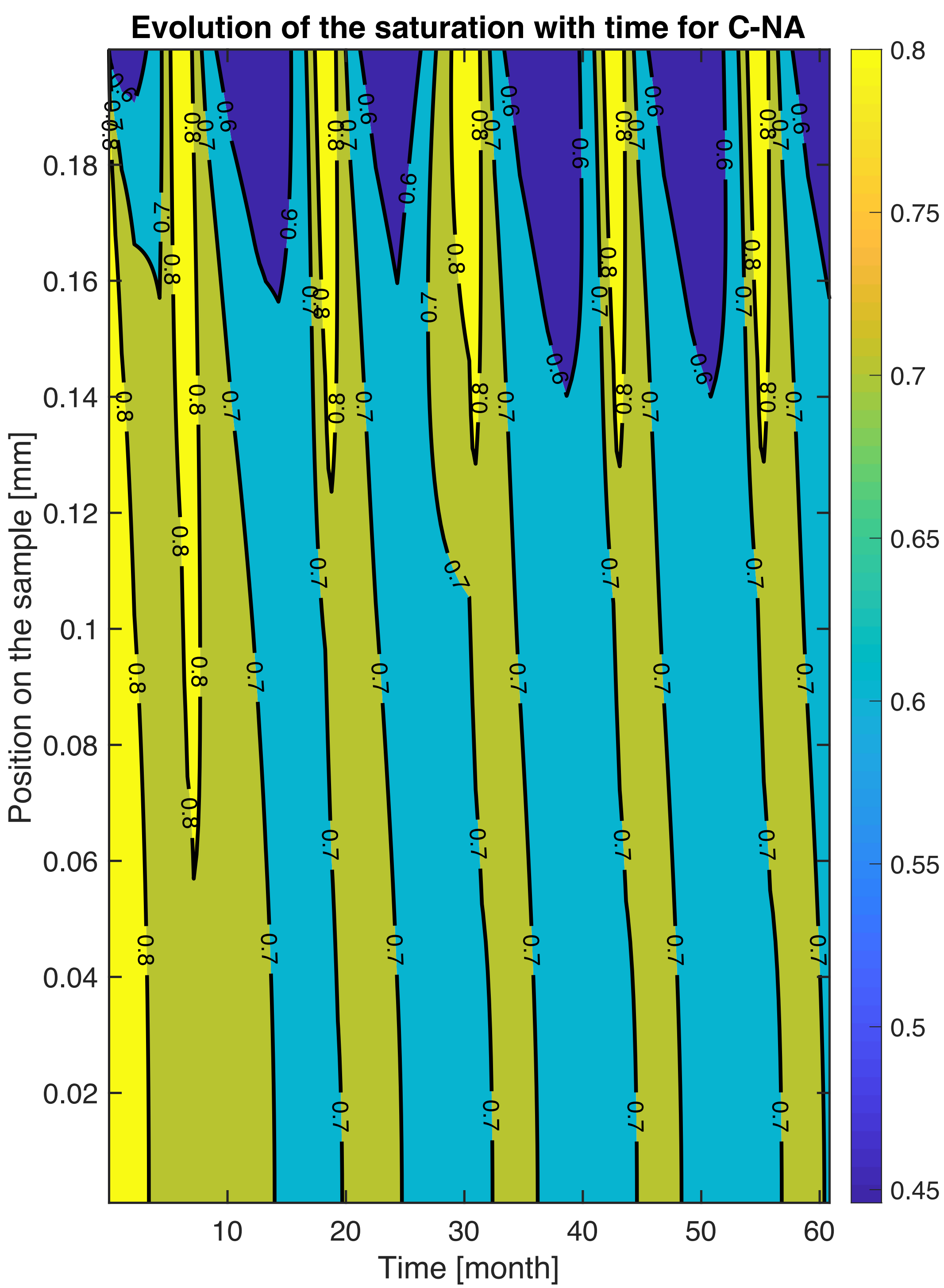
Results

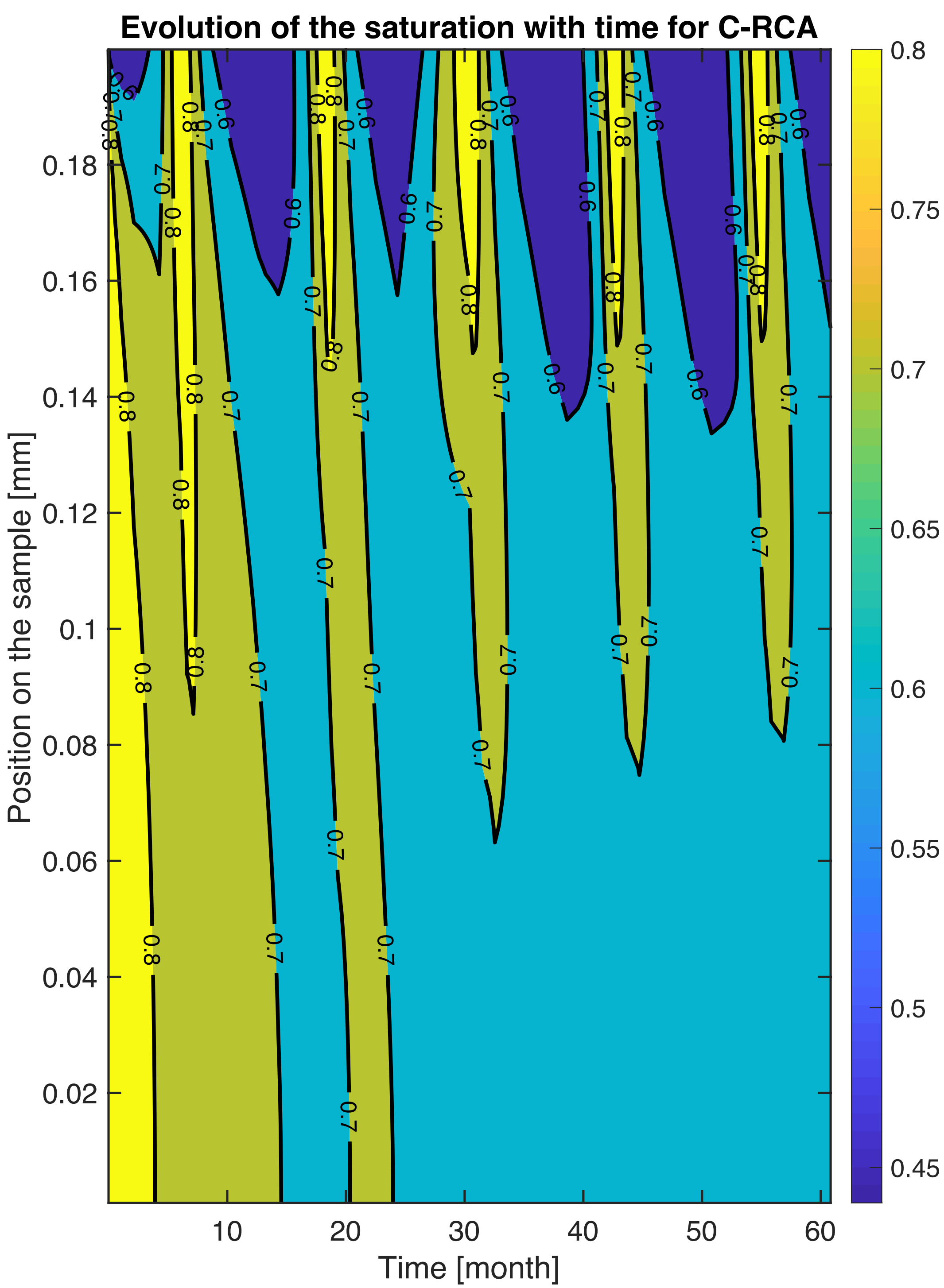




Application

Results





Conclusion

- Using RCA → Increased porosity, permeability and WRC
  → More water flows and easier exchanges
  → Decrease of durability

The use of Recycled Concrete Aggregates (RCA) inside concrete **reduces the durability of concrete** due to its composition and physical properties.

- 100% substitution of NA by RCA
- RCA from concrete made in laboratory
- Other degradation processes to be experimentally studied

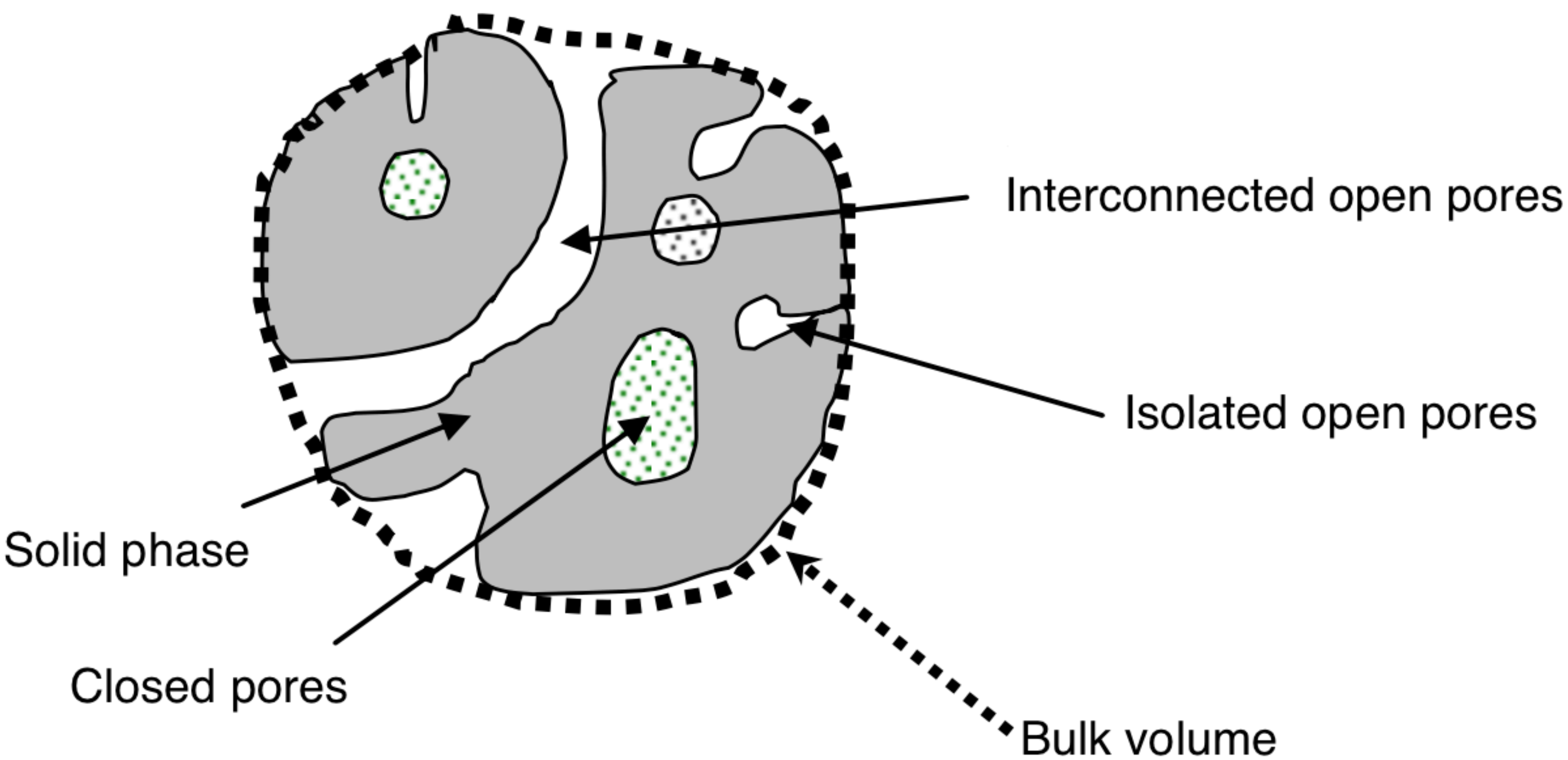
Thank you for your attention.

Perspectives

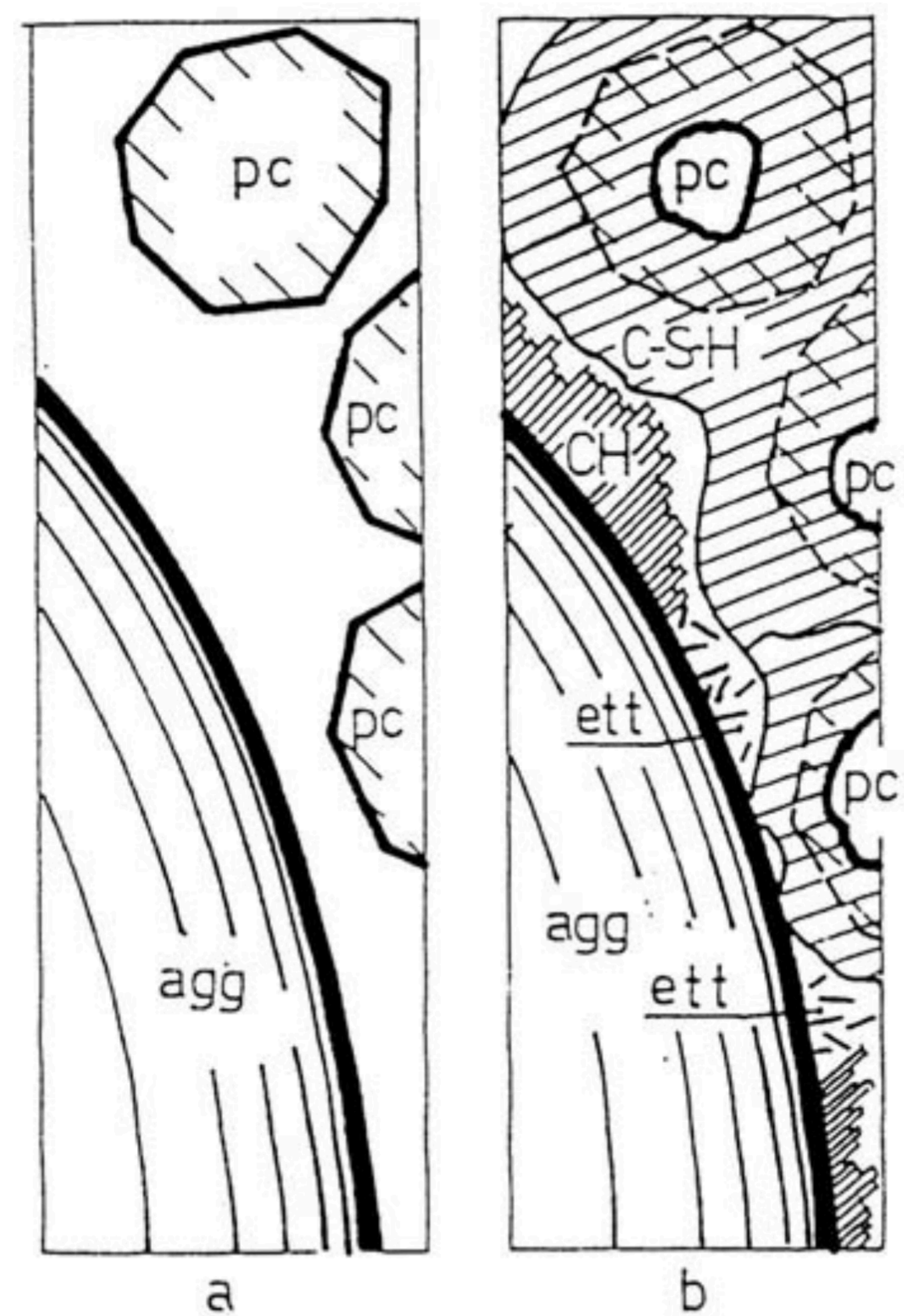
- Further testing and replications of the experiments conducted
- Convective drying for our C-NA and C-RCA (among others)
- Mercury porosimetry
- Resistance to chloride attacks
- Implementing the WRC’s hysteresis in Lagamine
- Using real RCA from real C&DW

Literature Review

Porosity of Concrete



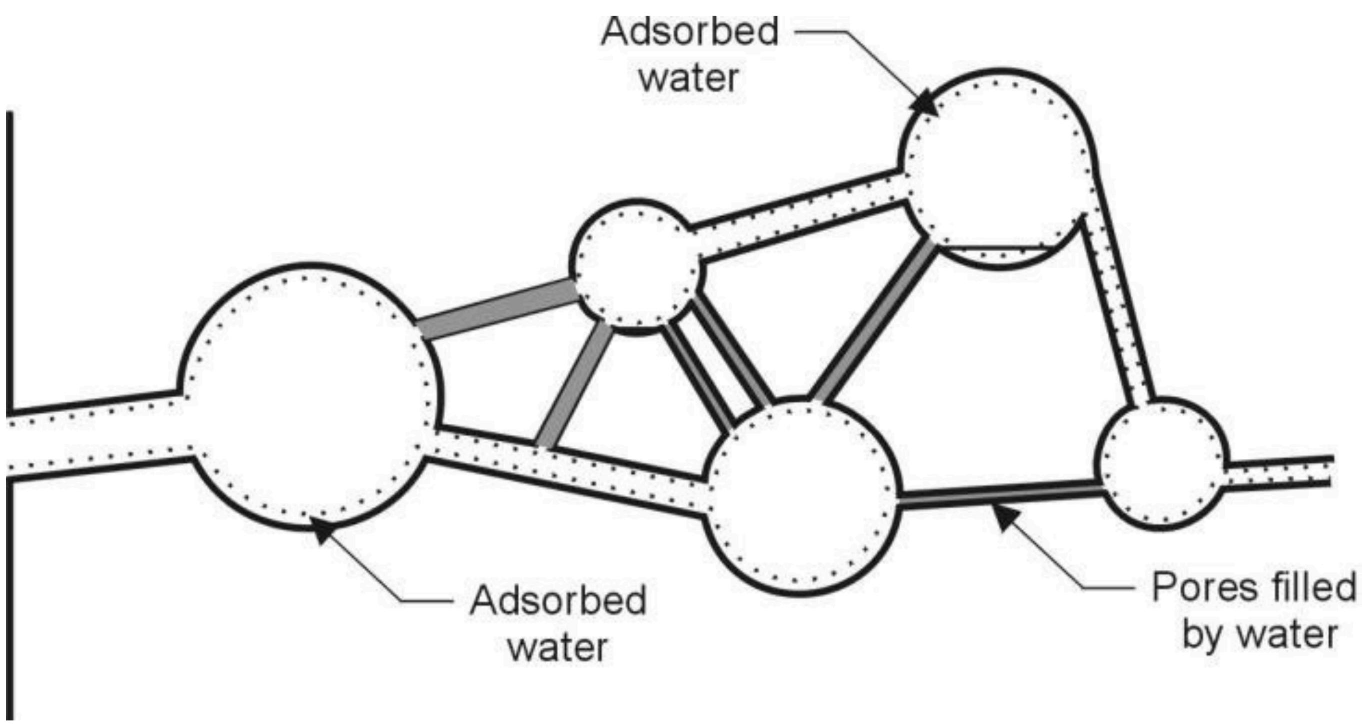
From [Ollivier & Torrenti, 2008]



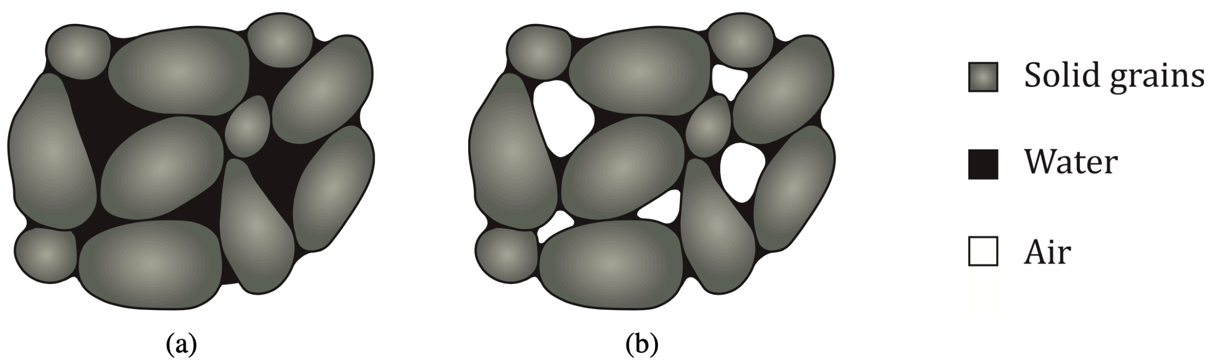
From [Bentur & Odler, 1996]

Literature Review

Porosity of Concrete



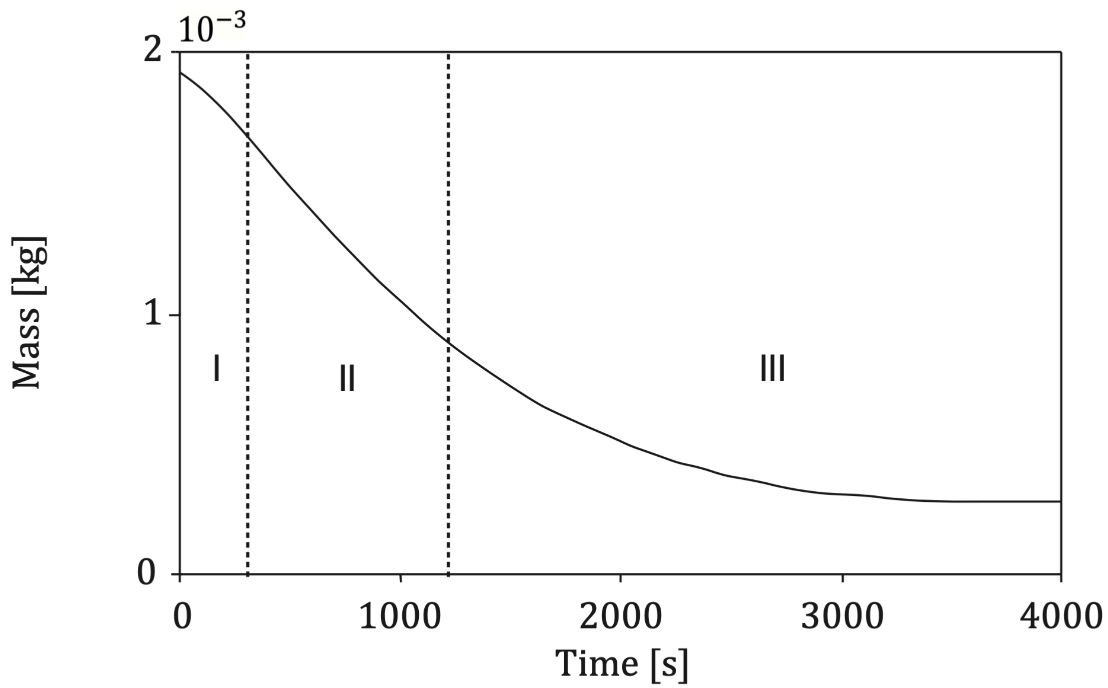
From [Bertolini et al., 2004]

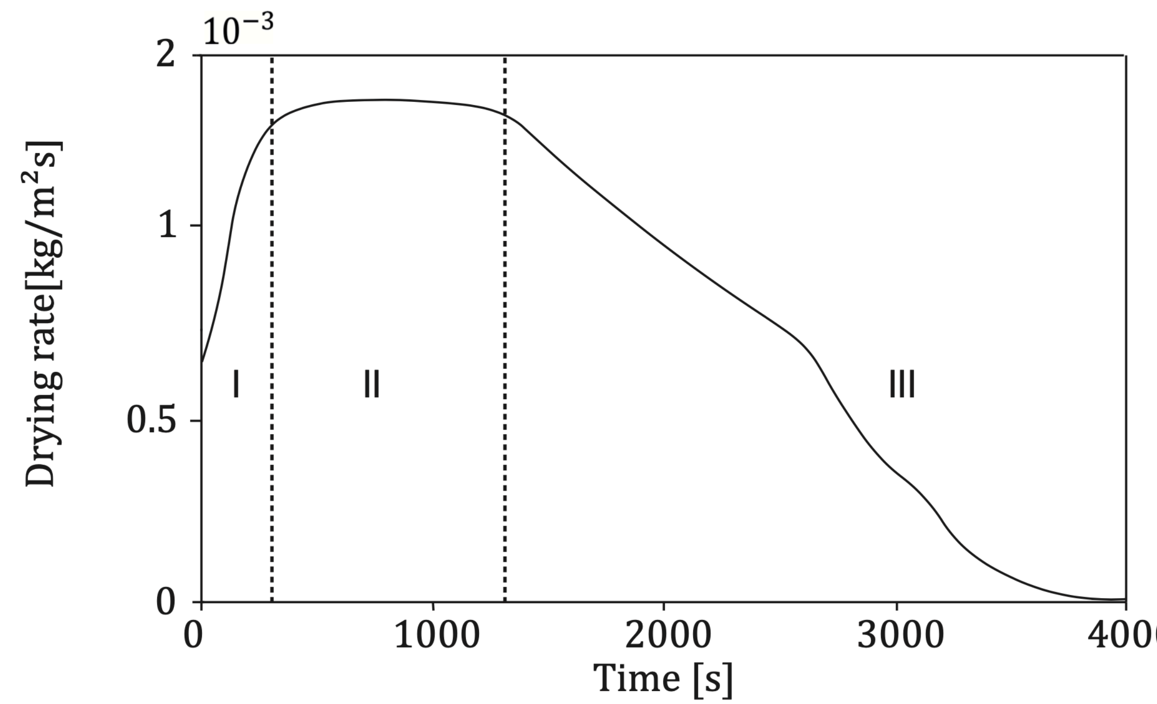


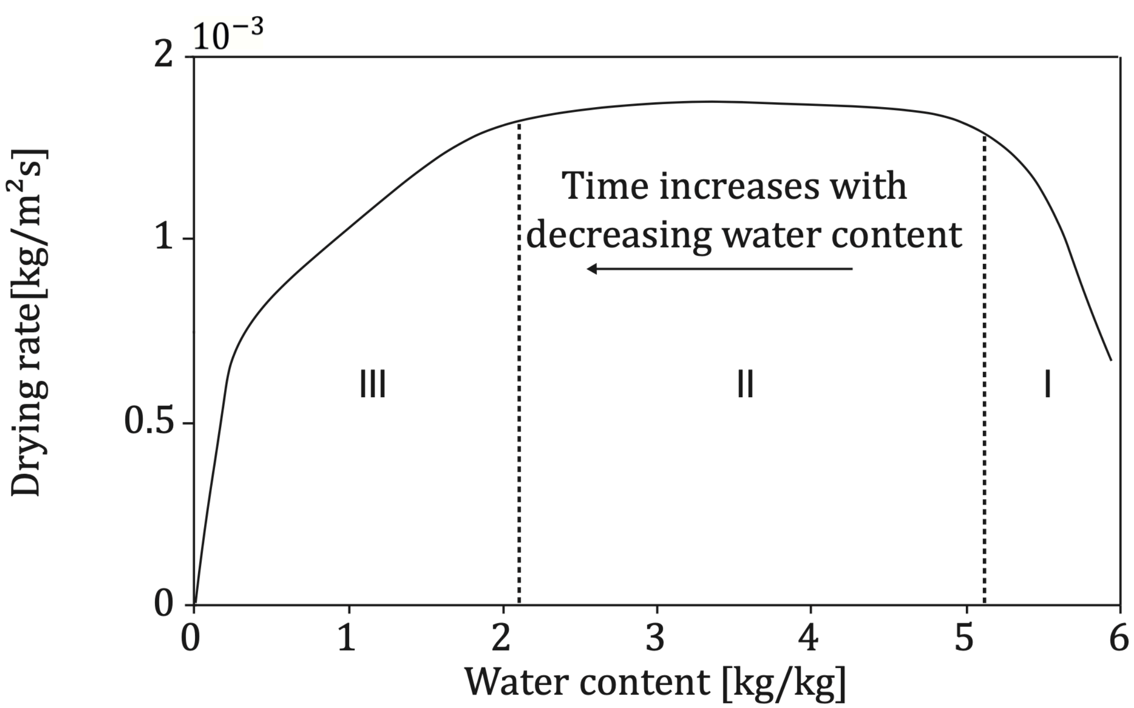
From [Hubert, 2018]

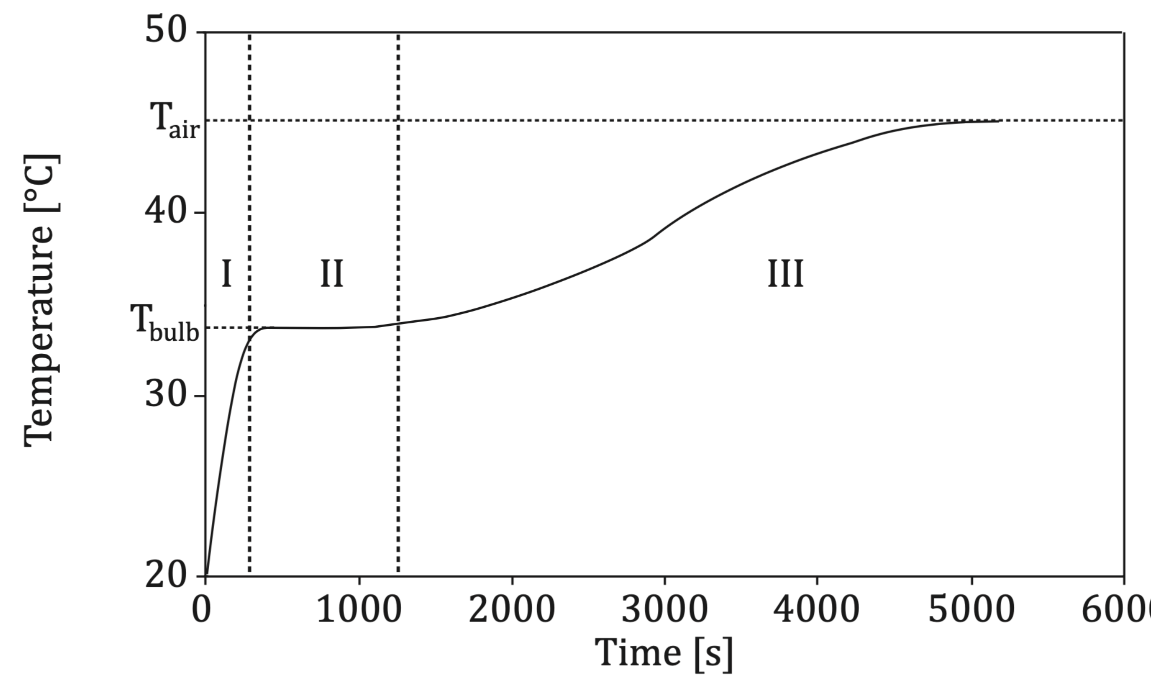
Literature Review

Convective Drying (Kinetics)







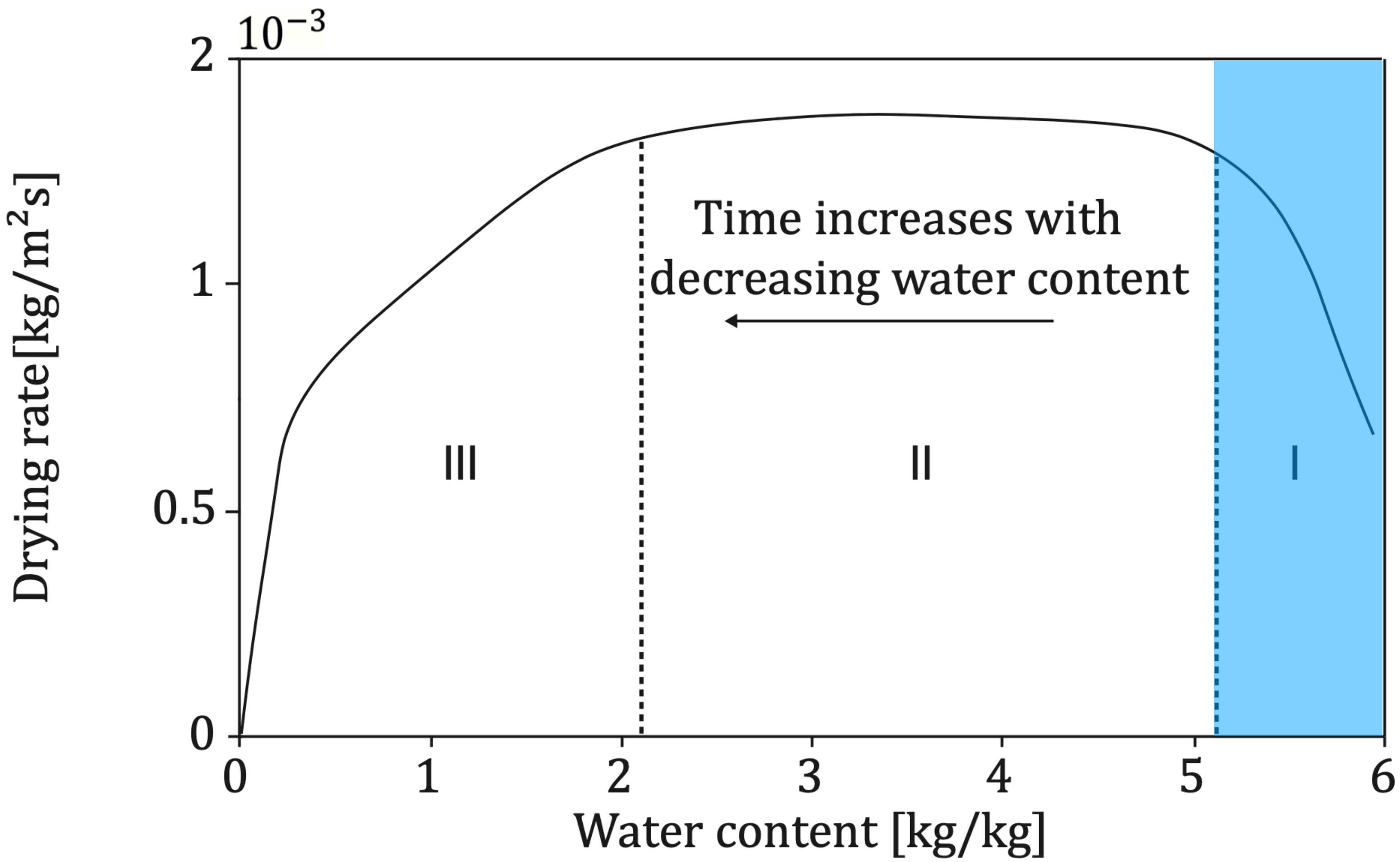


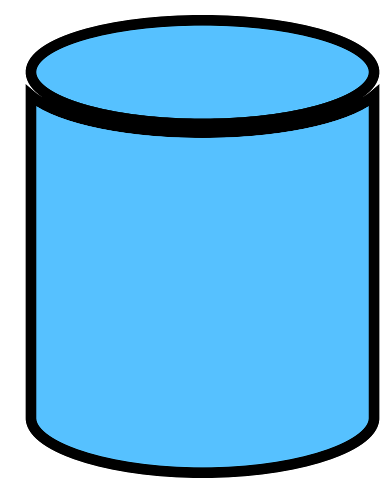
From [Hubert, 2018]

Literature Review

Convective Drying (Kinetics)

Preheating Period



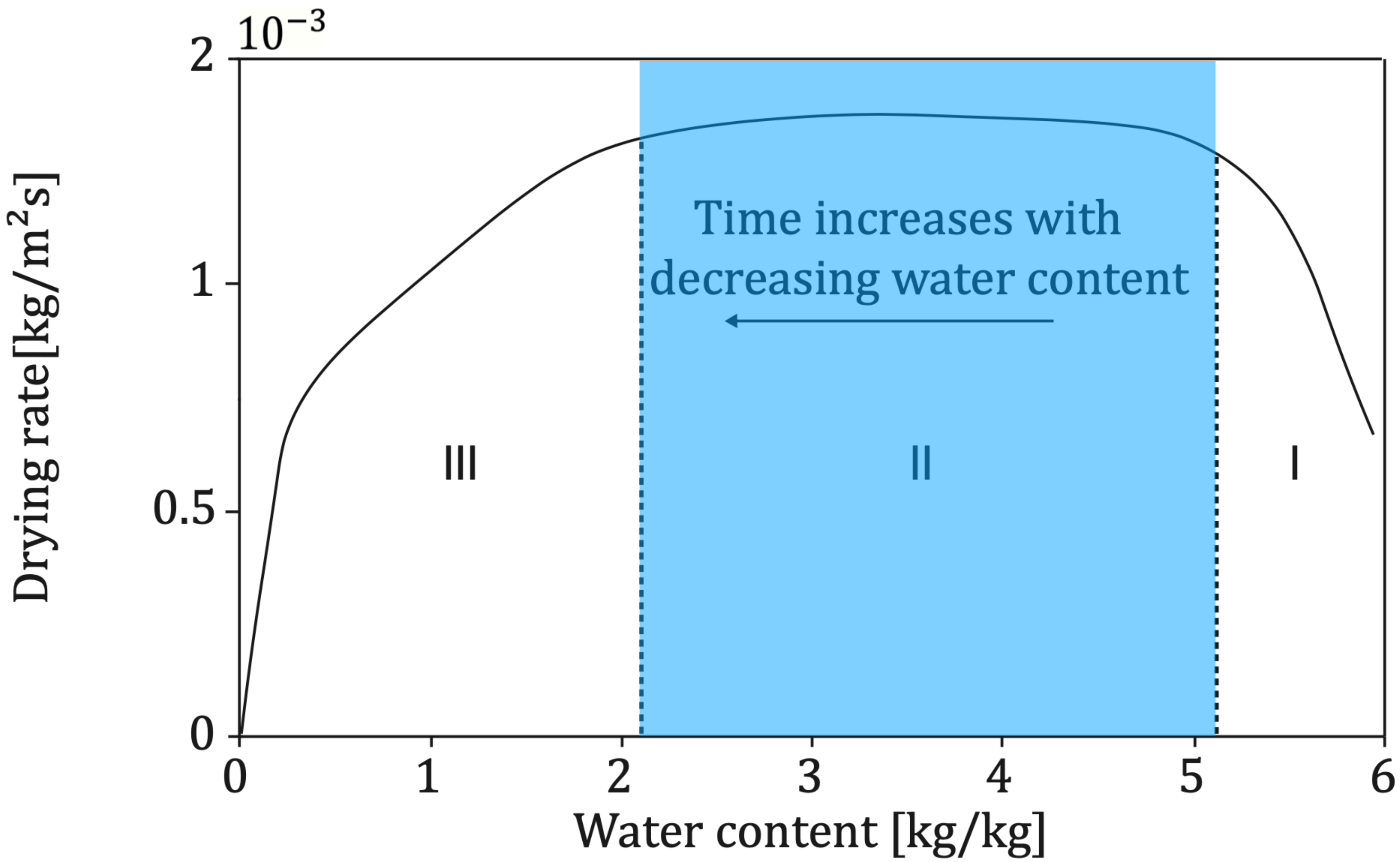


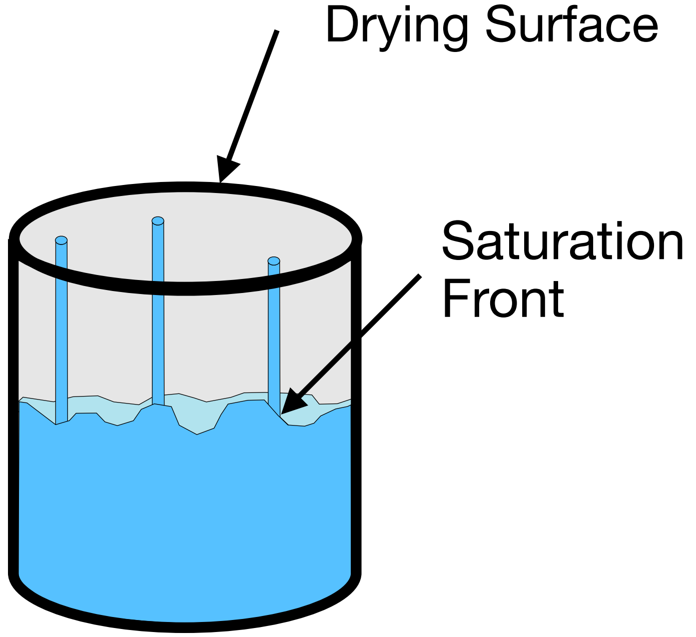
From [Hubert, 2018]

Literature Review

Convective Drying (Kinetics)

Constant Rate Period (CRP)

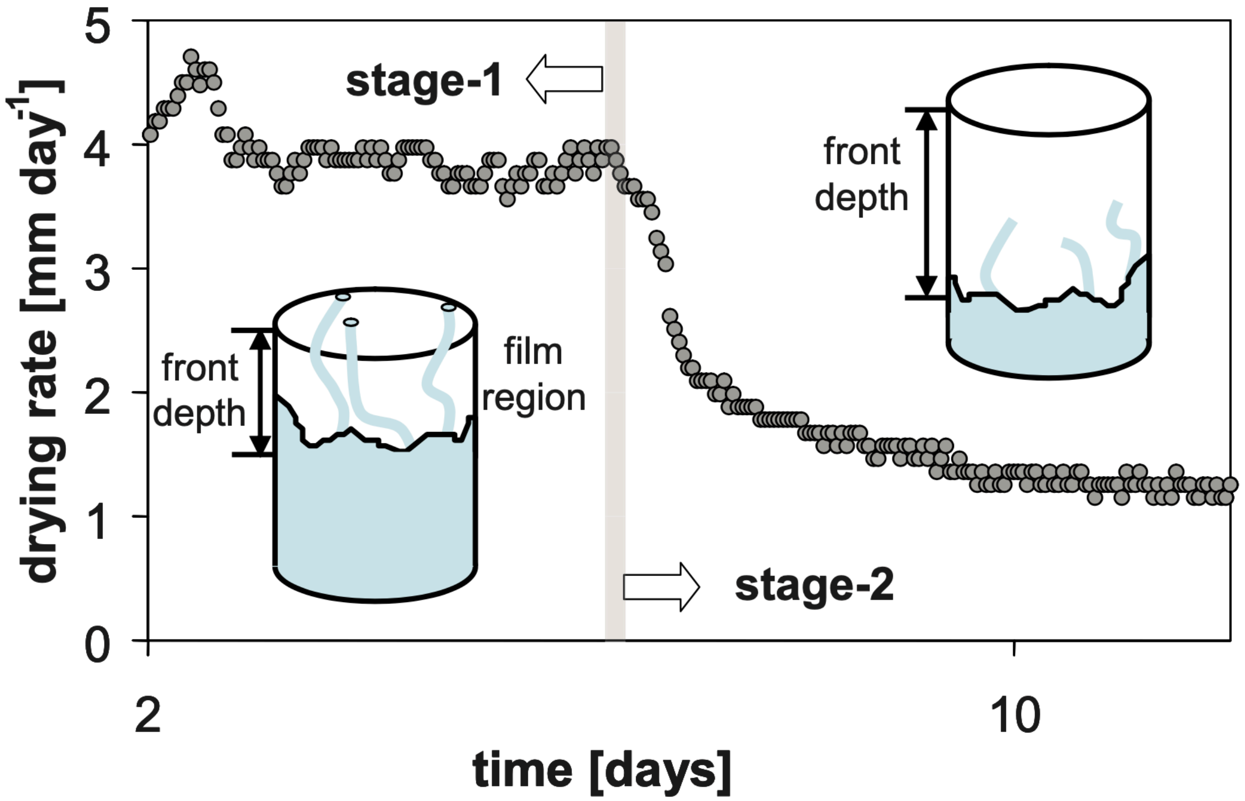


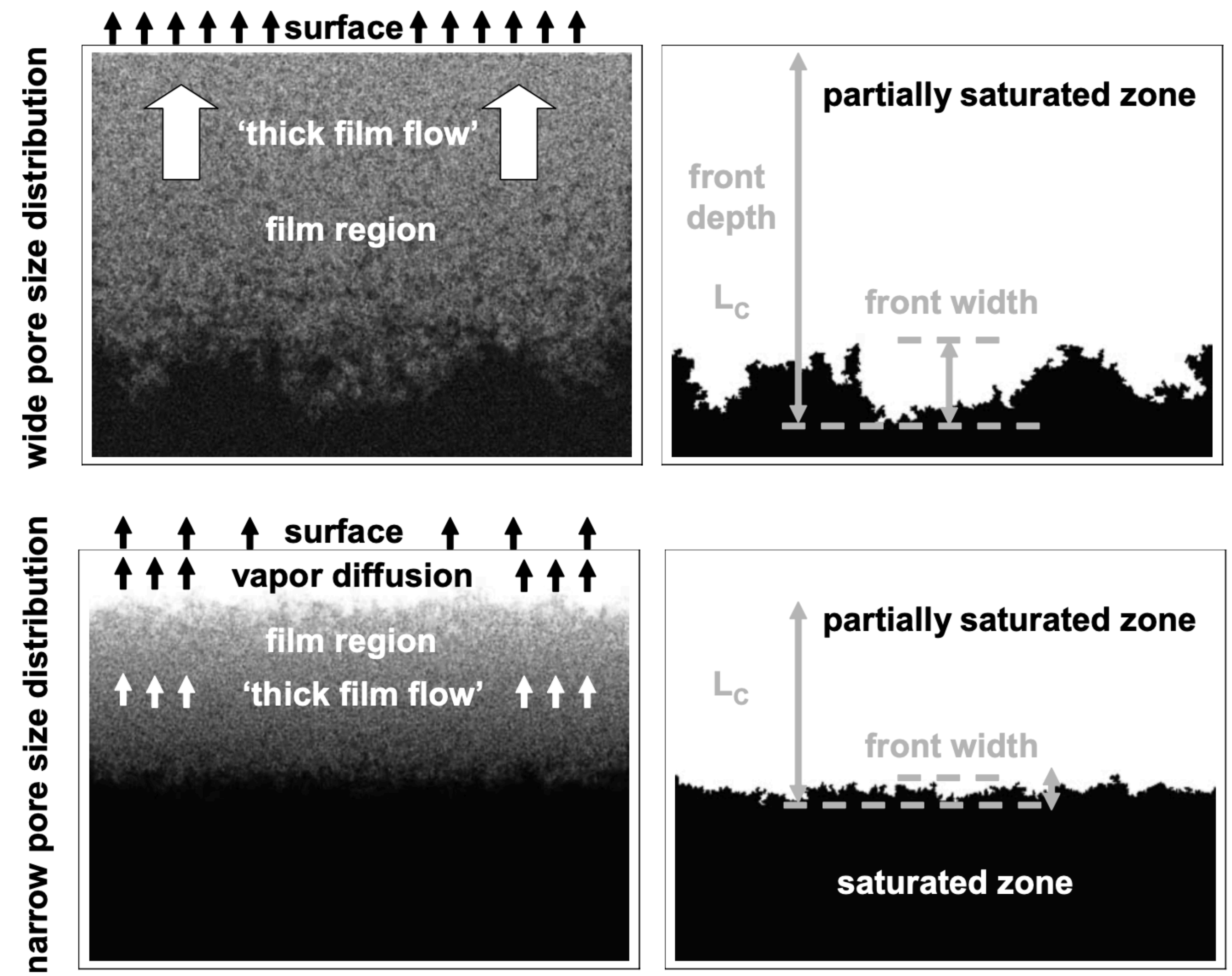


From [Hubert, 2018]

Literature Review

Convective Drying (Kinetics)



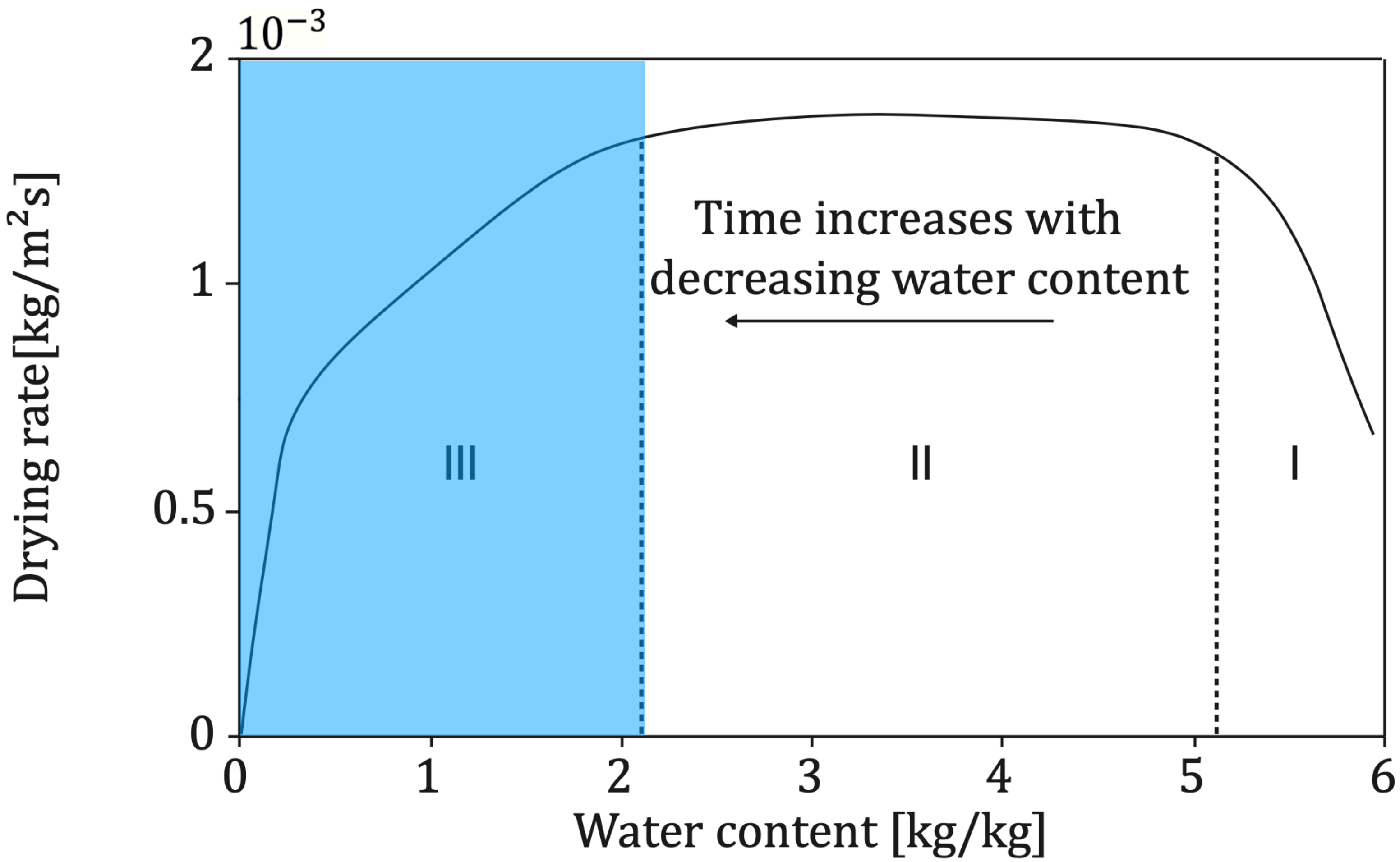


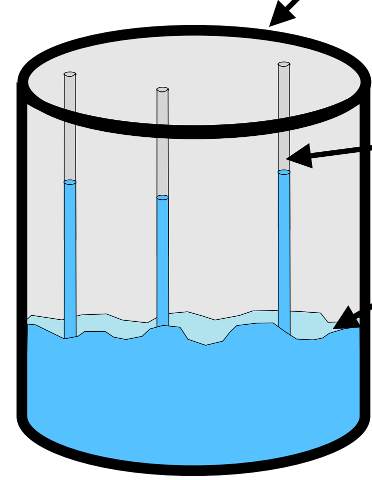
From [Lehmann et al., 2008]

Literature Review

Convective Drying (Kinetics)

Falling Rate Period (FRP)

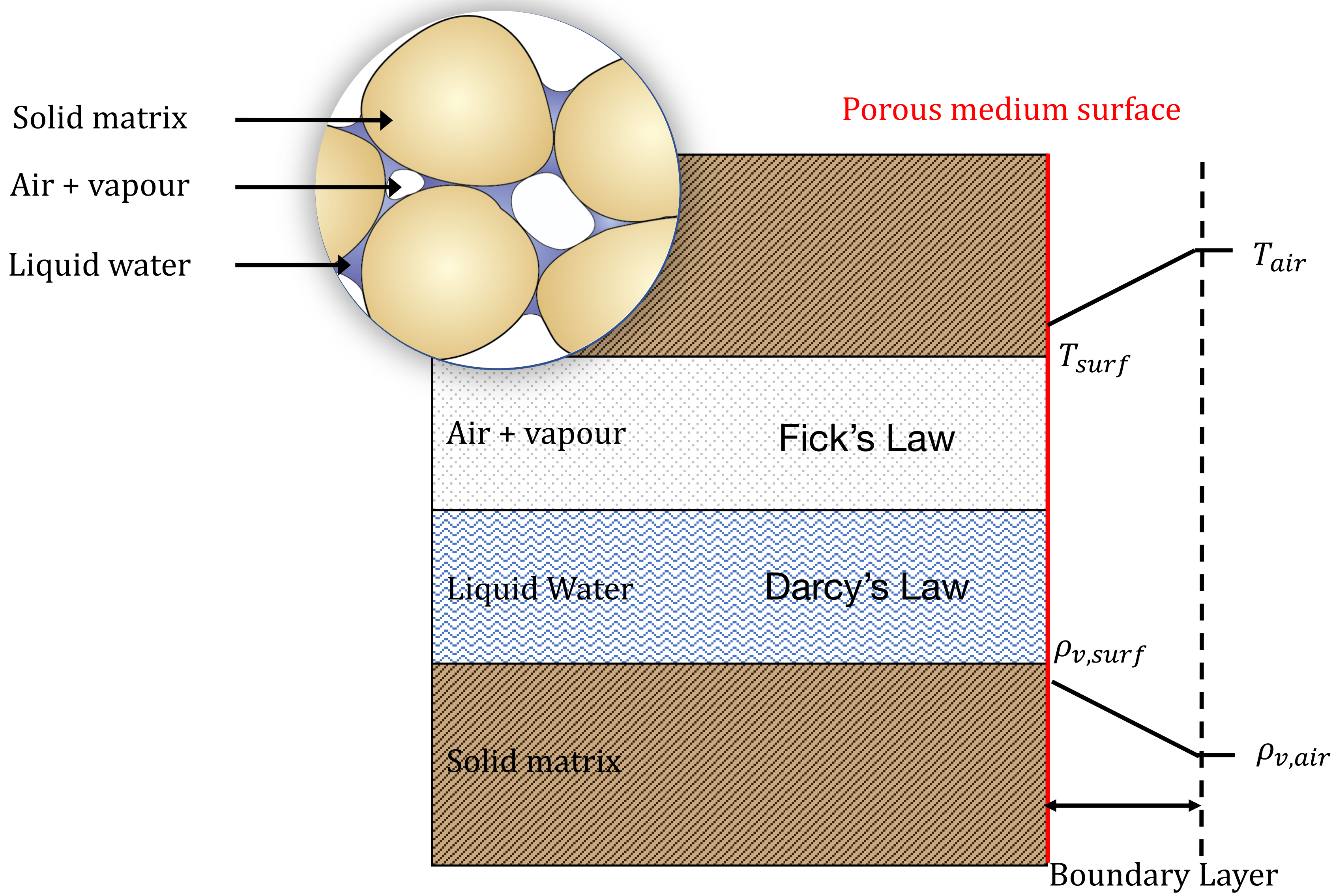




From [Hubert, 2018]

Literature Review

Boundary Layer Model



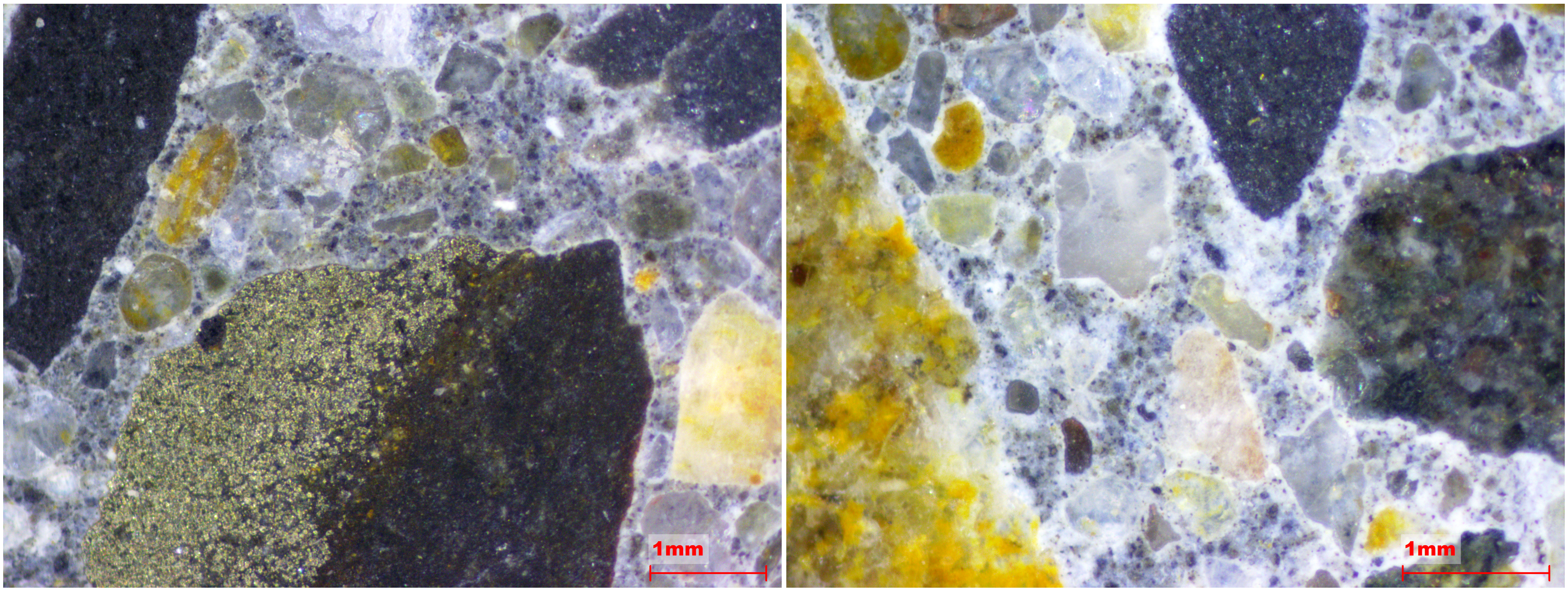
$$\beta = \frac{L\ \bar{q}_{CRP}}{T_{air} - T_{wb}}$$

$$\alpha = \frac{\bar{q}_{CRP}}{\rho_{v,surf} - \rho_{v,air}}$$

From [Hubert, 2018]

Experimentation

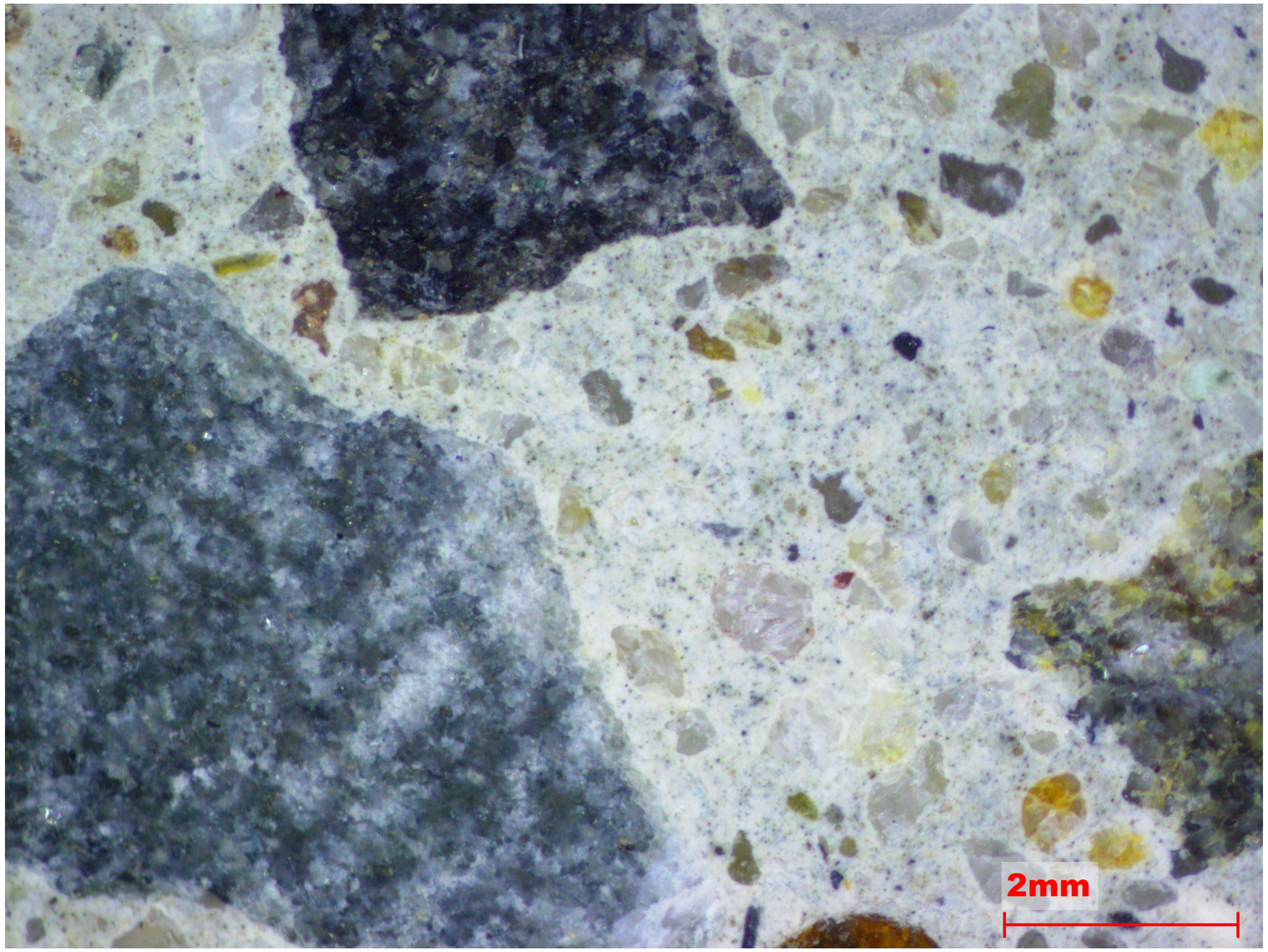
Micro-photography



Composition: C-NA

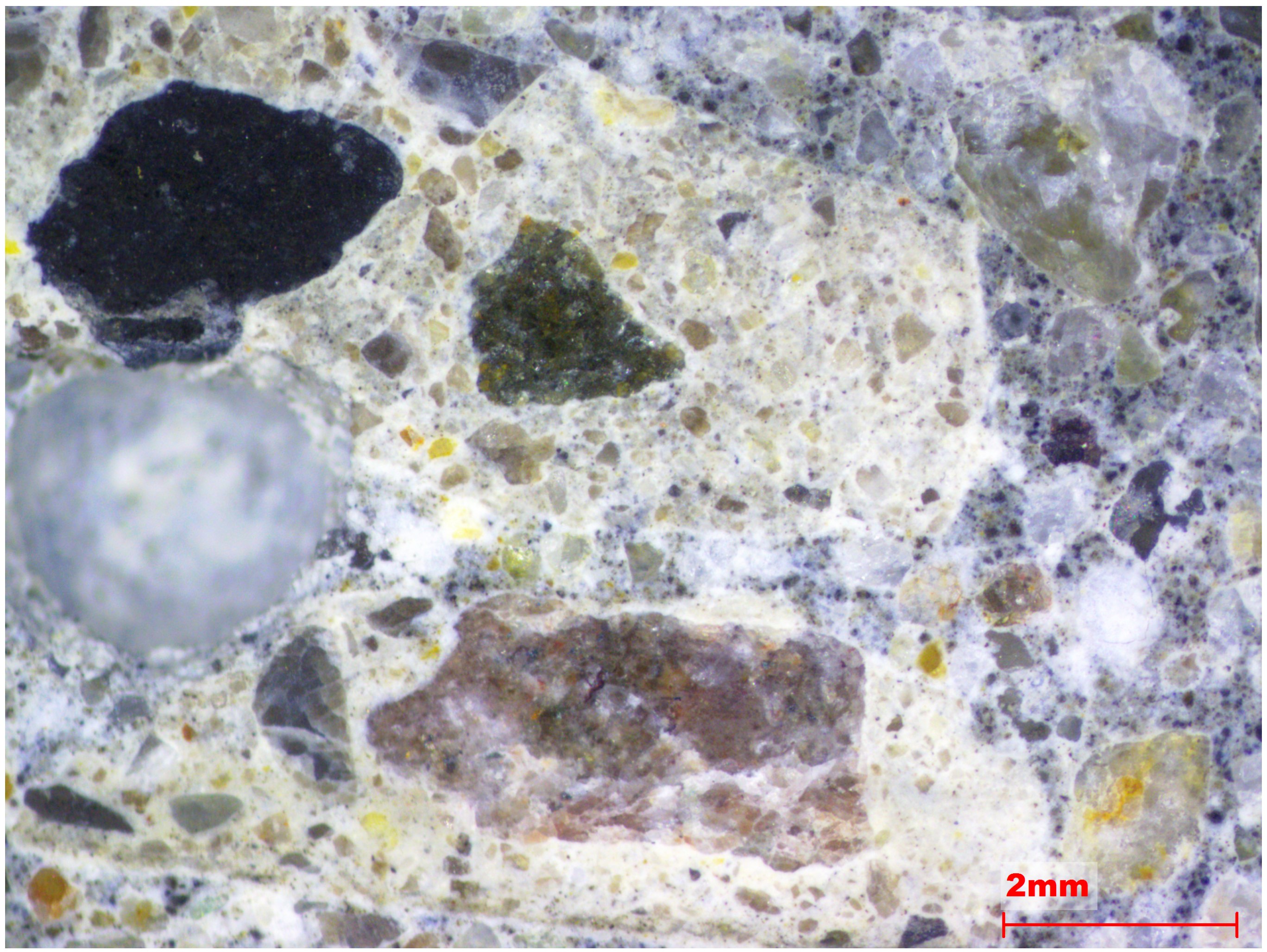
Experimentation

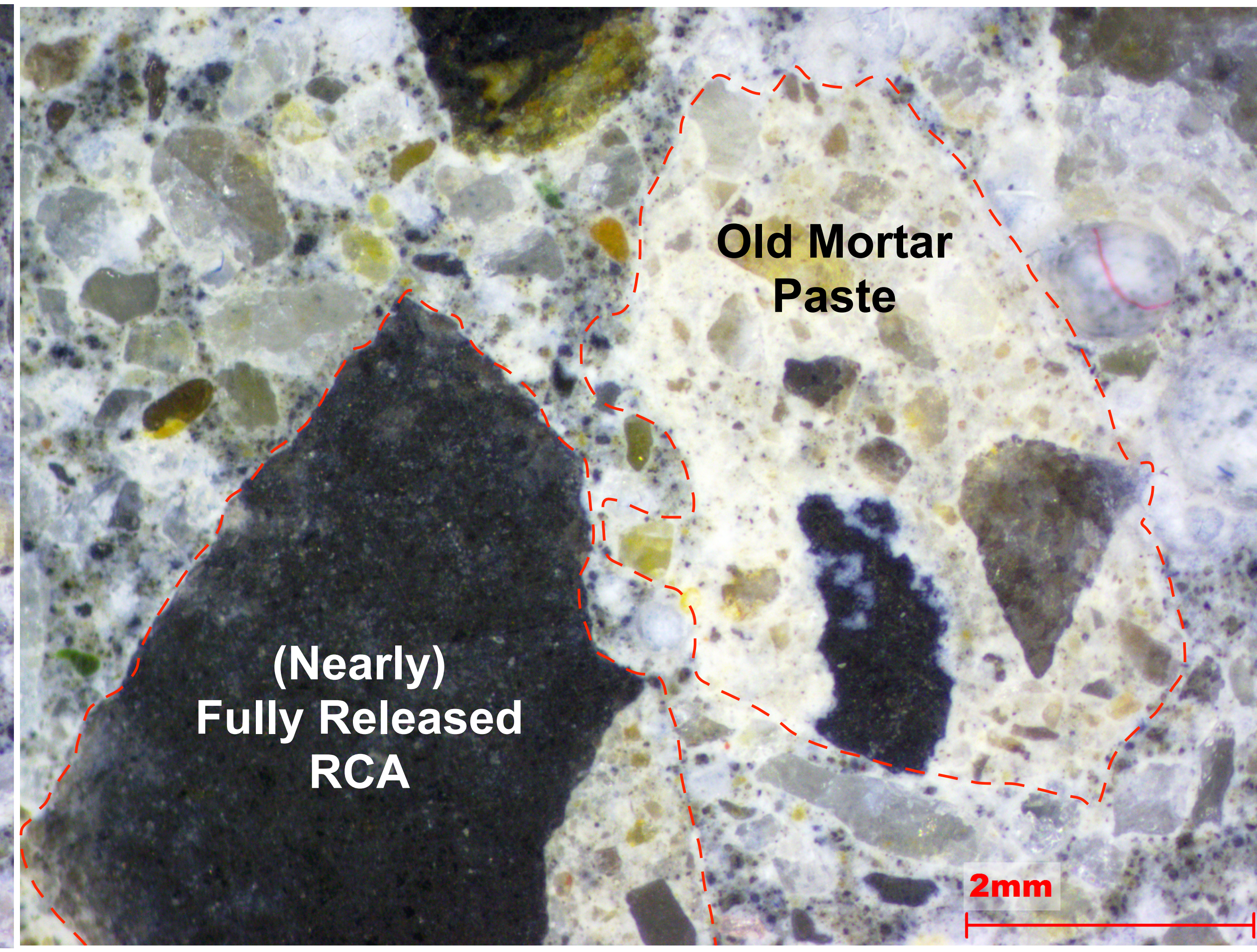
Micro-photography



Composition: C-NA-CEMIII

Experimentation
Micro-photography

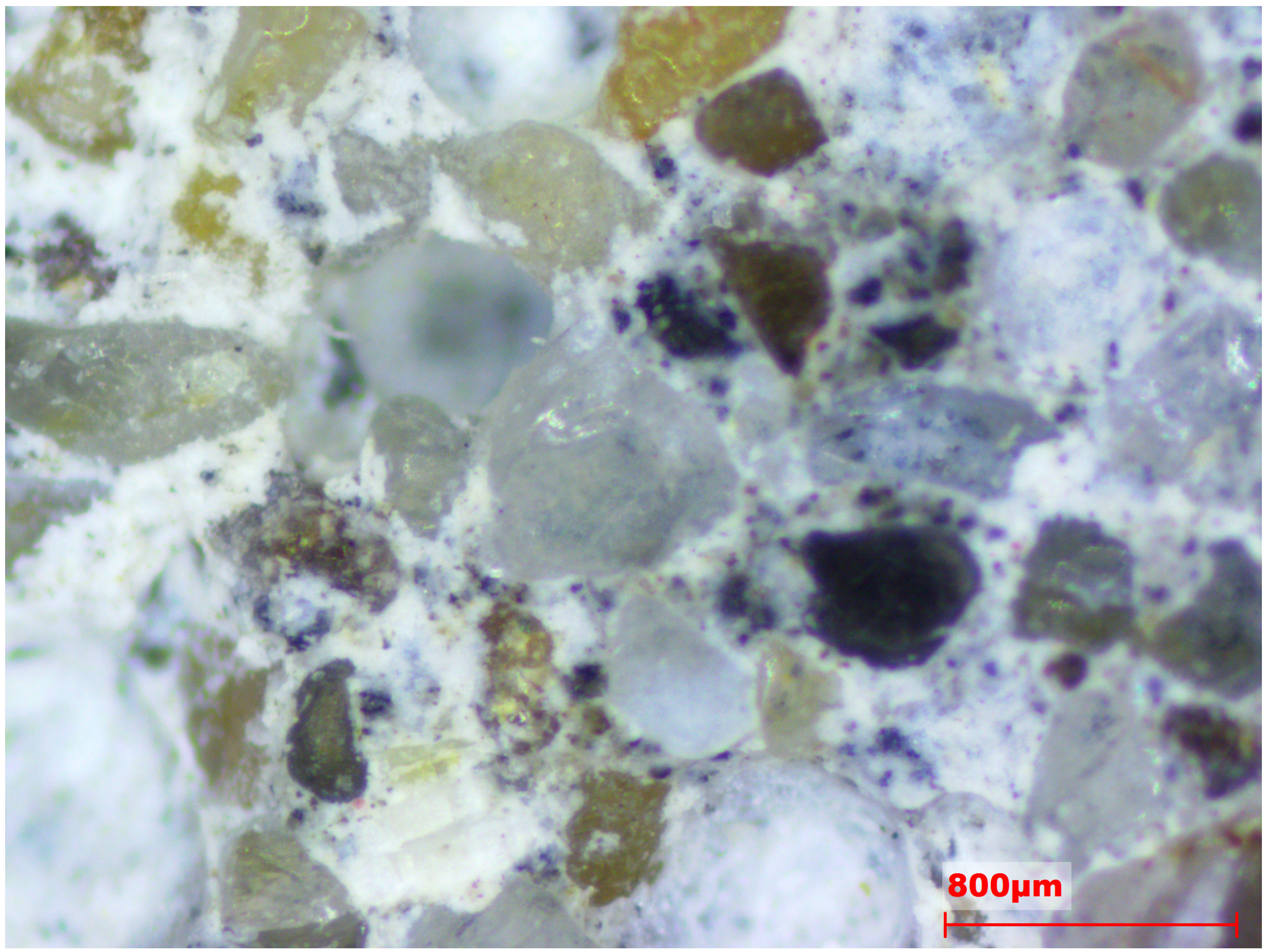


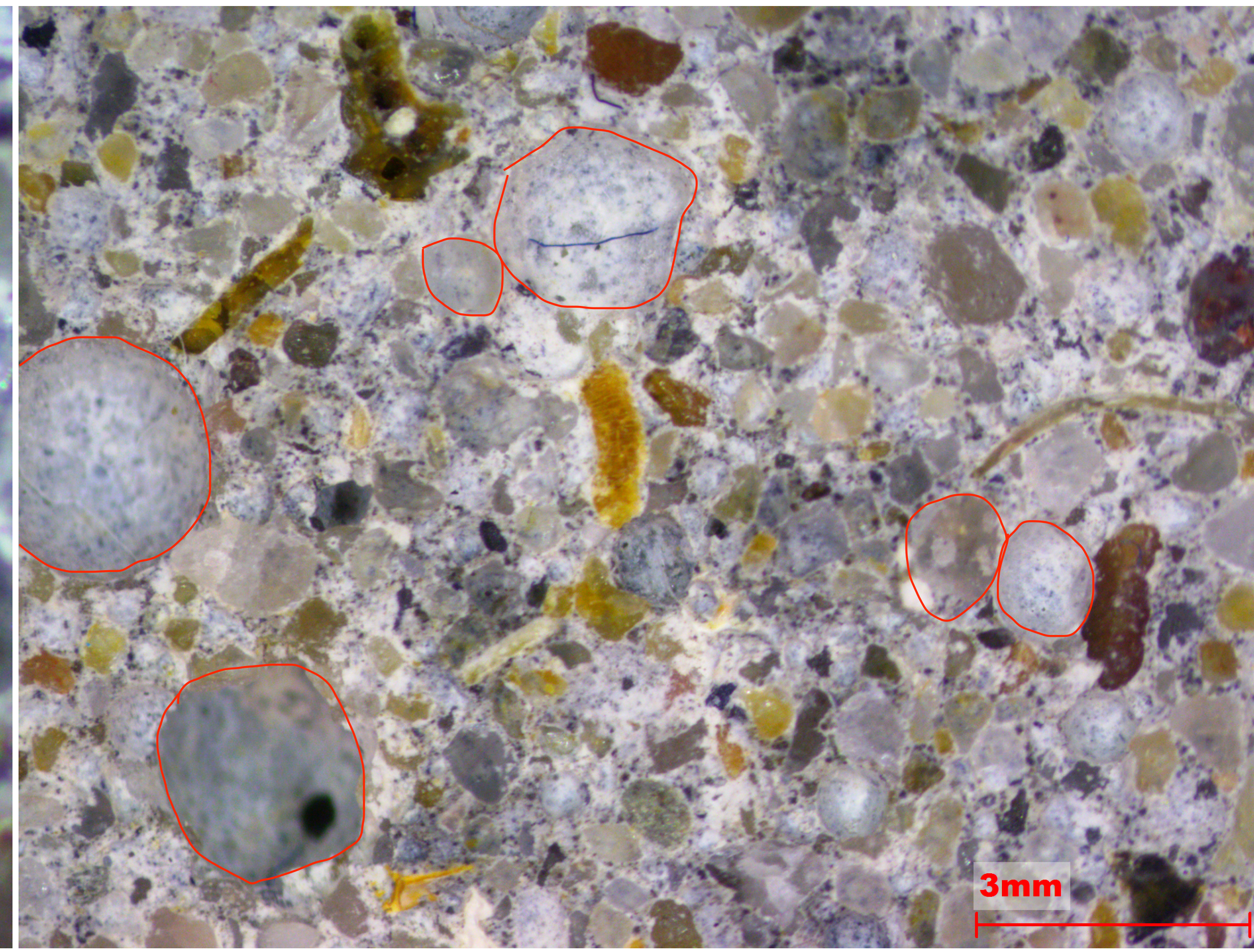


Composition: C-RCA

Experimentation

Micro-photography

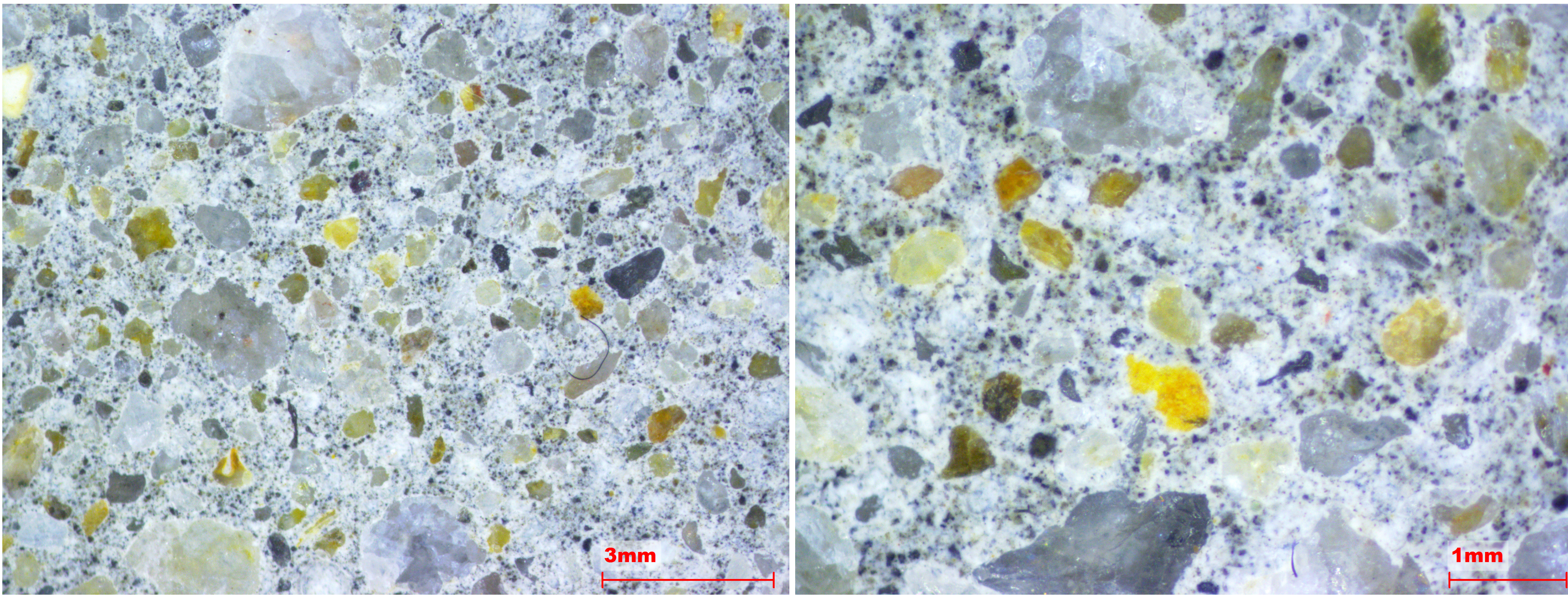




Composition: M1-CEMI

Experimentation

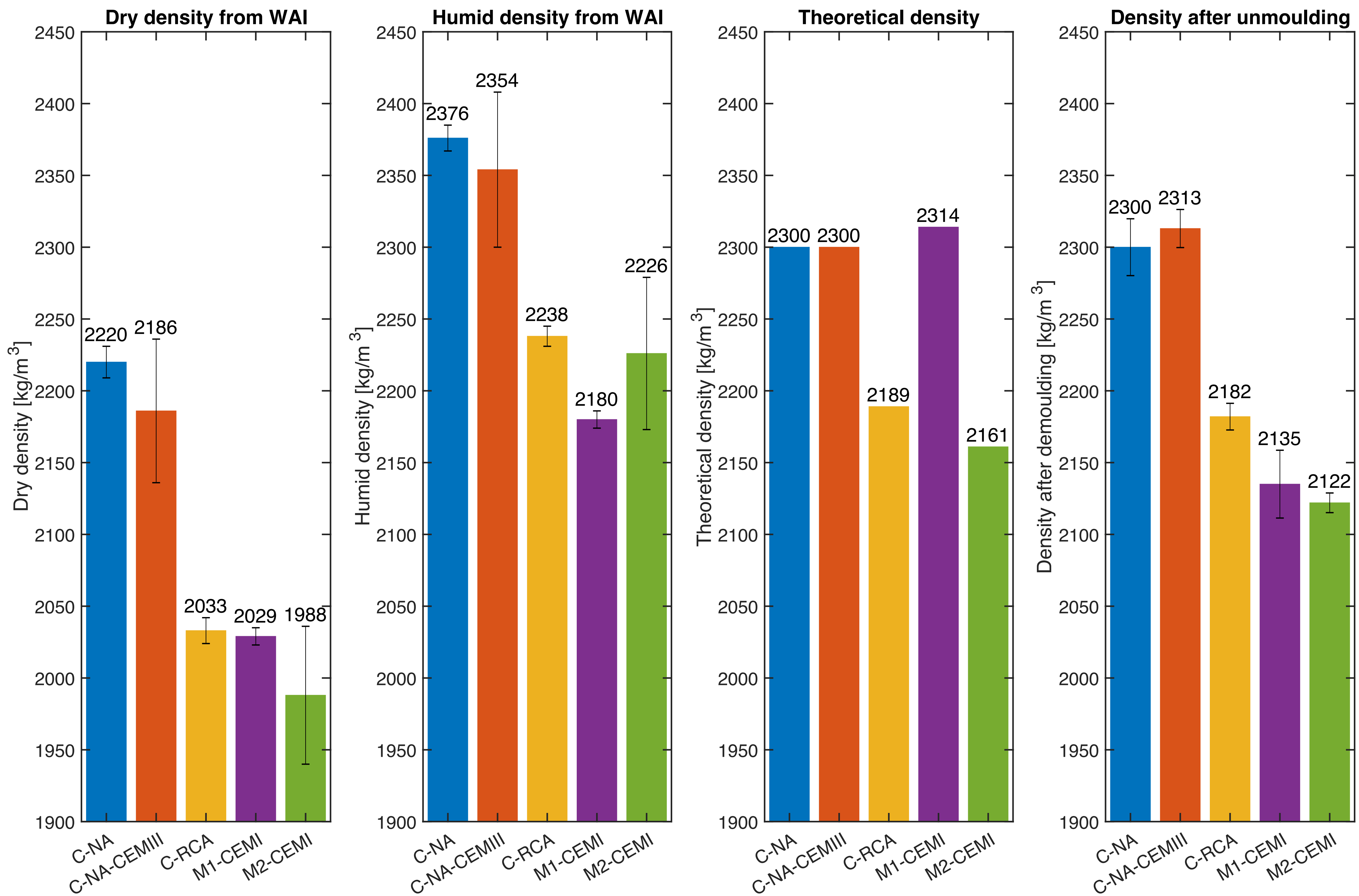
Micro-photography



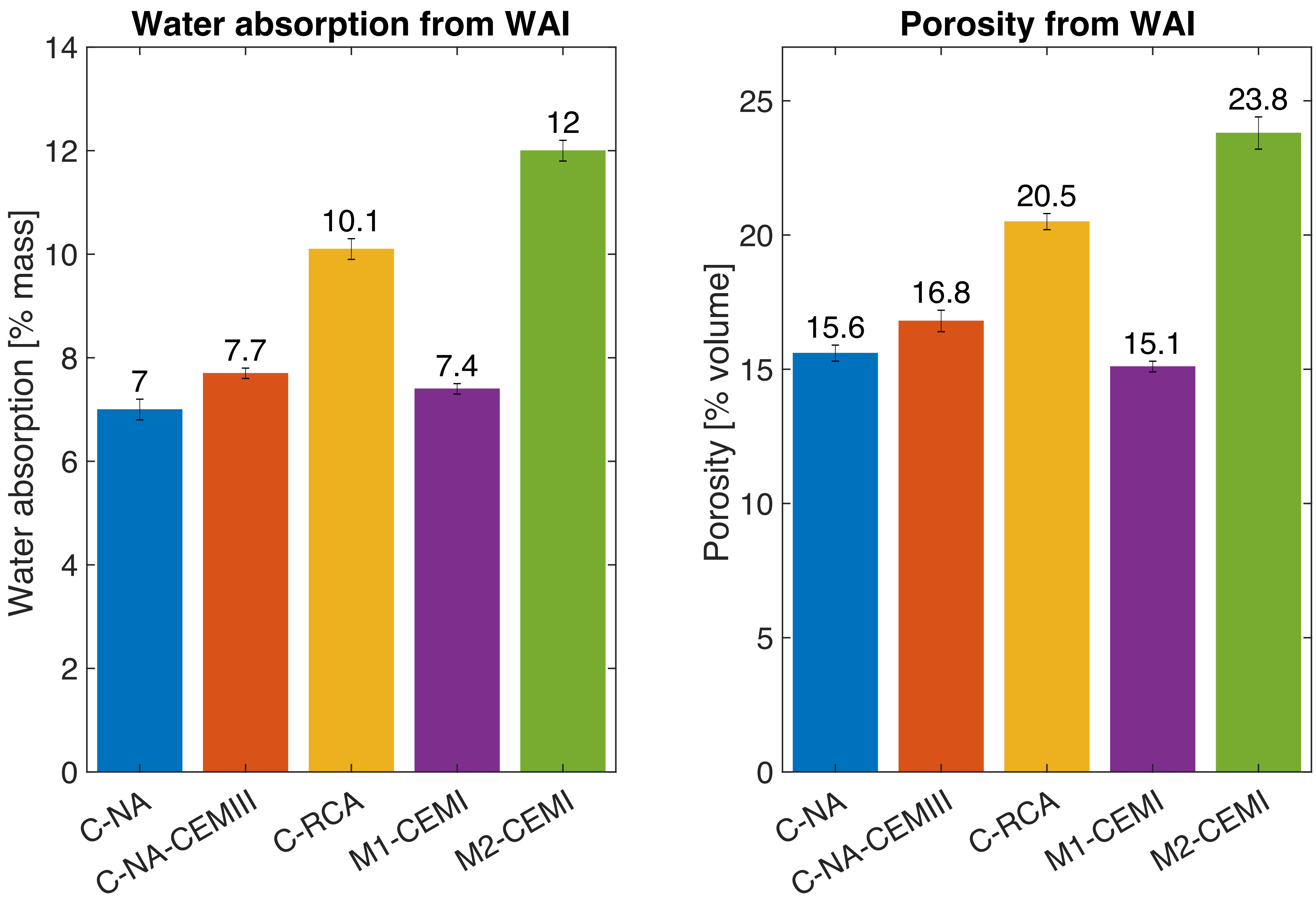
Composition: M2-CEMI

Experimentation

Water Absorption by Immersion

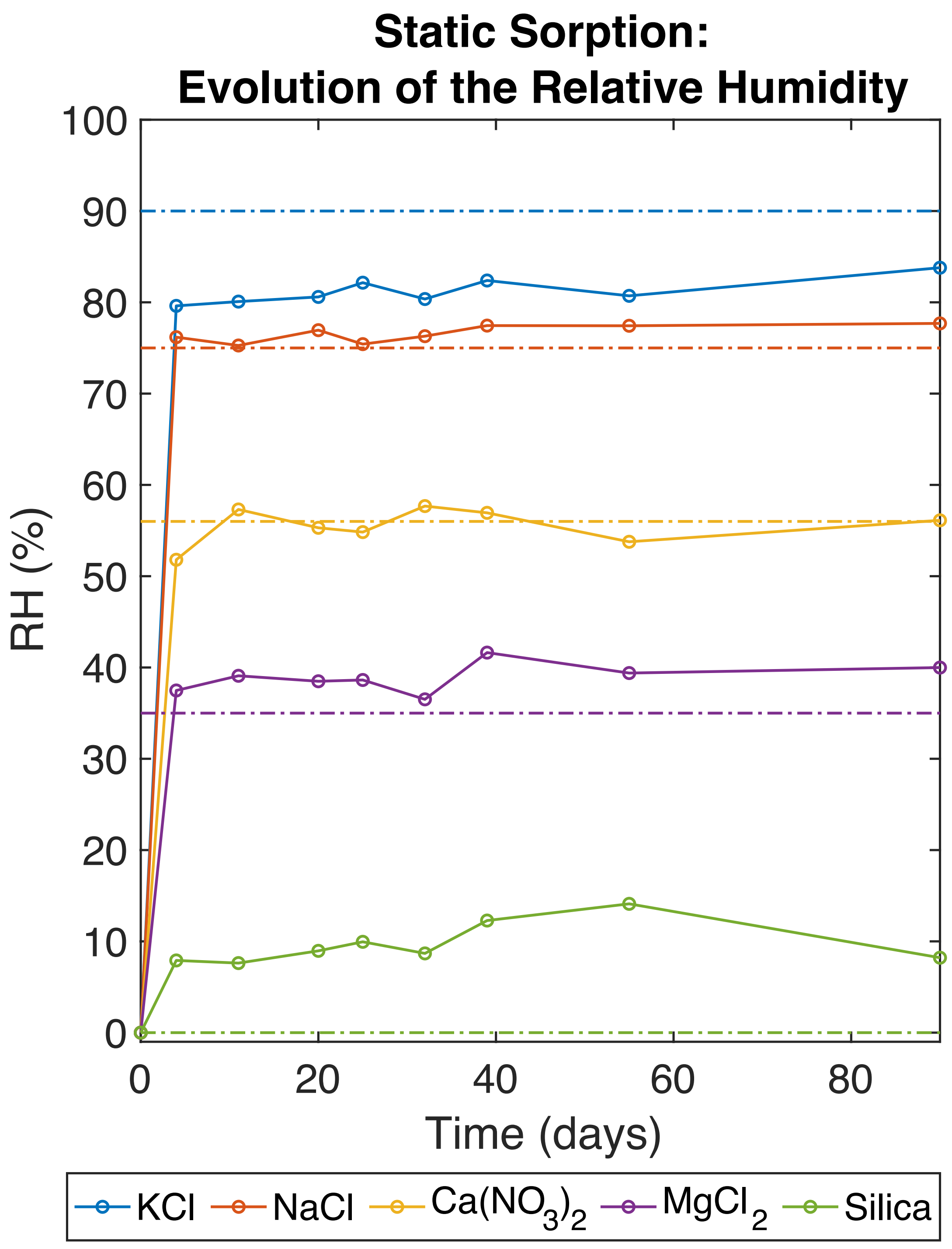


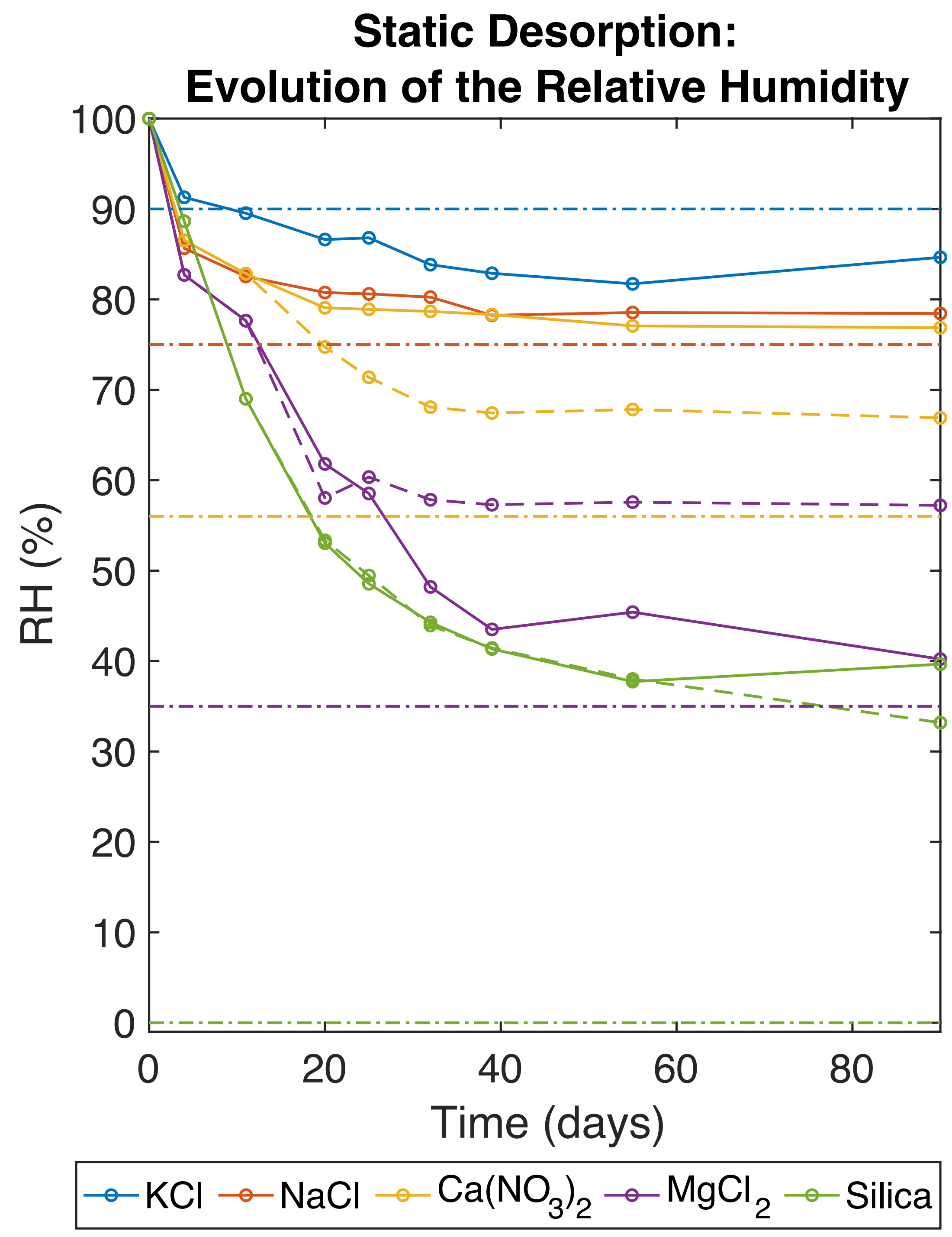
Experimentation
Water Absorption by Immersion



Experimentation

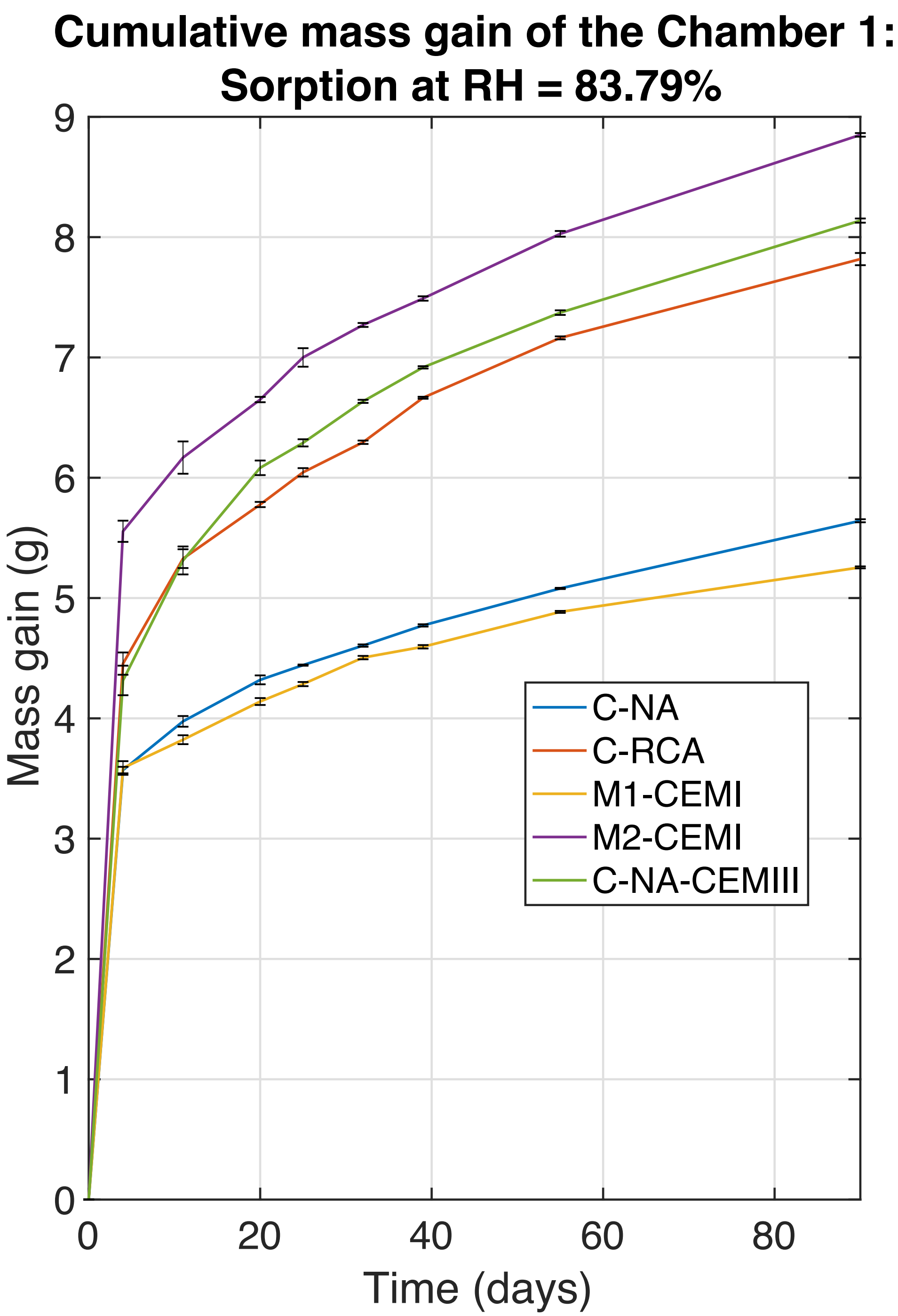
Vapour Control Drying

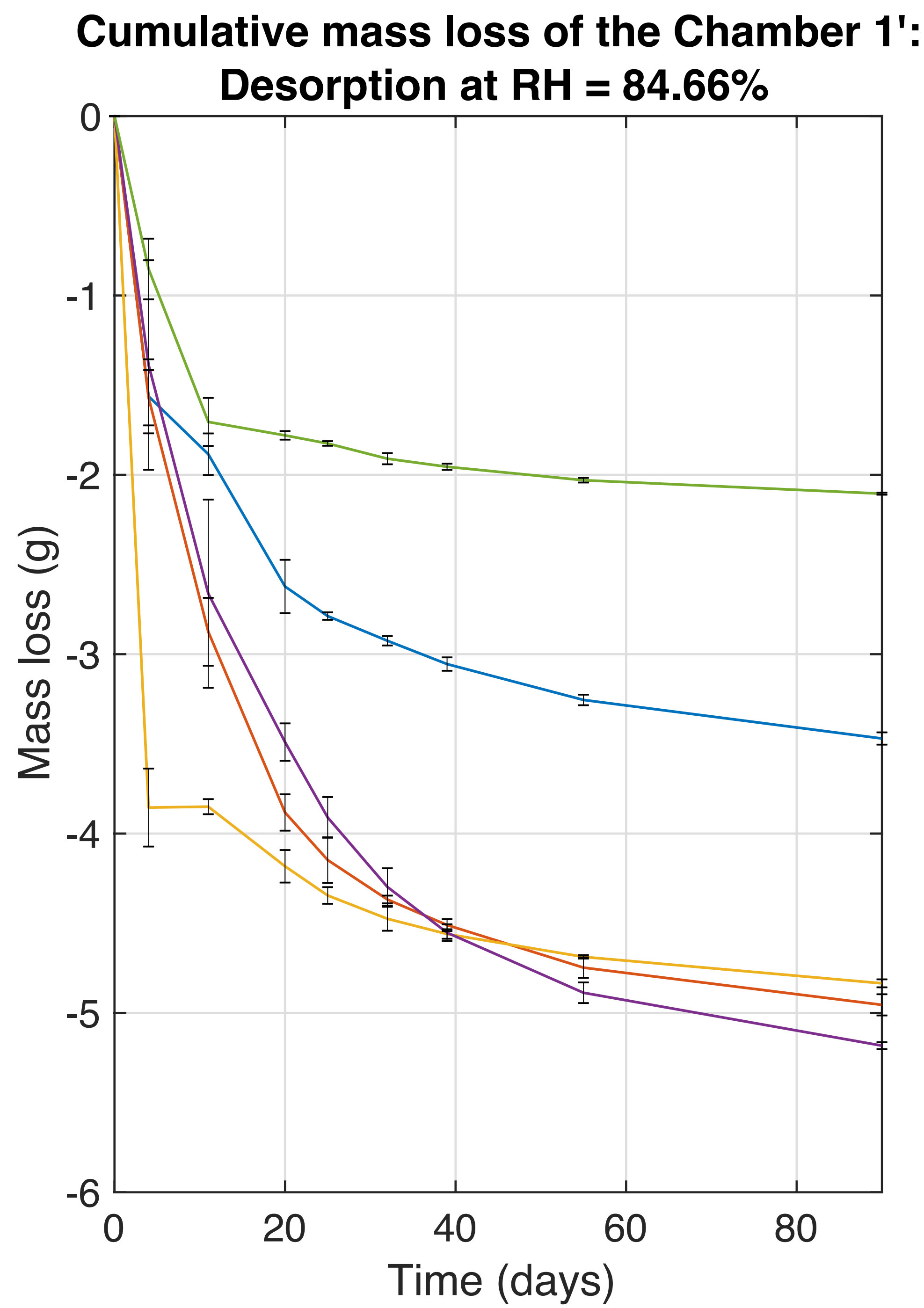




Experimentation

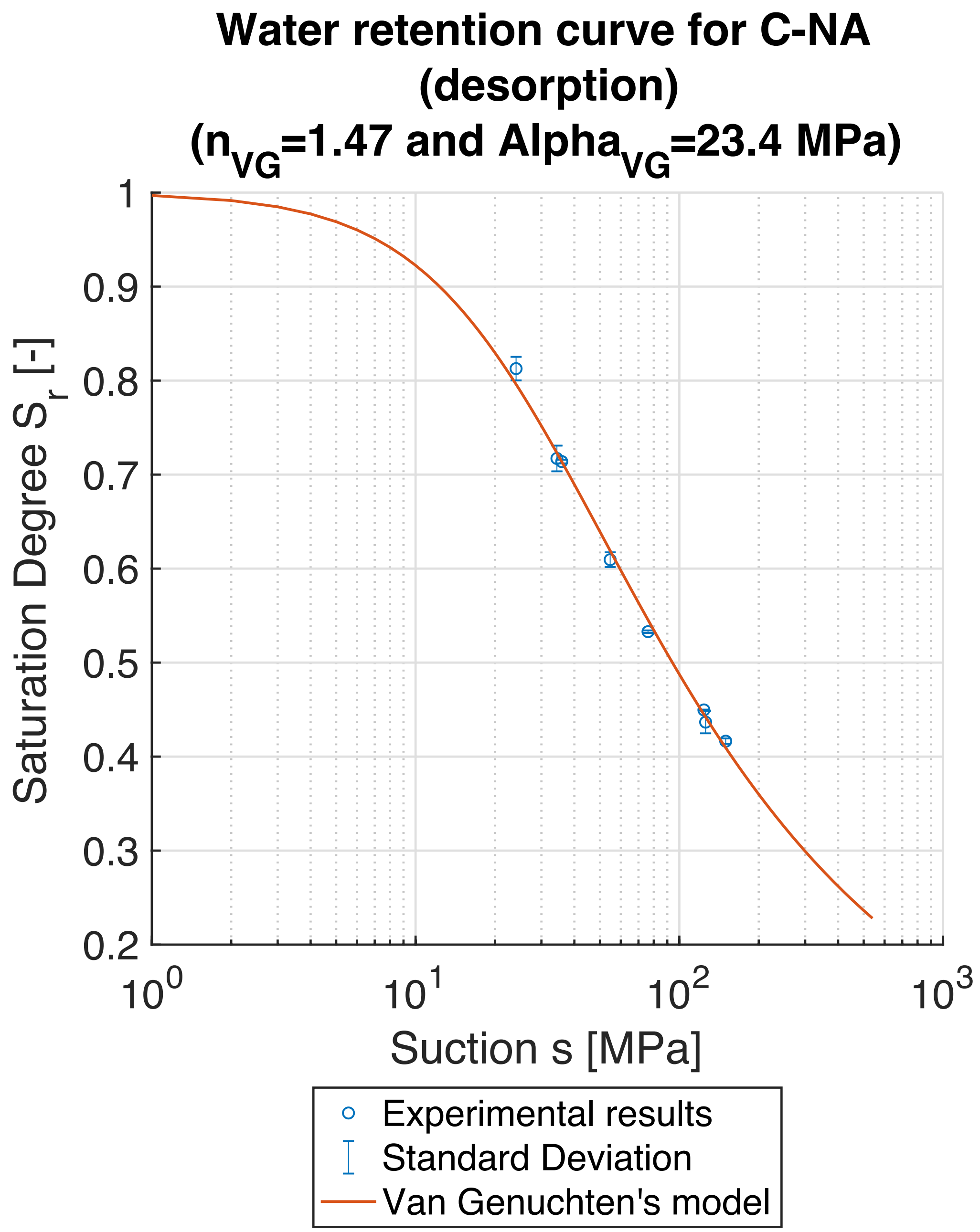
Vapour Control Drying

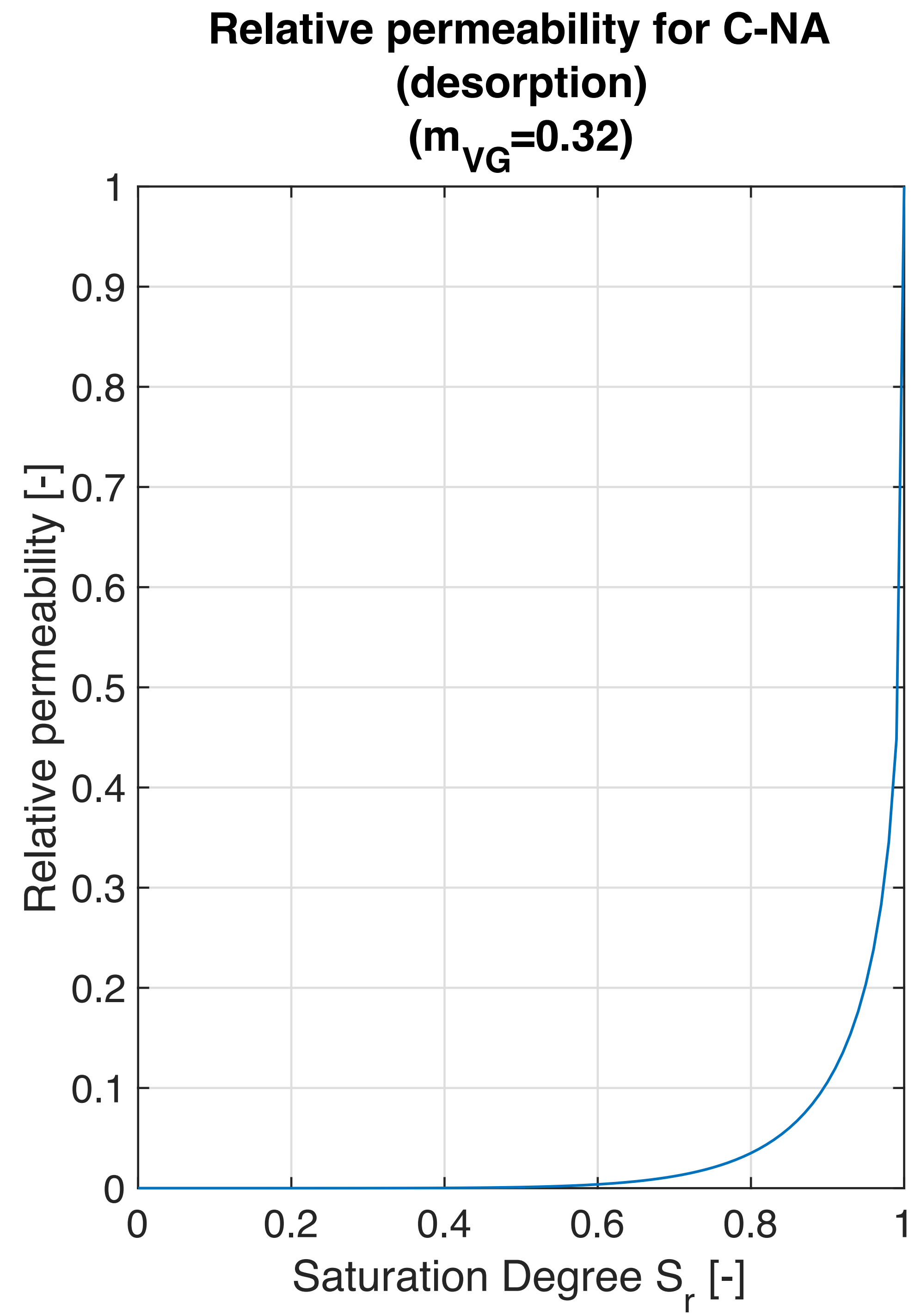




Experimentation

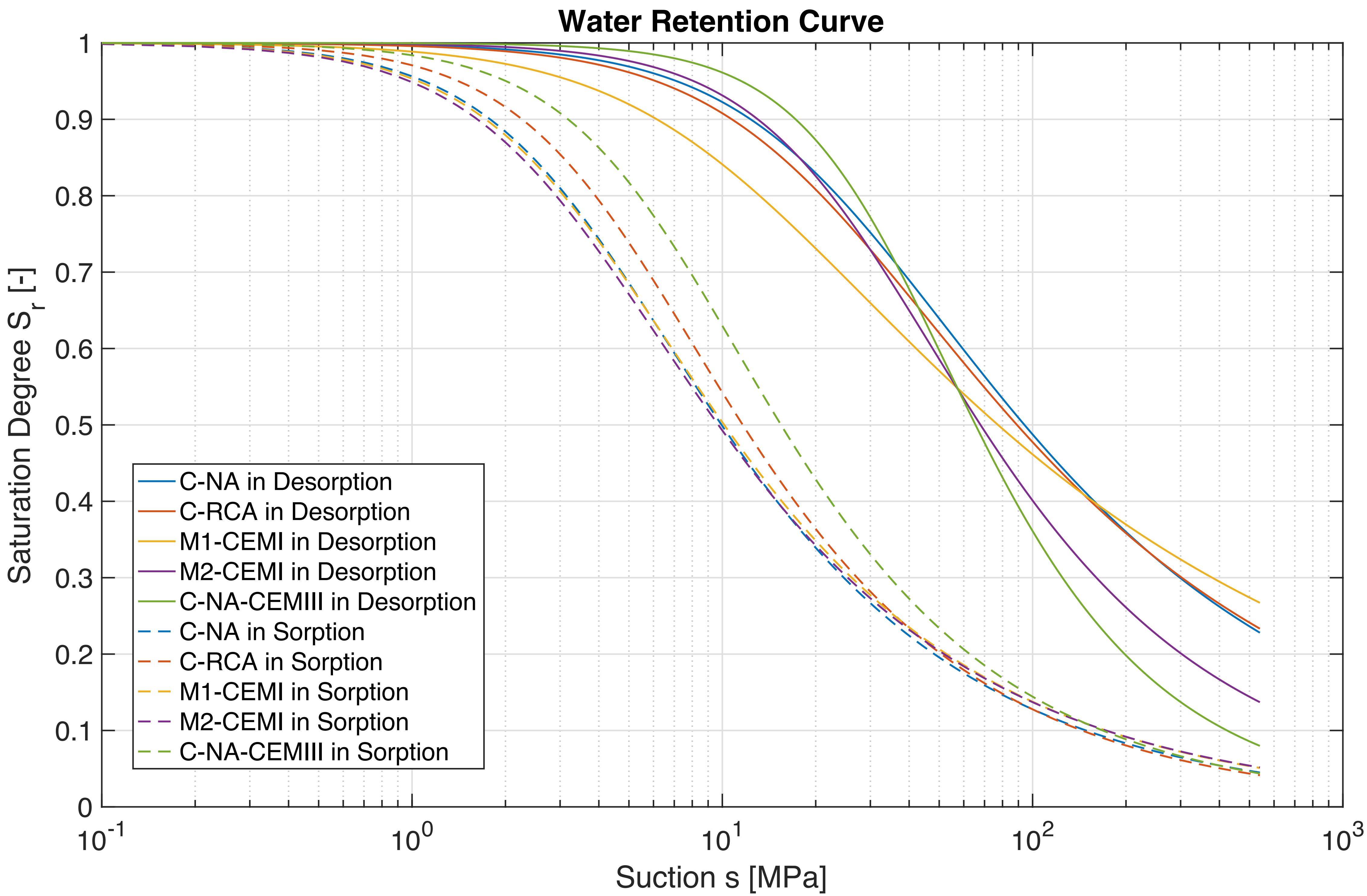
Vapour Control Drying





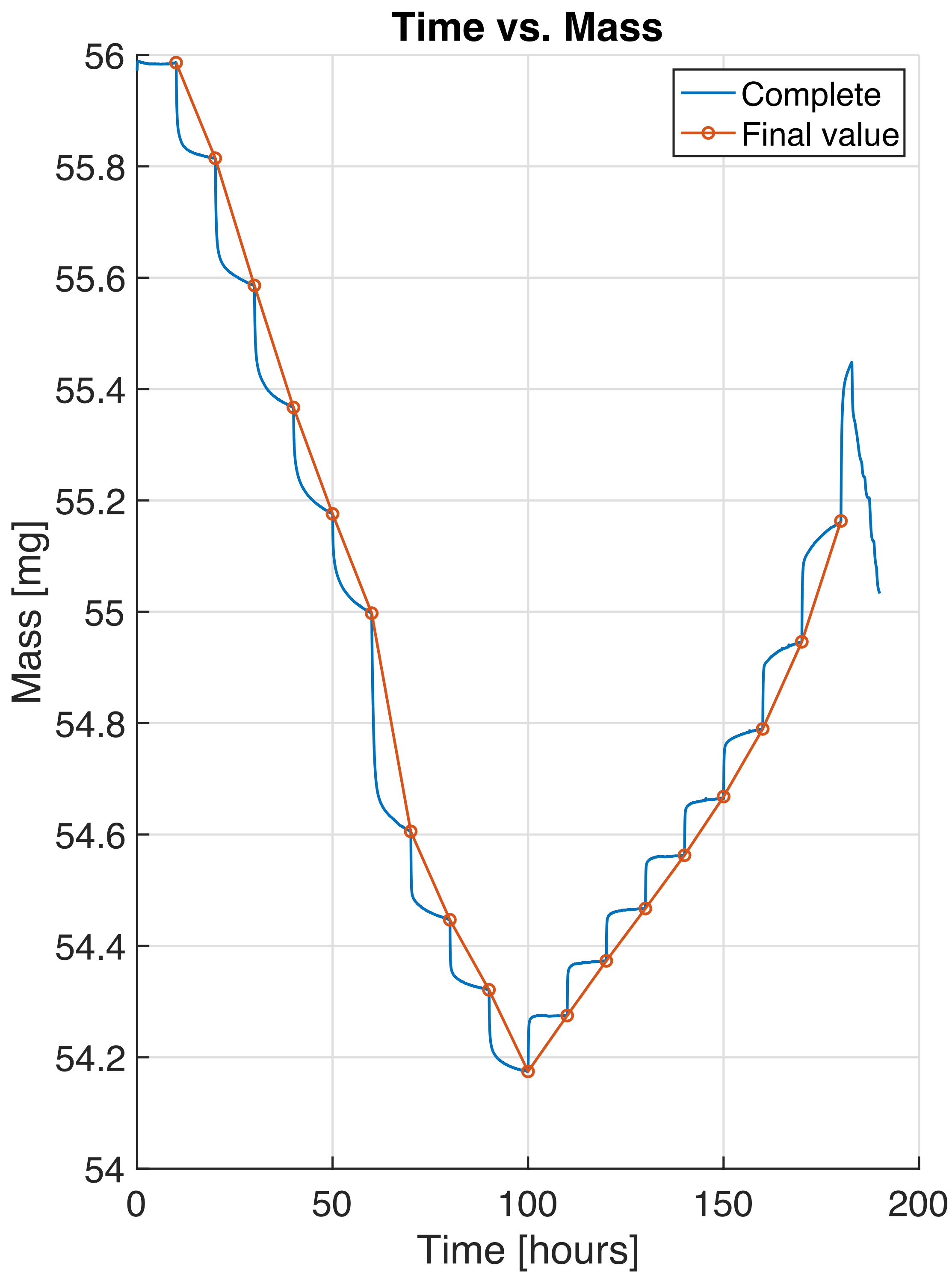
Experimentation

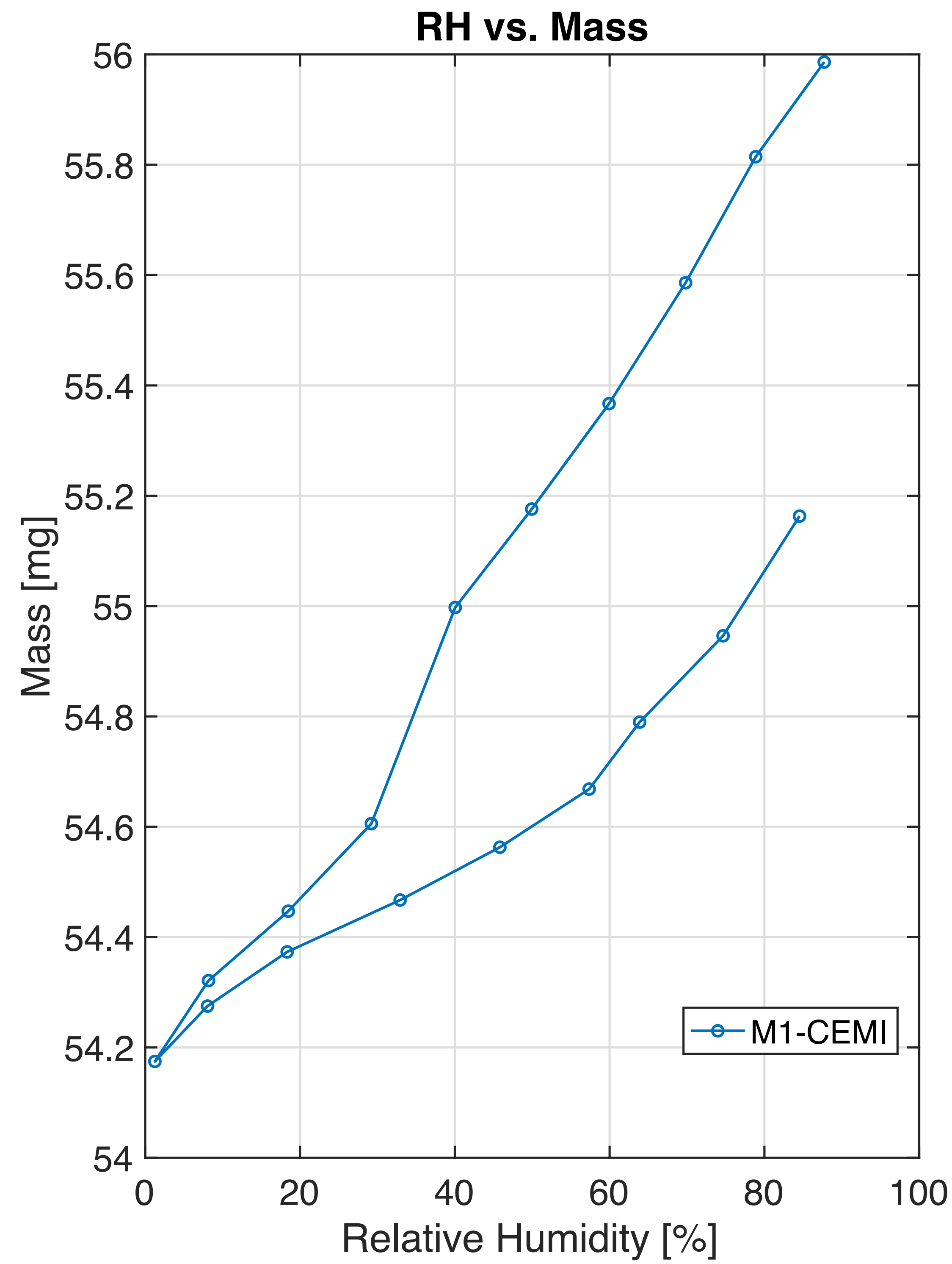
Vapour Control Drying



Experimentation

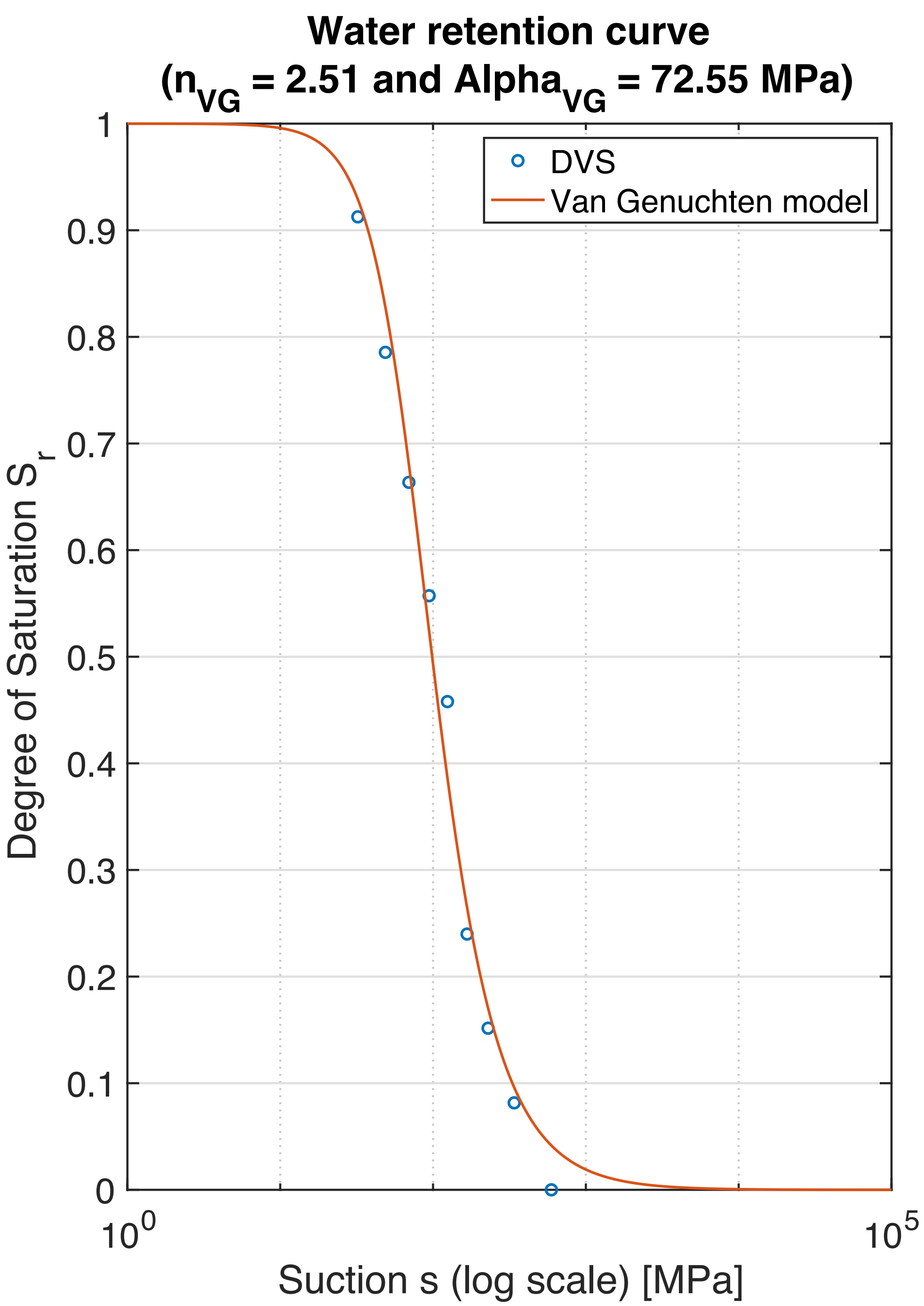
Dynamic Vapour Sorption (DVS)

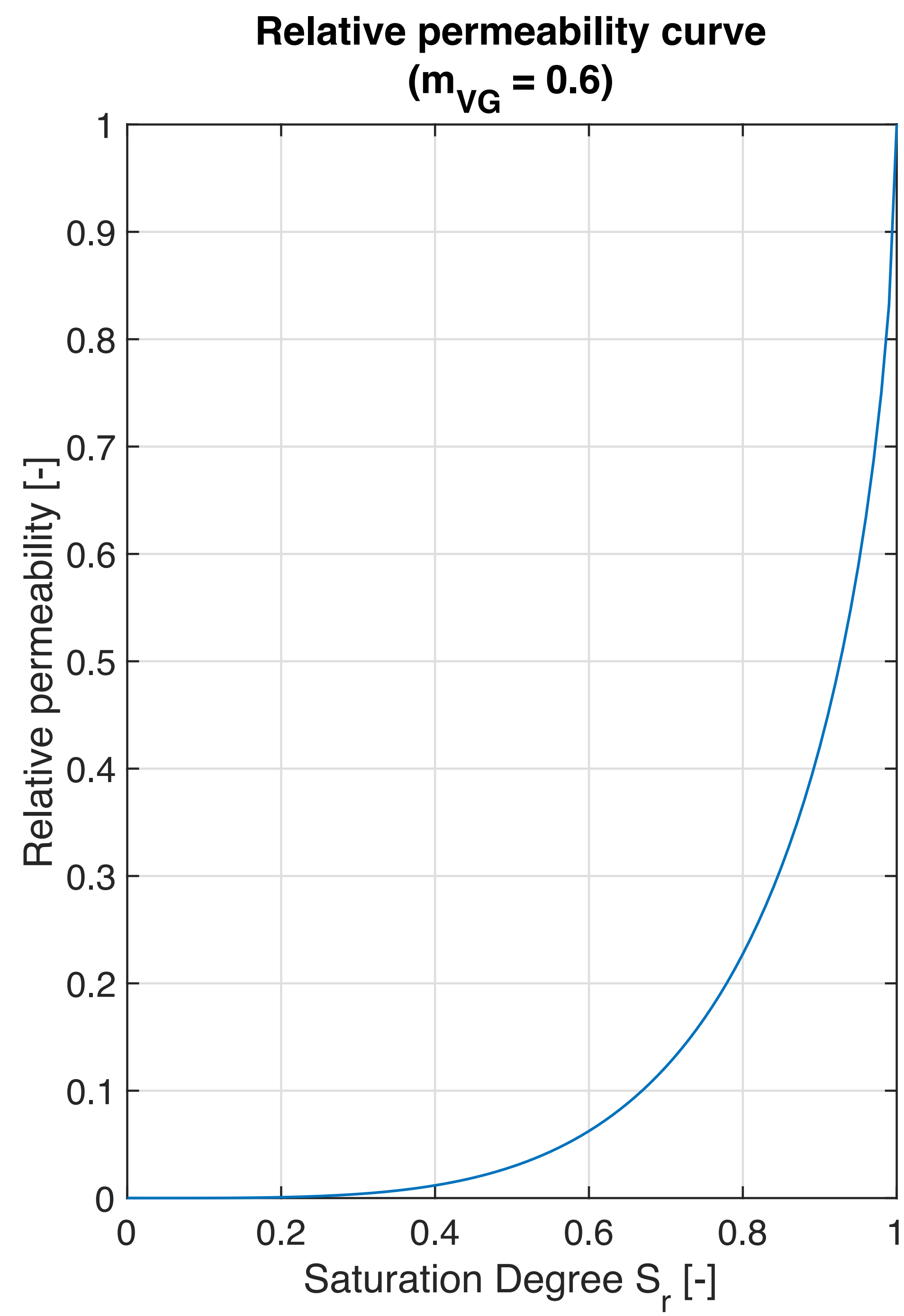




Experimentation

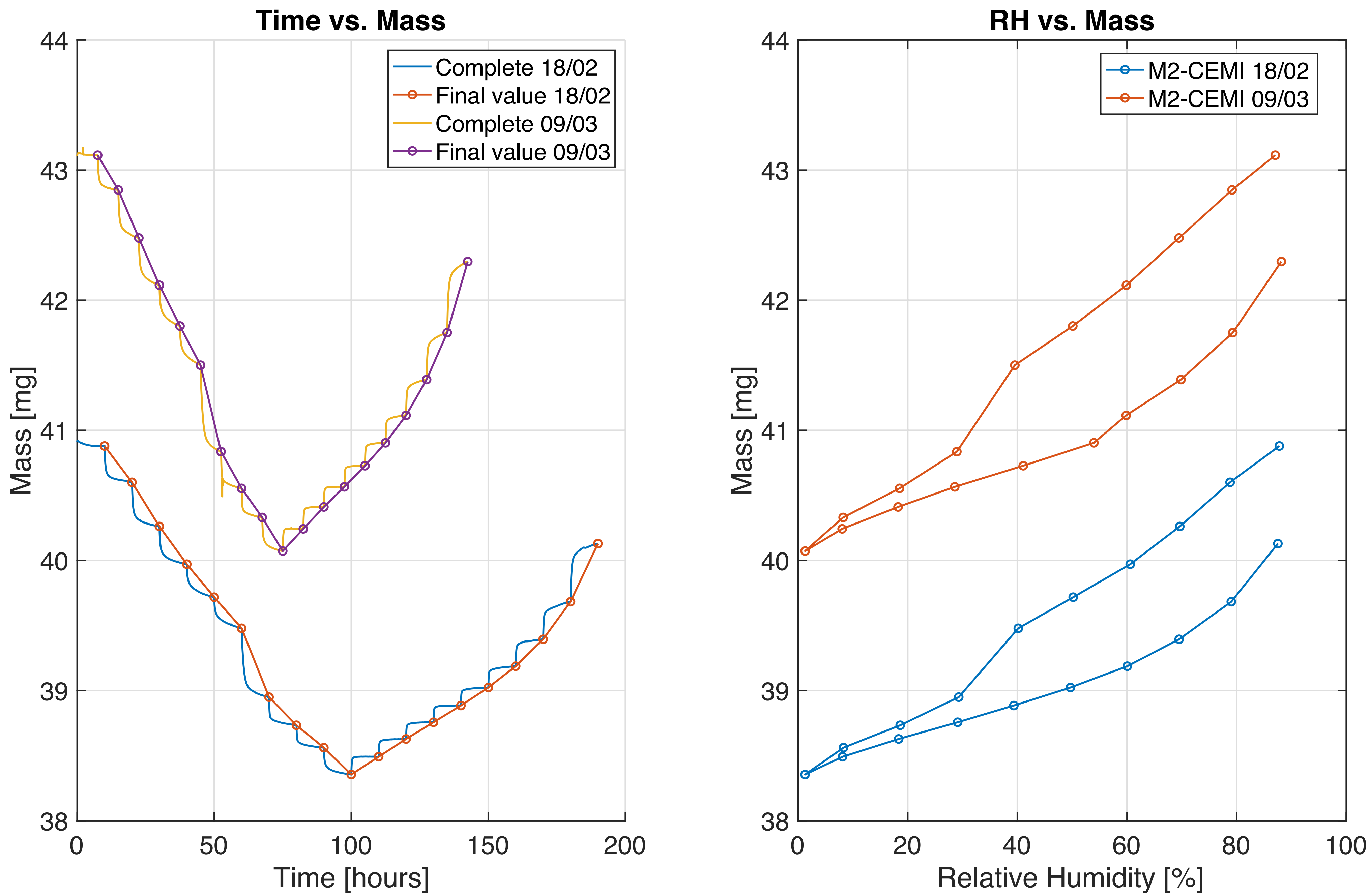
Dynamic Vapour Sorption (DVS)





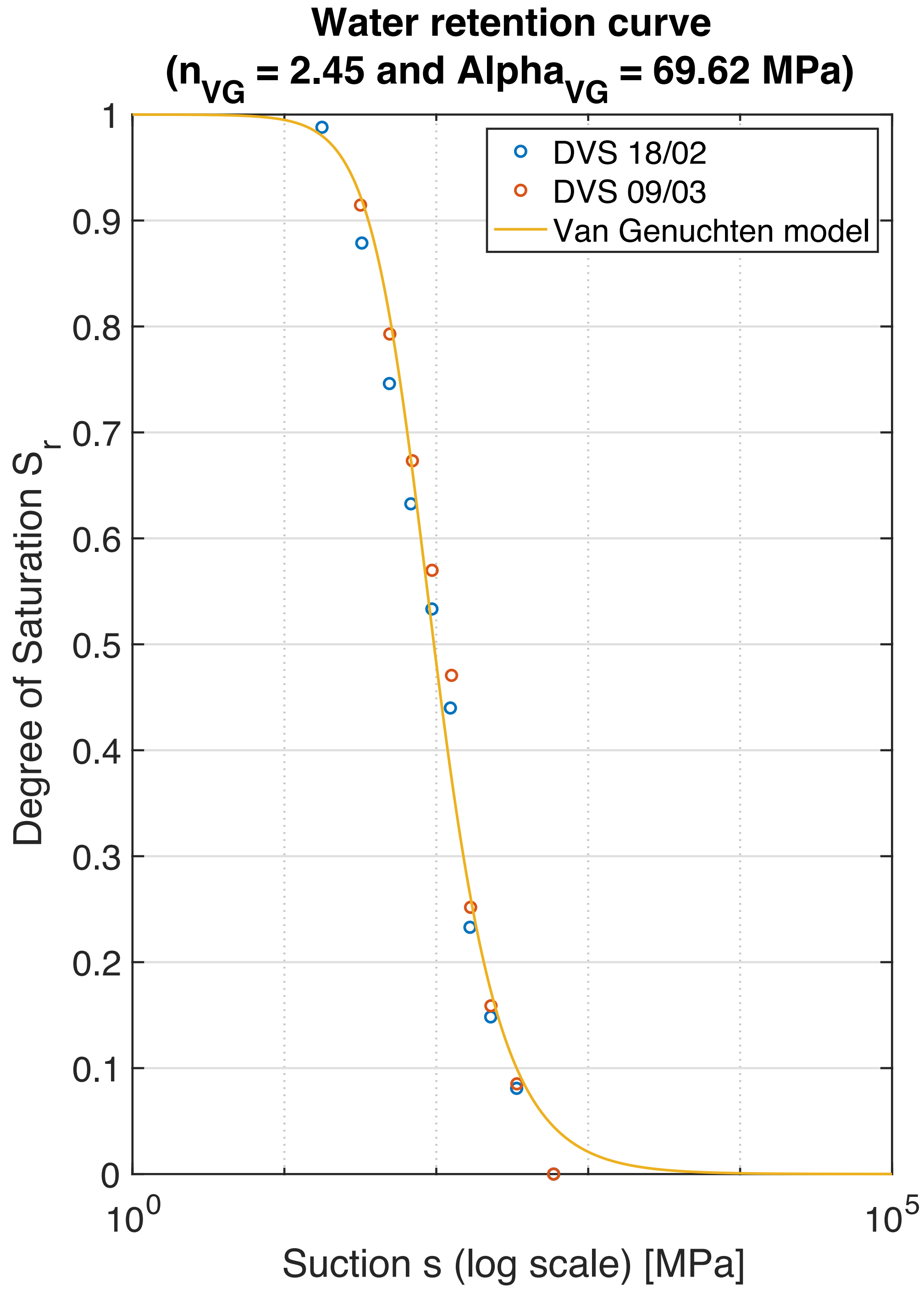
Experimentation

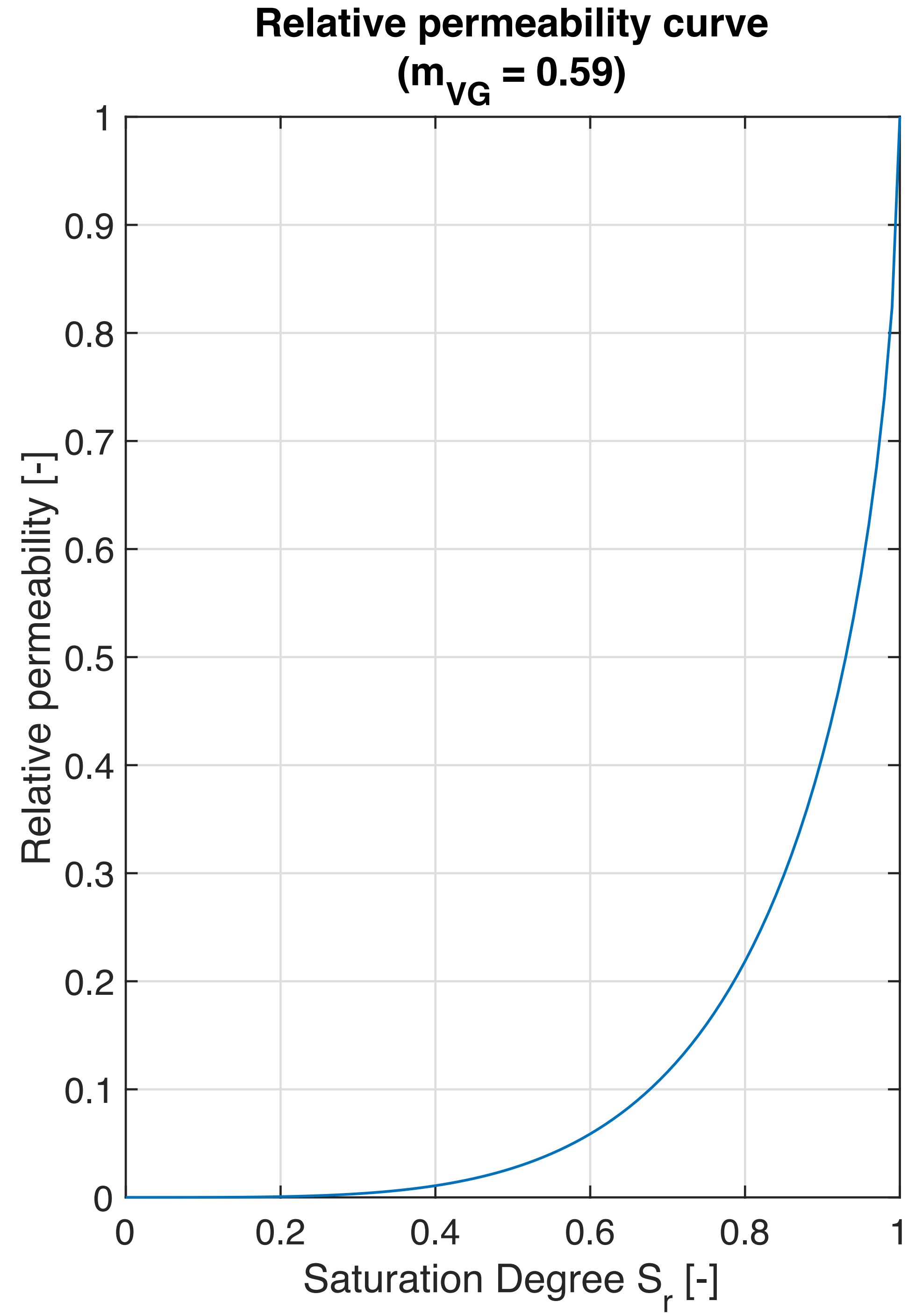
Dynamic Vapour Sorption (DVS)



Experimentation

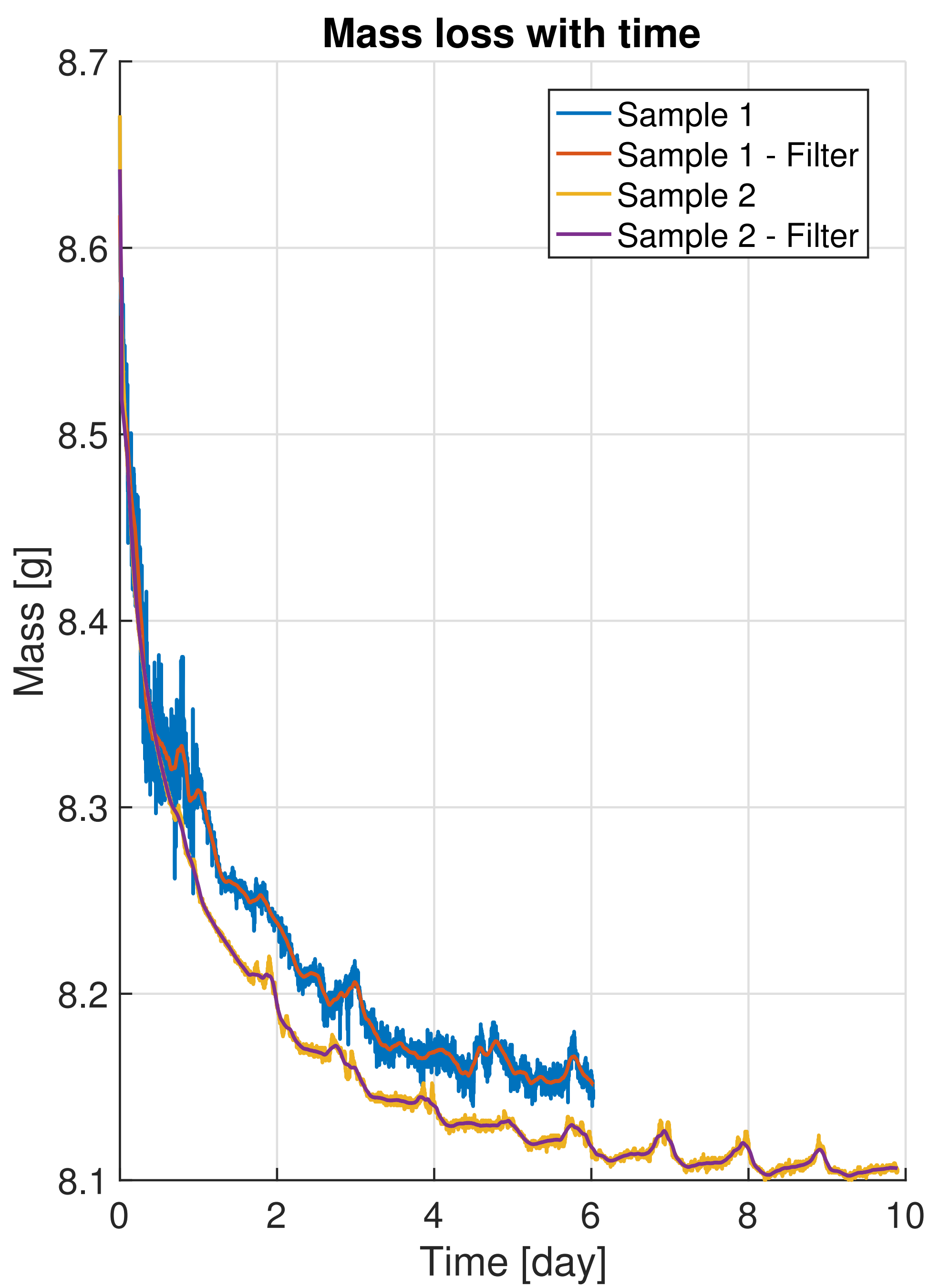
Dynamic Vapour Sorption (DVS)

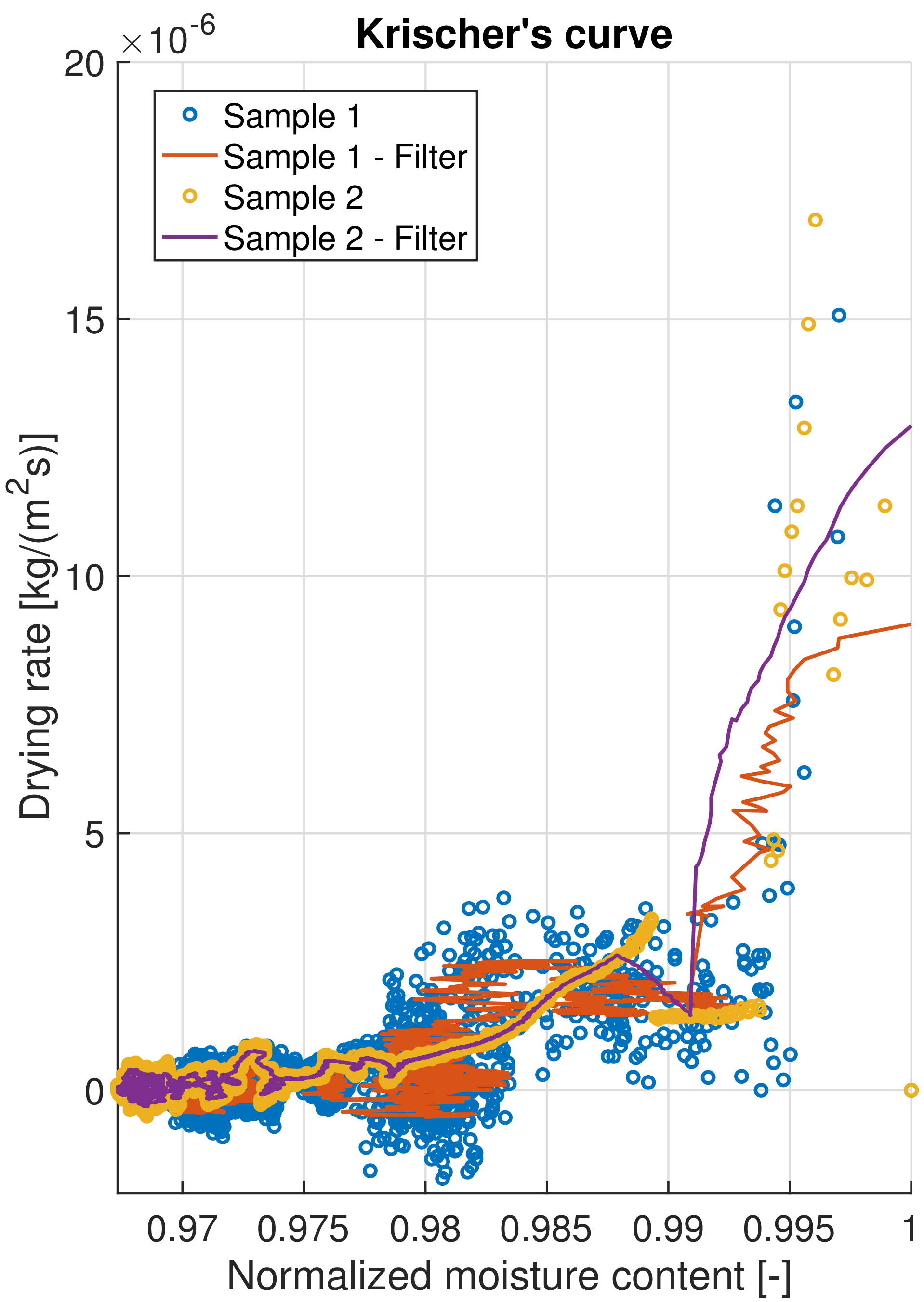




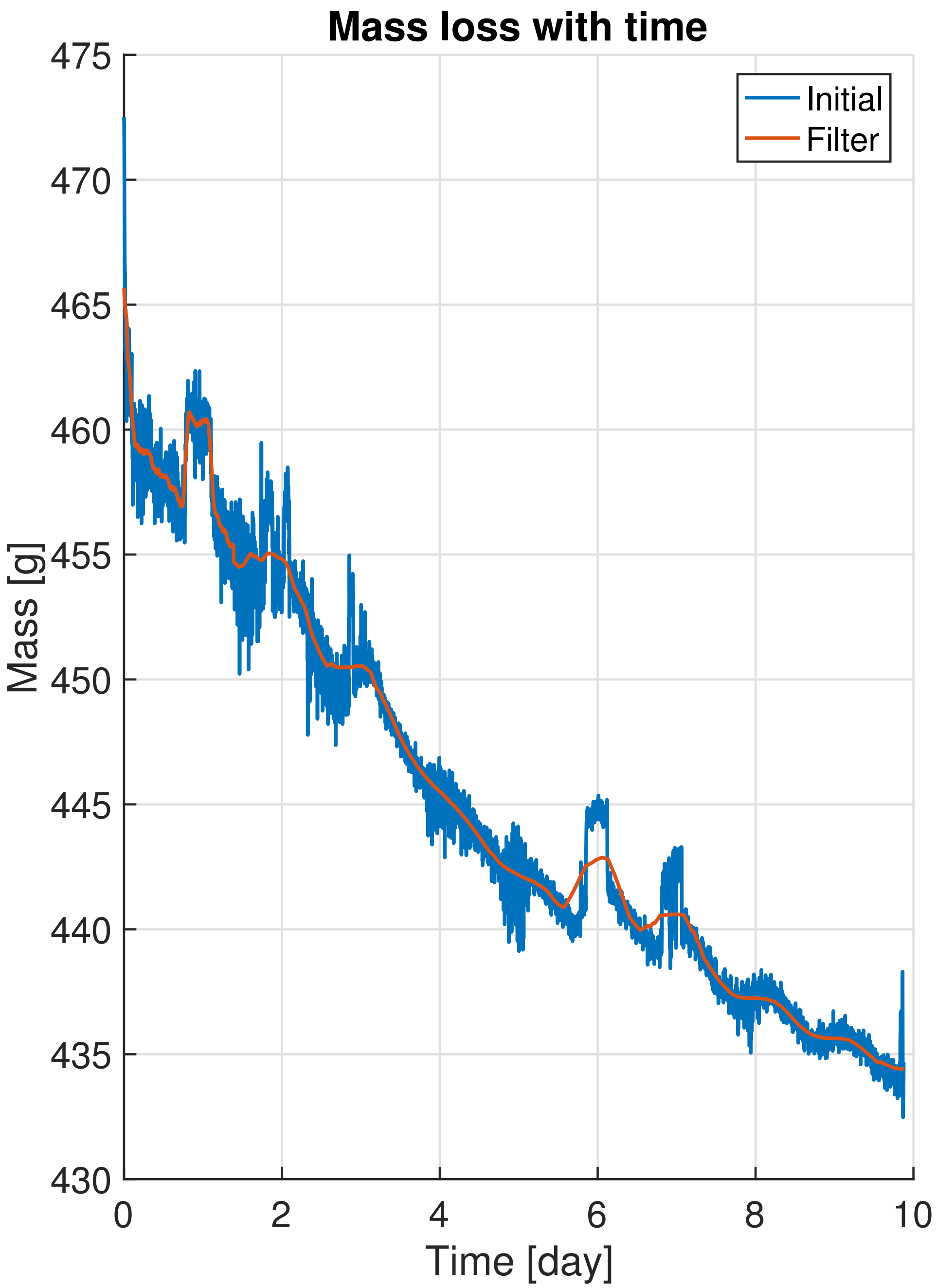
Experimentation

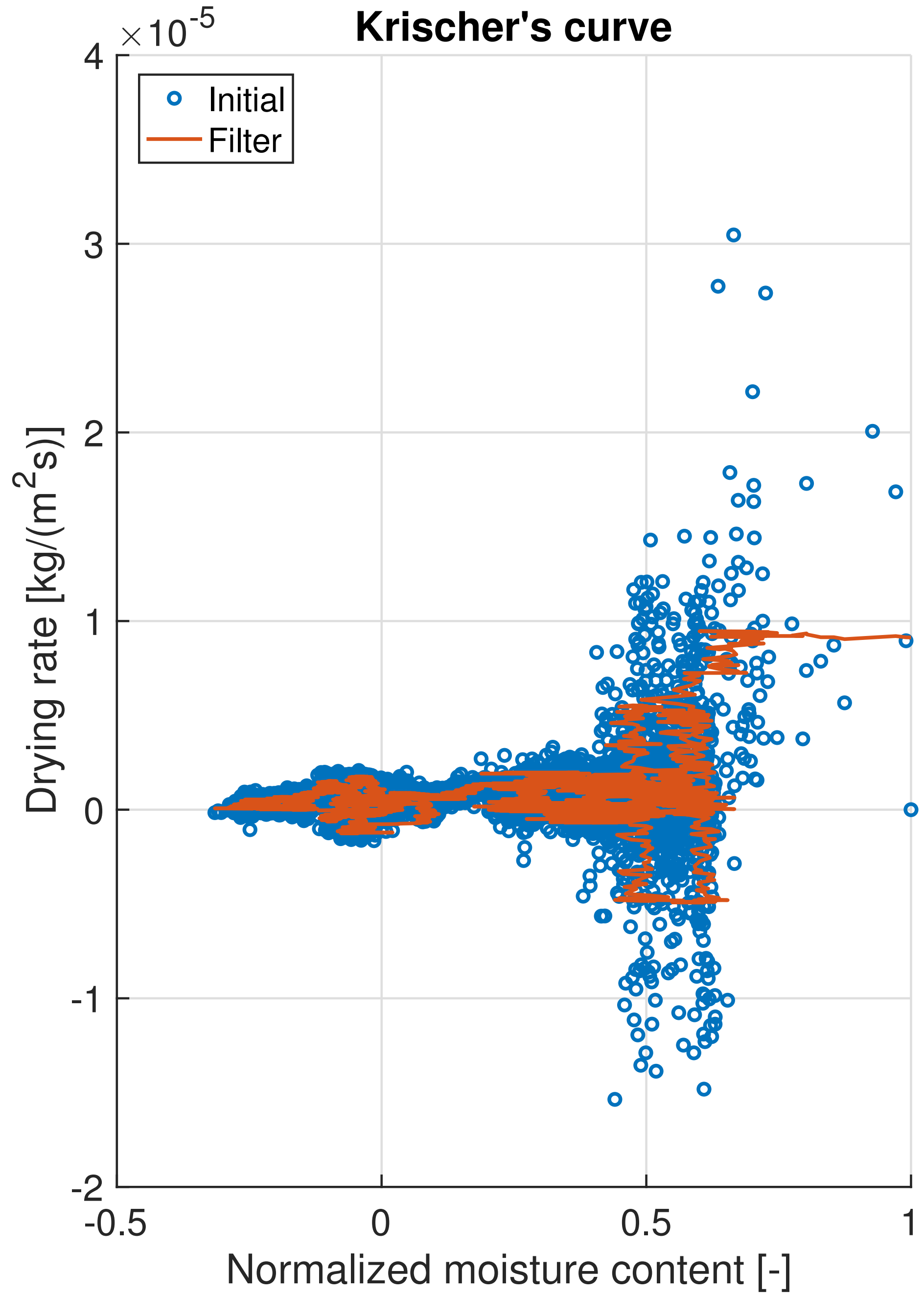
Convective Drying (Micro-dryer)





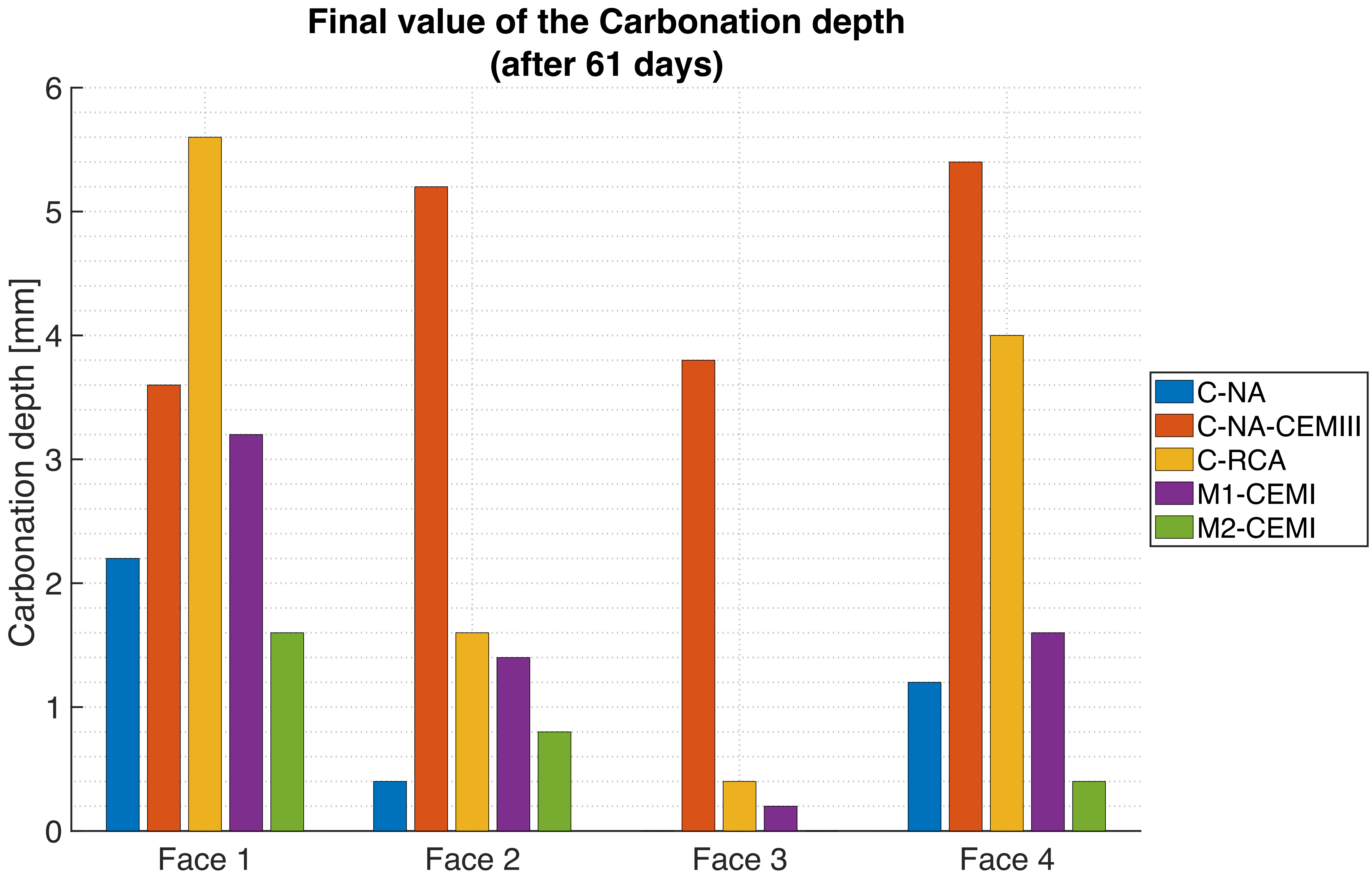
Experimentation
Convective Drying (Macro-dryer)





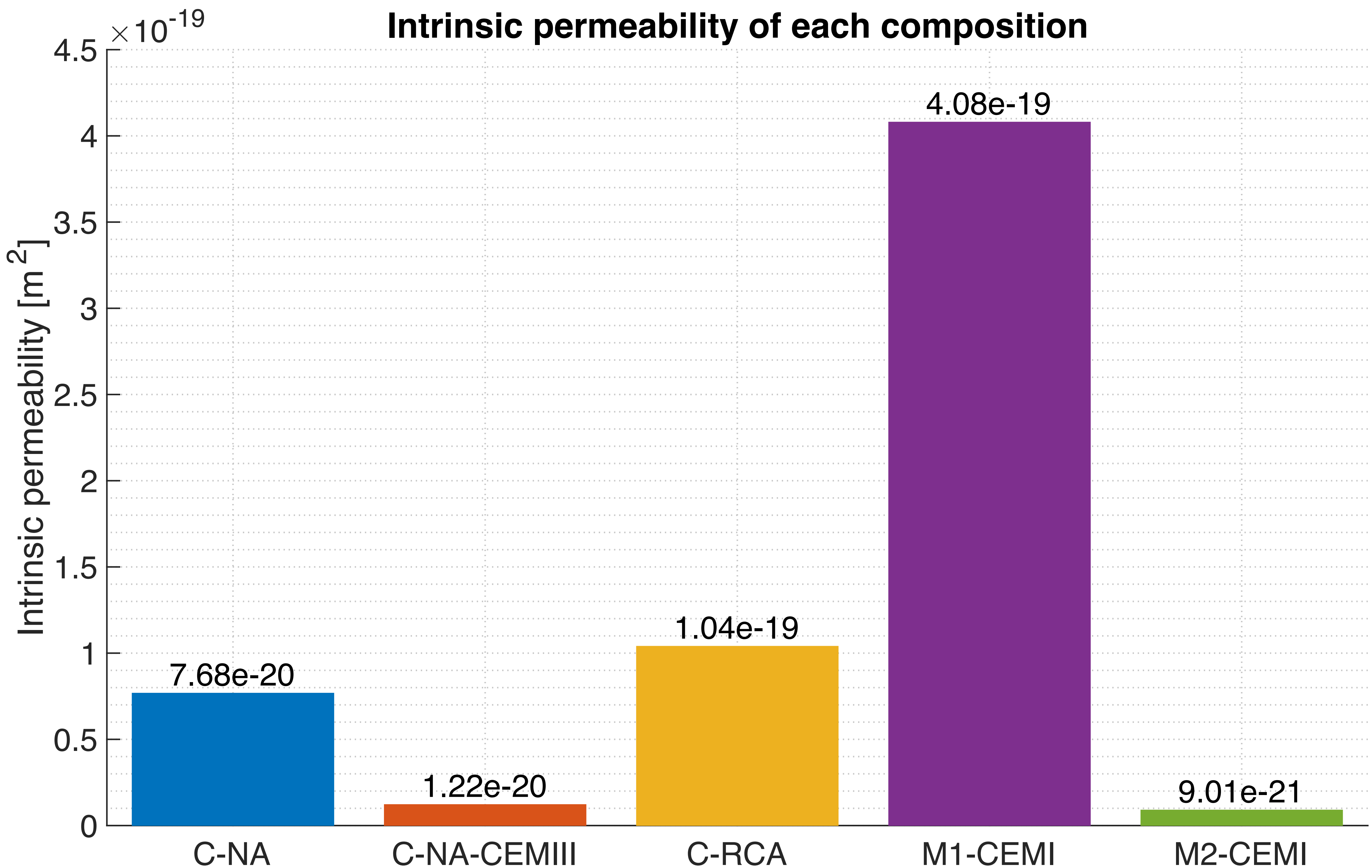
Experimentation

Resistance to Carbonation



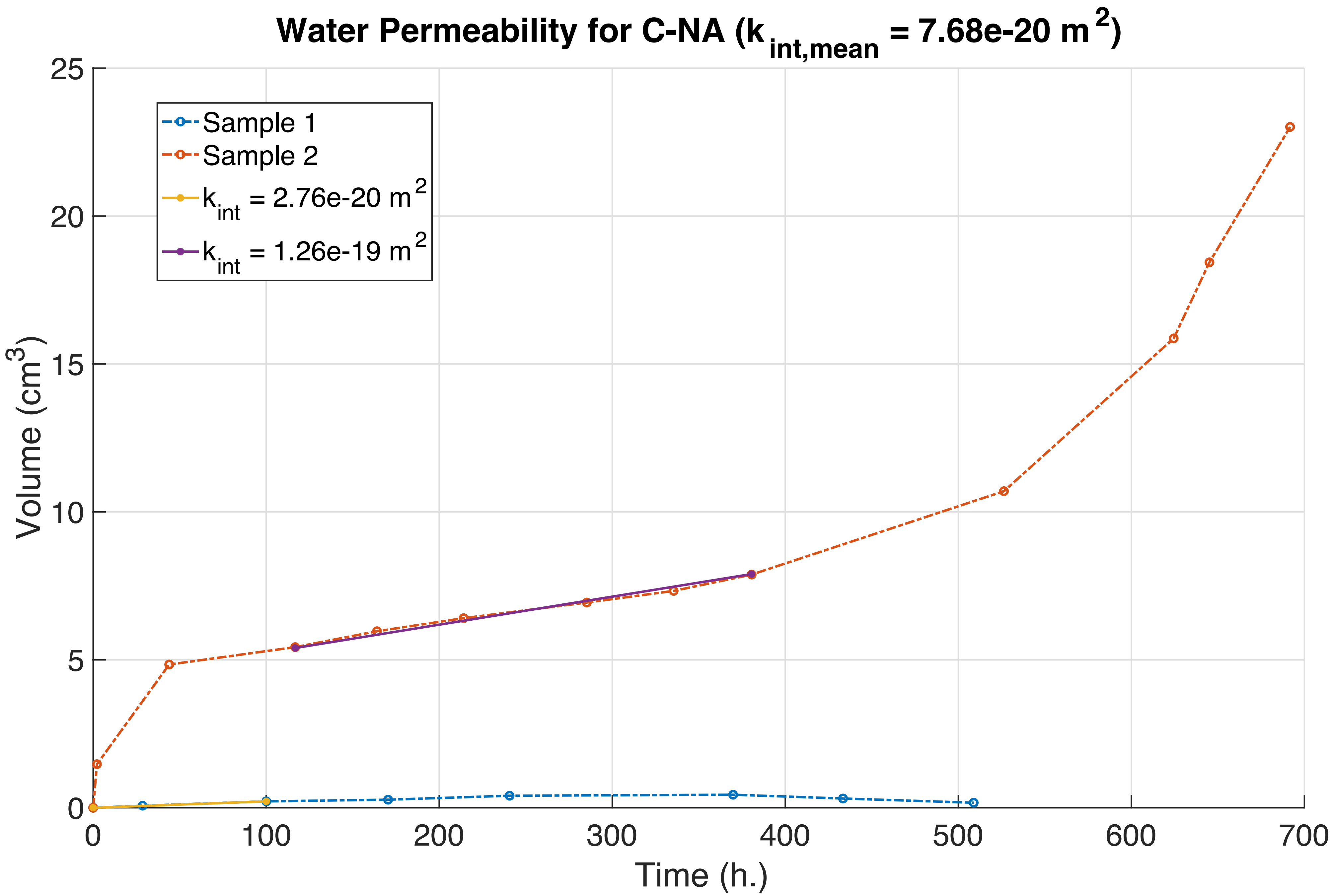
Experimentation

Water Permeability



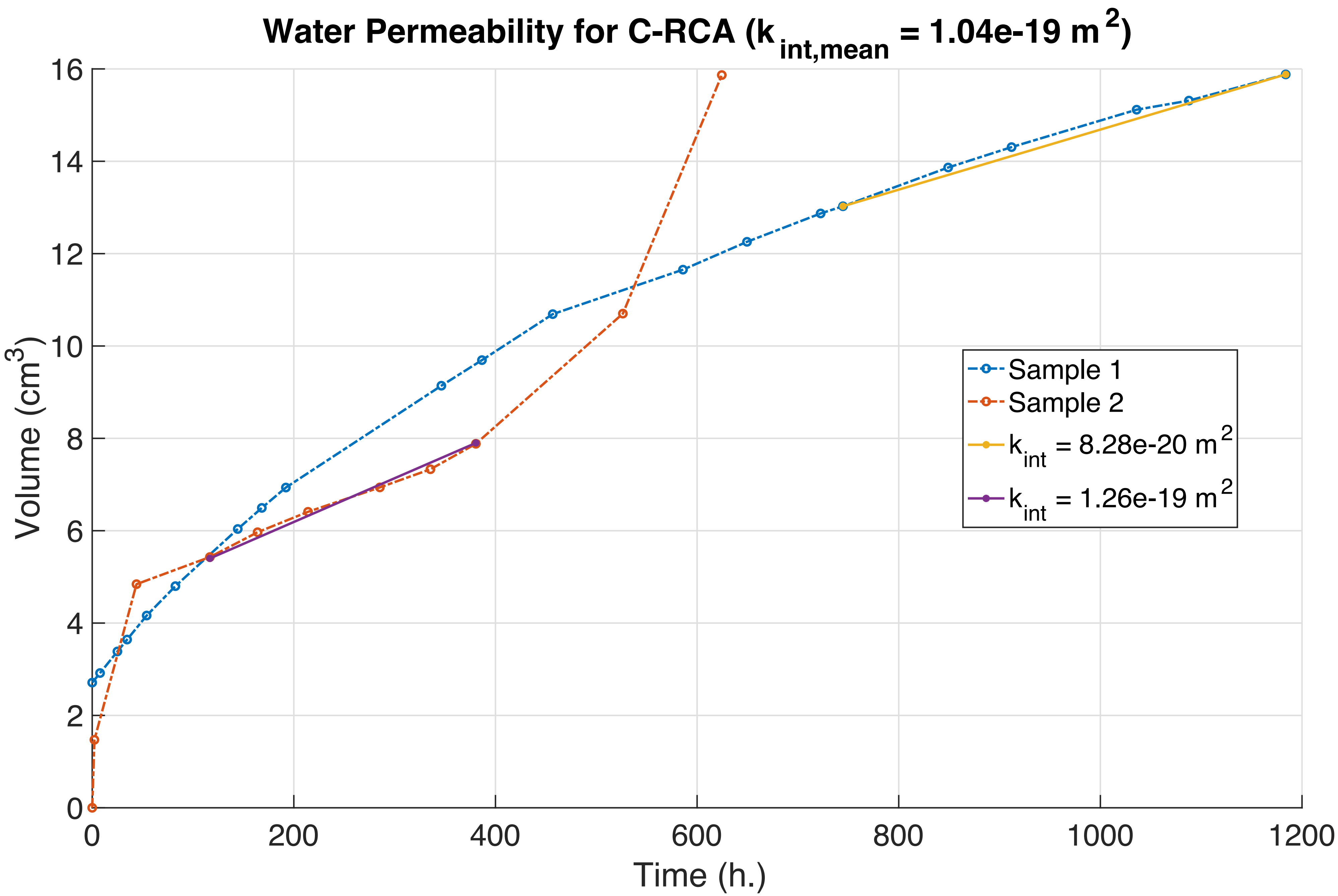
Experimentation

Water Permeability

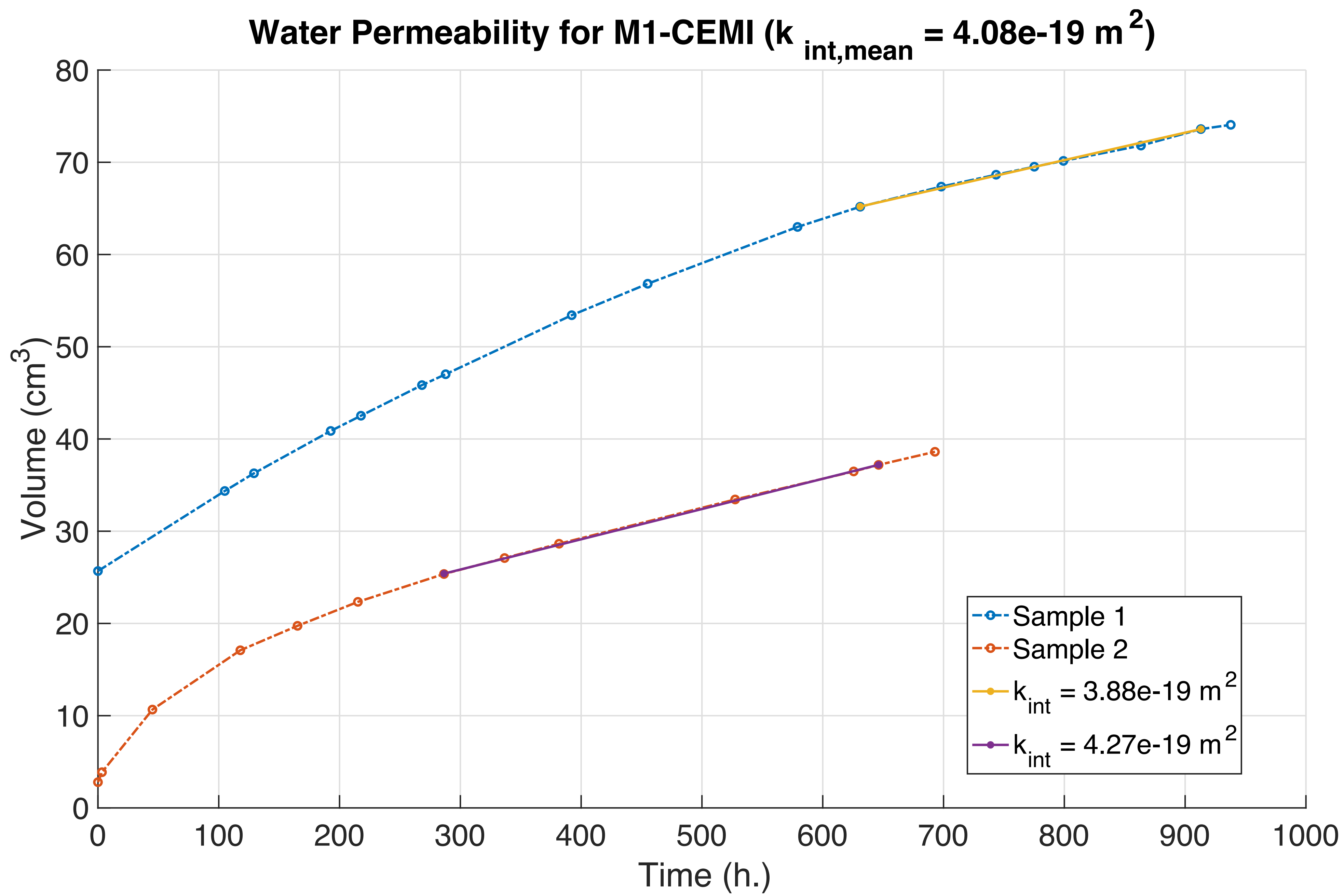


Experimentation

Water Permeability

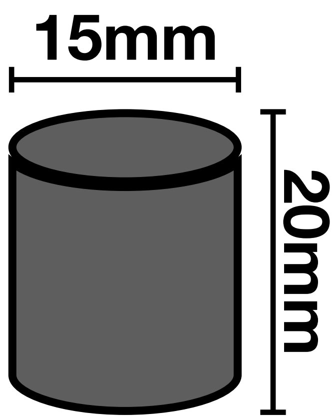


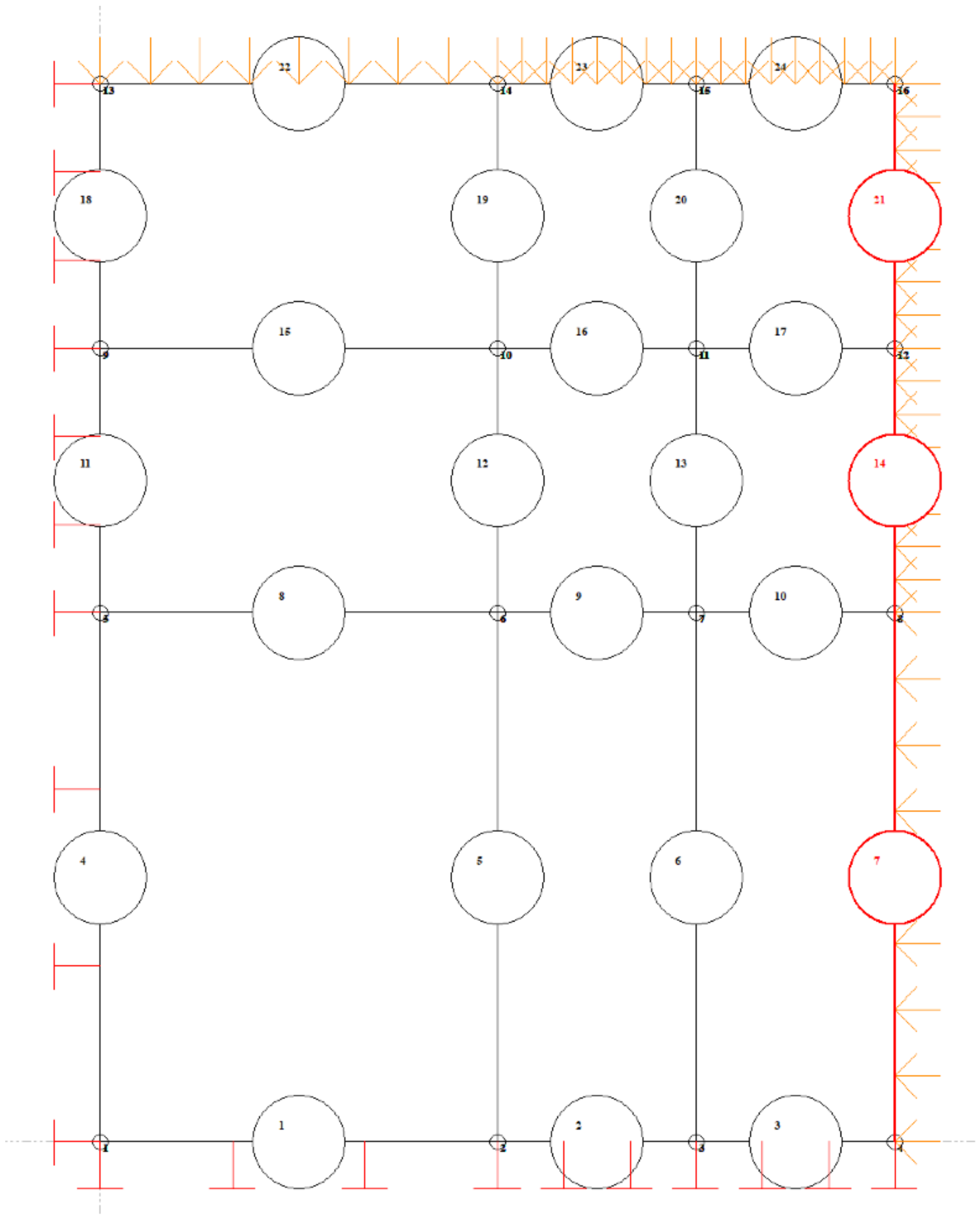
Experimentation
Water Permeability

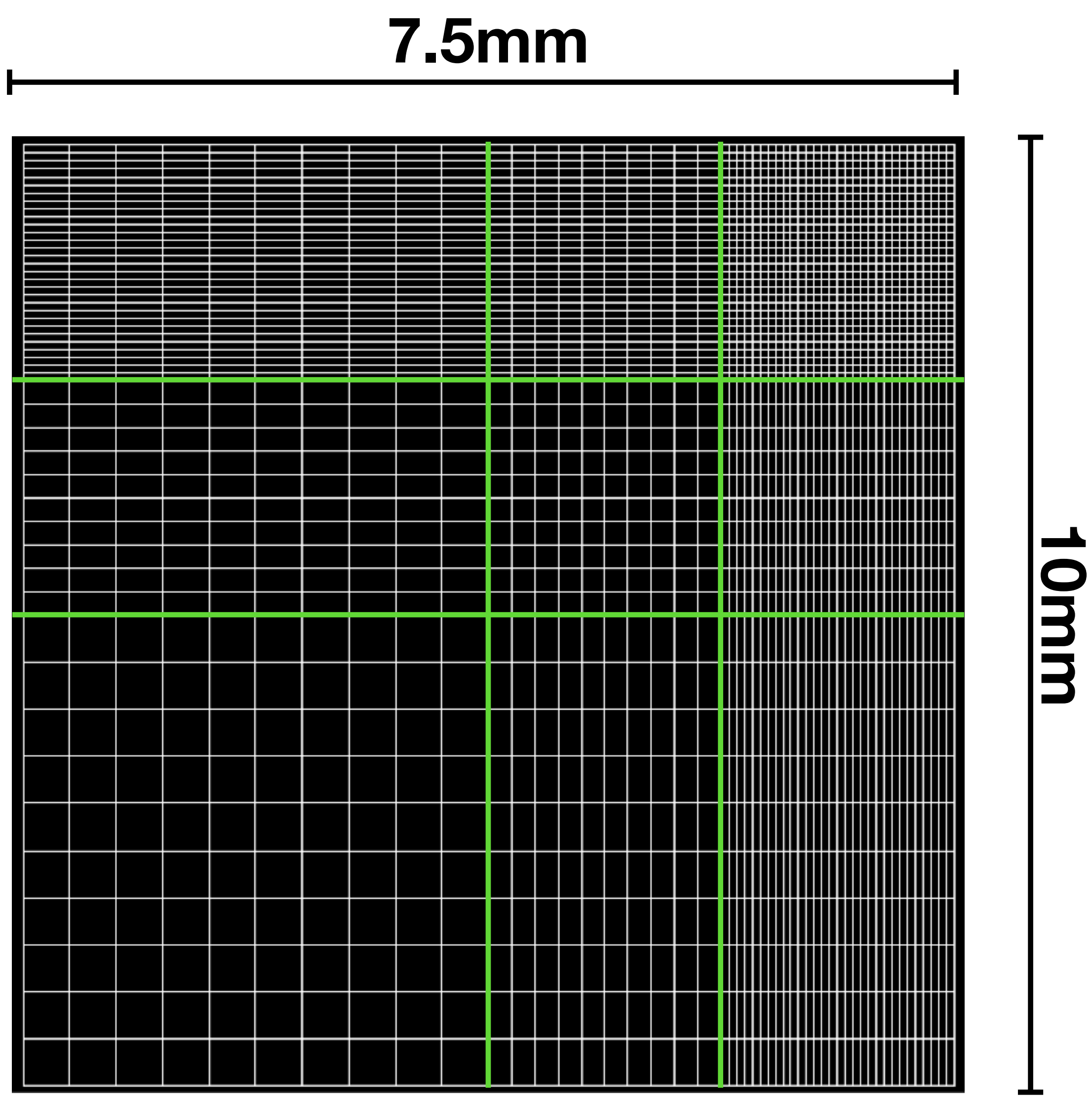


Modelling

Validation (M1-CEMI)

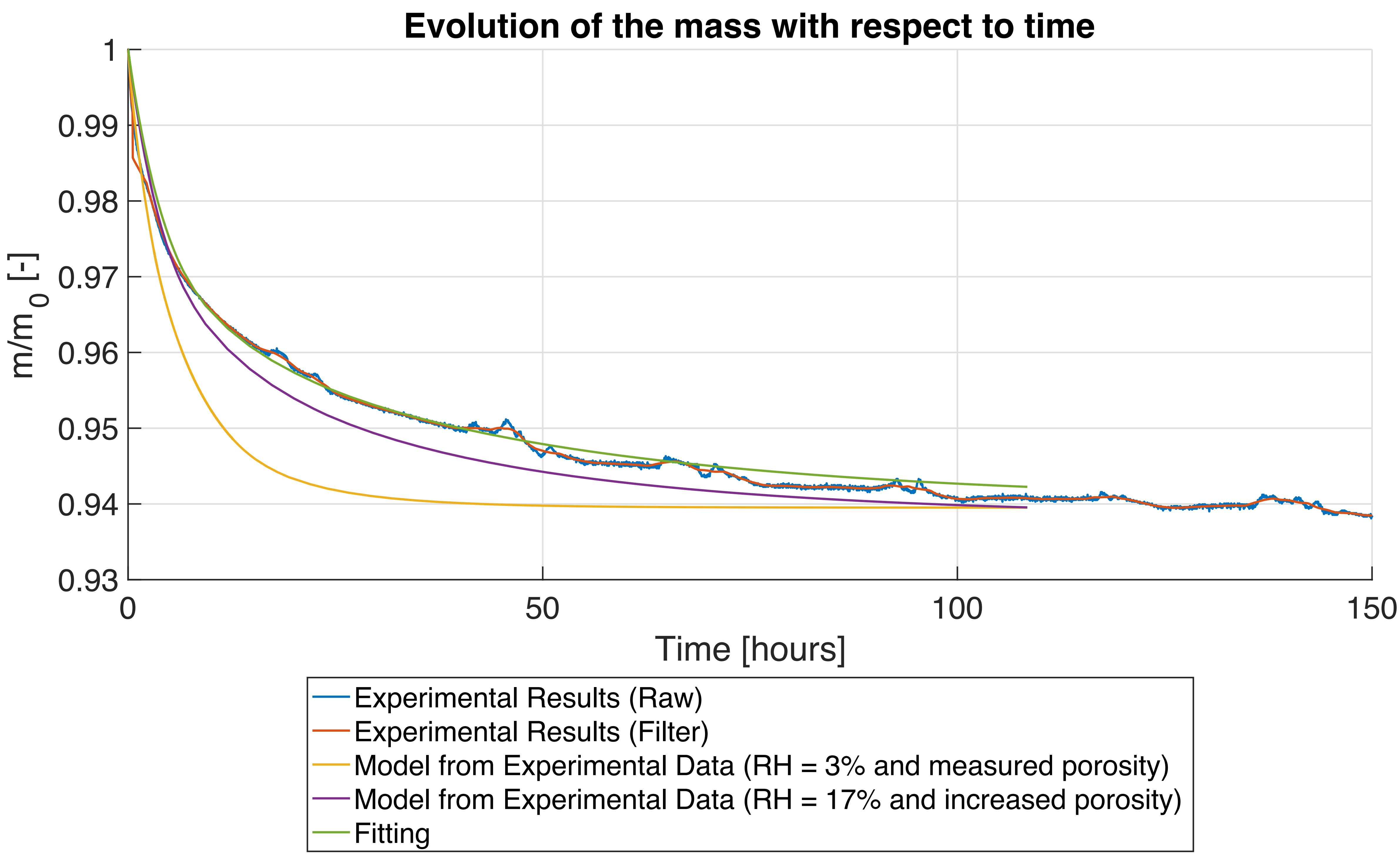






Modelling

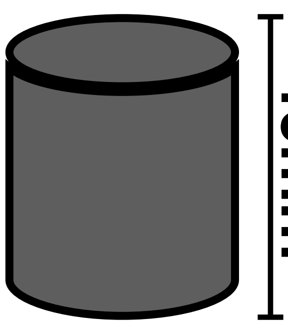
Validation (M1-CEMI)



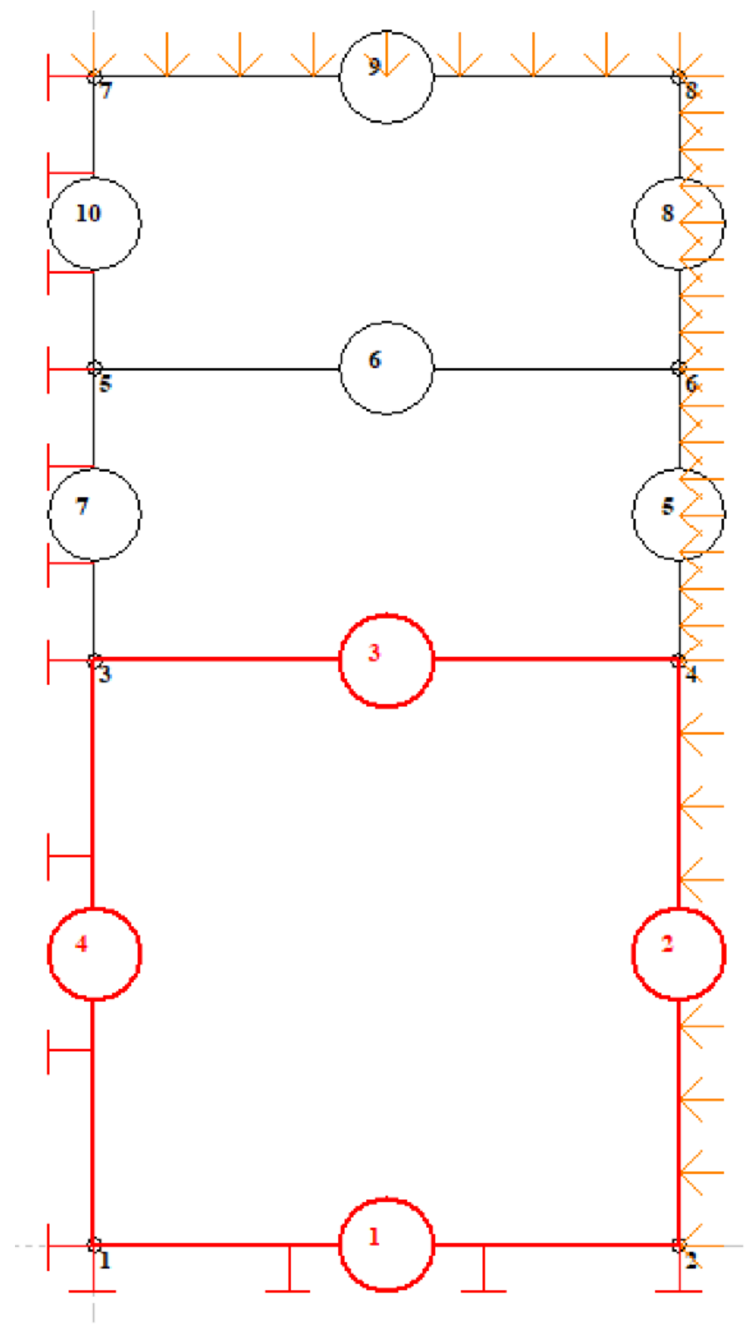
Modelling

Validation (Expertise's concrete)

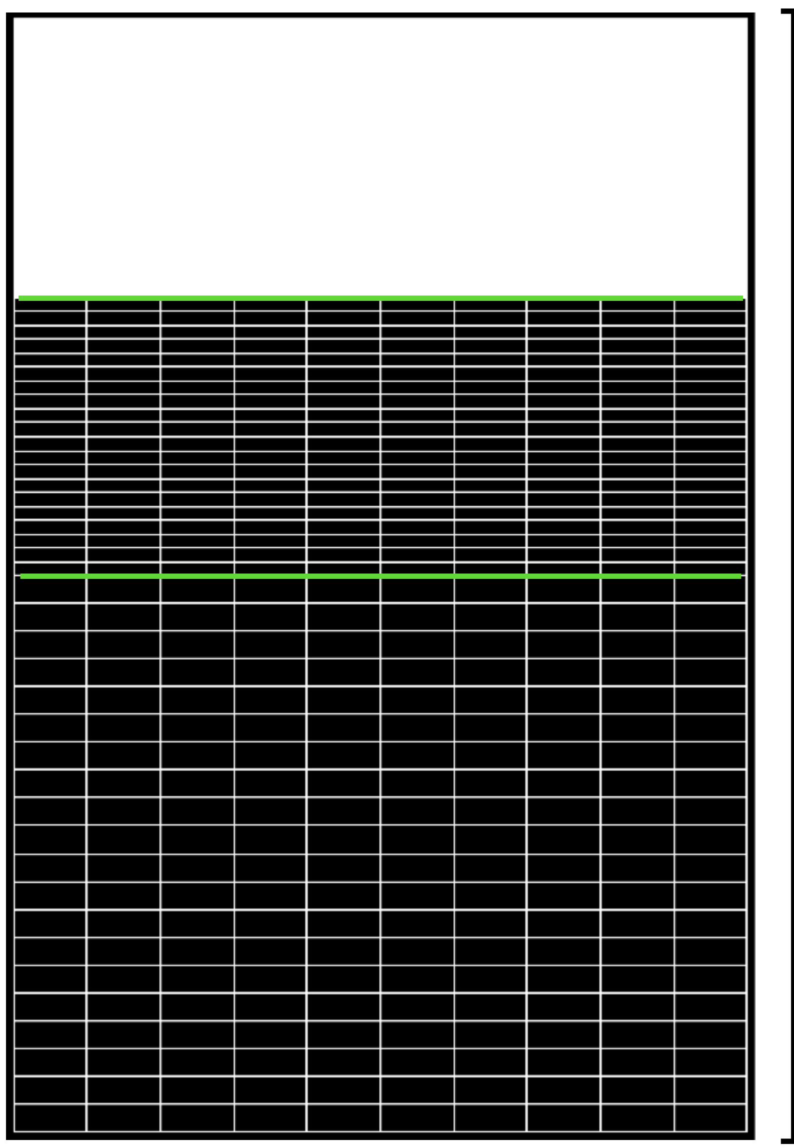
40mm



40mm



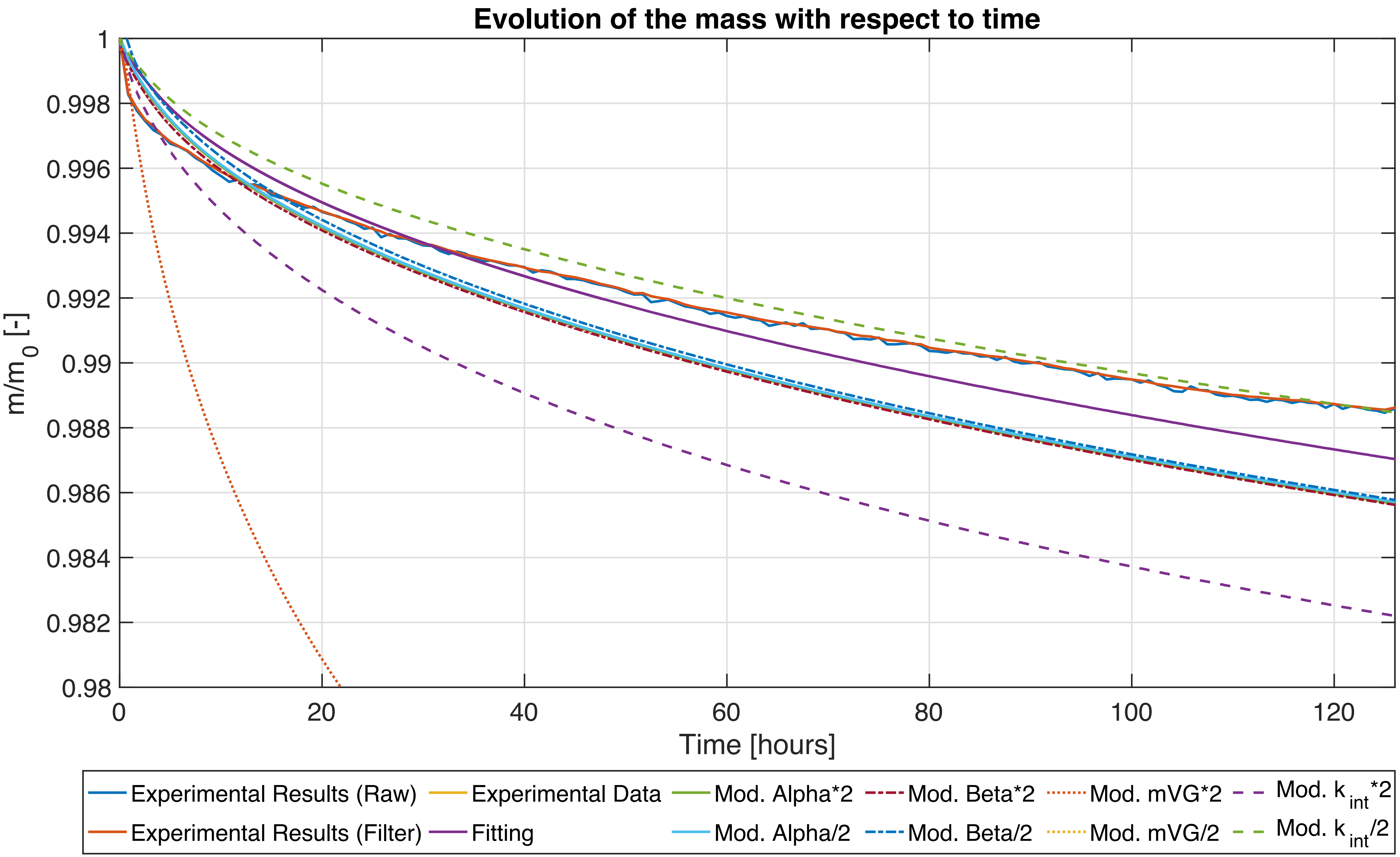
20mm



40mm

Modelling

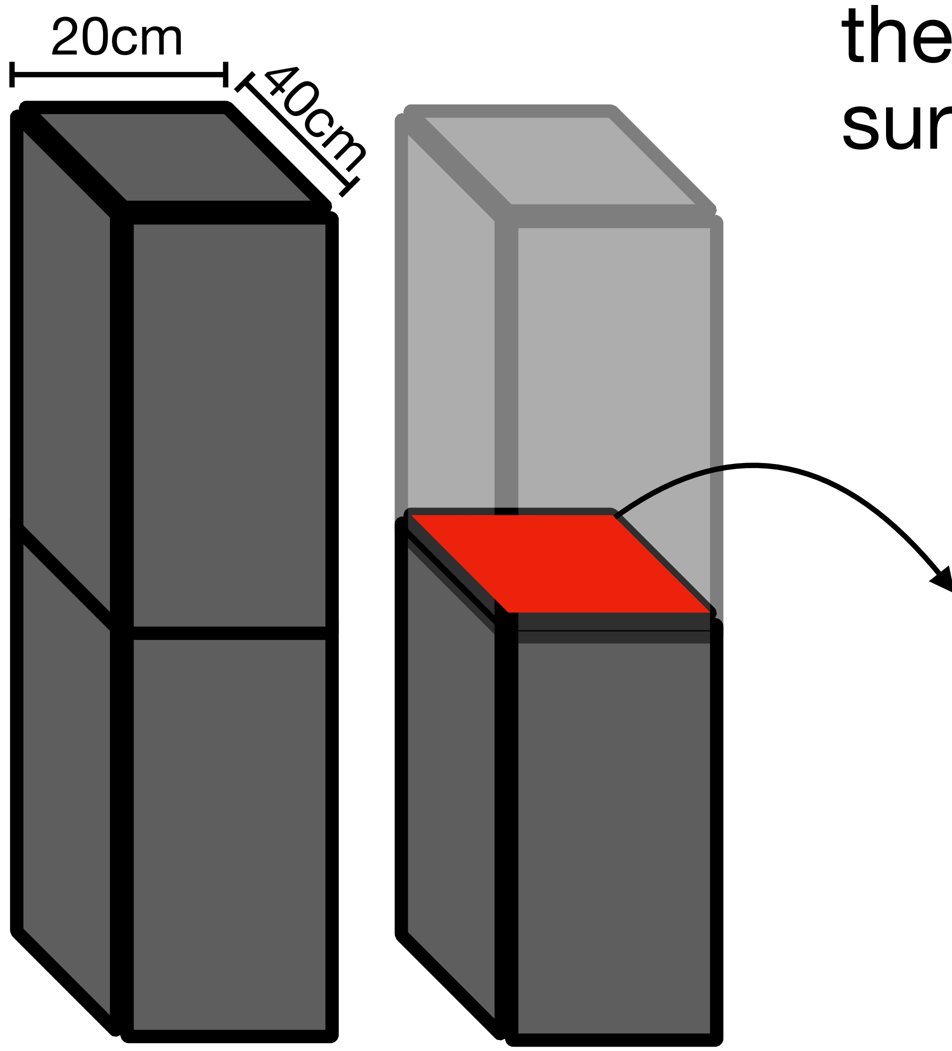
Validation (Expertise's concrete)

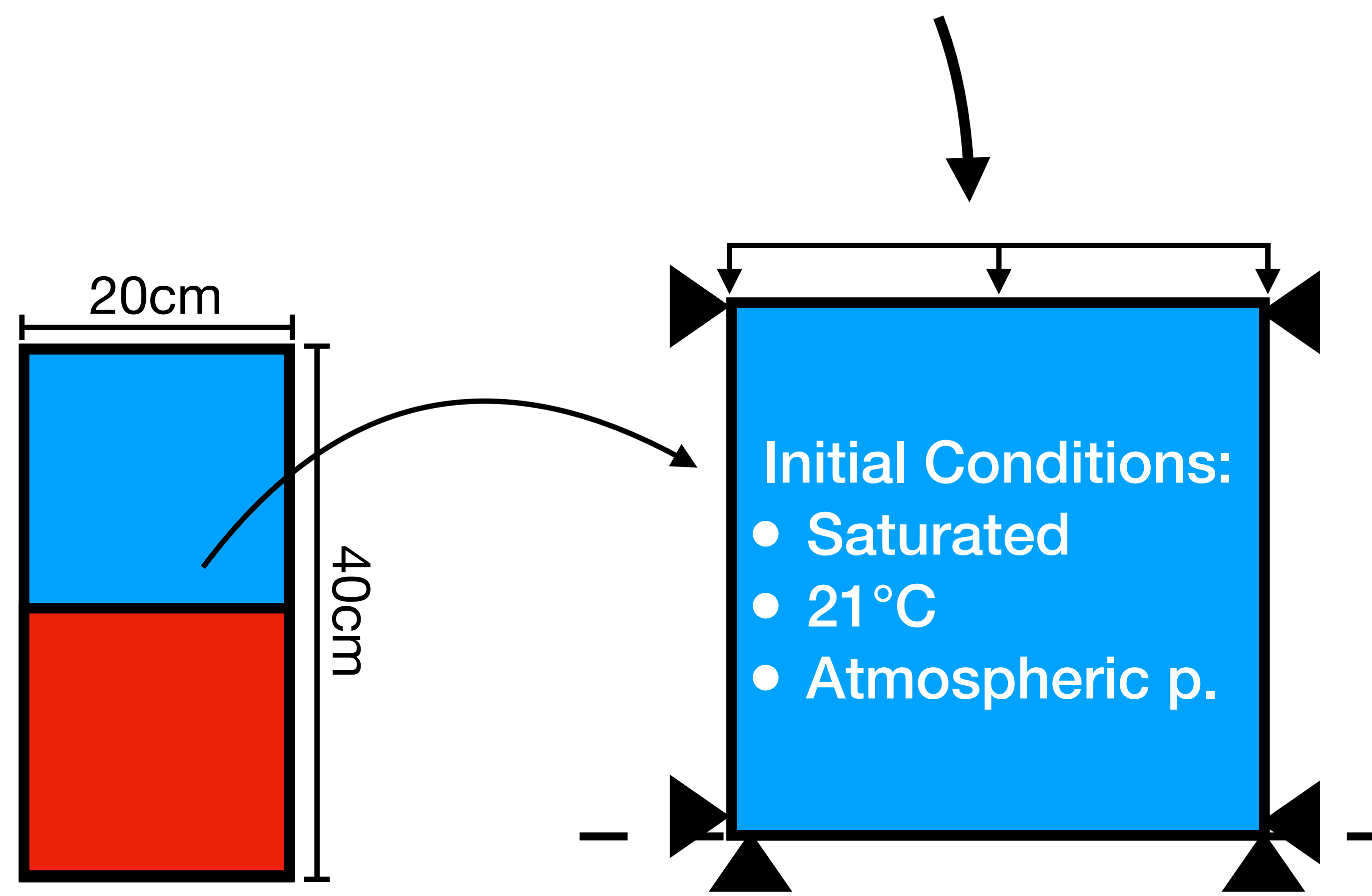


Application

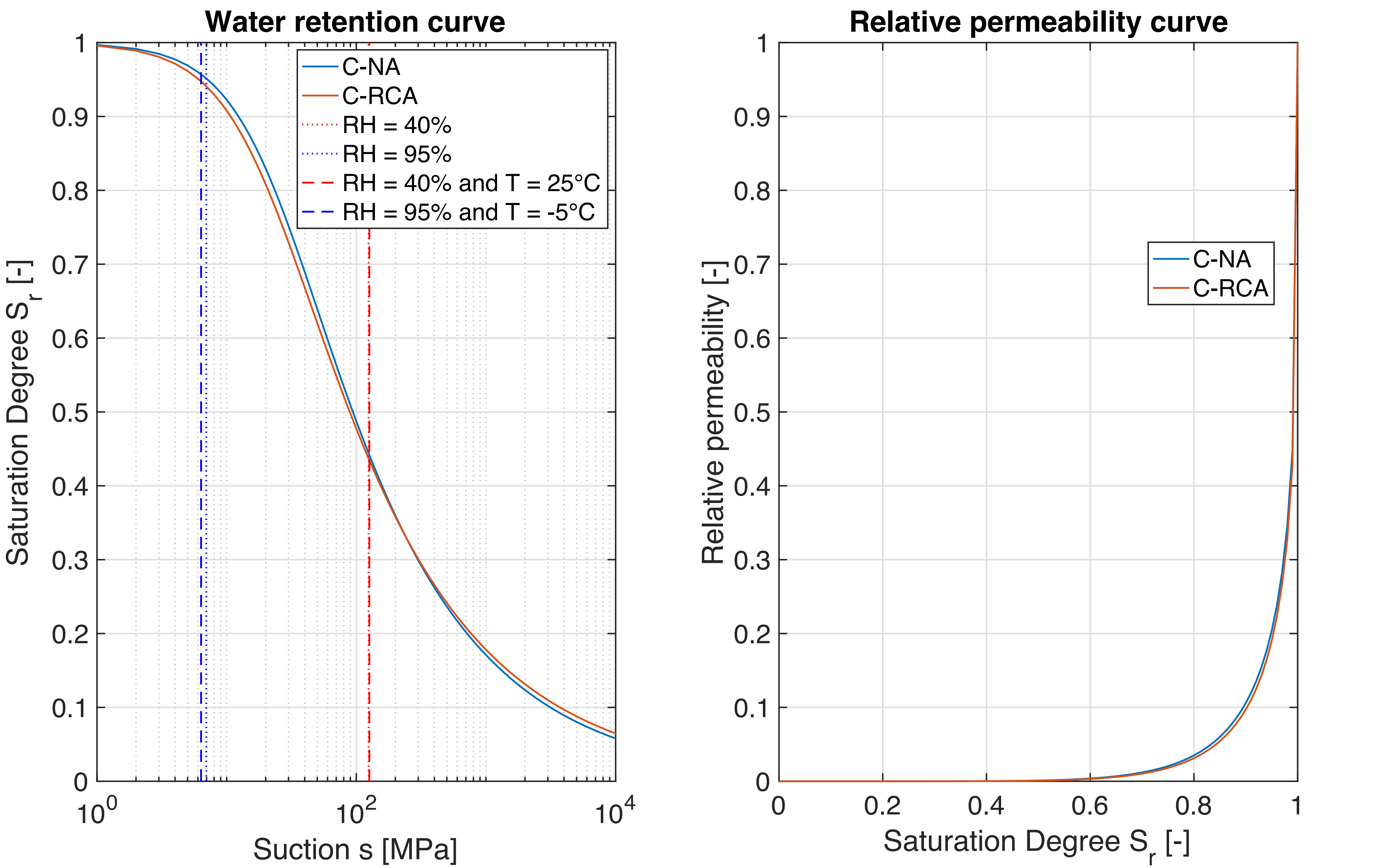
Mesh and applied conditions

FMIVP: Water flux depends on the RH (p_c) and T° of the environment as well as on the ≠ of densities between the vapour of the drying air and the vapour of the drying surface

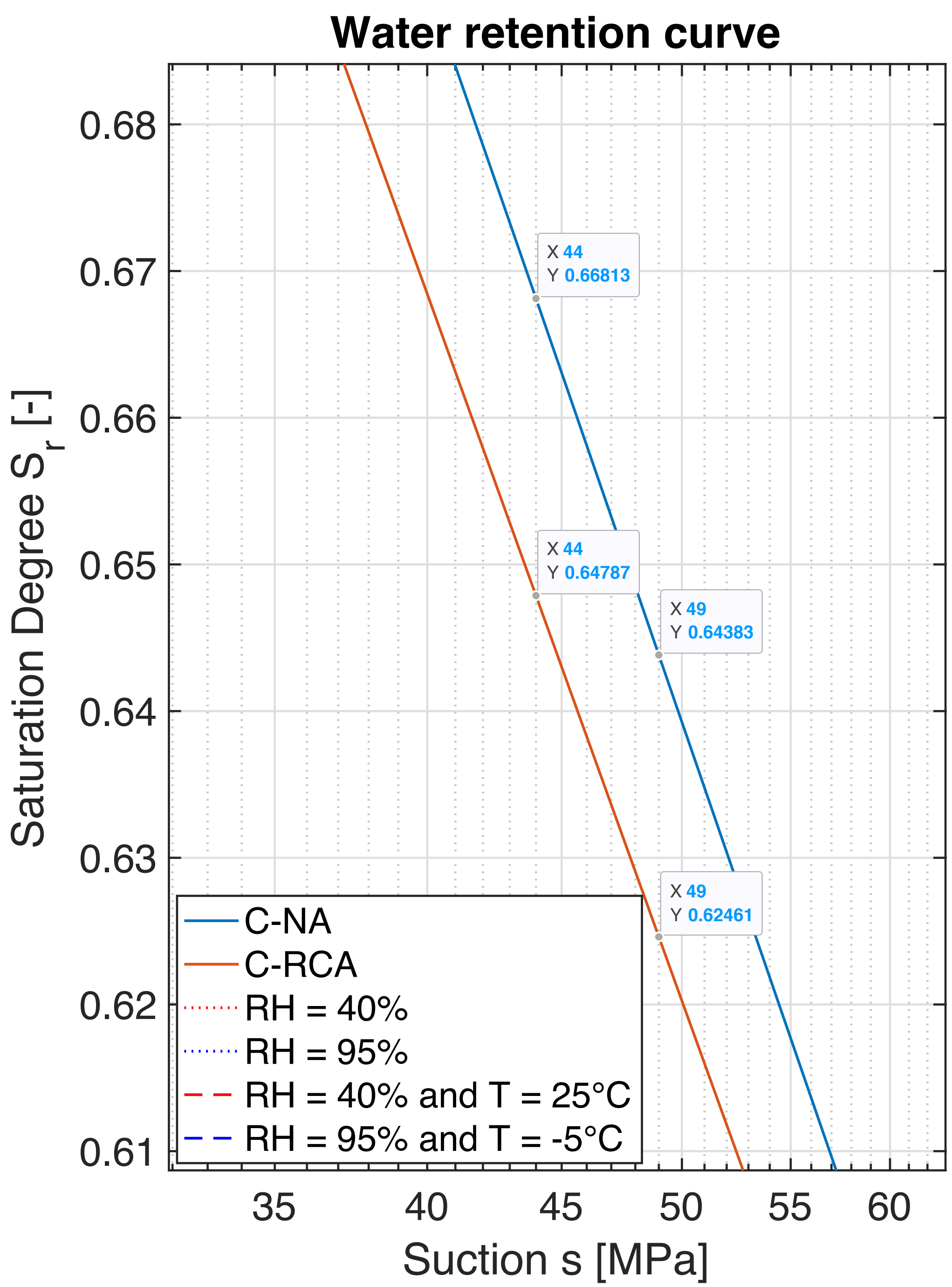


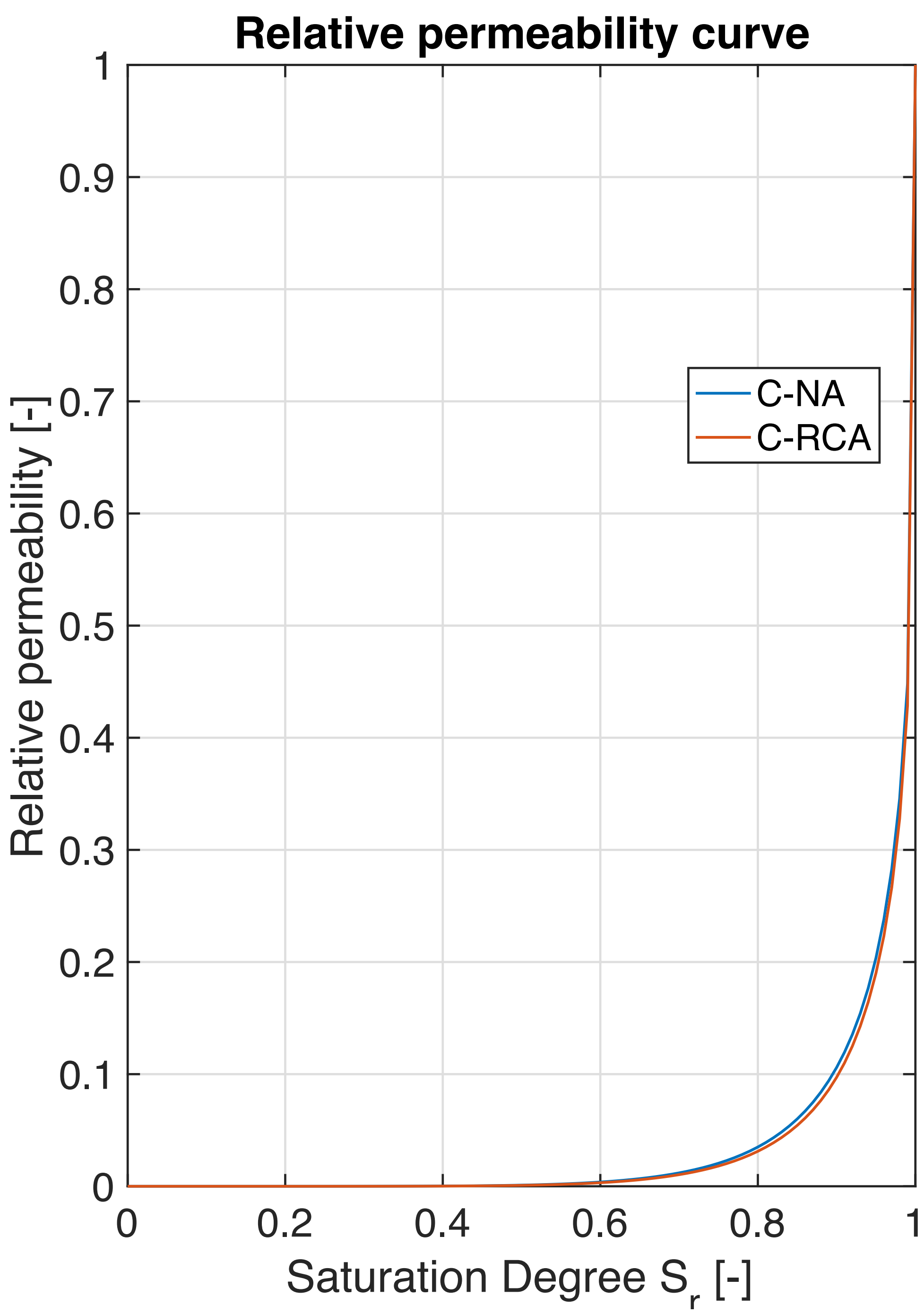


Application
Water Retention Curve



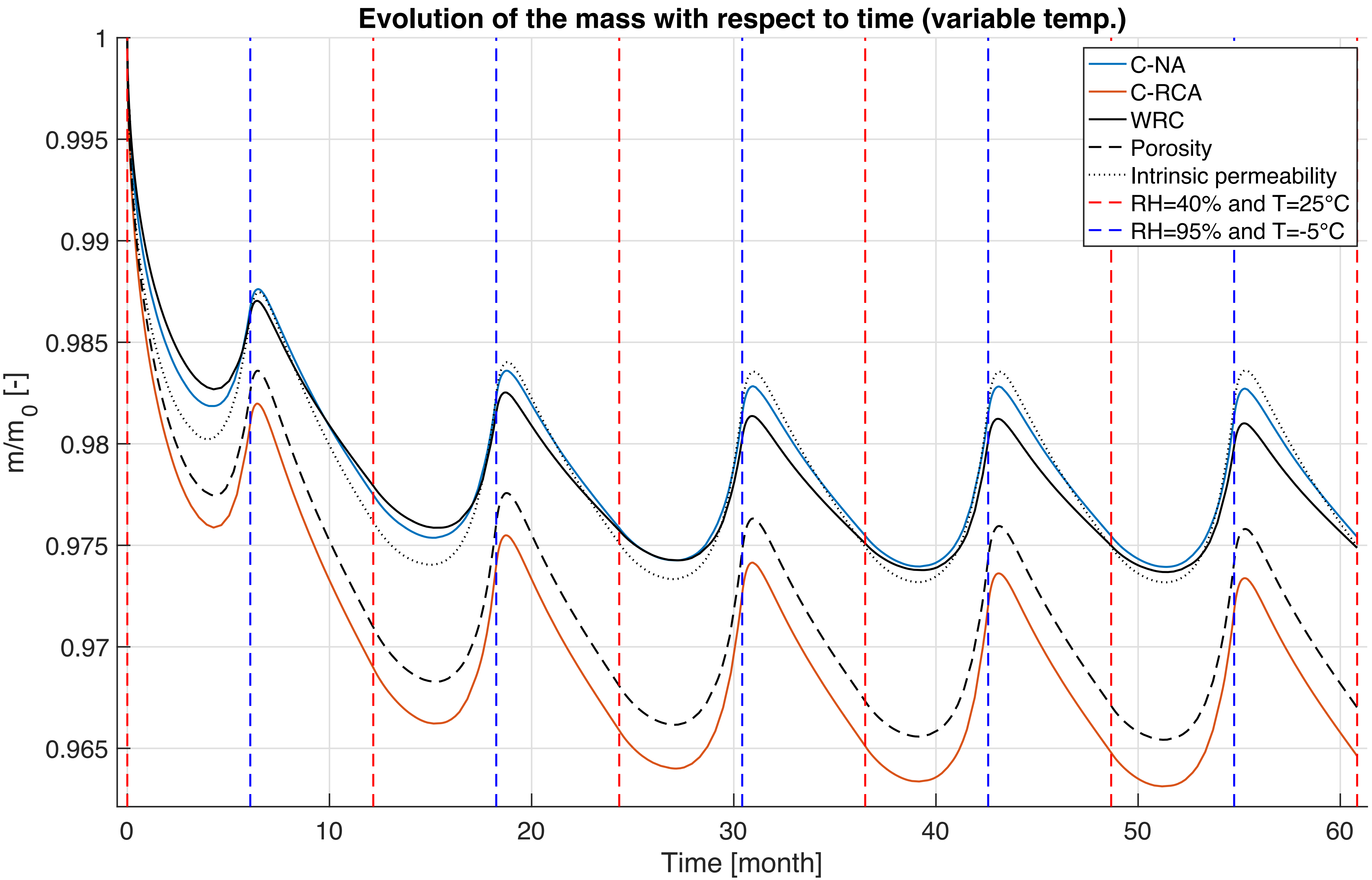
Application
Results





Application

Results



Application
Results