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Effective moisture diffusivity determination in food products of varying moisture sorption properties

Elisabeth ROCA, B. BROYART, V. GUILLARD, N. GONTARD, S. GUILBERT

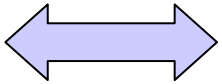
Join Research Unit IATE, Agropolymer Engineering and Emerging Technologies, University Montpellier II - Agro.M / INRA, Montpellier, France

Join Research Unit GENIAL, ENSIA-INAPG / Cemagref / INRA, Massy, France

Determination of effective moisture diffusivity (Deff) in food products

Experimental moisture kinetics

Average moisture contents
Local moisture contents



Data processing

Specific assumptions for the model can be made

$$\frac{\partial X}{\partial t} = D_{eff}\left(\frac{\partial^2 X}{\partial x^2}\right)$$

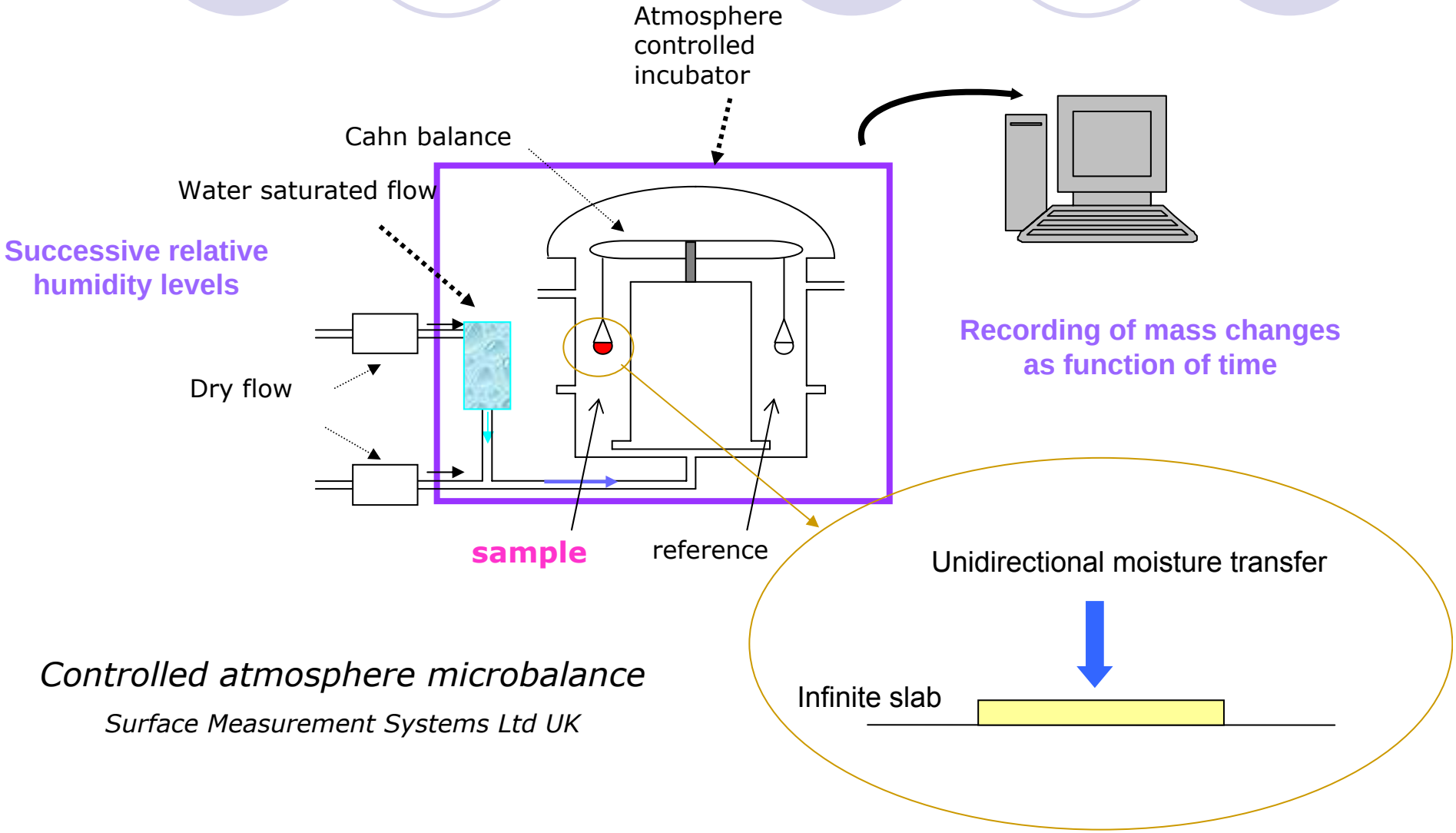
Fick's Second law

Simplifying assumptions:	Complex assumptions:
Unidirectional transfer	Multidirectional transfer
Simple geometries	Δ Diffusivity
No deformation of the matrix	Δ Volume
Negligible external resistance	Resistance at the interface
Analytical solution	**Numerical solution**

Which method coincides better with specific food products for Deff determination using moisture adsorption kinetics?

Methodology

Experimental moisture sorption kinetics were analyzed



Controlled atmosphere microbalance

Surface Measurement Systems Ltd UK

3 Models were compared for Deff estimation

Models written in Matlab® language of technical computing (The Mathworks Inc, Natick, Mass, U.S.A.)

Analytical resolution

1

~~External resistance Deformation~~

Instantaneous equilibrium of surface water activity with the relative humidity of the surrounding atmosphere

Evolution of moisture content as a function of time:

$$\frac{X - X_0}{X_\infty - X_0} = 1 - \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2 \pi^2} \exp\left\{ - \frac{D_{eff} (2n+1)^2 \pi^2 t}{4L^2} \right\}$$

3 Models were compared for Deff estimation

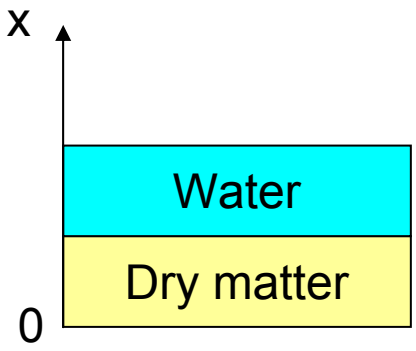
Analytical resolution

External resistance
Deformation

Numerical resolution

2

External resistance
Deformation



Additivity of partial volumes of water and dry matter

Lagrangian coordinates related
to the dry matter

3 Models were compared for Deff estimation

Analytical resolution

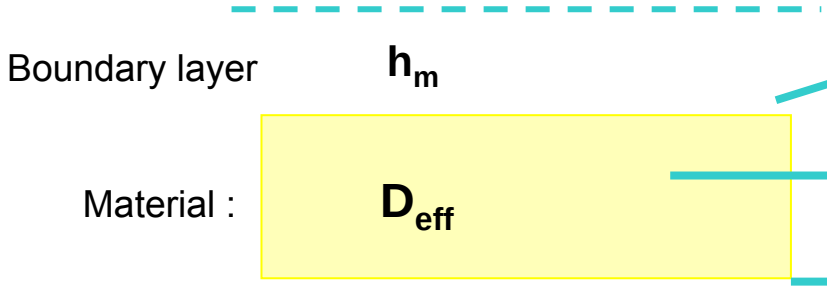
~~Mass transfer resistance~~
~~Change of volume~~

Numerical resolution

3

External resistance
Deformation

~~Mass transfer resistance~~
~~Deformation~~



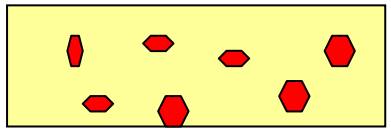
$$-\rho D_{eff}\left(\frac{\partial X}{\partial x}\right)=\frac{h_m P_{Vsat} M}{RT}\left(aw_{surface}-\frac{RH}{100}\right)$$

$$\frac{\partial X}{\partial t}=D_{eff}\left(\frac{\partial^2 X}{\partial x^2}\right)$$

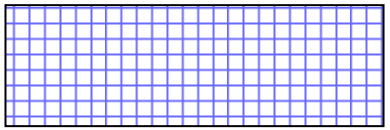
$$-D_{eff}\left(\frac{\partial X}{\partial x}\right)=0$$

4 types of food materials were investigated

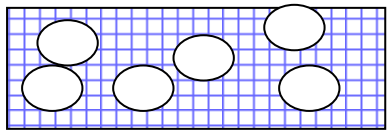
Hydrophobic dense matrix
lipidic edible film



Solutes dispersion in an hydrophobic dense matrix
dark chocolate



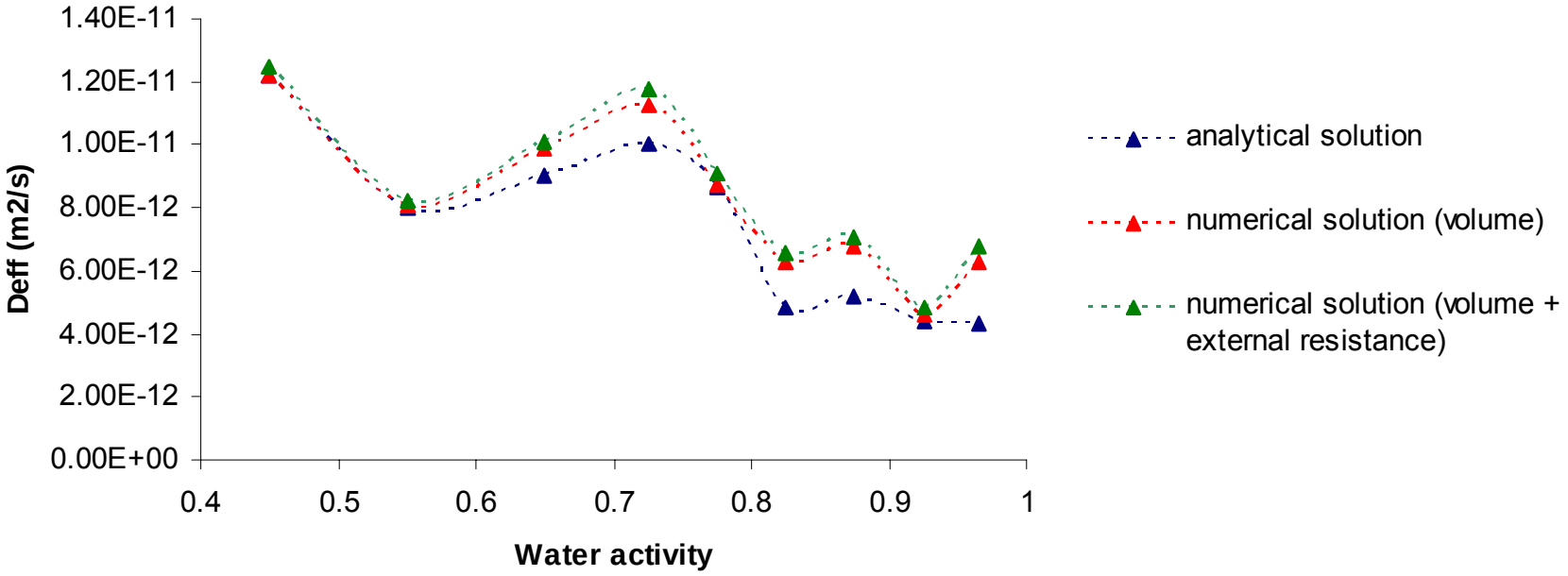
Dense matrix of protein network
wheat gluten film



Porous matrix of protein network
sponge cake

Determination of Deff

Estimation of Deff within lipidic edible film



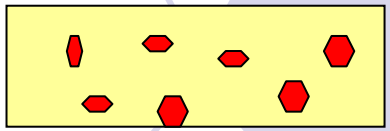
Deformation V

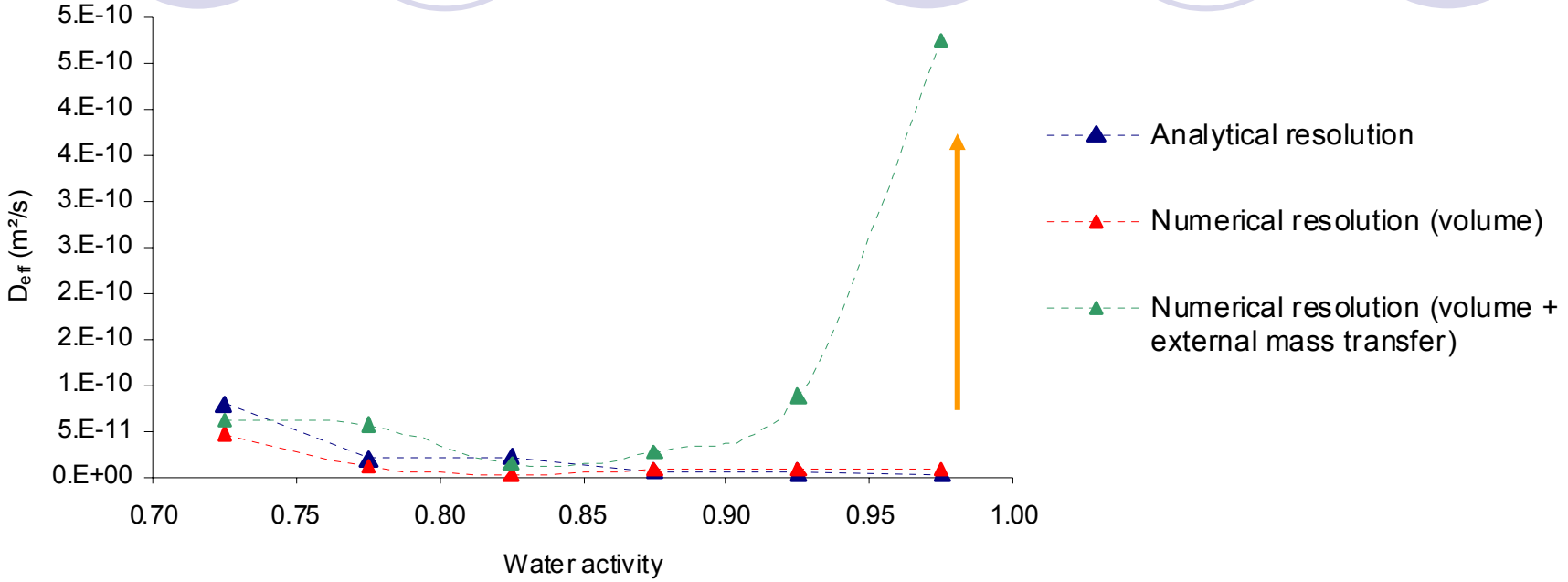
Negligible swelling of the matrix

External mass transfer hm

No significant difference of Deff values by taking into account the external resistance to mass transfer

Estimation of Deff within dark chocolate





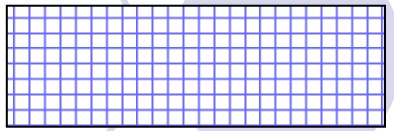
Deformation V

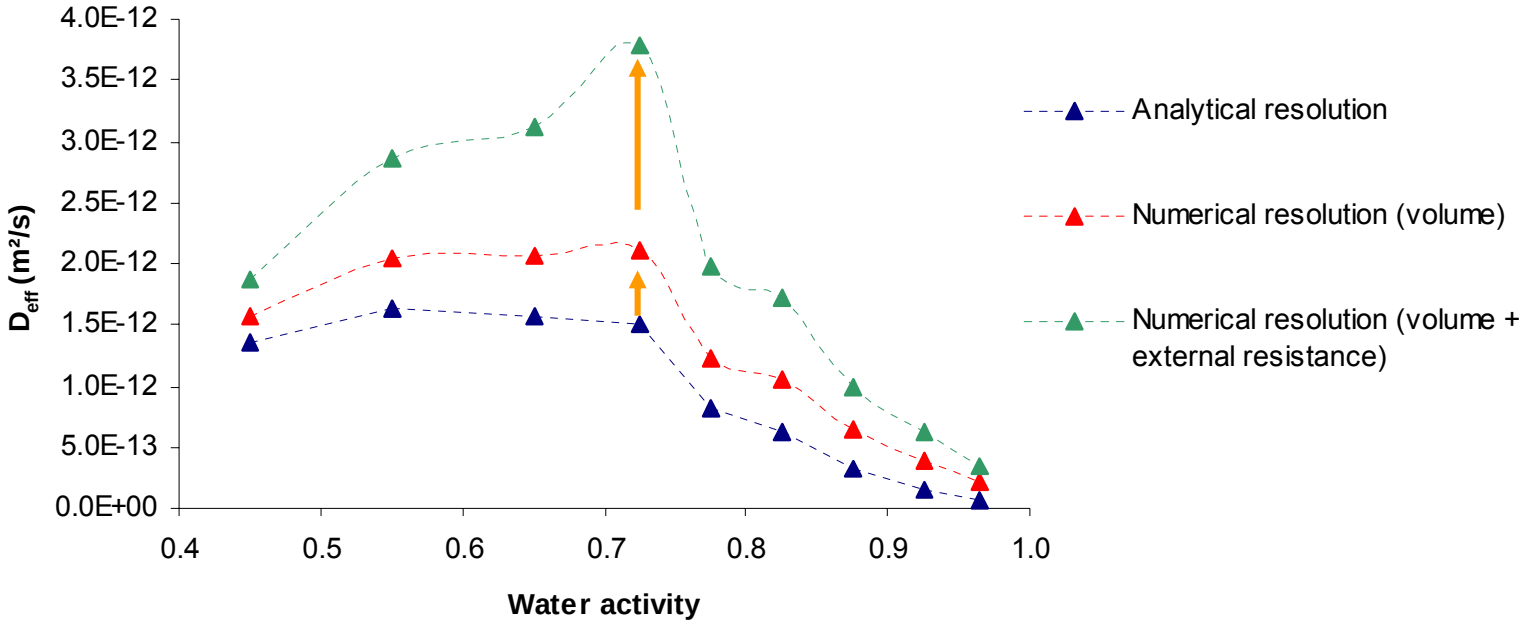
Impact of the deformation assumption only for aw higher than 0.85

External mass transfer hm

Important under-estimation of Deff with the analytical solution for aw higher than 0.85

Estimation of Deff within wheat gluten film





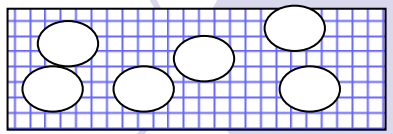
Deformation V

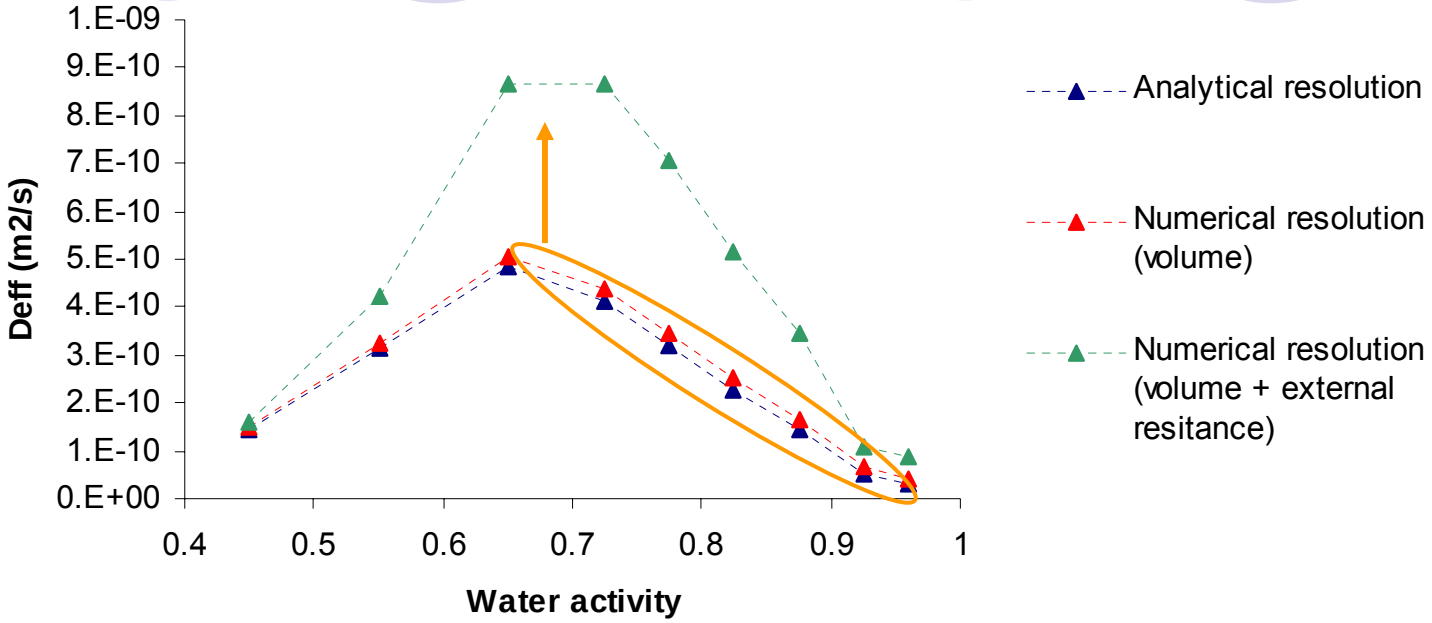
Under-estimation of Deff with the analytical solution : the thickness is continuously under-estimated

External mass transfer hm

Under-estimation of Deff when the external resistance is neglected => Deff accounts both for external and internal mass transfer resistance

Estimation of Deff within sponge cake





Deformation V

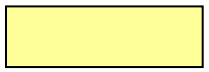
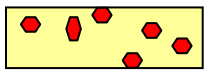
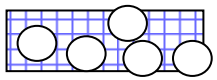
Very slight effect of taking into account the deformation of the solid matrix

External mass transfer hm

Important under-estimation of Deff with the analytical resolution

Not the same effect depending on products !

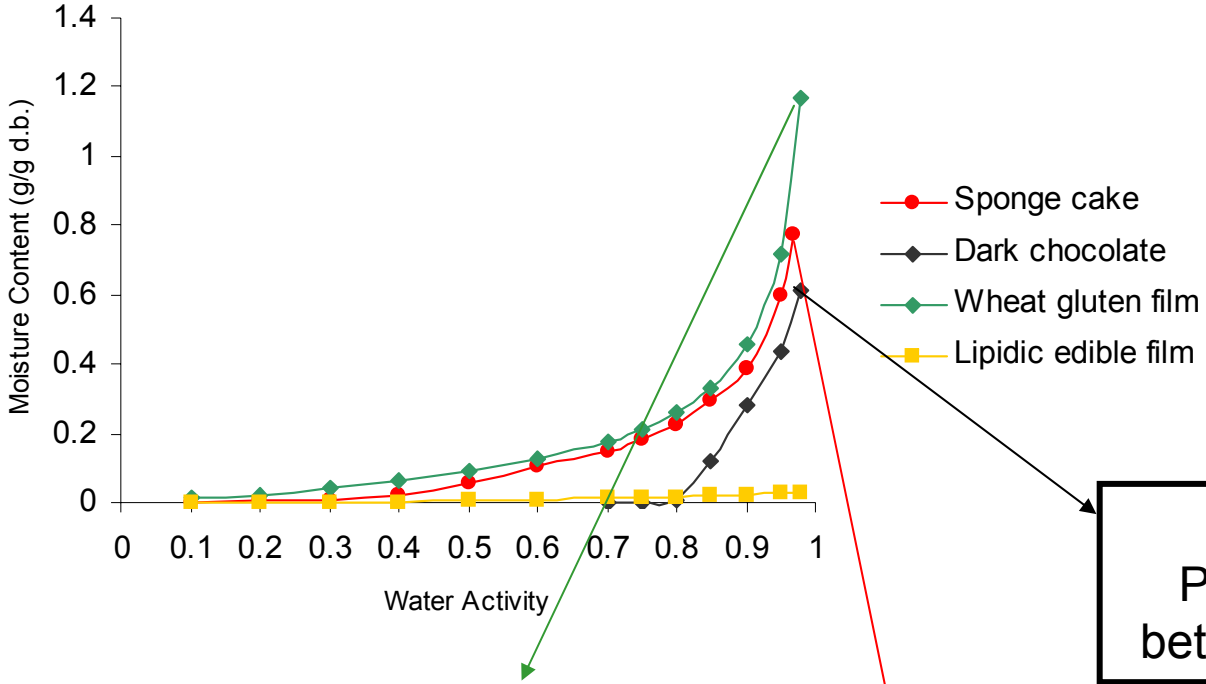
Differences of calculated Deff values according to the model assumptions

	Taking into consideration:	*Deformation*	*External resistance*
Hydrophobic material	Hydrophobic dense material 	10%	4%
Hydrophobic material	Solute dispersion in an hydrophobic matrix 	**30%**	**270%**
Hydrophilic material	Hydrophilic dense material 	**40%**	50%
Hydrophilic material	Hydrophilic porous material 	7%	**80%**

Related to their moisture sorption properties

When considering the deformation?

- **Deformation:** addition of the volume of adsorbed water



Chocolate
Partial distribution of moisture between sugars and cocoa solids

Wheat gluten

Sponge cake: low density
⇒ Little swelling

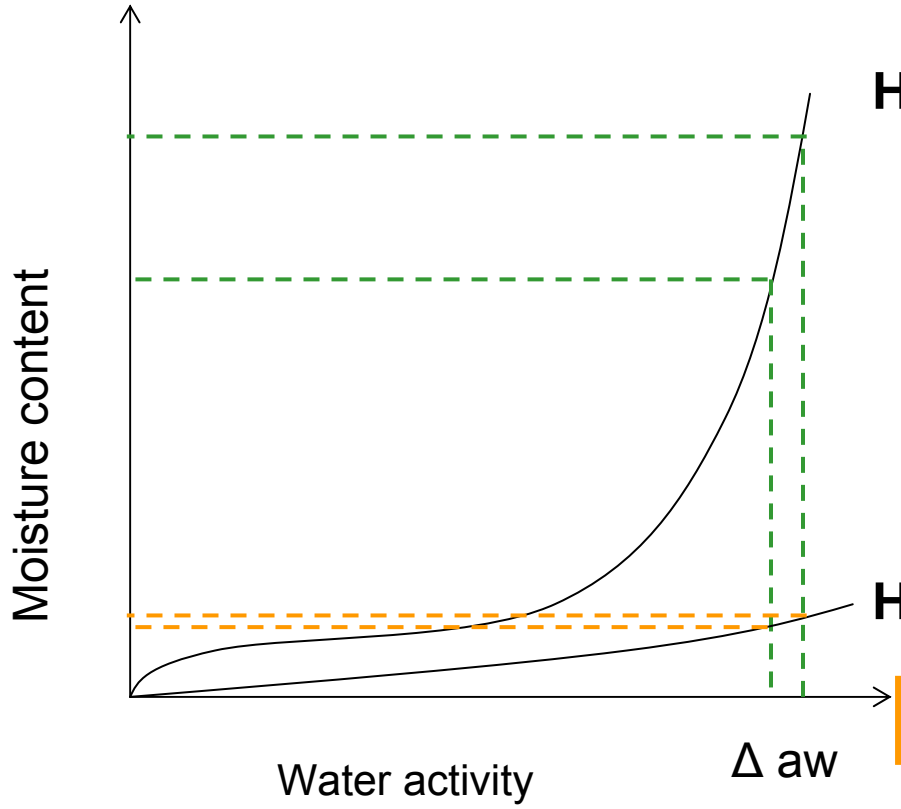
When considering the external resistance ?

Assumptions at the interface of the product with air

Analytical solution	*Numerical solution*
aw surface = RH/100 ↕ Surface moisture content = constant	$h_m \left(aw_{surface} - \frac{RH}{100} \right)$ Surface moisture content is function of time
Approximation of a constant surface aw	**Estimation of the surface aw at anytime**

When considering the external resistance ?

External mass transfer coefficient ⇔ Slope of moisture sorption isotherm



Hydrophilic material

Chocolate: dissolution of sucrose for aw higher than 0.8

Hydrophobic material

Lipidic edible layer

Conclusion of the study

- Analytical solution is acceptable for hydrophobic products without deformation

- Numerical solution is required
  - For food products with deformation
  - When the external resistance to mass transfer is not negligible:
    - Air velocity almost zero
    - Sharp slope of the moisture sorption isotherm