MATHEMATICAL MODEL OF VACUUM FOAM DRYING

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Introduction

The presented mathematical model relates closely to the development of a vacuum drying method for highly viscous, sticky and heat and oxygen sensitive materials. The dried materials are closed-pore foams.

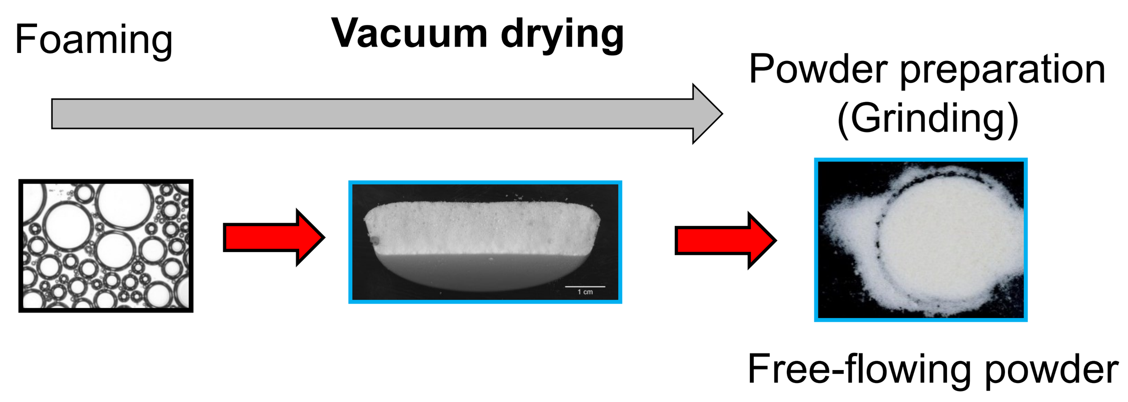

Figure 1: Process flow vacuum foam drying

The model objectives were to predict local and time dependent temperature and moisture distribution during drying.

Computational Methods

The model is considering foam layer as a repetition of unit cells. The unit cell geometry (fig.1) i.e. the air bubble size *A* and the lamellae thickness *B* are characterizing foam microstructure. The unit cubic cell consists of air and liquid domains, which were approximated by square geometries for simplification. The relationship of air volume fraction ϕ and bubble size/lamellae thickness ratio is given in fig 2. *A/B*-ratio

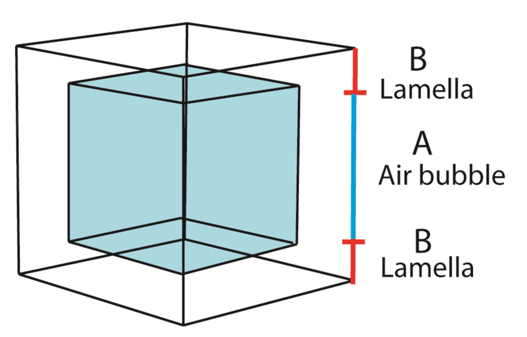

Figure 2. Unit cubic cell

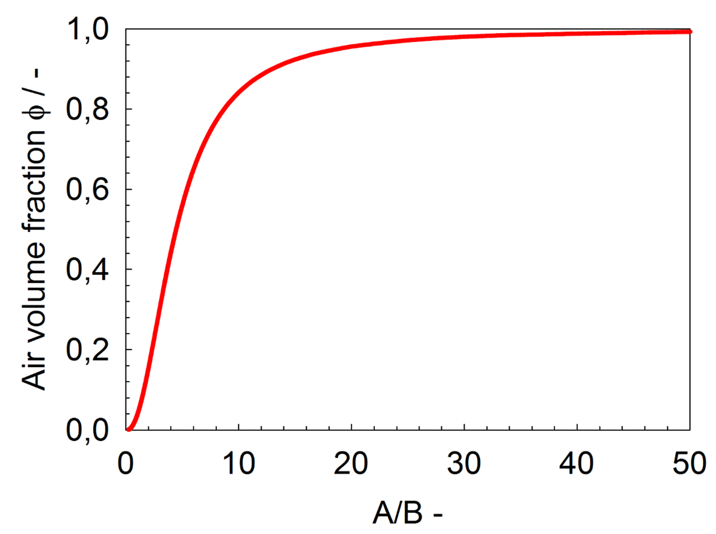

Figure 3. Foam air volume fraction vs. Bubble size / Lamellae thickness ratio A/B

The vacuum foam drying process was modelled in a simultaneous heat and mass transfer. As governing equations Fick law and Fourier law were used. The simulation was solved in a 2D coordinate system.

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (\lambda \nabla T) \qquad \frac{\partial w}{\partial t} = \nabla \cdot (D \nabla c)$$

Basic assumptions

The heat transfer is conducted majorly by conduction in foam lamellae and less by evaporation/condensation of vapor in air bubbles. The mass transfer is conducted majorly by vapor diffusion which is driven by vapor partial pressure difference. The partial pressure gradient arises by spatial temperature difference.

The detailed heat and mass balance and model set-up is given in figure 4 and 5.

Table of main used parameters

Process parameters	Value
Heat transfer coefficient λ	50 [W/(m*K)]
Mass transfer coefficient β	0.0001 [m/s]
Initial temperature T_0	323 [K]
Absolute pressure	100 [mbar]
Layer thickness	10 [mm]

Liquid physical properties	Value
Heat capacity cp	3000 [J/(kg*K)]
Density ρ	1170 [kg/m³]
Thermal conductivity λ	0.5 [W/(m*K)]
Initial water concentration w_0	20000 [mol/m³]
Diffusion coefficient Dl	$1*10^{-10}$ [m²/s]
Vapor physical properties	
Diffusion coefficient Dv	$1*10^{-4}$ [m²/s]
Enthalpy of evaporation dH	40000 J/mol
Initial vapor concentration cv0	2800 [Pa]

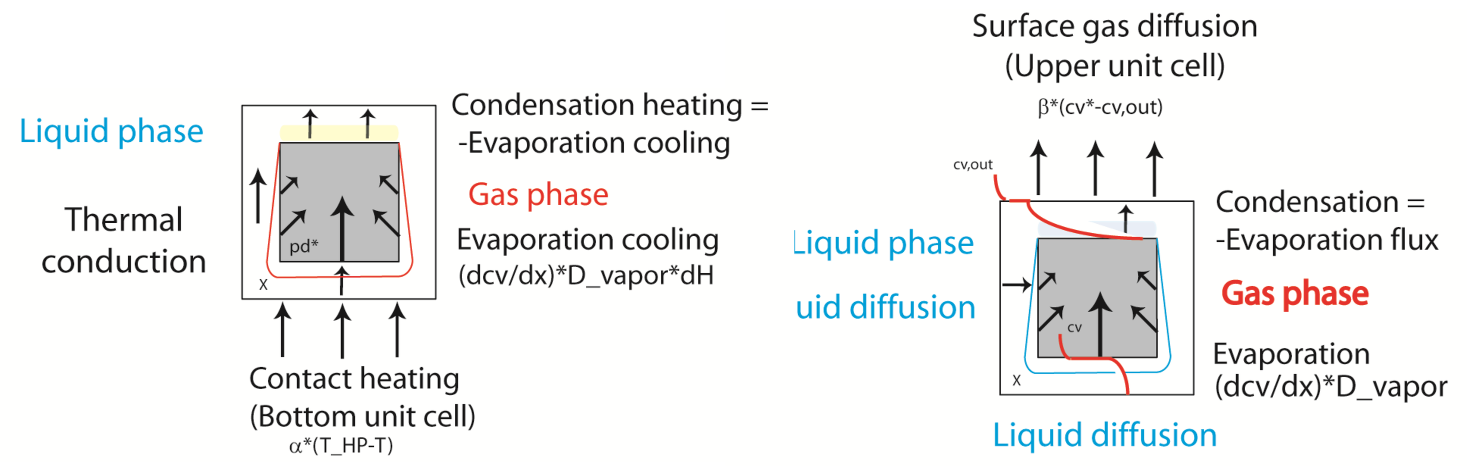

Figure 4. Scheme of heat and mass transfer in unit cell

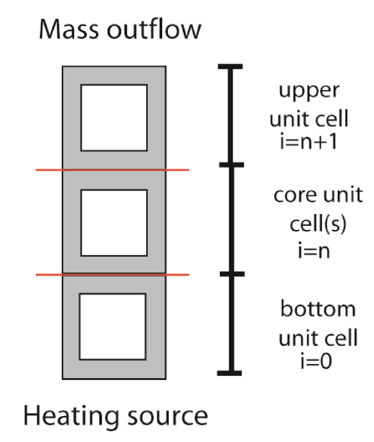

Figure 5. Schematic of multilayer cubic unit cell

Results

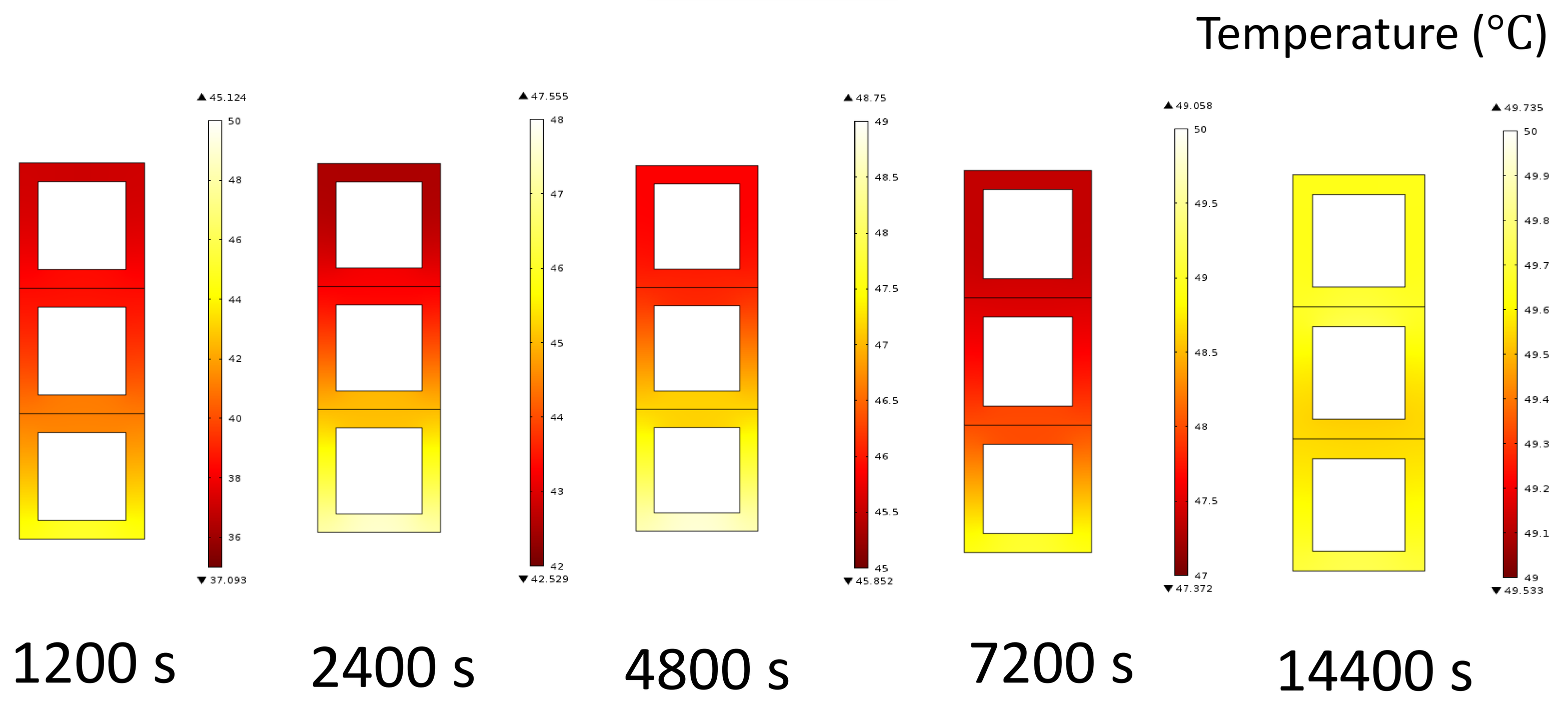

Figure 6: Simulation of heat transfer in 3 layer system

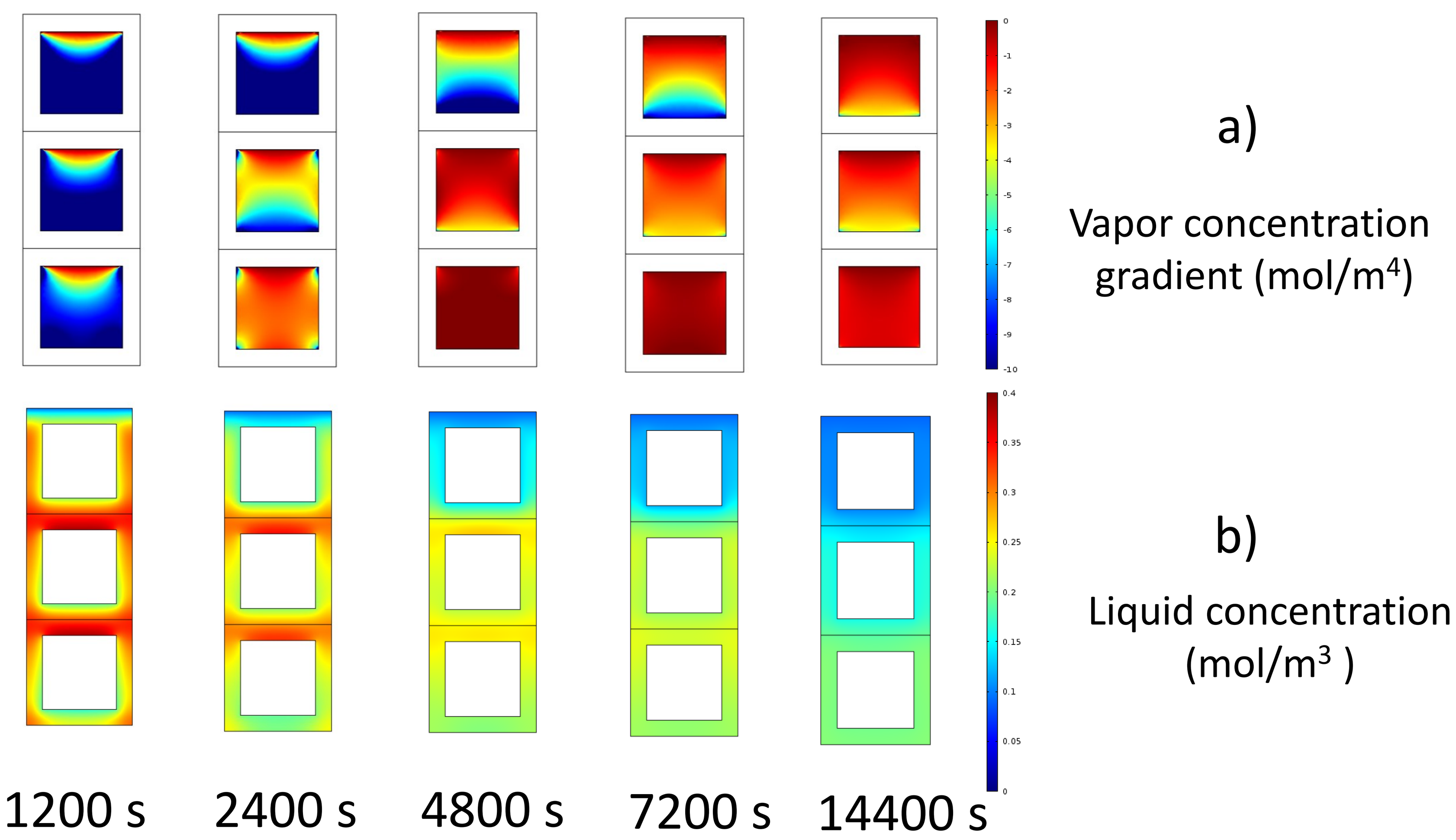

Figure 7: Simulation of mass transfer in 3 layer system: a)development of vapor concentration gradient during drying, b)mass transfer in foam lamellae

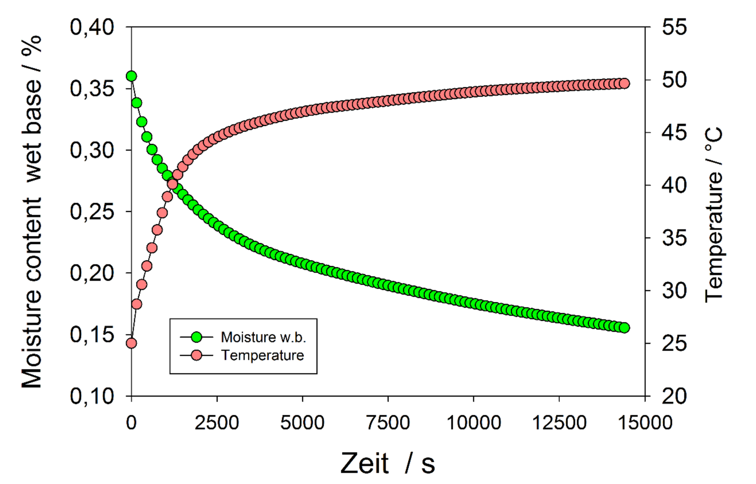

Figure 8: Simulated drying curve with average temperature profile

Conclusions

- The model provides in simplified form insights to the drying process within a foam microstructure.
- The model allows to estimate discrete heat and mass fluxes during drying in individual unit cell. In each cell conduction, water diffusion, vapor evaporation, condensation can be tracked.
- The model allows a distinction in drying mechanism of foam and non-foamed liquid.

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