Neutron imaging for the investigation of the lyophilisation of amorphous bulk solids

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Motivation
Lyophilisation as gentle dehydration technique for pharmaceuticals and foods (e.g. vaccines)
Lyophilisation of bulk solids is not yet fully understood (Fig. 2)
Sublimation front structure is an important process indicator (Fig. 2)

Aim: Quantitative evaluation of local ice content

Experimental Setup
Instrument Antares, L/D = 800
LiF:ZnS Scintillators 50 / 100 µm
Test material: Maltodextrin DE 12
Particle sizes 70 µm / 3500 µm
Particles frozen in liquid N
Solid concentrations 0.05 and 0.2 w/w
Small particles: radiography
Large particles: continuous tomographies

Sample environment
Newly designed sample stick with better insulation / heat conductivity and heater (Fig. 1)
Chamber pressure: 10 Pa
Shelf temperature: -18 °C
Sample stick heater temperature: 0 °C / -20 °C
Cryostat (chamber walls) temperature: -42 °C

Image analysis
Dark field (DF), Open Beam (OB) and gamma spot correction
Grey values:

\[ T = \frac{IM - DF}{OB - DF} \]

\[ T' = \frac{T(t)}{T(t_0)} \]

Definition of sublimation front:
Evaluation of 1st derivative of averaged grey values \( T' \)

Results from the radiography
Position of sublimation fronts for small particles
Sublimation front observed at bottom and top
Particles with higher solid concentration dry faster
Behaviour in contrast to existing models in literature and in contrast to frozen solutions
Possible explanation lies in intercorrelation between heat conductivity and sublimation front position (large difference in heat conductivity of dry and frozen particles)

Results from the tomography
Continuous tomography during drying cycle (43 tomographies)
Multiple sublimation fronts occur in large particles
Sublimation front structure depends on distance from heating shelf

Publications
Gruber et al. (2020), CES https://doi.org/10.1016/j.ces.2019.115268
Foerst et al. (2020), CET 10.1002/ceat.201900500