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Commentary

Micro Computed X-ray Tomography and its Significance in Forecasting Structure Transport Correlations

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DESCRIPTION

Drying typically requires a lot of energy. This is explained by both the slow kinetics of heat and water vapour transfer as well as the large phase transition enthalpy of water alone. Long drying durations and an increase in energy consumption are typical outcomes of the limiting of transport kinetics. Additionally, lyophilization, also known as freeze-drying, is carried out at low temperatures and pressure, which further compromises drying kinetics and raises energy usage. The procedure is sped up by raising the temperature in the freeze-dryer. However, it also raises the possibility of the material suffering structural harm.

As a result, substantial safety margins are frequently used to ensure consistent product quality. If the dynamics of the freeze-drying conditions can be improved, better processing condition control is anticipated. The relationship between heat and mass transfer kinetics and the material's porous structure is one modern method. This is particularly important for materials having a Pore Size Distribution (PSD), where the distribution of the ice and solid content is irregular. Local heat transmission in this instance varies in line with structural variation. Additionally, the vapour transfer *via* dry pores is impacted by the different pore diameters. Mass transfer resistances are typically lower for bigger holes than for smaller ones. The formation of the sublimation front, which spreads more quickly in larger pores, might be impacted by the heterogeneity of transport conditions resulting from scattered pore space. A structured sublimation front, a phenomenon like that described in, is the end consequence. Determining pore shapes that are conducive to heat and mass transfer required a thorough investigation of the freezing process, or the formation of the solid matrix.

With great contrast between the propagating dry pores, solids, and ice, in operando imaging techniques can be used to analyse the dynamic temporal evolution of the sublimation front. Pore scale models can evaluate the kinetics of mass and heat transfer at the front at the same time. With the exception of our own research, pore network models have not yet been widely used to analyze freeze-drying. Pore network models are a frequent tool for studying drying processes in porous media. These models can be created using data that is realistic for the porous material, such as data from micro-Computed X-ray Tomography (-CT), and they can therefore forecast intriguing structure-transport correlations.

Using in operando studies with neutron imaging methods and μ-CT, freeze-drying kinetics rely on pore structure based on the comprehensive view of the sublimation front propagating inside frozen maltodextrin solutions. Neutron imaging offers a similarly low local resolution despite offering a good contrast between water-ice, solid maltodextrin, and pores. For this reason, μ-CT is used to get extra important information regarding the pore size distribution of the dried samples. μ-CT has a high resolution of up to 1 μm.

The maltodextrin samples under investigation were generated with various solid contents and annealings to produce various porous morphologies. Using a freeze-drying stage that allowed in operando neutron imaging throughout the procedure, freeze-drying was carried out under constant circumstances. Tomography was used in addition to continuous radiography imaging to gather further information about the sublimation front's structure.

CONCLUSION

Radiographic images were utilized to calculate sublimation fluxes and freeze-drying kinetics, including the temporal evolution of the overall ice saturation. The structure of the sublimation front was qualitatively described. The main finding of the study is that both the solid content and annealing considerably altered the pore structure, which had a negative impact on the overall freeze-drying kinetics. According to the structural characteristics of the maltodextrin samples, several sublimation front structures were also seen, varying between roughly convex and concave shapes. The sublimation front clearly extended in each of the situations examined here without appearing to have any impact on the sublimation rates. Future research on the pore scale effects of freeze drying will build on this data.

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