Investigation of Electromagnetic Field Modulation via Solid State-Technology in Microwave-Assisted Freeze-Drying

GAUKEL V. (1), SICKERT T. (1)
1 Karlsruhe Institute of Technology, Institute of Process Engineering in Life Sciences, Food Process Engineering, Karlsruhe, Germany

Conventional freeze-drying (CFD) is a well-established and product-friendly drying process in the life science, food and pharmaceutical industries. Microwaves in microwave-assisted freeze-drying (MFD) enable shorter process times by a direct conversion of electromagnetic energy into heat inside the product, bypassing heat transport resistances in the insulating product matrix.

Challenges associated with microwaves in MFD are the inhomogeneous energy input into the material and a frequency-dependent energy efficiency. One approach to solve these problems is to modulate the electromagnetic field over the course of drying. A new generation of solid state-microwave generators (SMG) enables this concept. SMGs allow frequency, power and phase shift of the electromagnetic field to be adapted in the sub second range by electrical control. Frequency-based control concepts have already demonstrated more homogeneous microwave heating compared to operation at fixed frequencies. During FD, however, the product constantly changes from the frozen to the dried state, which changes the interactions of the material with the electromagnetic field due to the dielectric properties.

The resulting challenge is to explore the principles of a targeted control of the electromagnetic field in MFD depending on the progress of thermodynamically complex freeze-drying. The aim is to achieve an acceleration of drying, while the quality of the product remains comparable to that from CFD.

A frequency-based control concept, developed from electromagnetic simulations in CST Microwave Studio®, was applied to MFD in a lab-scale plant. The control concept is based on the repeated search and targeted excitation of multiple energy-efficient frequencies in the ISM band 2.4-2.5 GHz. The process and product parameters were classified with respect to CFD and MFD processes with alternative control concepts. Tylose gel was used as a chunky model food.

MFD combined with the developed control concept turned out to be advantageous taking into account energy efficiency, drying time and homogeneity as well as structure retention. The ingredient retention was comparable. Furthermore MFD was able to generate products with similar or even lower residual moisture contents in comparison with CFD. Therefore, the targeted modulation of microwaves presents an approach for optimization of the already highly promising MFD process.