A Three Dimensional (3D) Thermo-Hydro-Mechanical Model for Microwave Drying

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Abstract

Microwave drying of fruits and vegetables has been found to be more effective than conventional drying resulting in a better quality product having better rehydration capabilities, higher porosity and minimal case hardening effects. Microwave drying of foodstuffs is a complex interplay of mass, momentum and energy transport coupled with large deformation of the solid. To be able to better understand the microwave drying process, a fundamentals-based three dimensional (3D) multiphase porous media based model is developed to simulate the drying process. Microwave drying of a potato cube in a domestic microwave oven operating at 10% power level is taken as an example. Maxwell's equations for electromagnetics are solved inside the oven cavity to obtain the electric field distribution inside the potato. For transport modeling, three phases are considered in the system: solid (skeleton), liquid (water) and gas (water vapor and air). Modes of transport include capillary flow binary diffusion between vapor and air and gas pressure driven flow. Evaporation of liquid water to vapor is modeled assuming non-equilibrium between water and water vapor. Shrinkage effects have been included as part of the modeling framework by treating the solid matrix as hyperelastic.

A 3-D geometry of the oven cavity was constructed in COMSOL Multiphysics® software. Electric fields distribution inside the microwave cavity was obtained using the RF Module. Concentration of different species were solved for using the Transport of Dilute Species interface (for liquid water) and Maxwell-Stefan Diffusion model (for vapor and air) together with Darcy Law (to calculate Gas Pressure). Temperature of different species was obtained by solving one Heat Transfer equation assuming thermal equilibrium between different phases. Shrinkage and solid displacements were obtained using the Hyperelastic Material model in the Structural Mechanics Module.

An elaborate experimental system comprising of infrared camera, optical fiber probe and digital balance was built to measure key process parameters such as surface temperature profiles, point temperature data, average moisture content and dimension changes of the potato sample at different times during the drying process.

The model developed above was validated by comparing temperature and moisture histories and good agreement was found between experimental data and predicted values. A mechanistic approach to understanding microwave drying of foodstuffs is developed that could aid in predicting key quality attributes associated with microwave drying.