Three-Dimensional (3D) Modeling of Heat and Mass Transfer During Microwave Drying of Potatoes

H. Zhu[1], T. Gulati[2], A. K. Datta[2], K. Huang[1]

[1]Institute of Applied Electromagnetics, Sichuan University, Chengdu, China
[2]Department of Biological and Environment Engineering, Cornell University, Ithaca, NY, USA

Abstract

Introduction: Microwave drying of fruits and vegetables in a domestic oven has been found to result in large textural changes in the product such as puffing, crack formation and even burning due to the inhomogeneous heating of the microwaves. Moreover, microwave drying characteristics are different for different sizes and shapes of the same product, a thicker sample has been found to have a higher drying rate. Microwave drying of foodstuffs is a complex interplay of mass, momentum and energy transport. To be able to better understand the microwave drying process and address the problems encountered therewith, 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 is taken as an example. Three phases are considered in the system: solid (skeleton), liquid (water) and gas (water vapor and air). Modes of liquid water transport include capillary flow and gas pressure driven flow; transport in gas phase is due to diffusion and gas pressure. Evaporation of liquid water to vapor is assumed to be spatially distributed and is modeled assuming non-equilibrium between water and water vapor. Shrinkage effects have been ignored.

Use of COMSOL Multiphysics®: A 3-D geometry of the domestic oven with a potato cube inside was constructed in COMSOL Multiphysics® 4.3a. Concentration of different species was solved for using the Transport of Dilute Species module (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.

Results: 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 and average moisture content 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.

Conclusion: A mechanistic approach to understanding microwave drying of foodstuffs is developed to provide a better understanding of microwave drying and that could aid in predicting key quality attributes associated with the microwave drying process.