Modeling Flow and Deformation During Hot Air Puffing of Single Rice Kernels

T. Gulati[1], A. Datta[1]

[1]Cornell University, Ithaca, NY, USA

Abstract

Hot air puffing of biomaterials involves mass, momentum and energy transport along with large volumetric expansion of the porous material. Development of physics-based models that can describe heat and moisture transport, rapid evaporation and large deformations of the solid matrix is required to understand the factors affecting the puffing processes in order to avoid spending large amounts of time and effort in conducting experiments. In this study, a fundamentals based study of hand operated salt puffing process of a long grain milled parboiled rice were described by performing a two-way coupling of complex multiphase transport and large deformations of the solid matrix. A multiphase porous media model involving heat and mass transfer within the rice kernel was implemented using finite elements. The transport model involves different phases, solid, liquid (water), and gas (air and water vapor), and multiple modes of transport (capillary flow, binary diffusion, and pressure driven flow) along with rapid phase change inside the material. During puffing, intensive heating of the porous solid leads to rapid evaporation of liquid water to vapor, which is spatially distributed. As a consequence, large pressures are built within the material causing it to puff (Figure 1). For the present study, a 2-D axisymmetric geometry 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. Volumetric expansion and solid displacements were obtained by assuming the material as elasto-plastic in the Structural Mechanics Module. Experiments were conducted to validate the model and to determine the dependence of moisture diffusivity on rice temperature and instantaneous moisture content and vapor pressure. The slow motion shots from a high-speed camera were used to determine the expansion ratio and to visualize the puffing phenomena for a single rice kernel during the puffing process. The transport model developed in this study could successfully predict the final moisture content and expansion ratio of the rice kernel after the puffing process. Sensitivity analysis was carried with respect to the evaporation rate constant and intrinsic permeability of the solid matrix to the final expansion ratio of the rice kernels as a key quality parameter.

Figures used in the abstract

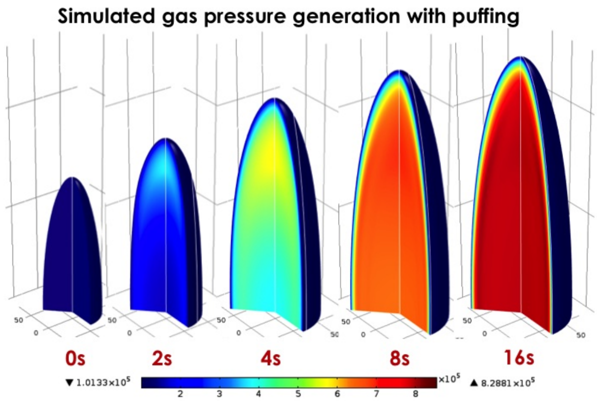

Figure 1: Simulated gas pressure generation with puffing.