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

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Introduction

- Microwave drying of fruits and vegetables 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.
- Microwave drying of potatoes is a complex interplay of mass, momentum and energy transport.
- Three phases are considered in the system: solid (skeleton), liquid (water) and gas (water vapor and air).
- 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).
- Microwave oven worked in 10% power level (Cycle Way). Shrinkage effects have been ignored.

Modeling Framework

Transport Model
- Conservation of energy
  - Bulk flow
  - Conduction
  - Phase change
- Conservation of mass
  - Water: bulk flow, capillary flow and vapor phase change
  - Gas (air, vapor): bulk flow phase change, binary diffusion
- Conservation of momentum
  - Darcy's flow

Electromagnetic Model
- Maxwell's Equations
  - Faraday's Law of Induction
  - Ampere's Law
  - Gauss Law for electricity
  - Gauss Law for magnetism
- Power Dissipation
  - Poynting Theorem

Governing Equations

Conservation of Mass

Water:

\[
\frac{\partial c_w}{\partial t} + \nabla \cdot (v_w c_w + c_w \nabla v_w) = \nabla \cdot \left( D_w \nabla c_w \right) - I
\]

Gas:

\[
\frac{\partial c_g}{\partial t} + \nabla \cdot (v_g c_g + c_g \nabla v_g) = I
\]

Vapor:

\[
\frac{\partial c_v}{\partial t} + \nabla \cdot (v_v c_v + c_v \nabla v_v) = \nabla \cdot \left( \phi_S c_v^2 \mu_S M_c D_{cg} \nabla c_g \right) + I
\]

Conservation of Energy

\[
\frac{\partial}{\partial t} \left( \sum_{i \neq j} \left(c_{ci} T_i \right) + \sum_{i \neq j} (v_i - v_j) \nabla (c_{ci} T_i) \right) + \sum_{i \neq j} \left[ c_{ci} T_i \nabla \cdot (v_j c_{ci} T_i) - c_{ci} T_i \nabla \cdot (v_j c_{ci} T_i) \right] = \nabla \cdot (k_{cg} \nabla T) - 2l
\]

Conservation of Momentum

Darcy’s Law:

\[
v_i - v_j = - k_{cg} \nabla P
\]

Maxwell’s Equation

Faraday’s Law of Induction:

\[
\nabla \times E = - \frac{1}{\mu_0} \frac{\partial B}{\partial t}
\]

Ampere’s Law:

\[
\nabla \times H = \frac{1}{\mu_0} \left( J + \sigma \frac{\partial E}{\partial t} \right)
\]

Gauss Law for electricity:

\[
\nabla \cdot E = \rho_f
\]

Gauss Law for magnetism:

\[
\nabla \cdot H = 0
\]

Power Dissipation

Poynting Theorem:

\[
P(x,t) = \frac{1}{2} \epsilon_0 \epsilon_r c^2 (E \cdot E^*)
\]

Geometry & COMSOL Implementation

Results

Conclusions

- A mechanistic approach that predicts the microwave drying process of potatoes has been developed.
- The model could aid in predicting key quality attributes associated with the microwave drying process.

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