Developing Microwave Heat Transfer Model for Frozen Mashed Potato Packed in Microwavable Tray

K. Pitchai\textsuperscript{1}, J. Raj\textsuperscript{1}, J. Chen\textsuperscript{1}, S. Birla\textsuperscript{1}, R. Gonzalez\textsuperscript{2}, J. Subbiah\textsuperscript{1}

2012 Annual International Meeting
Dallas, TX

July 30, 2012
Session: Microwave and Radio Heating and Drying

\textsuperscript{1}University of Nebraska – Lincoln
\textsuperscript{2}ConAgra Foods, Inc.
Introduction

- Increasing demand for microwaveable foods
- Non-uniform heating is an inherent issue
- Main cause of concern is in food safety
- Modeling can be used as a tool to:
  - understand microwave interactions with food
  - design food products with better heating performance
Objectives

- Develop a fully coupled microwave electromagnetic-heat transfer model for homogeneous model food (mashed potato) packed in 10-oz food tray
- Validating the model qualitatively and quantitatively with experimental work
Coupled Electromagnetic – Heat Transfer Microwave Model

Power dissipation

Heat equation

Maxwell's equation

Temperature field

EM properties

\[ \rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + Q \]

\[ \oint E \cdot dA = \frac{q_{enc}}{\varepsilon_0} \]

\[ \oint B \cdot dA = 0 \]

\[ \oint E \cdot ds = -\frac{d\Phi_B}{dt} \]

\[ \oint B \cdot ds = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc} \]
Solution Approach

• Finite element based commercial software
• COMSOL 4.2a Multiphysics
Meshing

- Adaptive meshing scheme was used for different model domains (air, turntable, food tray)
- Tetrahedral elements
- Number of elements is \(~196\) K
Assigned Inputs

- Frequency - 2.45 GHz
- Power - 1100 W
- Wave feed - Coaxial magnetron
Solver Setup

- Electromagnetic and heat transfer equations were solved in fully coupled approach.
  
  - Electromagnetic and temperature fields solved for smaller time step within a time step.
Experiments

- Temperature dependent properties measured from -10°C to 110°C
- Mashed potato tray heated for 5 min
- Thermal images collected at three layers
- Four point temperatures measured
Validation Tools

Top image
Middle image
Bottom image

Graph showing temperature over time for Sensor 1, Sensor 2, Sensor 3, and Sensor 4.
Mashed Potato Preparation

- Fill 500 g of mashed potato in the tray
- Covered with shrink wrap film
Measuring Dielectric and Thermal Properties

Dielectric properties setup

Differential Scanning Calorimetry

KD-2 Pro
Dielectric Properties of Mashed Potato

Dielectric properties

Temperature, °C

-10 0 10 20 30 40 50 60 70 80 90 100 110 120 130

Dielectric Constant

Loss Factor
Specific Heat Capacity of Mashed Potato

[Graph showing the specific heat capacity of mashed potato as a function of temperature. The x-axis represents temperature in °C, ranging from -20 to 140, and the y-axis represents specific heat capacity in KJ/Kg°C, ranging from 0 to 120.]
Qualitative Validation

<table>
<thead>
<tr>
<th></th>
<th>Simulation</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td><img src="image1" alt="Simulation Top" /></td>
<td><img src="image2" alt="Experiment Top" /></td>
</tr>
<tr>
<td>Middle</td>
<td><img src="image3" alt="Simulation Middle" /></td>
<td><img src="image4" alt="Experiment Middle" /></td>
</tr>
<tr>
<td>Bottom</td>
<td><img src="image5" alt="Simulation Bottom" /></td>
<td><img src="image6" alt="Experiment Bottom" /></td>
</tr>
</tbody>
</table>
Quantitative Validation

Experiment and Simulation Comparison

Temperature, °C vs. Time, min

- Temperature, °C
- Time, min
- Experiment
- Simulation
Quantitative Validation

![Graphs showing temperature over time for experiment and simulation.](image-url)
Conclusion

- Electromagnetic-heat transfer model developed for microwave interactions with homogeneous food

- Qualitatively, the model agreed well with thermal images

- Quantitatively, the model performance need to be improved.
Future work

- Quantitative prediction accuracy need to be improved
- Include mass and momentum transfer physics
- Validate for real-world food products
Acknowledgement

- ConAgra Foods, Inc.
- USDA CSREES – NIFSI grant (Project number: 2008-51110-04340)
Questions?

pkrishnamoorthy@huskers.unl.edu