Heat Transfer Model for Rotating Frozen Food Tray in Domestic Microwave Oven

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Problem Statement
• Increasing demand for convenient microwavable not-ready-to-eat foods.
• Global frozen food industry to reach US $186 billion by 2015.
• Non-uniform heating is a critical issue in microwave heating of these products.
• The interaction of microwaves with foods and packages are complex and dynamic.
• Thus, a computer simulation model is highly desirable in understanding the complex interaction of microwaves with foods in the process of innovative product and package development.

Objectives
Develop a coupled electromagnetic-heat transfer model to predict temperature in 10 oz frozen mashed potato during microwave heating in rotating turntable.

Model Physics
Electromagnetic Maxwell's equations
\[ \nabla \times E = j \omega \mu H \\
\nabla \times H = -j \omega \varepsilon E \]

Heat transfer equations
\[ \rho C_p \frac{dT}{dt} = k \nabla^2 T + P_f (x,y,z,t) \]

Model Development
• Geometry created in Solidworks, Inc.
• Complex features of the oven like crevices and metal bump included.
• Meshing elements consist of ~162,000.
• Microwave input as coaxial feed.
• Simulation performed using partially coupled approach.
• Iterative solver is used in both electromagnetic and heat transfer solutions.
• Simulation took more than 48 h.

Materials and Methods
Sample preparation
• Mashed potato widely used as model food.
• It can be formulated to match real food shape, size and its properties.
• Mixture of 53.5% water, 23.8% dehydrated potato flakes, 18.5% milk, and 4.2% margarine.
• Potato flakes dissolved in deionized water and stirred for 10 min.
• 500 g of mashed potato filled in tray and stored at -10 °C until used.

Properties measurement
• Dielectric and thermal properties were measured in the range of frozen to thawing temperature.
• Measured properties are dielectric, specific heat capacity, and thermal conductivity.

COMSOL–MATLAB Interface
• Moving mesh (ALE) algorithm of COMSOL does not work for irregular shaped objects rotating on with turntable.
• Developed a custom built MATLAB algorithm to rotate the food at different discrete positions and communicating with COMSOL Multiphysics.

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Experiment setup
• 1100 W rated power microwave oven.
• Tray placed in center of the turntable.
• Mashed potato heated for 3 min.
• Thermal imaging camera was used to collect temperature profiles.
• Spatial temperature profiles collected at three layers : top, bottom, and middle of the tray.
• Experiments repeated after every 4 h to cool down magnetron.

Conclusion
• Simulated spatial temperature profiles were in good agreement with the corresponding experimental profiles.
• Simulation of microwave heating of rotating objects was performed using MATLAB-COMSOL interface.
• Developed model can be used to validate other food products.

Future Work
• Model will be extended to simulate microwave heating of multi-component and multi-compartment meals.
• In the modeling physics, mass and momentum transfer will be included to capture product heating characteristics changes.

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