Simulation of Microwave Heating of Porous Media Coupled with Heat, Mass and Momentum Transfer

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Session : RF & Microwave Engineering

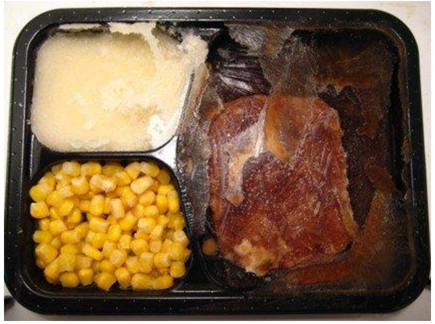
University of Nebraska – Lincoln
ConAgra Foods, Inc.

Excerpt from the Proceedings of the 2012 COMSOL Conference in Boston

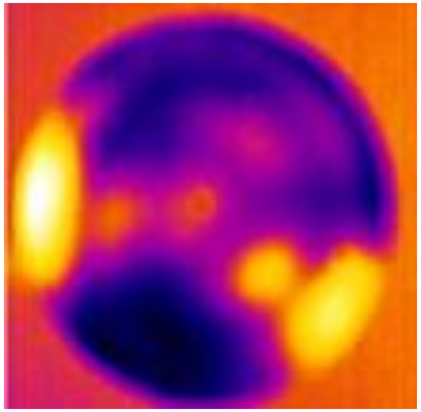
COMSOL CONFERENCE BOSTON 2012

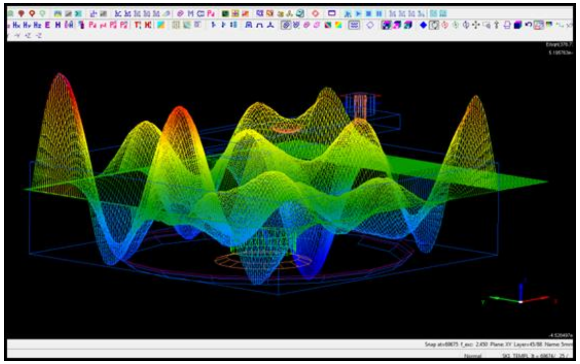
Microwave Heating
Convenient but Non-uniform

- Growing –Billion dollar industry



- Standing wave pattern





Food Quality and Safety Issues

- Vision, Taste, Smell, Nutrition
- Outbreaks

CDC Home | Search | Health Topics A-Z

MMWR

Weekly

November 28, 2008 / 57(47);1277-1280

Multistate Outbreak of *Salmonella* Infections Associated with Frozen Pot Pies --- United States, 2007

On June 6, 2007, a cluster of four human *Salmonella* serotype I 4,5,12:i:-* infections sharing a pulsed-field gel electrophoresis (PFGE) pattern was identified by the Pennsylvania Department of Health and reported to PulseNet.† Initial investigations conducted during June--September 2007 by state and local health departments in collaboration with

Marie Callender recall: Linked to salmonella outbreak

Mitch Lipka

Jun 18th 2010 at 10:02AM

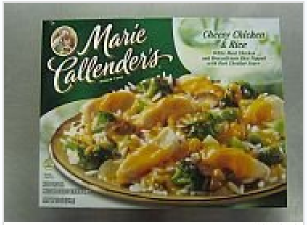
More

Text Size A | A | A

Filed under: Food, Health, Consumer Ally, In the News

7 tweets

retweet



USDA

ConAgra Foods Packaged Foods has issued a recall of Marie Callender's Cheesy Chicken and Rice frozen meals after more than two dozen people were diagnosed with salmonella poisoning.

The U.S. Department of Agriculture's Food Safety and Inspection Service said all of those frozen meals, regardless of when they were made, are subject to this recall. Consumers are urged to not eat the meals.

The USDA said the recall was issued after an investigation by the U.S. Centers for Disease Control and Prevention (CDC) connected a specific type of salmonella poisoning to illnesses of 29 people in 14 states. The last illness reported was May 22, the USDA said.

Product Development Approach

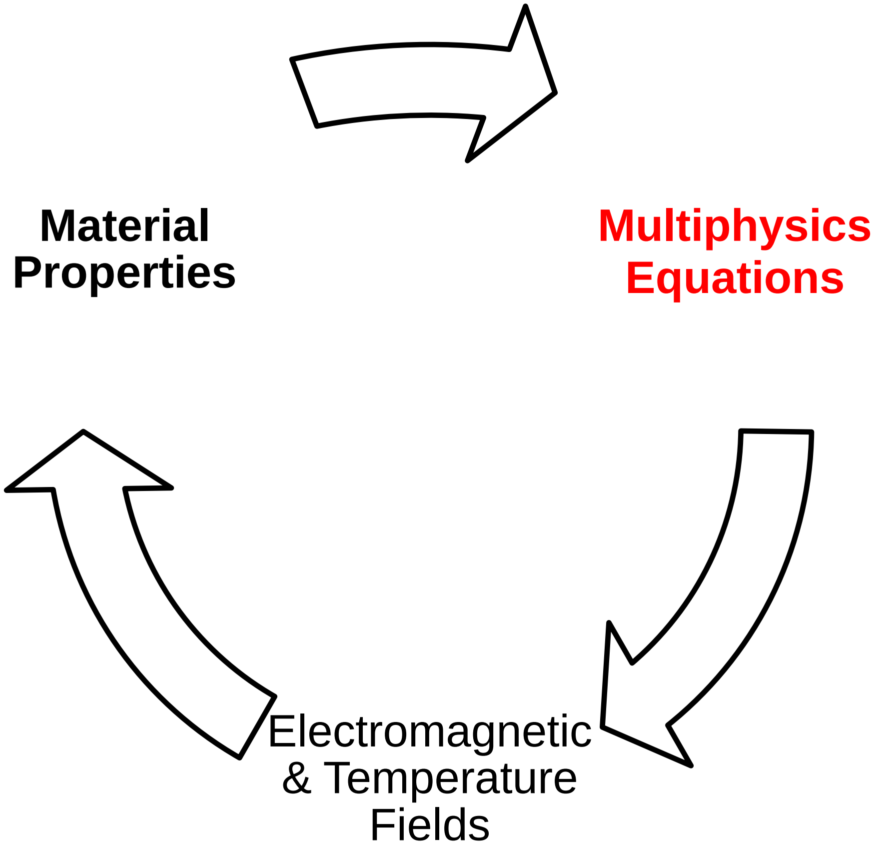
- Food product design…
  - “Designing food products that respond well to microwave cooking is a mixture of art and science, with heavy emphasis on the science.”

Need of Simulation Tool

Computer model use science based approach for :

- product formulation
- design product layout
- design package
- develop cooking instructions

Microwave Heating Modeling



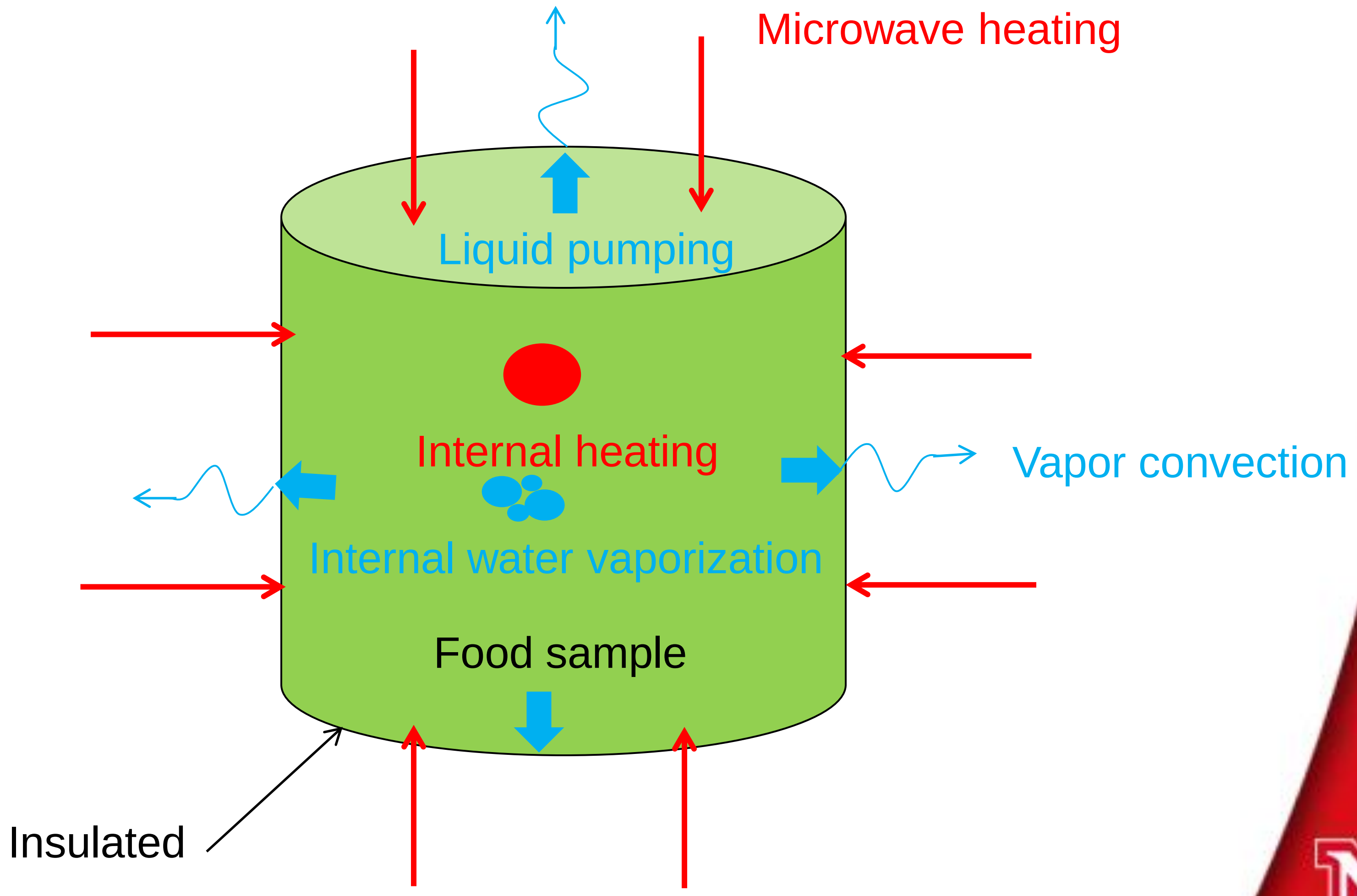
- ✓ Electromagnetic heating
- ✓ Heat transfer
- × **Mass transfer**
- × **Momentum transfer**

Objective

- Develop a comprehensive fully coupled multiphysics model that includes:
  - heat transfer
  - mass transfer
  - momentum transfer

Model Development

Problem Description



Governing Equations

Electromagnetics – Maxwell's Equations

$$\nabla \times \mu_r{}^{-1}(\nabla \times \mathbf{E}) - \left(\frac{2\pi f}{c}\right)^2 (\varepsilon_r - i\varepsilon'')\mathbf{E} = 0$$

$$Q = 2\pi f \varepsilon_0 \varepsilon'' \mathbf{E}^2$$

f	frequency
c	speed of light
ε_r	dielectric constant
ε	dielectric loss factor
μ_r	permeability
Q	power dissipation density

Governing Equations

Mass Conservation

$$\frac{\partial c_i}{\partial t} + \underbrace{\nabla \cdot (-D_i \nabla c_i)}_{\text{Diffusion}} + \underbrace{\mathbf{u} \cdot \nabla c_i}_{\text{Convection}} = \underbrace{\dot{\mathrm{I}}}_{\text{Phase change}}$$

c	concentration of the species
D	diffusion coefficient
$\dot{\mathrm{I}}$	water vaporization rate
u	velocity vector

Governing Equations

Momentum Conservation – Darcy's Law

$$\mathbf{u} = -\frac{k}{\mu}\nabla p$$

$$\frac{\partial}{\partial t}(\rho\emptyset) + \nabla\cdot(\rho\mathbf{u}) = Q_m$$

$\mathbf{u}$	velocity
k	permeability
μ	dynamic viscosity
p	pressure
ρ	density of fluid
ϕ	porosity
Q_m	mass source term

Governing Equations

Energy Conservation

$$(\rho C_p)_{eff}\frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T = \nabla \cdot (k_{eff} \nabla T) + Q$$

ρ	fluid density
C_p	fluid heat capacity
$\mathbf{u}$	fluid velocity field
Q	heat source
$(\rho C_p)_{eff}$	effective heat capacity
k_{eff}	effective thermal conductivity

Governing Equations

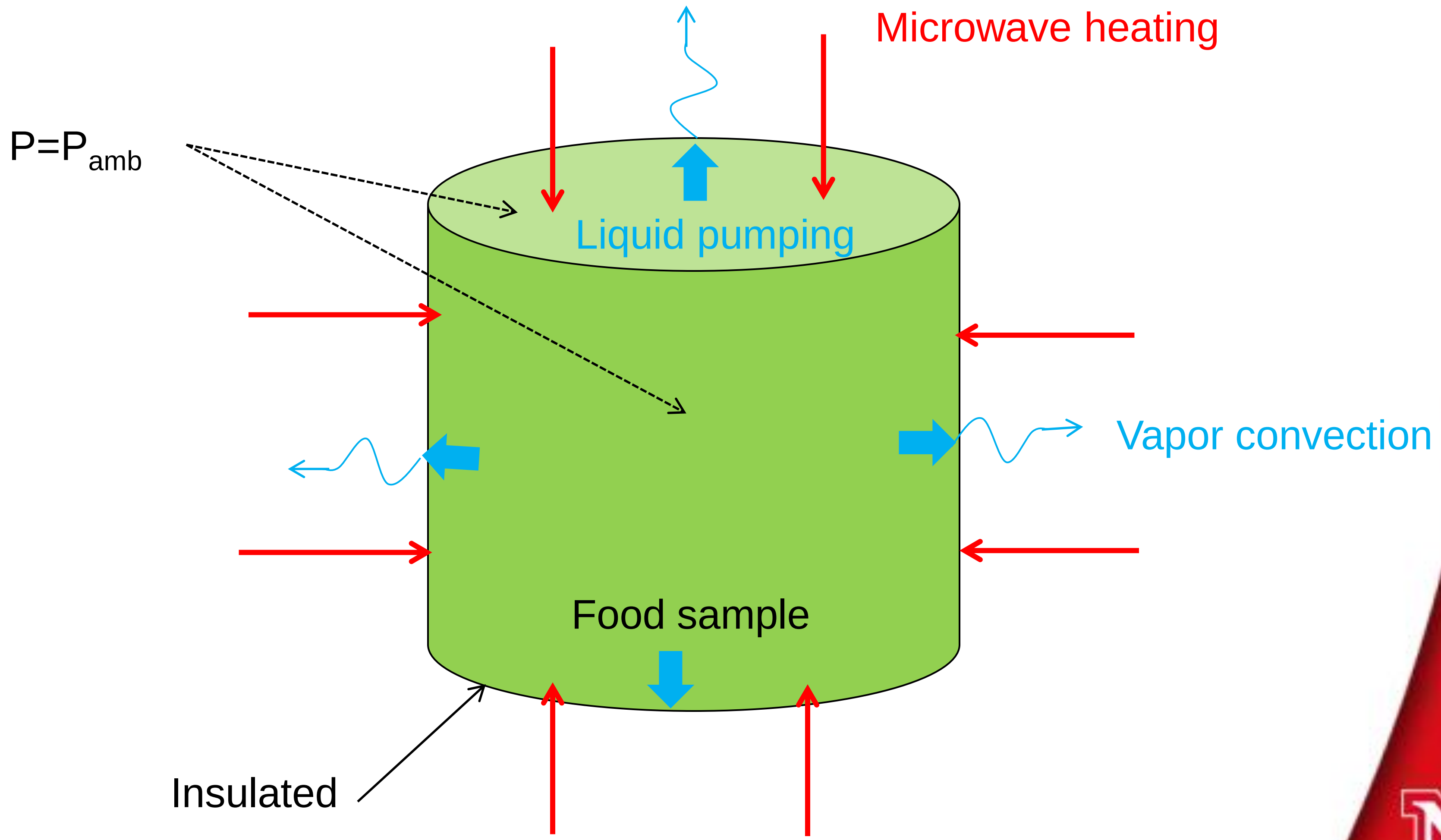
Phase Change (Water Vaporization / Condensation)

$$\dot{I} = K(\rho_{v,eq} - \rho_v)$$

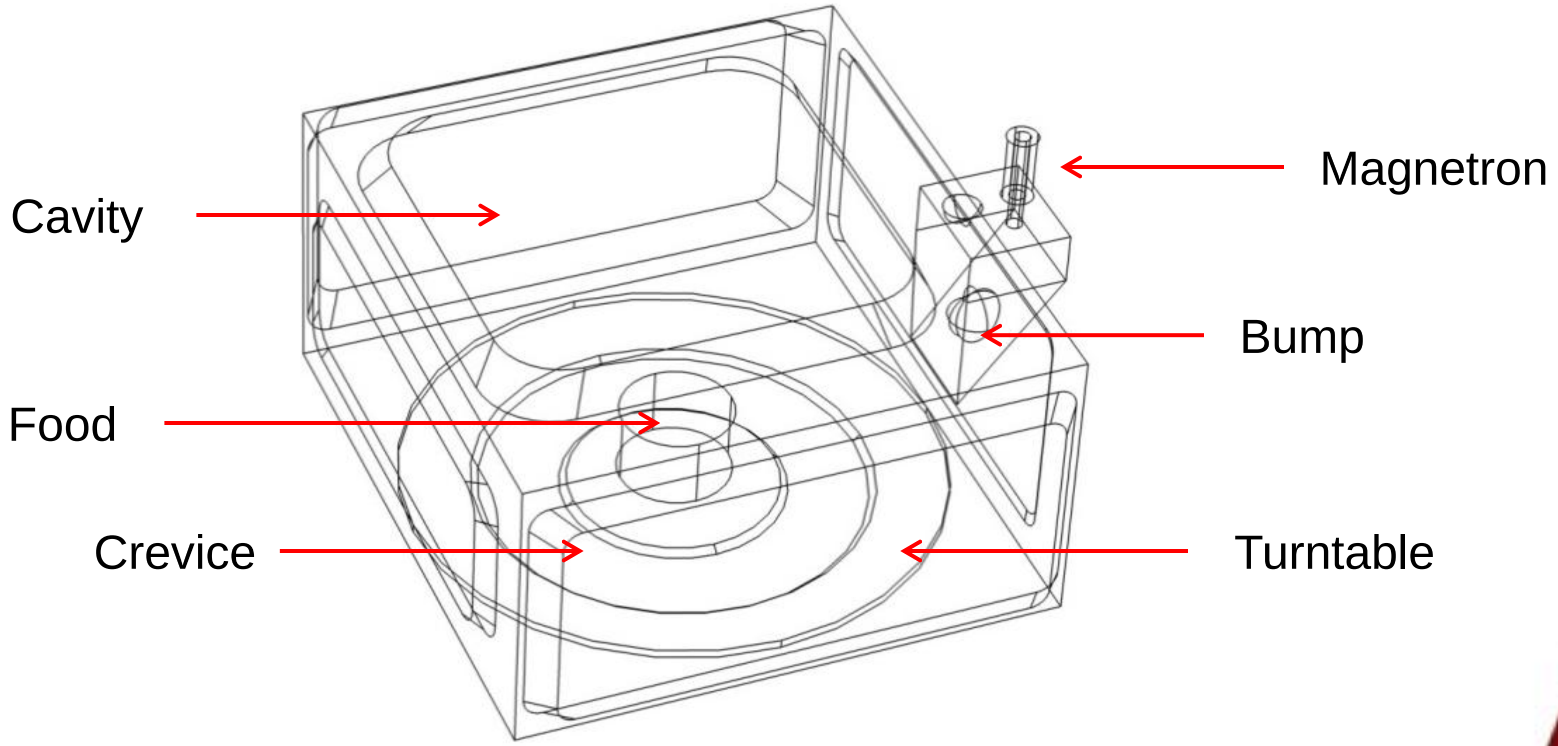
$\rho_{v,eq}$	equilibrium vapor density
K	parameter for the rate constant of vaporization
	order of 1 for hygroscopic material

Halder, A., et al., An improved, easily implementable, porous media based model for deep-fat frying, Part I: model development and input parameters, Food and Bioproducts Processing, 85, 209-219 (2007).

Boundary Conditions



Geometric Model



Assumptions

- Frequency 2.45 GHz
- Constant air temperature 20 ℃
- No bound water in the food domain
- No shrinkage
- Air in the food domain was ignored

Simulation Strategy

- Domains consisted of 82,574 tetrahedral elements.
- A direct solver
- Fully coupled solution
- Various input parameters used in the simulations were obtained from literatures (Rakesh et al., 2012).

Rakesh et al., Microwave combination heating: coupled electromagnetics-multiphase porous media modeling and MRI experimentation, *Bioengineering, Food, and Natural Products*, 58, 1262-1278 (2012).

Material Properties

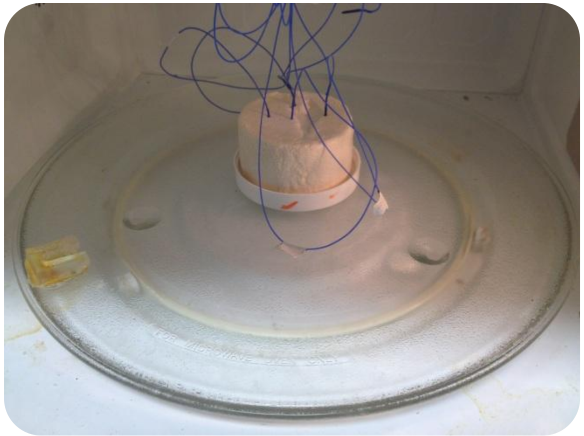
- Dielectric properties

- Thermal conductivity

- Specific heat capacity

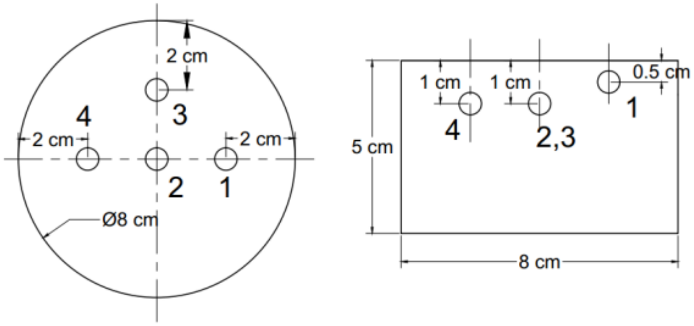
Experimental Validation

Whey protein gel



Experiment setup

Thermal camera

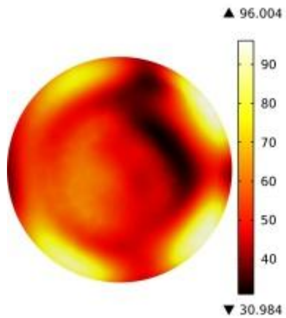
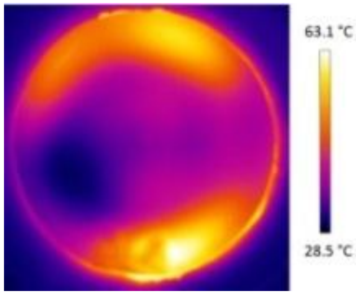
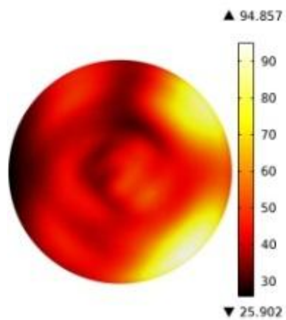
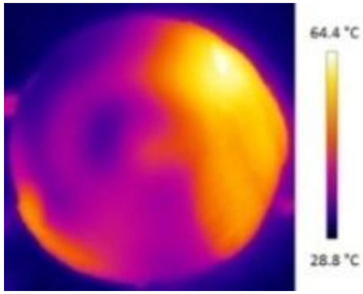
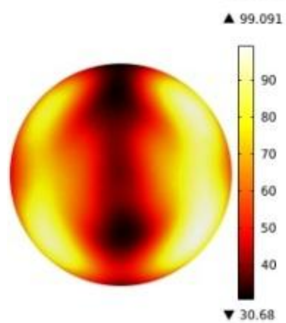
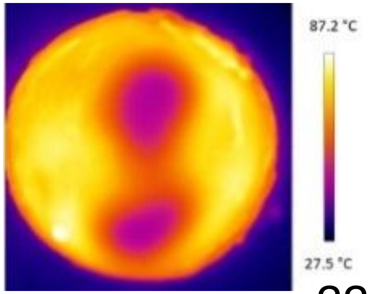


(a) Top view **(b) Front view**

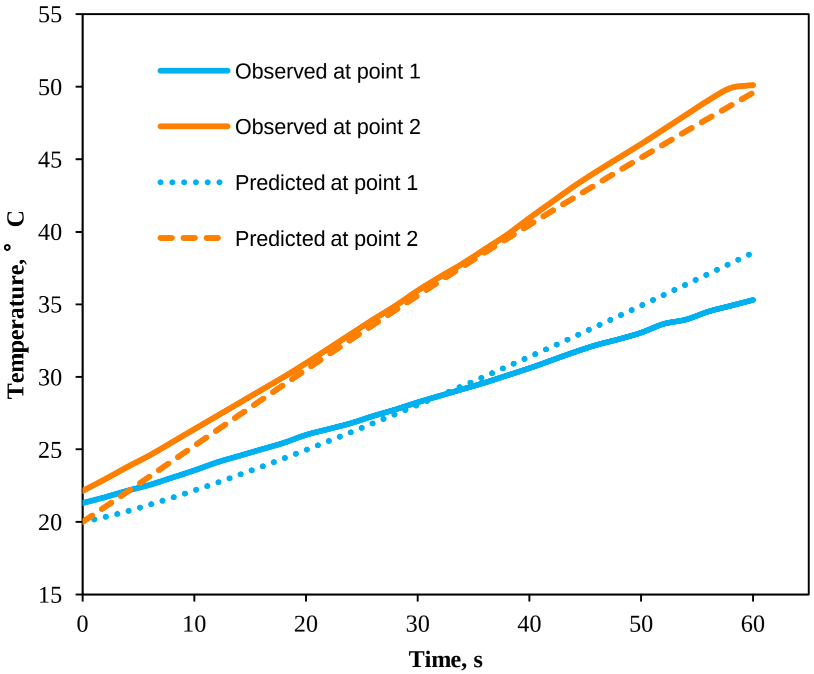
Locations of fiber-optic sensors

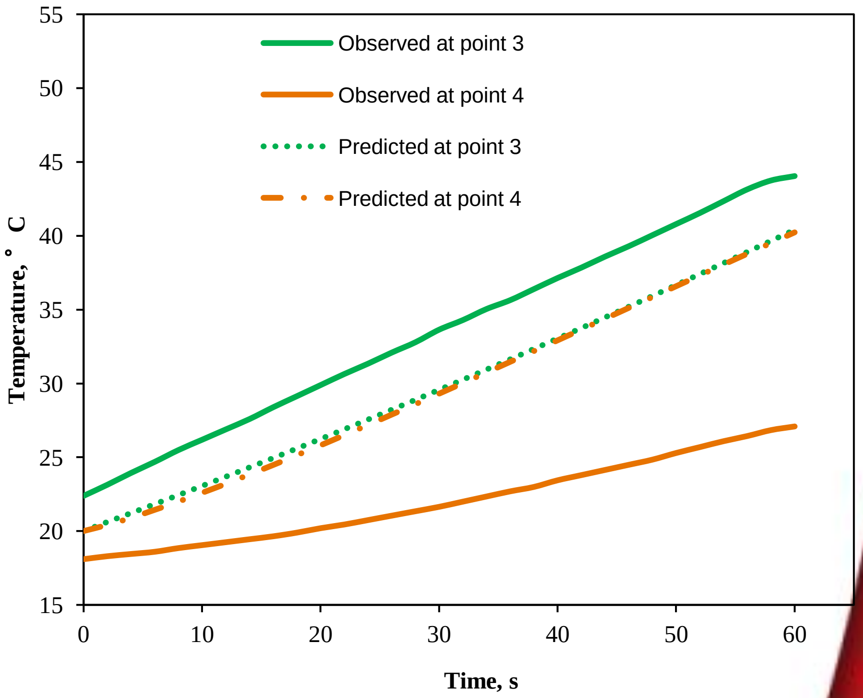
Results and Discussion

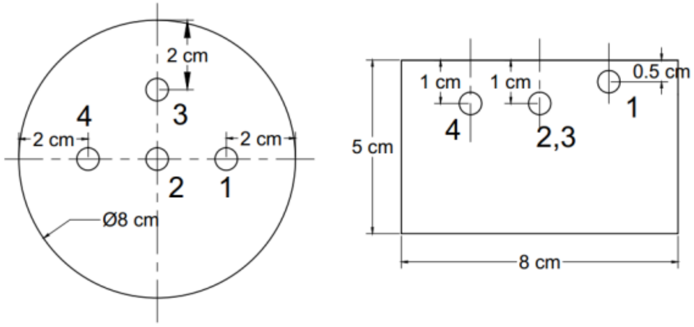
Predicted and Experimental Spatial Temperatures Profiles

Layer	Simulation	Experiment
Top		
Middle		
Bottom		

Predicted and Experimental Transient Temperature Profiles





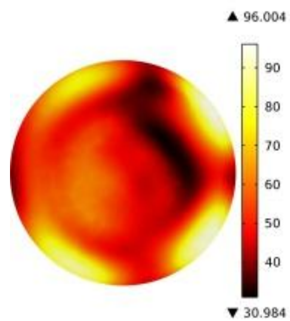


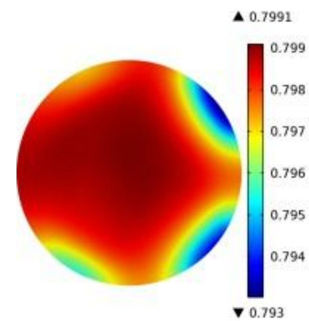
(a) Top view **(b) Front view**

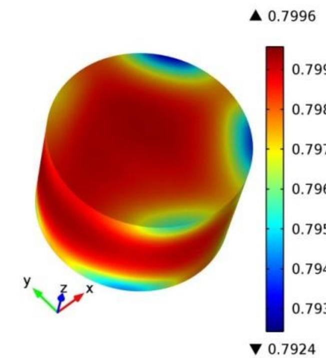
Predicted Temperature Profiles & Moisture Content

Layer | **Temperature** | **Moisture content**

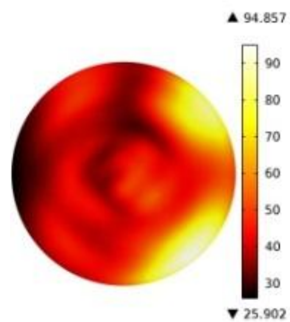
Top

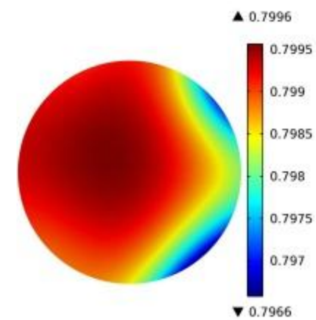






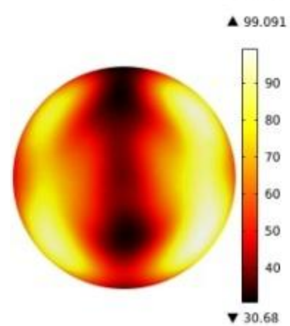
Middle

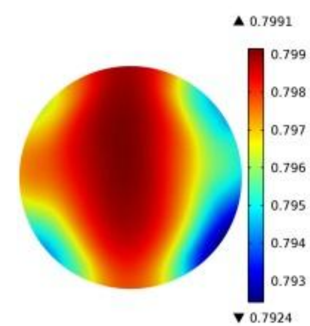




The average experimental moisture content was 0.8.

Bottom





Conclusions

- A comprehensive model of microwave heating coupled with heat, mass, and momentum transfer was developed.
- The predicted spatial and transient temperature profiles showed good agreement with experimental results.
- A longer heating process and accurate spatial moisture content measurement are needed to further validate the models.

Acknowledgements

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Thank you

Questions?

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