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

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Introduction

- Insufficient microwave heating of food may not adequately kill the microorganisms responsible for foodborne illnesses.
- A microwave heating model coupled with heat, mass, and momentum transfer is needed to fully understand the microwave heating process.

Computational Methods

- Microwave heating is a multiphysics process of electromagnetic heating coupled with heat, mass, and momentum transfer.
- Electromagnetics:

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

- Mass conservation:

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (-D_i \nabla c_i) + \mathbf{u} \cdot \nabla c_i = \dot{I}$$

- Momentum conservation:

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

- Energy conservation:

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

E: Electromagnetic field
c: concentration
u: velocity
$\dot{I}$: vaporization
Qm: mass source
Q: heat source

- The material dielectric properties, thermal conductivity, and specific heat capacity were determined as functions of temperature.
- Model input parameters were obtained from Rakesh, et al., 2007.
- COMSOL 4.3 was used to create the geometry, meshes, and solve above equations.

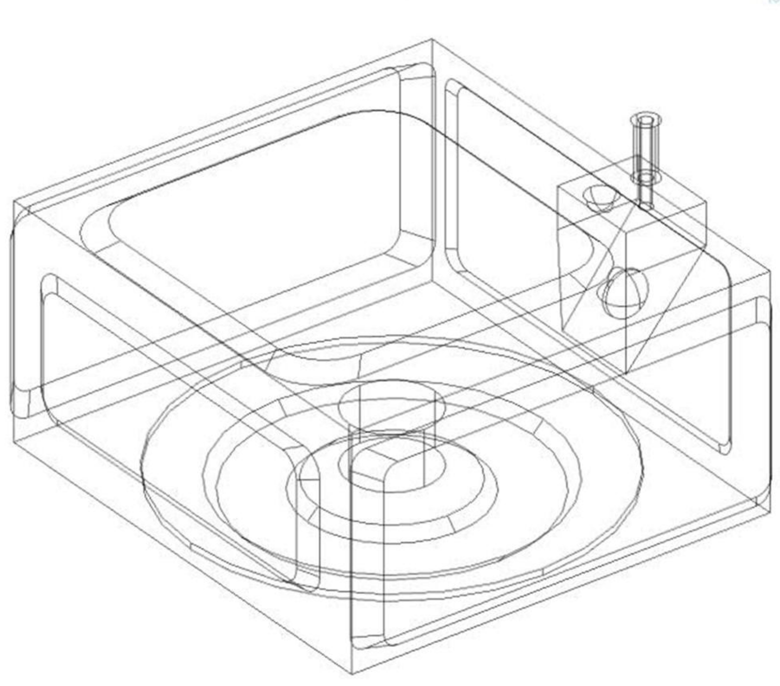

Fig 1. Geometric model.

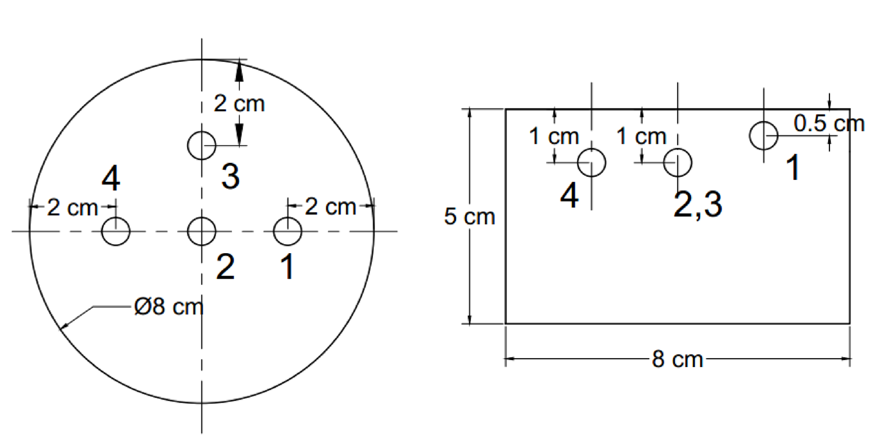

Fig 2. Locations of temperature fiber-optic sensor measurement points.

Experiment Validation

- Cylindrical whey protein gel was heated for 60 s. Spatial and transient temperature profiles and moisture content were determined to validate the model.
- Spatial and transient temperature profiles were determined by thermal imaging camera and fiber-optic sensors, respectively.

Results

- The predicted and experimental transient temperature profiles of points 1 and 2 followed the similar trend.
- There was still large deviation for points 3 and 4, as the RMSE values are 2.7 and 6.0 ℃, respectively.

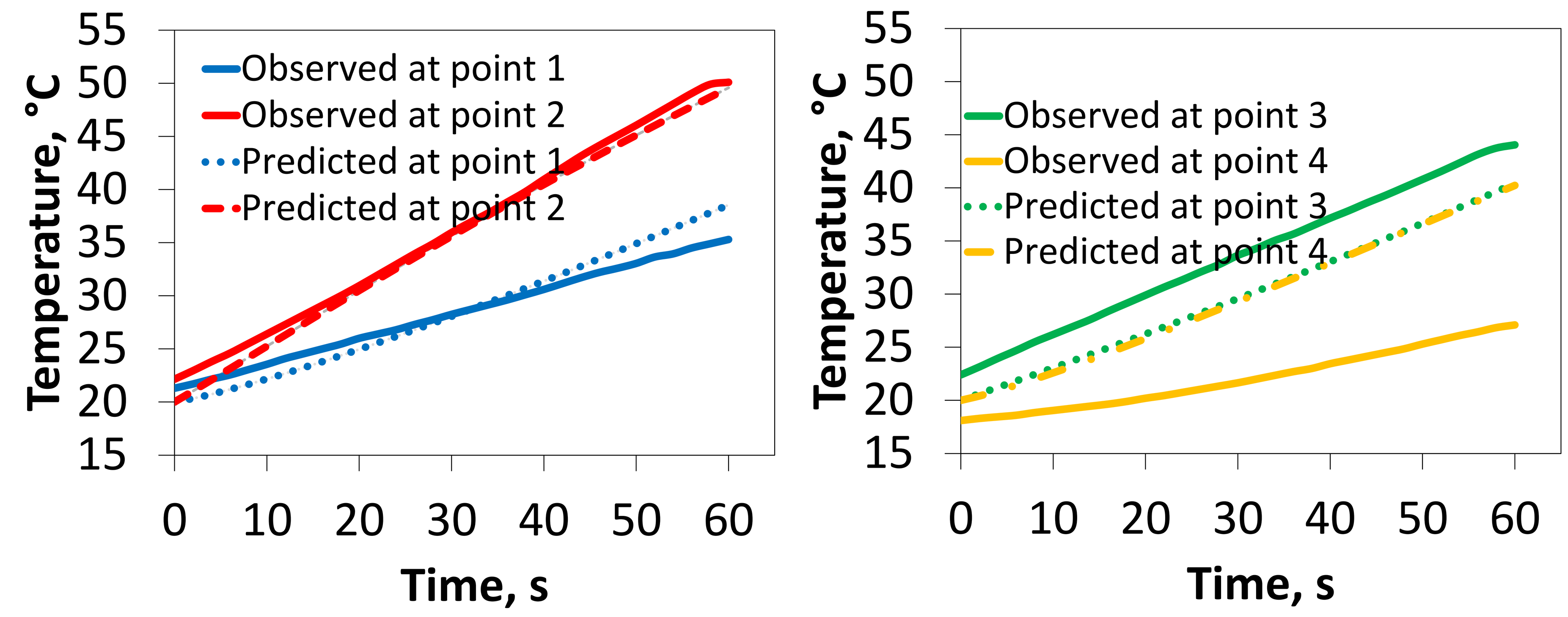

Fig 3. Predicted and observed transient temperature profiles.

- The predicted spatial temperature patterns (hot and cold spots) show a good agreement with the experimental spatial temperature profiles.
- The predicted moisture content correlated with the predicted spatial temperature profiles.

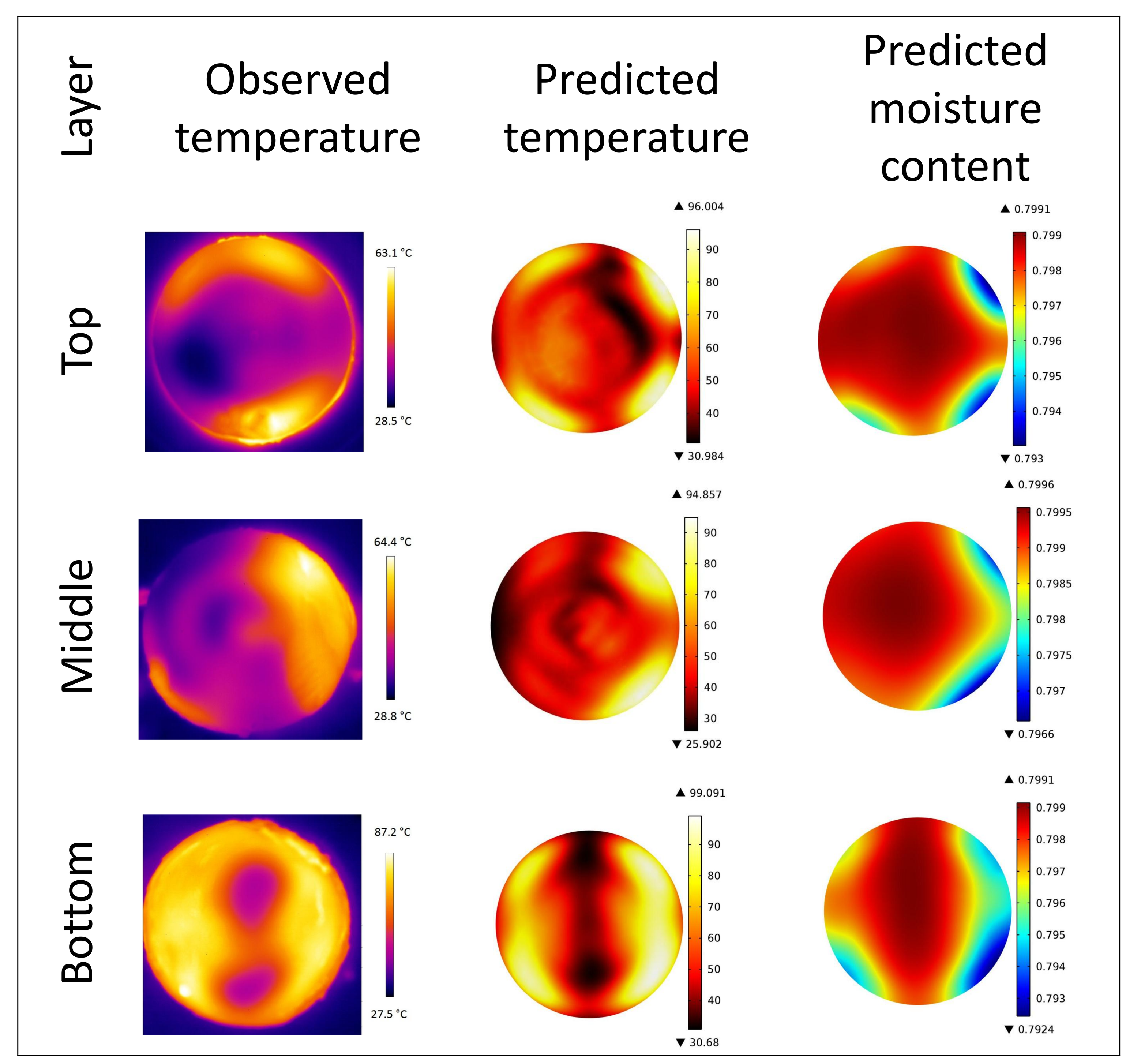

Fig 4. Predicted and observed spatial temperature profiles and predicted moisture content at three layers.

Conclusions

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

References

Rakesh, V., Datta, A.K., Walton, J.H., McCarthy, K.L., and McCarthy, M.J., Microwave combination heating: coupled electromagnetics-multiphase porous media modeling and MRI experimentation, *Bioengineering, Food, and Natural Products*, **58**, 1262-1278 (2012).

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