Finite Element Modeling of Heat and Mass Transfer in Radio Frequency Drying Process: Using Potato as An Example

Xiangqing Chen[1, 2], Yang Jiao[1, 2]
[1] College of Food Science and Technology, Shanghai Ocean University, Shanghai, China
[2] Engineering Research Center of Food Thermal-processing Technology, Shanghai, China
Email: yjiao@shou.edu.cn

Abstract

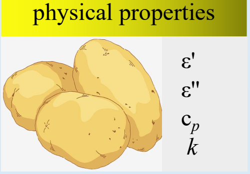
To study the mechanism of heat and mass transfer in porous food material and explore its coupling effect in radio frequency (RF) drying processes, experiments were conducted with potato cubes subjected to RF drying. COMSOL Multiphysics® package was used to establish a numerical model for heat and mass transfer process in porous media and solved with finite element method, then validation by a 27.12 MHz RF heating system. This study showed that the simulation results were in agreement with the experimental results from the temperature distribution, water distribution, and water vapor concentration distribution in the sample. Both experiments and simulations showed that the temperature distribution and water vapor concentration distribution were similar to water distribution after finishing RF drying. The water concentration within the volume was non-uniform, and the maximum difference of which was 0.03 g/cm³. The central area had a higher water concentration than the corner. The distribution of water vapor concentration in the sample is similar to that of water content since a pressure gradient from center to corner would guarantee the mass transfer from the sample to the surrounding in the drying process. In general, the moisture distribution in the sample affects the temperature and water vapor concentration distribution, since the dielectric characteristics of the sample were mainly decided by the moisture content during RF drying. This study reveals the mechanism of RF drying of porous media and provides an effective approach for analyzing and optimizing the RF drying process.

Objects

- To develop and solve a fundamental-based mathematical model for a RF drying process with an example sample of potato cube;
- and to predict the electromagnetic field intensity, moisture distribution, vapor concentration, and temperature distribution within samples during RF drying.

Technical route

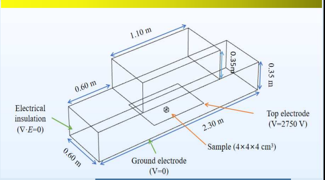
Measurement of physical properties



ε'
ε''
c_p
k

Input

Simulation



Validation

Export results

Electric field
Temperature
Water concentration
Vapor concentration

Experiment

RF dryer

Thermal imager

Condition: P = 6 kW, d = 10 mm, t = 12 h

Results

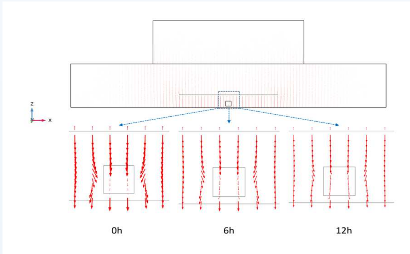


Fig1. Electric field distribution in the central section of the RF heater cavity (y = 0.3 m)

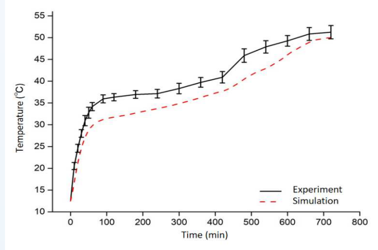


Fig2. Time-tempreature curve of the center point of potato during RF drying from both experiment and simulation

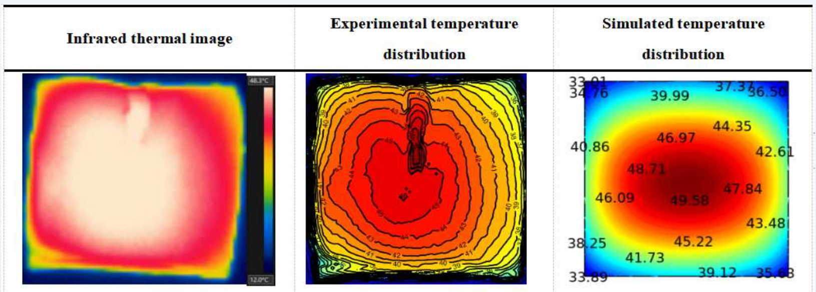


Fig 3. Temperature distribution on the cross-sectional (the zx-section at the center) surface of potato sample from simulated and experimental results

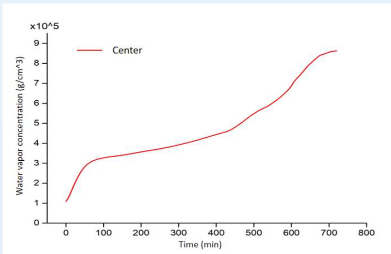


Fig 4. The water vapor content in potato samples with RF drying duration from simulation

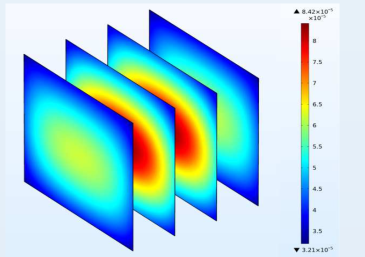


Fig 5. Distribution of vapor concentration in potato samples during RF drying from simulation (t = 12 h) (mg/cm³)

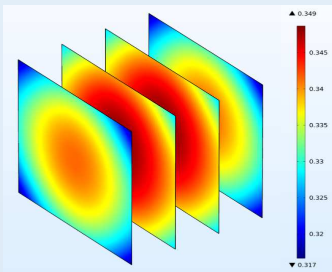


Fig 6. Distribution of water concentration in potato samples from simulation (t = 12 h) (mg/cm³)

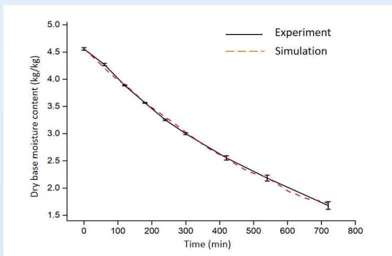


Fig 7. Moisture content of potato samples during RF drying from both simulation and experiment

Conclusion

(1) The prediction model was proved to be reliable and effective through experiments.
(2) The distribution of water concentration and water vapor concentration corresponds to the temperature, that is, the edge of the sample is smaller than the inside of the sample.
(3) The finite element model is used as a tool to explore the method of the RF drying process.

References

[1] Alfaifi B , Tang J , Rasco B , et al. Computer simulation analyses to improve radio frequency (RF) heating uniformity in dried fruits for insect control[J]. Innovative Food Science & Emerging Technologies, 2016, 37:125-137.
[2] Datta A . An Improved, Easily Implementable, Porous Media Based Model for Deep-Fat Frying: Part II: Results, Validation and Sensitivity Analysis[J]. Food and Bioproducts Processing, 2007.