Simulation and Experimental Verification of Porous Media in Radio frequency Drying Based on Finite Element Method

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Introduction

- During the RF drying process, the internal and external temperature of the food material is elevated simultaneously when traditional heating method relies on heat transfer from the surface to the inside, which greatly enhancing the drying rate.
- A commercial software COMSOL Multiphysics® was used to build up a physical model and solve coupling heat and mass transfer equations in porous media for obtaining the temperature, vapor pressure and moisture distribution in potato cubes in RF drying. The model was validated by experiments.
- This study reveals the mechanism of RF drying of porous media and provides an effective method for revealing the RF drying principle.

Governing equations

Electromagnetic field:

$$-\nabla\cdot((\sigma+j2\pi f\varepsilon_0\varepsilon')\nabla V)=0$$

$$\varepsilon^*=\varepsilon_0(\varepsilon'-j\varepsilon'')$$

Mass transfer:

$$\frac{\partial c_i}{\partial t}+\nabla\bar{n}_i=-\dot{I} \qquad i=w,g,v$$

Water flux: $\bar{n}_g=-\rho_g\frac{k_{in,g}k_{r,g}}{\mu_g}\nabla P$

Gas flux: $\bar{n}_w=-\rho_w\frac{k_{in,w}k_{r,w}}{\mu_w}\nabla P_w$

Vapor flux: $\bar{n}_v=-\rho_v\bar{v}_g-\left(\frac{c_g^2}{\rho_g}\right)M_vM_aD_{bin}\nabla x_v$

Momentum transfer:

$$\bar{n}_i=-\frac{k_{in,i}k_{r,i}}{\mu_i}\nabla P \qquad i=w,g,v$$

Heat transfer:

$$\rho_{eff}C_{p,eff}\frac{\partial T}{\partial t}+\sum_{i=w,v,a}\left(n_i\nabla(C_{p,i}T)\right)=\nabla\left(k_{eff}\nabla T\right)-\lambda\dot{I}+Q_{mic}$$

Boundary conditions

Magnetic field $E_{Tangent}=0$

Mass flux

$$j_{\bar{n},w|surf}=h_m\phi S_w\left(p_v-p_{v,oven}\right)+c_w\bar{v}_{\bar{n},w} \quad (\text{When } S_w=1)$$

$$j_{\bar{n},v|surf}=h_m\phi S_g\left(p_v-p_{v,oven}\right)+c_g\bar{v}_{\bar{n},g}$$

Heat transfer boundary

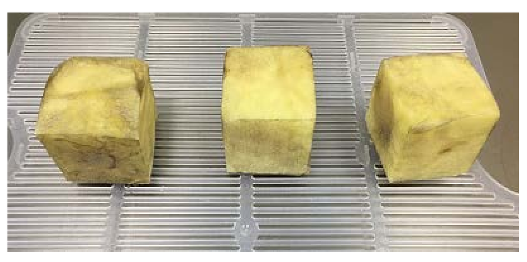
$$q|_{surf}=h_t(T_{surf}-T_{oven})-\lambda j_{\bar{n},w|surf}-$$

$$\sum_{i=w,v}\left(j_{\bar{n},i|surf}\right)C_{p,v}T_{surf}-c_w\bar{v}_{\bar{n},w}C_{p,w}T$$

Phase change $\dot{I}=K_{evap}\frac{M_v}{RT}(p_{v,eq}-p_v)S_g\phi$

Methods

27.12 MHz, 12 kW,
Electrode gap: 10 cm
Drying time: 60 min



Potatoes cubes

Results

Surface temperature Distribution

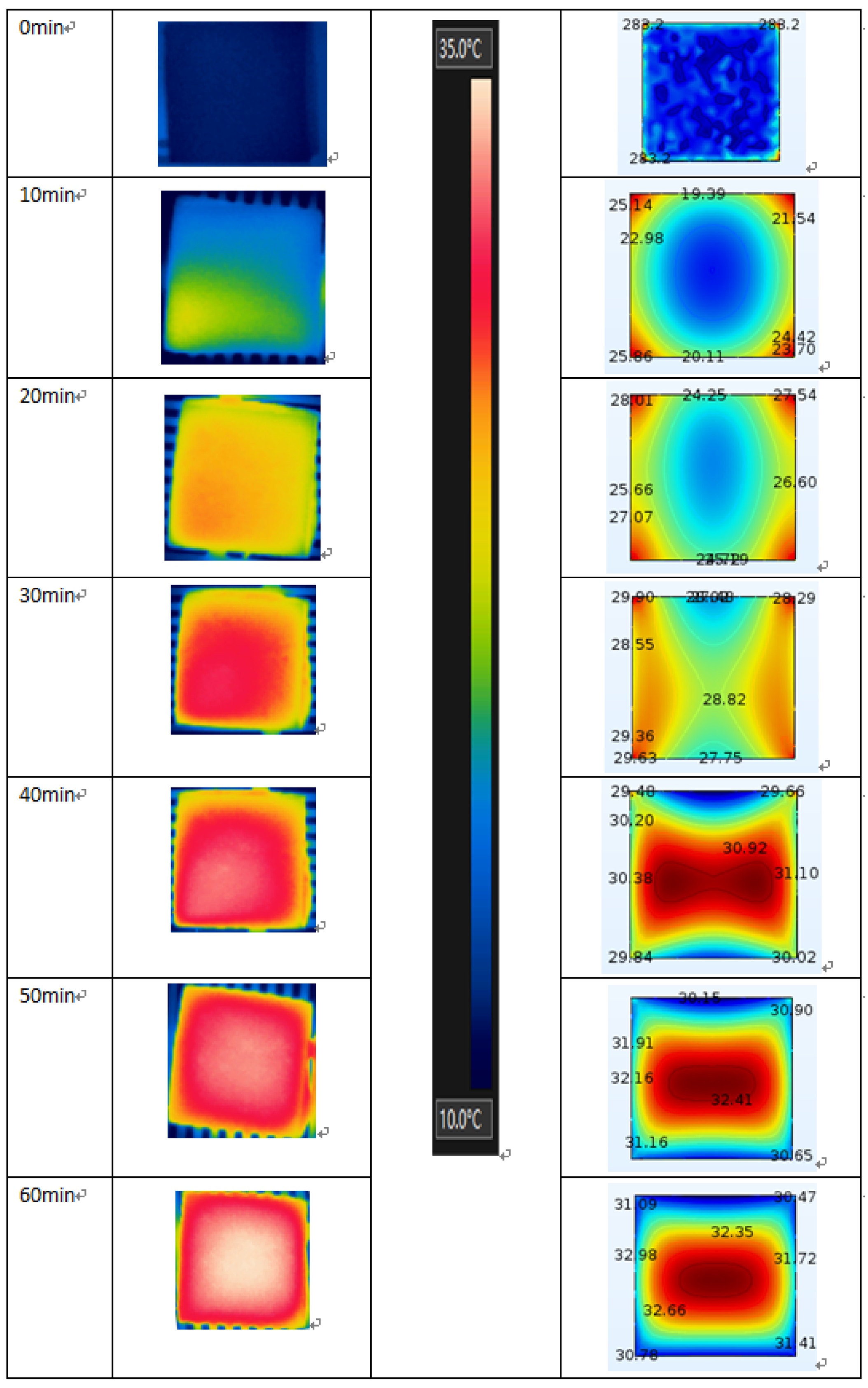


Table.1 Comparison of experimental results with simulation results.

Center temperature distribution

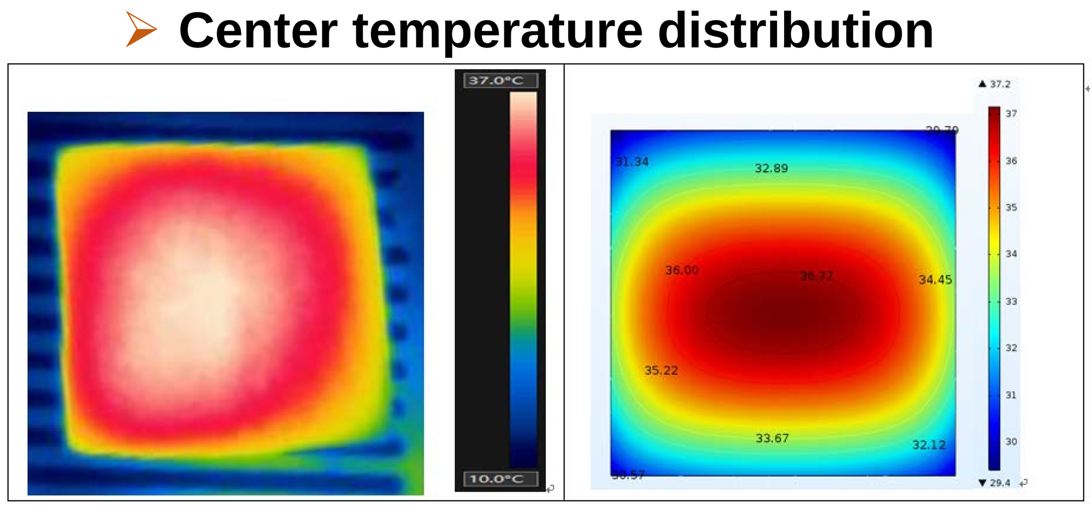


Table.2 Comparison of experimental results with simulation results.

Center temperature

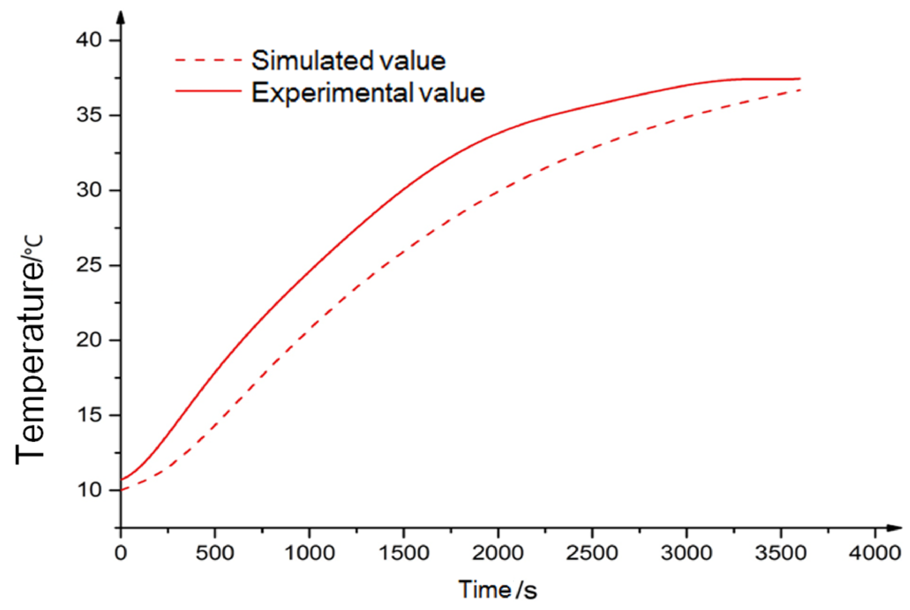


Fig.1 Center temperature curve

Moisture change

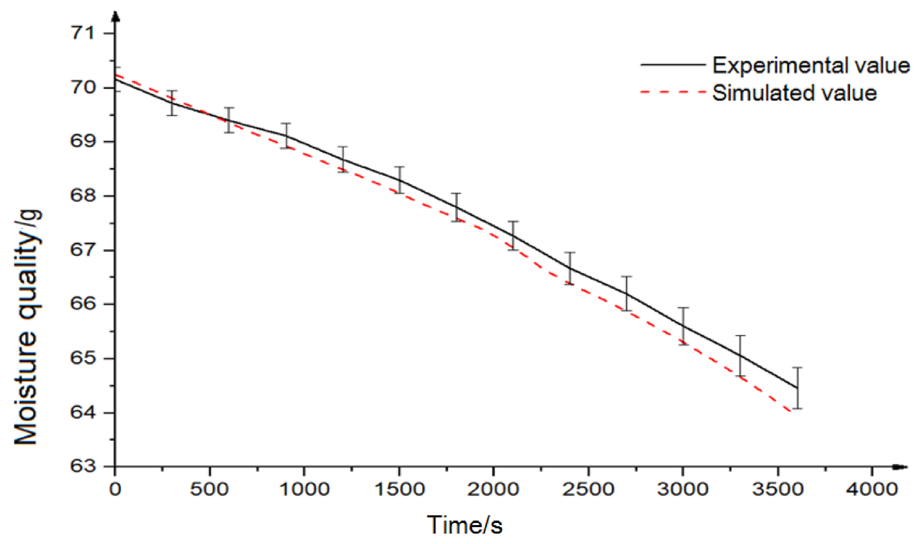


Fig.2 Moisture changes during drying

Electromagnetic field distribution

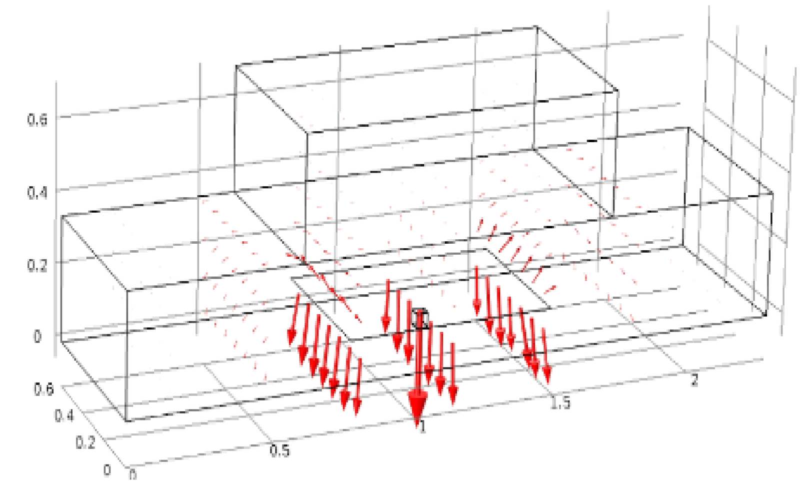


Fig.3 electric field distribution in RF heating chamber

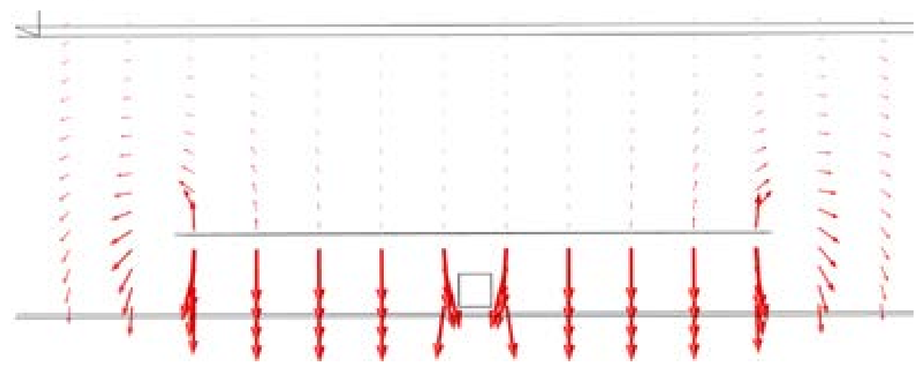


Fig.4 Center section (x=0.3 m) electric field distribution

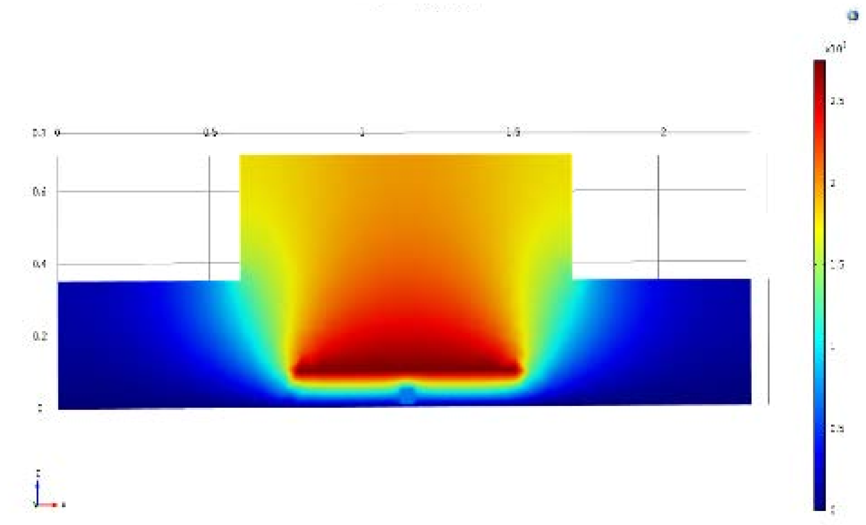


Fig.5 Center section (x=0.3 m) electric potential distribution

Vapor changes

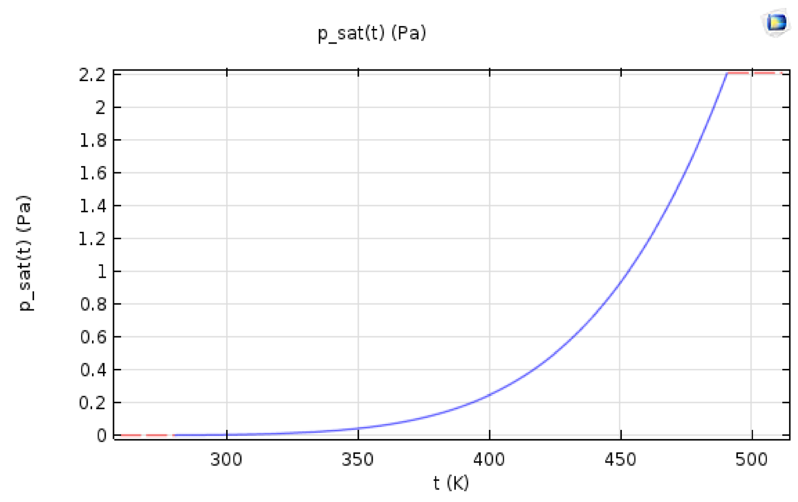


Fig.6 Saturated steam pressure curve

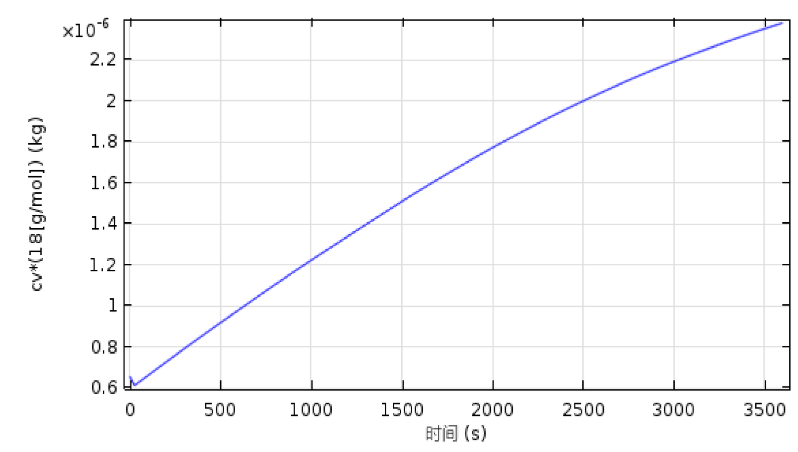


Fig.7 Water vapor amount.

Conclusion

This article uses the finite element model as a tool to explore the moisture and temperature distribution of potato cubes in RF drying process. FEM method provides valid prediction for porous food RF drying and would he helpful for RF drying process optimization.

References

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