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Study on the Temperature Uniformity of Water with Rotation or Stir under Microwave Heating

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Stir, rotation and other methods have been widely used to improve the heating uniformity during microwave heating nowadays. In this paper, the heating uniformity of water with rotation or stir and their combination under microwaves were investigated through multi-physics calculation. It was found that among the three above cases, the temperature uniformity of water under microwave heating with the combination of stir and rotation is the best. The improvement of temperature uniformity of microwave heating water with rotating tray is poor while the speed is increasing; within a certain range, contrarily,increase of the stir speed can significantly improve the temperature uniformity of water. The hotspots cannot be completely dispelled by stir.

Key Words: Microwave heating, Stir, Rotation, Temperature uniformity.

INTRODUCTION

In the early 1980's, microwaves were proposed to be used for accelerating chemical reactions by their efficient heating of the reactants. Many recent reports indicated that microwave could evidently accelerate reactions and the rate enhancement factor could reach over one thousand. Currently, microwaves have been widely used in chemistry[1,2]. In conventional thermal processing, energy is transferred to a material through conduction, convection and radiation and heating is introduced into the sample from the surface. In contrast, microwave energy is delivered directly to materials through molecular interactions with the electromagnetic field[3]. Thus microwave heating has the advantages such as greater time and energy savings, easy to control as well as clean heating *etc.*, which present an impressive application prospect[4]. Microwave heating, however, exists some problems, among, which hot spot, thermal runaway and heating inhomogeneous are obvious problems[5,6]. Stir and rotation are employed to overcome the inhomogeneous problem during heating process. Multi-physics calculation method is used to simulate and analyze the effects of temperature distribution when heating water in microwave oven under the conditions of rotation, stir and their combination within this paper.

METHODS AND SIMULATIONS

Numerical simulation of multiphysics during the microwave heating: The coupled Maxwell's equations, fluid field equations and heat transport equations were solved by using finite-element (FEM) method. The flow chart of the numerical simulation of multiphysics is shown in Fig. 1 and the calculation model is shown in Fig. 2.

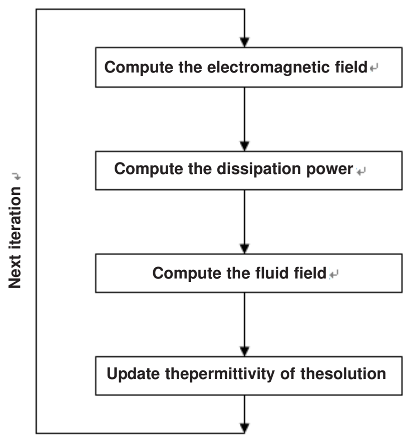

Fig. 1. Flow chart of the numerical simulation of multiphysics

The modified Galanz household microwave oven was used for this research, which was operated at the frequency of 2.45 GHz with the maximum output power level of 700 W. A beaker was taken as a reactor, which was placed in the center of the oven. Deionized water was put in the beaker; the stir oar made of glass, located in the center of the beaker with a height of

TABLE-1
COMPARISON OF RESULTS IN DIFFERENT CASES WITH THE SAME RATE

Cases/ indexes	Still	Rotating	Stirring	Rotating and stirring
Maximum temperature (K)	313.341	311.874	298.065	289.814
Minimum temperature (K)	274.188	274.165	277.6	279.027
Average temperature (K)	279.920721	280.3945	280.57	280.346
Temperature gradient (K/m)				
Maximum	9874.876	8089.716	5079.803	3156.933
Minimum	18.927	18.026	2.25	0.527

10 mm from its bottom. The stir oar has a size of 50 mm × 10 mm × 20 mm, the radius of rotation axis was 3.25 mm with a length of 30 mm, the rest dimensions are shown in Fig. 2 (note: the origin coordinate is located in the center just near the bottom of the beaker). Parameters of materials (complex permittivity, thermal conductivity and heat capacity) used in the simulation are found in previous references[7,8].

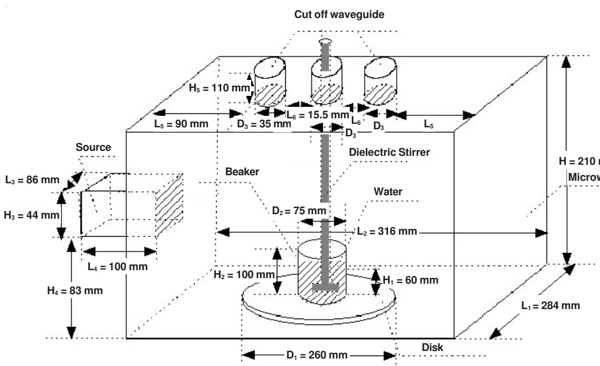

Fig. 2. Schematic of simulation model

The boundary conditions of the microwave oven and waveguide were set as perfect electric conductor and the beaker's was supposed as insulation. During the heating process, water does not exchange heat with air in the microwave oven. The initial temperature was supposed to 0 ºC.

RESULTS AND DISCUSSION

Simulation and analysis of microwave heating water under different conditions: The temperature distributions of water heated by microwave under four conditions are simulated and calculated: (1) still; (2) rotating the beaker; (3) stirring the water with stir rod; (4) stirring the water with stir rod and rotating the beaker simultaneously. The effects of rotation or stir with different rate on temperature uniformity were compared. Calculation results are shown in Figs. 3-6 and the comparisons are shown in Table-1.

As we can see from those figures, the temperature distribution of water heated by microwave is not absolutely uniform at any case. However, among the cases, the temperature uniformity is obviously different. The details about temperature are shown in Table-1.

From the Tables 1 and 2, some conclusions can be drawn as follows:(1) Among the cases of rotating the beaker, stirring the water, rotating the beaker and stirring the water simultaneously, the temperature uniformity of water heated by microwave with rotating the beaker and stirring the water simultaneously was proved to be the best. (2) The temperature uniformity of water heated by microwave was not improved signifi-

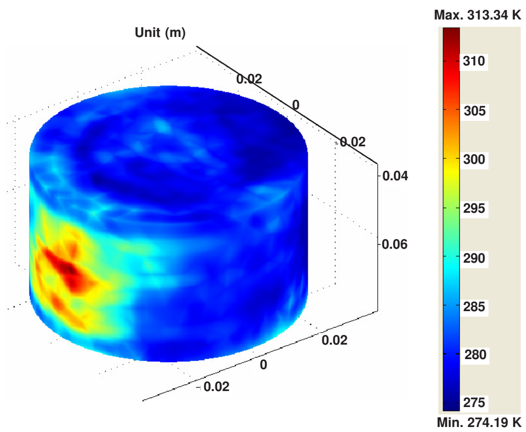

Fig. 3. Temperature distribution of still water after 10s microwave heating

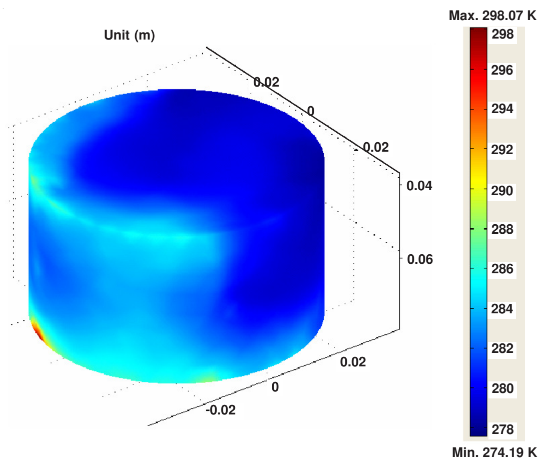

Fig. 4. Temperature distribution of water after 10s microwave heating when the water is stirred with 30 rpm

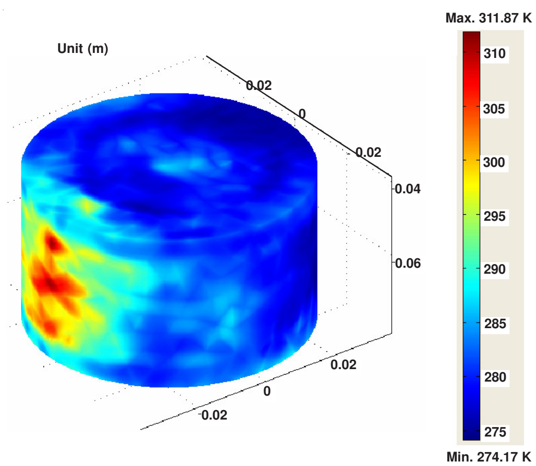

Fig. 5. Temperature distribution of water after 10s microwave heating when the beaker is rotated with 30 rpm

TABLE-2
COMPARISON OF RESULTS BY ROTATION OR STIR WITH DIFFERENT RATE

Cases/Indexes	Rotating (r/min)			Stirring (r/min)		
	30	60	90	30	60	90
Maximum temperature (K)	311.874	311.856	311.776	298.065	289.814	288.343
Minimum temperature (K)	274.165	274.165	274.055	277.6	279.027	279.498
Average temperature (K)	280.3945	280.393	280.3475	280.570	280.346	280.37
Temperature gradient (K/m)						
Maximum	8089.716	8080.496	7999.817	5079.803	3156.933	3141.933
Minimum	18.026	18.065	28.684	2.25	0.527	0.497

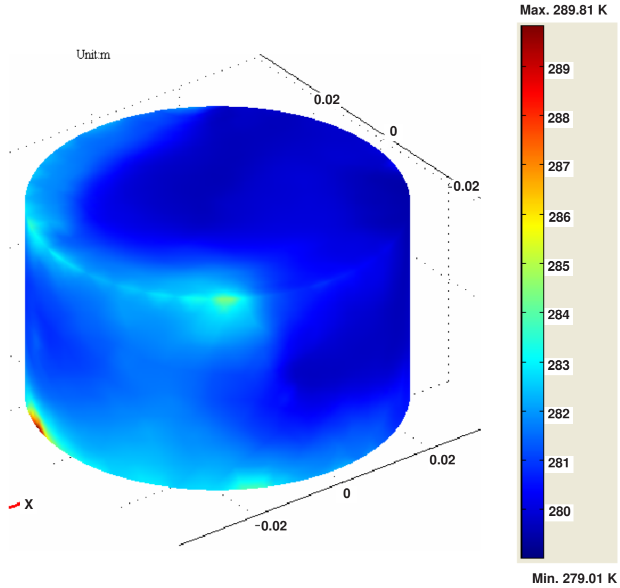

Fig. 6. Temperature distribution of water after 10s microwave heating when the beaker is rotated with 30 rpm and stir the water with 30 rpm

cantly by increasing the rotation speed. (3) The temperature uniformity of water heated by microwave was extremely improved by increasing the stir rod's rotation rate. The uniformity was not obviously enhanced when the stir speed is high enough.

Conclusion

The heating uniformity of water with rotation or stir and their combination under microwaves were investigated through multi-physics calculation. Some conclusions can be drawn as follows :the temperature distribution of water heated by microwave is not absolutely uniform at any case, the hotspots cannot be completely dispelled by stir. The temperature uniformity of water under microwave heating with the combination of stir and rotation is the best. The improvement of temperature uniformity of microwave heating water with rotating tray is poor while the speed is increasing within a certain range, contrarily,increase of the stir speed can significantly improve the temperature uniformity of water. This work will help to analyses and overcome the inhomogeneous problem during heating process.

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