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Influences of Stir and Viscosity Coefficient on the Formation of Hotspots During Microwave Heating

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A numerical model was presented to study the microwave heating on saline water, in order to study on the influences of stir and viscosity coefficient on the formation of hotspots during microwave heating on saline water. The coupled Maxwell's equations, fluid field equations and heat transport equations were solved by using finite-element (FEM) method. The results show that hotspots can't be completely dispelled by stir. In case of the certain stir, the lower the viscosity coefficient, the easier the hotspots occur while the *vice versa* without stir.

Key Words: Microwave heating, Multiphysics, Stir, Viscosity coefficient, Hotspot.

INTRODUCTION

Most of the chemical reactions are sensitive to temperature. Therefore using microwaves to heat reactants presents an impressive application prospect. Up to now, microwaves have been widely used in various chemical fields, from inorganic reactions to organic reactions, from medication chemistry to food chemistry and from simple molecule reactions to complex life processes[1]. However, it is found that during the application of microwave energy, reactants may be burned out due to hotspots or local overheating; in very serious situations, reactors may be destroyed, resulting in explosion. For example, it was found that specific phenomena such as explosion took place during the crystallization process of calcium sulfate under microwave irradiation[2]. It has been reported that the explosion or burnout of reactants has been caused by hotspots while food, rubbers and ceramics heated by microwave[3]. In some cases, it is noted that the hotspots to accelerate chemical reactions. For example, during the research of desulfurization and denitration of active carbon bed under microwave irradiation, it was found by Mingos that there were many local hotspots formed in active carbons which became the active centers for reduction reaction and thus greatly accelerated the thermal chemical reaction[4]. So, it is necessary to analyze the formation of hotspots under microwave heating.

Generally speaking, the formation of hotspots is due to the following three causes: (1) non-uniform distribution of materials with different dielectric losses; (2) non-uniform distribution of microwave field; (3) different thermoconductivities[5].

Conventionally, the researches on hotspots under microwave radiation focus on non-fluid objects such as solids. Therefore, in this paper, numerical method is used for combined solution of multiphysics including Maxwell's equations, the heat transport equations and fluid field equations and to study the influence of the stirred speed and viscosity coefficient change on the formation of hotspots in the saline solution in the process of microwave heating. The results show that hotspots can't be completely dispelled by stirring. In case of stir, the lower the viscosity coefficient, the easier the hotspots occur while the *vice versa* without stir.

EXPERIMENTAL

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.

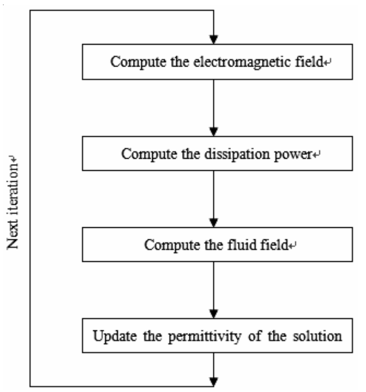


Fig. 1. Flow chart of the numerical simulation of multiphysics

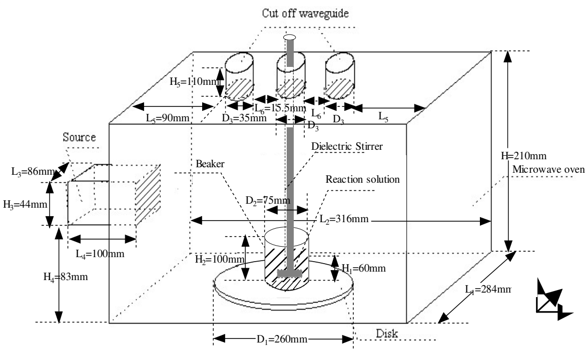
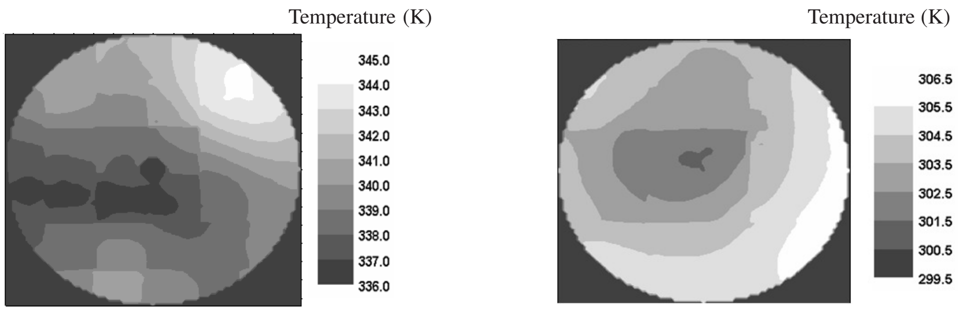


Fig. 2. The numerical simulation model

The modified Galanz household microwave oven as a microwave chemical reactor; in the beaker is saline water (0.5 mol/L); the stirring oar is made of glass, located in the center of the beaker and 10 mm high from its bottom. The stirred oar has the size of 50 mm ×10 mm × 20 mm, the radius of rotation axis r = 3.25 mm, the length l = 30 mm and the rest sizes are shown in Fig. 2 (note: the origin of coordinate is located at the center on the bottom surface of the beaker). Parameters of materials used in the simulation are found in some references[6,7].

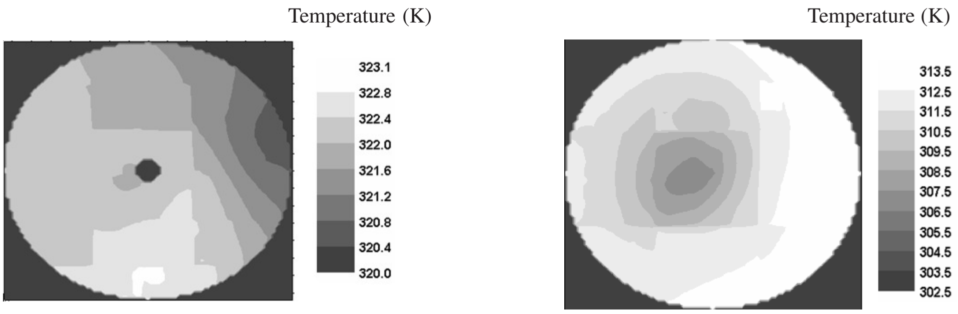
RESULTS AND DISCUSSION

Saline solution was heated repeatedly by microwave at different stirred speed for 30 s. It was found that all of the hotspots occurred on the upper interface of saline solution (XY cross-section at Z = 60 mm) while all of the lowest temperature occurred on the bottom interface of the beaker and saline water (XY cross-section at Z = 0 mm). Fig. 3 is the simulation results of the temperature distribution on the upper and bottom interface of saline water heated by microwave for 30 s at different stirred speeds. Figs. 4 and 5 are the simulation results of the hotspot temperature and difference in temperature of saline water heated by microwave for 30 s at different stirred speeds. It is shown in Figs. 4 and 5 that hotspots can't be completely dispelled by stir.



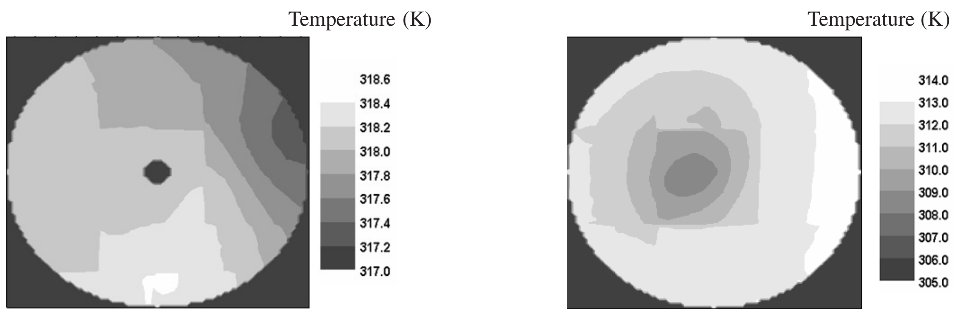
(a) Z = 60 mm (top of the saline water) (b) Z = 0 mm (bottom of the saline water)

(1) Stirred speed = 10 r/min



(a) Z = 60 mm (top of the water) (b) Z = 0 mm (bottom of the water)

(2) Stirred speed = 100 r/min



(a) Z = 60 mm (top of the water) (b) Z = 0 mm (bottom of the water)

(3) Stirred speed=200r/min

Fig. 3. Temperature distribution in the saline water after simulating 30 s different stirred speeds

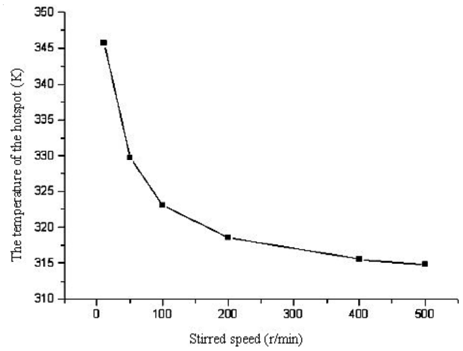


Fig. 4. The highest temperature curve at different stirred speed

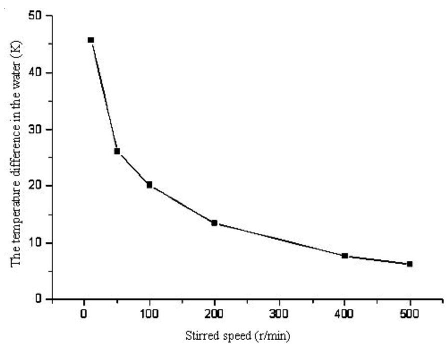


Fig. 5. The curve of difference in temperature at different stirred speed

In addition, at the stirred speed of 50 r/min, when viscosity coefficient of the saline water is changed, the calculated corresponding hotspot temperatures and the temperature difference distribution are as Figs. 6 and 7. It can be seen from the figures, the lower the viscosity coefficient, the easier the hotspots occur. It is presumed that probably under the forced convection conditions caused by stir, thermal diffusion is more favorable if the viscosity coefficient is bigger. Then, the same heating process without stir is calculated and the computational result is shown in Figs. 8 and 9. Without stir, on the contrary, the bigger the viscosity coefficient, the easier the hotspots occur.

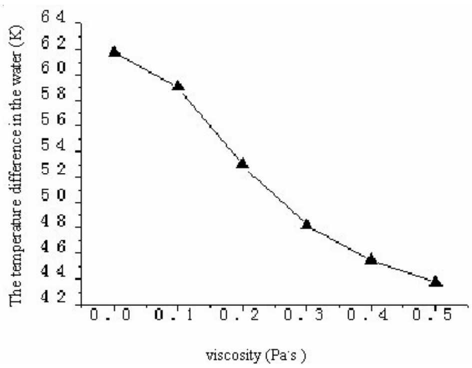


Fig. 6. The highest temperature curve at different viscosity

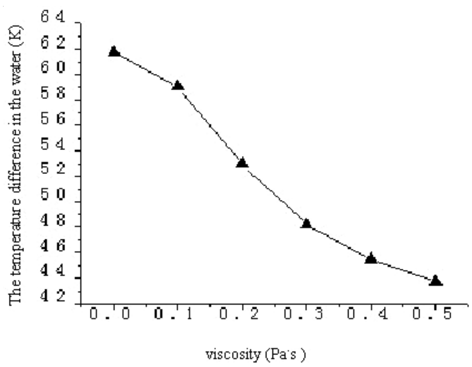


Fig. 7. The curve of difference in temperature at different viscosity

Conclusion

In order to study on the influences of stir and viscosity coefficient on the formation of hotspots during microwave heating on saline water, the multiphysics equations were solved by using finite-element (FEM) method. The results show that hotspots can't be completely dispelled by stir. In case of the certain stir, the lower the viscosity coefficient, the easier the hotspots occur while the *vice versa* without stir.

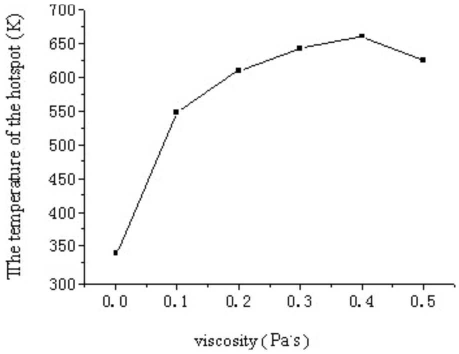


Fig. 8. The highest temperature curve at different viscosity without stir

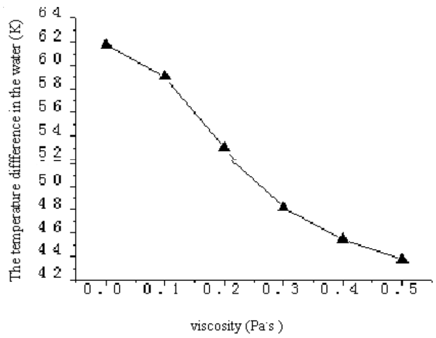


Fig. 9. The curve of difference in temperature at different viscosity without stir

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