Modeling of ohmic heating of solid food with non-uniform electric properties

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修士学位論文内容要旨
Abstract

専攻 Major	食機能保全科学 Food Science and Technology	氏名 Name	郭　雯 Guo Wen
論文題目 Title	不均一電気特性を有する固体食品の通電加熱のモデル化 Modeling of Ohmic heating of solid food with non-uniform electric properties		

【Background and Objective】

Being a novel energy-efficient method, ohmic heating (OH) has attracted the interest of food industry recently. Since the main critical factor in thermal processes is the thermal history and the temperature distribution during OH requires special consideration of the current knowledge, the non-uniform temperature distribution inside heterogeneous food after OH indicates the importance of investigation on the thermal behavior of complex system. However, there is not a lot of data available for heterogeneous food especially for the solid composite food. Therefore, modeling of the thermal behavior of composite food with various electric conductivities during OH has been a challenge. In this study, the temperature distributions and profiles of four typical solid composite food systems designed for the parallel and series model and two typical surrounding-cases: pure-inside-salt model and salt-inside-pure model were investigated undergoing OH. And a new method of predicting the heat generation inside the food during OH based on electromagnetic field analysis by Maxwell's equations was proposed instead of Joule's law.

【Materials and Methods】

Electric conductivity measurement

Mashed potato and mashed potato with 1wt % sodium chloride (water content of both were 80wt %) were used as the pseudo food samples in this study. Electric conductivity, σ (S m^{-1}) of the two materials, which was the important parameter used in simulating, could be calculated from the impedances that were measured in water bath by LCR meter **(**HiTESTER3532-50, HIOKI Co. Ltd., Japan) from 20 to 80 ℃, every 5 ℃.

Investigation of temperature distribution undergoing OH

Temperature distributions of four filling patterns after OH were investigated. And during heating, an OH machine (FJB-55, Frontier Engineering Co. Ltd., Japan) was applied for supplying the alternating current (50V, 20 kHz). After OH of certain time, the thermal pictures of the cross-section were captured by an infrared thermal camera (TH7102WV, NEC San-ei Instruments, Ltd., Japan) to verify the estimations.

Temperature analysis by 3D finite element computational model

Two commercial finite methods based software packages, FEMAP (V10.2, Siemens PLM Software Inc., USA) and PHOTO-Series (V7.2, PHOTON Co. Ltd., Japan), were used for geometry model building and temperature prediction. The internal volumetric heat generation term (Q, J s^{-1} m^{-3}) was estimated after electromagnetic field analysis based on Maxwell's equations.

【Results and Discussion】

The electric conductivity (σ), the key factor which influenced the current distribution inside food during OH, was found that increased with the temperature increasing as a linear function, explained by the less impotent opposition to the movement of the ions for higher temperature. The empirical equations were successfully obtained. And there was a logarithmic function relationship between σ and frequency. Furthermore, σ increased along with the growth of salt concentration to a certain extent.

Different components and their arrangement conditions were observed to have a significant influence on the temperature distribution during OH. For example, the completely opposite effect was found in parallel and series model. In parallel circuit, the temperature was lower in the middle where filled with mashed potato due to the easier for current to pass through the ingredient with higher σ. In contrast, the temperature was higher in mashed potato in series connection. Because the whole currents pass through each ingredient are same, while mashed potato has bigger impedance resulted in the higher temperature. Otherwise, the modeling and experiment showed a good agreement that implied a potential application for OH processing to get uniform temperature of solid composite food by electrode configurations.