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Simulation and Analysis of Efficiency Dielectric Properties of Core-shell Agricultural Products

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Abstract. Dielectric properties are important characteristic parameters in the microwave-assisted application of hygroscopic agricultural media. In order to expand the application of electromagnetic wave in the drying of core-shell agricultural products, a numerical model is established by discrete element method, finite element method and average energy method. The internal correlation between the thickness, volume fraction, conductivity, and dielectric constant of each component with the efficiency dielectric properties of core-shell agricultural materials is simulated and obtained. The results can provide the data for the development of electromagnetic drying process of agricultural products and the setting of process parameters of drying equipment. This simulation model is suitable for the analysis of RF range.

1 Introduction

Drying plays an important role in the processing, storage and transportation of agricultural products. During actual agricultural production, many newly harvested agricultural products or seeds exist in the form of core-shell particles (such as walnuts, Australian nuts and peanuts.), which have complex structure, high water content of kernel and easy mildew (such as 23%~30% water content of mature nuts in newly harvested Australian nut shells). Drying these agricultural products is an important link in their initial processing and the main factor affecting the efficiency of enterprises.

In recent decades, many scholars have put forward the single drying or combined drying technology of natural drying, hot air drying, microwave assisted vacuum drying, forced air drying and other agricultural products. These research results have promoted the development of related industries, but they are still faced with the practical problems of long drying period, high cost, large energy consumption, edge heating or central heating [1]. The microwave drying method of agricultural products based on new energy and new technology has attracted the attention of scholars [2].

It is well known that electromagnetic heating technology based on dielectric properties is widely used in industrial production and food processing by virtue of its advantages of integral and rapid heating. In the field of agricultural engineering, Tan Qiujin believes that microwave (or radio frequency) heating technology has great potential for uniform and rapid drying of agricultural products, and is expected to develop into an alternative to traditional drying technology. Yao Bin points out that the lack of reasonable selection of temperature change mode and the lack of modeling of drying process are the difficult problems facing the current variable temperature drying [3]. Li Wen believes that the domestic research on the theory of drying characteristics of agricultural products is insufficient, so it is necessary to systematically develop new drying equipment to make it develop in the direction of intensive, intelligent and integrated. Osepchuk thinks that the scholars should use electromagnetic theory, heat and mass transfer and electromagnetic calculation technology to carry out basic research on the dielectric properties of different agricultural materials[4]. In general, the current research results on the drying of agricultural products mainly focus on the traditional drying methods such as hot air drying. Although the low-cost, mass-produced electromagnetic heating system has been widely used in food hot processing, but the electromagnetic heating system for agricultural products is still in the stage of experimental exploration, and the relevant basic research depth is not enough. The research results of microwave heating for agricultural products with complex structure particles (core-shell type) are few. It is very valuable to carry out electromagnetic energy auxiliary application simulation analysis of core-shell agricultural products particles.

In this paper, the core-shell agricultural product particles in harvest season are taken as the object, and the theoretical research and computer simulation are used to analyze the change of efficiency dielectric properties of core-shell agricultural granular materials in microwave drying process under different parameters. It provides the basis for the development of green energy-saving microwave drying process and the setting of drying equipment process parameters.

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2 Theory and model

2.1 Efficiency dielectric properties of granular materials

The dielectric properties ($\varepsilon = \varepsilon' + j\varepsilon''$) refers to the response of the bound charge in the material molecule to the applied electric field and is an important parameter to study the microwave assisted application of agricultural products. Among them, the relative dielectric constant (ε') represents the storage of electromagnetic wave energy, and the relative dielectric loss factor (ε'') represents the transformation of electromagnetic wave energy, j is a unit of imaginary number.

In the field of agricultural engineering, because the physical characteristics of different kinds of agricultural particles are different, and the macroscopic dielectric properties of agricultural particles are determined by the dielectric properties of each component, the interaction between each other and the geometric configuration. Therefore, in the process of practical application, people often use the efficiency dielectric properties of granular materials to guide microwave assisted applications.

2.2 Calculation principle of efficiency dielectric properties of agricultural granular matter

When the size of the particles in the mixture is much smaller than the electromagnetic wave length, the efficiency dielectric properties of the mixture can be analyzed by using a parallel plate capacitor model under quasi-static conditions, as shown in figure 1[5]. ϕ_1 and ϕ_2 are the electric potentials of the upper and lower poles of the parallel plate capacitor, the side boundary condition is $\partial\varphi/\partial n = 0$. The plate is filled with particles. The efficiency dielectric properties (ε_{eff}) of the mixture can be obtained by finite element method of electromagnetic field and energy conservation principle [5].During the analysis of the influence of the dielectric properties of each component of the conductive mixture on the absorbing characteristics in the microwave frequency band, the dielectric properties of the medium are complex permittivity ($\varepsilon = 1 - j\left(\sigma / \omega\varepsilon_0\right)$), and σ is electrical conductivity, ω is angular frequency ($\omega = 2\pi F$), F is microwave frequency.

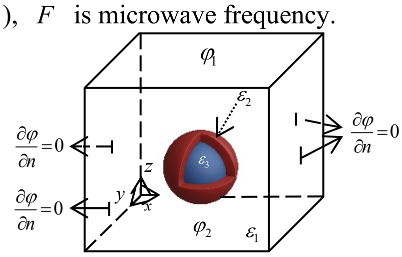

Fig. 1 The simulation model for calculating effective permittivity of mixture

2.3 Numerical model of efficiency dielectric properties of agricultural granular matter

Because the agricultural product particles exist in stacking state in the loader, different technical methods are used to realize the simulation of the stacking state of the agricultural product particles and the numerical calculation of the simulation model. The following steps are as follows: first, the modeling of core-shell structure agricultural product particles and the simulation of particle stacking process in the loader are completed by using discrete element method(EDEM software), and the position coordinates and direction vector matrix data of each particle in the loader are obtained, use MATLAB program is compiled to convert the direction vector matrix data into the direction vector corresponding to the x, y, z axis in Cartesian coordinate system. The second is to use the "App developer" function of COMSOL (multi-physical field coupling software) to generate the modeling code of different structure shape particles by "recording" method, and to read the position coordinates and direction vectors of each particle in turn. The state of particle accumulation is reproduced. A free tetrahedron mesh is used to divide the model by using the "physical" in the COMSOL mesh division function, and the physical properties of the matrix material and the matrix particle material are assigned. Fourth, according to the above steps, the material model with different volume fraction is generated in turn, and the capacitor model is solved numerically according to the principle of section 1.2, and the efficiency dielectric properties of agricultural particulate matter are obtained.

2.4 Data processing and analysis

The EDEM softwave (Edem solutions Inc., Edinburgh, UK) was used to complete particle construction and stacking simulation. The COMSOL Multiphysics 5.3(Comsol Inc., Stockholm, SWEDEN), Matlab R2012a (Mathworks, Massachusetts, USA) and Atos origin, Amsterdam, NETERLANDS) were used to complete stacking reproduction, model building, numerical computation, and data processing analysis.

3 Results and analysis

3.1 Effect of shell thickness on efficiency dielectric properties of agricultural materials

The efficiency dielectric properties of agricultural matter is: $\varepsilon_{eff} = \varepsilon'_{eff} + \varepsilon''_{eff}$, d as the thickness of shell, the radius of nucleolus after removing shell is R , and the volume fraction is f_v . The dielectric properties of the matrix phase dielectric constant $\varepsilon_1 = 1.5$, the shell and the core layer are set as $\varepsilon_2 = \varepsilon'_2 + \varepsilon''_2$, $\varepsilon_3 = \varepsilon'_3 + \varepsilon''_3$, respectively. where $\varepsilon'_2 / \varepsilon'_1 = 4、1/4$, $\varepsilon'_3 / \varepsilon'_1 = 2$, $\varepsilon''_2 = \varepsilon''_3 = \sigma / \omega\varepsilon_0$, and ε_0 is vacuum dielectric constant (the same below). Under the condition of $f_v \in (0.1, 0.45)$,

$d/R \in (0.05, 0.2)$, $\sigma = 0.058m/S$ and fixed microwave frequency, the relationship between ε_{eff} and f_v, d/R, ε_2 is calculated by using random stacking model. The result shows that the efficiency dielectric properties of the material vary with the volume fraction (f_v) and are related to the value of the d/R. If $\varepsilon_2 > \varepsilon_1$, the dielectric constant ($\varepsilon'_{eff}(f_v, d/R)$) increases with the increase of f_v and d/R. The dielectric loss factor ($\varepsilon''_{eff}(f_v, d/R)$)decreases but increases with the increase of f_v, d/R. If $\varepsilon_2 < \varepsilon_1$, the value of $\varepsilon'_{eff}(f_v, d/R)$ increases but decreases with the increase of f_v. The junction layer has a great influence on the imaginary part of the dielectric constant of the material.

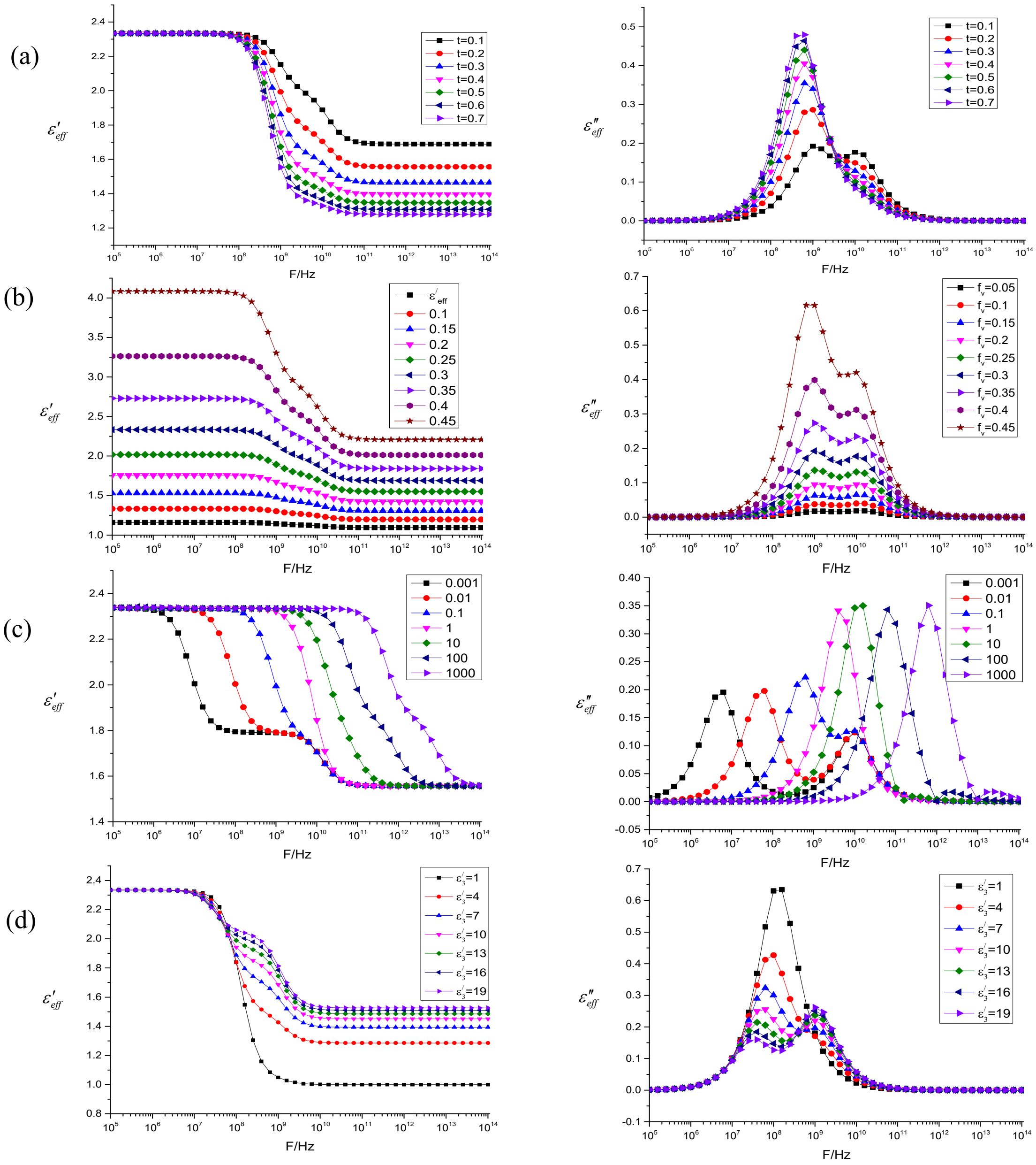

Fig.2 Varying efficiency dielectric properties of mixtures under different parameters

3.2 Effect of microwave frequency on efficiency dielectric properties of agricultural materials

The dielectric properties of the shell and core are set as $\varepsilon_2 = 1.5 - j(\sigma_2 / 2\pi F \varepsilon_0)$, $\varepsilon_3 = 10 - j(\sigma_3 / 2\pi F \varepsilon_0)$, and volume integral is $f_v = 0.3$, respectively. The varying of the efficiency dielectric properties of the mixture with the thickness of shell is simulated and shown in Fig .2(a).

The results shows that: (1) With the increase of shell thickness, the efficiency dielectric constant of the mixture in the low frequency region does not change much, but the value of the high frequency region decreases with the increase of shell thickness. When the frequency reaches a fixed point ($F_0 = 1 \times 10^{11}$ Hz), efficiency dielectric properties corresponding to different thickness values do not change with the frequency. (2) The efficiency dielectric loss factor of the mixture is bounded by $F_1 = 3.98 \times 10^9 Hz$ and two absorption peaks appear on both sides of the F_1. The amplitude of the low frequency absorption peak is larger than the high frequency absorption peak. With the increase of shell thickness, the low frequency absorption peak increases rapidly and the high frequency absorption peak decreases rapidly. The high frequency absorption peak disappeared at $t \geq 0.4$.

3.3 Effect of volume fraction of shell on efficiency dielectric properties of agricultural materials

Set t=0.1, the effect of the volume fraction of the shell on the efficiency dielectric properties of the mixture is simulated as shown in Fig .2(b). The diagram shows that: (1) The dielectric constant of the mixture increases with the increase of the volume fraction, but for a fixed volume fraction, the efficiency dielectric constant decreases with the increase of the frequency. (2) In the frequency range ($10^7 \sim 10^{12}$ Hz), the dielectric loss factor of the mixture appears two absorption peaks, both high frequency and low frequency, which increase with the increase of volume fraction.

3.4 Effect of shell conductivity on efficiency dielectric properties of agricultural materials

Set $f_v = 0.3$ and t=0.2, the influence of the conductivity of the shell material on the dielectric properties of the mixture as shown in Fig .2(c). The diagram shows that: (1) the maximum dielectric constant of the mixture remains constant as the conductivity of the shell material changes. When the conductivity of the shell is lower than that of the core, the minimum dielectric constant of the mixture remains unchanged, and when the conductivity of the shell is larger than that of the core, the minimum dielectric constant remains unchanged. (2) With varying of the conductivity of the shell material, two absorption peaks appear in the mixture. When the conductivity of the shell changes from 0.001 to 103, the central frequency of the low frequency absorption peak changes from 6×10^6 Hz to 2×10^{12} Hz. (3) when $\sigma_2 < \sigma_3$, the low frequency absorption peak increases with the increase of conductivity and moves to the high frequency direction, and the high frequency absorption peak remains unchanged with the increase of conductivity. At $\sigma_2 > \sigma_3$, the low frequency absorption peak remains unvaried with the increase of conductivity but moves to the high frequency direction, and the high frequency absorption peak increases slightly with the increase of conductivity and moves to the high frequency direction.

3.5 Effect of kernel dielectric constant on efficiency dielectric properties of agricultural materials

The effect of the dielectric constant change of the kernel on the efficiency dielectric properties of the mixture is shown in figure 2(d). The diagram shows that :(1) With the increase of the dielectric constant of the kernel, the maximum efficiency dielectric constant of the mixture appears in the low frequency region and the numerical change is not obvious, but the dielectric constant appears multiple intersection points in the calculated frequency range. (2) In the range of dielectric properties ($\varepsilon_3 \in$（1，19）), the efficiency dielectric loss factor of the mixture shows two obvious absorption peaks in the frequency range(10^7~10^{11} Hz), the high frequency absorption peak increases with the increase of the dielectric loss factor of the core and gradually tends to saturation, and the low frequency absorption peak increases with the decrease of the dielectric loss factor of the core and shifts to the high frequency. When $\varepsilon_3 = 1$, the high frequency absorption peak disappears.

4 Conclusion

The numerical simulation model is established by discrete element method, finite element method and average energy method. The variation of efficiency dielectric properties of core-shell agricultural materials under different parameters was analyzed and obtained. The numerical results obtained by simulation can provide basis for the development of electromagnetic drying process of agricultural materials and the setting of process parameters of drying equipment. This simulation model is suitable for the study and analysis of RF frequency range. The related research on temperature change and frequency change will be carried out in the next step.

Acknowledgments

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