Three-dimensional Random Modeling of Particle Packing Through Growth Algorithm and the Microwave Propagation in the Model

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***Abstract*-A three-dimensional random modeling method based on growth algorithm is proposed in this paper. The models can be employed to investigate practical problem of coal particle packing with different size range. Full-wave simulations based on the models are able to recognize microwave attenuation and propagation characteristics. Some useful conclusions are obtained for microwave power application.**

I. INTRODUCTION

Material will absorb some microwave energy when it was radiated by microwave. Microwave energy will cause some effects on the material such as temperature rising or promoting other chemical reactions. On the contrary, the existence of the material will change the field distribution of the microwave. Field interaction between material and microwave makes kinds of special process possible. It is a vast area of science, and has appealed an increasing interest from kinds of researchers [1]. An important factor in microwave field interaction is the complex permittivity of the material, especially the image part in other words the loss tangent. The loss tangent stands for the ability to absorb microwave energy [2]. Different materials have different loss tangents so as to different reaction to microwave. On the other hand, the absorption will also vary with the microwave frequency.

In practice, material is directly exposed to microwave for radiation. If the material is uniform field distribution in the material can be analyzed by classical electromagnetic theory. Then, the attenuation and propagation characteristics can be analyzed. However, many materials in practice are not uniform. Some of them are composed of thousands of small particles. The macro object used in practice is piled up by micro particles. There exist air interspaces everywhere in the object which means the object is a mixture of air and material. The microwave propagation in such models is worth investigation.

There is special modeling software for arbitrary shaped particle packed together in civil engineering [3]. Models can perfectly simulate the actual accumulation of stones in the concrete. However, such modeling method in electromagnetic field and analysis of the microwave attenuation and propagation in such models were scarcely reported. Some papers about mixtures were published, but they concentrated on equivalent permittivity of the mixture. They aimed to forecast the discipline between equivalent permittivity and the variation of the mixing ratio [4]-[6], paid little attention to modeling and microwave attenuation and propagation. Investigation of microwave attenuation and propagation in such models will help to improve the application of microwave power in material processing, such as microwave coal desulphurization, food heating, etc.

This paper proposes a random modeling method to investigate object piled up by small particles. Full-wave simulation based on such models is suggested to study microwave attenuation and propagation. The structure of this paper is as follows. Firstly, three-dimensional random modeling method is proposed. Models of the same size are built up to demonstrate the feasibility of the modeling method. Next, the measured complex permittivity of coal is employed to construct the model. With the full-wave simulation software Ansoft HFSS, the microwave attenuation and propagation in mixture of lossy medium coal and air is studied. Models composed of small particles of different sizes are simulated at different frequencies. Then, the influences of the operating frequency and the size of particle on the performance of the attenuation and propagation can be recognized. The propagation characteristic of the gapless objects is displayed for comparison as well.

II. MODELING OF PARTICLES PACKING

A. Model Process

Take the simplicity into consideration particles are all supposed to be spheres. Absolutely, sphere can be changed into polyhedron easily with further program. Polyhedron can constitute by several intersected planes which are picked randomly in the sphere, or linked by dots which are picked randomly in the sphere.

The modeling program starts with a region with specific sizes, the maximum and minimum diameter of spheres. Those parameters can be set according to practical requirement. A modeling flowchart is shown in Fig. 1 to present details of the modeling method.

In this modeling program, it is supposed that one unit of the incremental of sphere diameter is 0.05mm. When the distance between two spheres is less than 0.01mm they are assumed to be intersected.

The models obtained each time are different considering the randomness of the modeling process. Three models of the same size are shown in Table I. The length l, width s and height h of the investigated region are 50mm, 50mm and 20mm, respectively. The diameter range is 3mm~6mm. Another three models of different diameters and heights are displayed in Table II. The height is 10mm, 20mm, and 25mm, respectively.

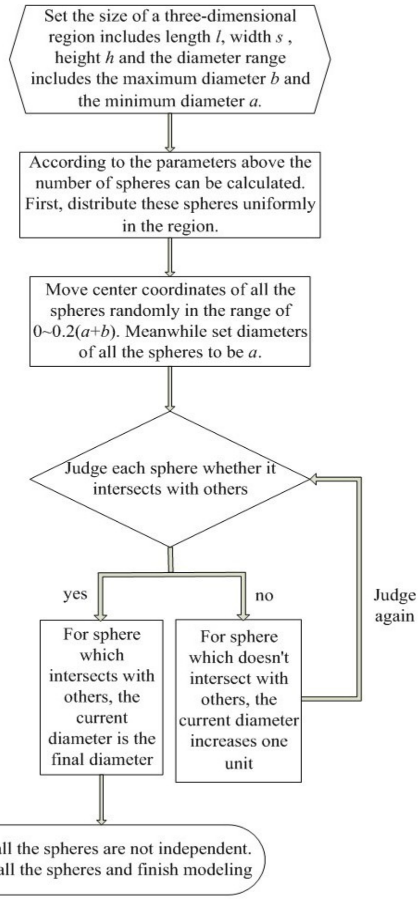


Figure.1 Flowchart of the modeling process

TABLE I

Three Random Models with the Same Size

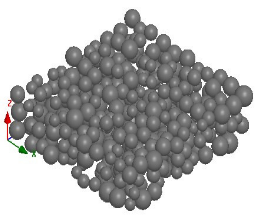
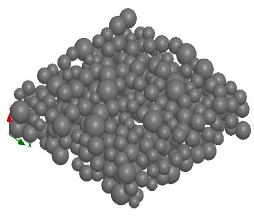
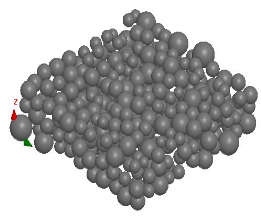
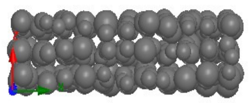
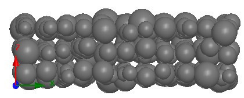
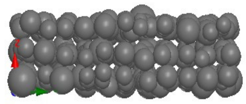
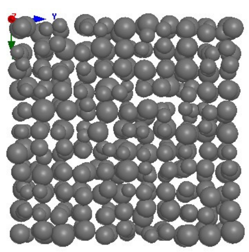
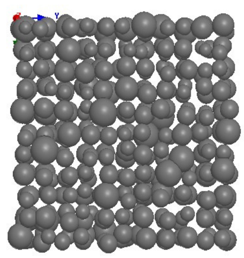
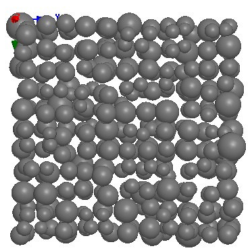
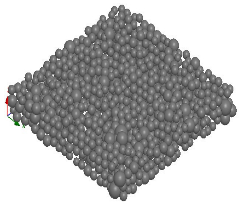
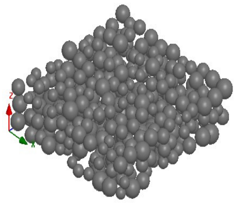
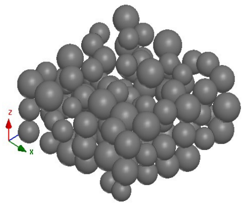
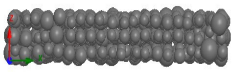
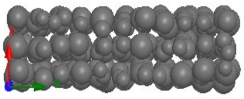
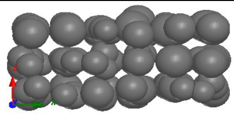
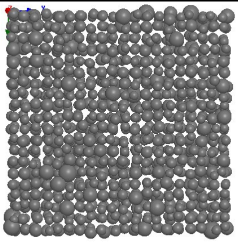
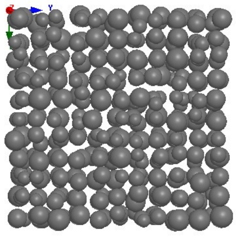
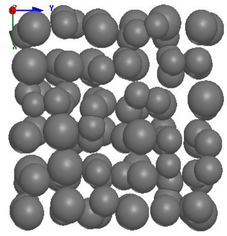
Southeast view			
Left view			
Top view			

TABLE II

Three Random Models with the Different Diameters

	Diameter 2-3mm	Diameter 3-6mm	Diameter 6-10mm
Southeast view			
Left view			
Top view			

B. *Model Analysis*

Random function was applied in the modeling program to investigate the practical situation of particle packing.As is well known, for objects with size that is far less than the microwave wavelength the inner structure has little effect on microwave field distribution. Generally, when c/d is less than 0.01, c is assumed to be far less than d. 3GHz is the highest frequency we investigated in this paper. The wavelength of 3GHz is 100mm. Sphere with radius less than 1mm can be considered negligible since 1/100 equals to 0.01. Thus, for diameters 2mm is set as a boundary. Actually, simulating models with very small spheres are both time-consuming and meaningless. Therefore, models will be analyzed all have diameters which are greater than 2mm.

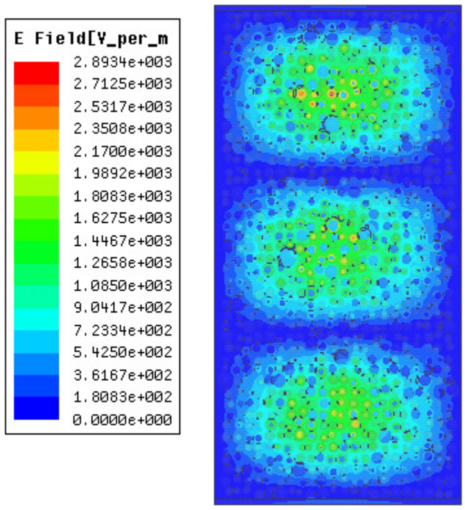


Figure.2 Field distribution at frequency 2.45GHz

III. SIMULATED RESULTS

The external shape of the model built by the above method is cuboids. Thus, it is convenient to put the model into perfect rectangular waveguide to analyze the characteristics of attenuation and propagation. The dielectric permittivity of the model is set as 4.5, while the loss tangent is 0.1, which are measured results of coal powder in our lab. When diameters of the spheres range from 3~6mm and microwave frequency at 2.45GHz field distribution is shown in Fig. 2.

As shown in Fig. 2, the field distribution is affected by the spheres. A number of simulations are conducted to recognize the effects of different sizes on the attenuation and propagation characteristics. Simulation results are listed in Table III. To ensure accuracy, several models of the same size are built and simulated. Transmission coefficients listed in Table III are transformed from γ of TE modes in perfect rectangular waveguide to γ of TEM modes in free space [7].

TABLE III

Transmission Coefficient $\gamma=\alpha+j\beta$ with Different Sizes under Different Frequencies

f / γ / d	0.915 GHz	1.5 GHz	2 GHz	2.45 GHz	3 GHz
0 mm	2.02+ j40.6	3.36+ j65.9	4.52+ j87.1	5.56+ j105.9	6.85+ j128.7
2~3 mm	2.02+ j40.9	3.13+ j66.1	4.52+ j86.9	5.56+ j105.9	6.84+ j128.8
3~6 mm	2.02+ j40.9	3.02+ j66.1	4.48+ j86.6	5.56+ j106.0	5.68+ j129.6
6~10 mm	2.02+ j40.9	3.01+ j66.1	5.68+ j86.5	5.56+ j106.0	5.68+ j129.5
10~15 mm	2.01+ j40.8	3.13+ j66.07	5.45+ j86.6	5.56+ j105.9	5.44+ j129.8
15~20 mm	2.01+ j40.9	3.36+ j65.9	4.52+ j87.0	5.56+ j106.0	6.85+ j128.8
30~35 mm	2.00+ j41.1	3.36+ j65.9	4.51+ j87.0	5.55+ j105.9	5.30+ j128.1

Higher attenuation coefficient indicates more microwave power is absorbed, and thus leads to a higher efficiency of microwave energy application. The overall trend in Table III is non-monotonic. For the frequency of microwave from 915MHz to 3000MHz the wavelength ranges from 327mm to 100mm. Results of the first group vary little from the model without air. The results verified the fact that spheres with small size have little effect on microwave propagation. Generally, objects are ground to powder in order to be radiated completely. However, according to the results above there is no need to grind objects when low-frequency microwave is used for material processing. With crushed objects of small size, the same performance of processing and efficiency can be achieved. This will greatly decrease physical pre-treatment processes.

Take the convenience of physical pre-treatment processes and penetration depth into consideration, the best size for different frequencies can be obtained. This will help to simplify grinding treatment and increase utilization efficiency of microwave power application significantly.

IV. CONCLUSION

A three-dimensional random modeling method is proposed in this paper. The model is able to investigate the problem of practical particle packing. Simulations based on the model are conducted to investigate the microwave attenuation and propagation characteristics. Through several simulations, some useful conclusions are obtained to guide the microwave power application, especially for application like coal desulphurization.

ACKNOWLEDGMENT

This work is supported in part by the National Basic Research Program of China under Grant No. 2012CB214900 and in part by the Program for Changjiang Scholars and Innovation Team in University under Grant No. IRT1113.

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