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Visualization of the Particle Dendrite Deposition Phenomenon by Using Computer Technology

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Abstract

The phenomenon of dust particles surface deposition in the fibrous medium showed the dendrites structures, which had been confirmed and could be visualized by using computer technology for better understanding particle deposition behavior on filtration process of fibrous media. The pseudo-random movement model was used and the impact of particle inertia movement and diffusion movement on the dust cake growth process in the fibrous filtration media surface were studied by simulation. The simulation method and programs were introduced in detail in the paper, and the result simulation of particle deposition was in good agreement with experimental test result. The results showed that more irregular the dust cake morphology structure was, the greater the dust particles dispersion was and the greater dust cake porosity was.

Keywords

Dust Cake, Porosity, Fibrous Filtration Media, Dendrite Structure, Numerical Simulation

Subject Areas: Water, Energy, Environmental Modeling and Simulation

1. Introduction

Dendrites structure of dust cake formation process [1]-[3] was studied earliest using computer simulation by Payatakes (1976) trying to understand knowledge of dust particles in the fibrous filtration media surface deposition. Ideal tree structure was proposed which was as similar as the actual tree structure and a kinetic equation of

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the single ideal tree growth was established by Payatakes and Tien (1976) for predicting the instantaneous filtration acts. Two basic characteristics of aerosol filtration simulation [4] [5] were put out by Tien *et al.* (1977) and Wang *et al.* (1977). Three-dimensional simulation model was established by Baumgartner *et al.* (1987), multi-size dust particles were used in the simulation, the process of particles deposition [6] could only be used to demonstrate phenomenon that simulation computing workload was too great. Dust deposition process in fibrous media was simulated by Jie Cai [7] (1992) using multi-size dust particles in three-dimension. Filtration properties of fibrous filter in the blocking state were studied by D. Thomas *et al.* (2001) using fluorescence soda aerosols; dust filter sections were divided into a number of thin films by using sticky tape, and changes of particle deposition along with filtration depth were observed by using electron microscopy scanning. These results showed that particles deposited on the depth of filter structure and formed dendrites deposition in initial filtration stage, dust particles mainly deposited on the surface of filter and formed cake structure with the dust load increasing [8]. Dust cake pore structure was studied by BHKaye (1989) to prove that the cake structure could be described by Sierpinski fractal [9]. Particle motion mechanism and impact of the interaction between particles and particles on the dust cake morphological structure had been inspected [10] by DHoui basis on DLA model. Dust cake growth process in fibrous medium and dust cake morphology structure changing relationship between the characteristics of particle motion and particle size distribution were simulated by using pseudo-random model. The dendrite deposition phenomenon was visualized by using computer simulation technology in this paper.

2. Cake Formation Simulation Model

The physical mechanism of dust cake formation was very complex, the relationship between the physical mechanism and dust cake growth and morphological structure were not clearly understood. Generally speaking, Van der Waals force; static electricity force; gravity; Brownian diffusion force would exist in particles. Brownian diffusion force and several other forces would exist when the particle radius was less than 1 μm.

These forces would existed at same time or existed partially, The role of these forces size and strength were closely related to surface roughness of fibrous media, the physical and chemical properties of dust particles when dust cake forming. How did these forces lead to dust cake forming and how did its affect dust cake morphological structure, the quantitative description and analysis could not be obtained at present yet.

Fibrous medium were expressed by a row of circles column, dust particles were expressed by a lot of circle ball. Dust particles were assumed to generate randomly in the control surface when dust particles arrived near to fibrous media surface or deposition particles, particles were adhered in the fiber or deposition particle due to van der Waals force action and the particles deposited continuously to form dust cake in fibrous media surface.

As the interaction between particles and particles occurred in real particles deposition process, the interaction between particles and fibrous media and the interaction between particles and gas flow were very complex, there were great difficulty in computer simulation and visualization of real dust cake formation process. Therefore, following assumptions were put out to establish the simplified model on basis of considering the impact of the main factors. Firstly dust particles were assumed as spherical shape, secondly static electricity, gravity and other forces were assumed to no exist in particles, thirdly dust particles were assumed to deposit gradually in fibrous medium surface and to form dust cake dendrite structure, inter-particle interaction force were assumed to no affect particle motion, dust cake was assumed as incompressible, finally dust particles were adhered by Van der Waals force once its moving to contacted with fibrous media or dust particles.

Numerical simulation program flow chart of dust cake forming process in fibrous media surface was shown in **Figure 1**.

3. Dust Particles Motion Simulating

The particle motion was divided into ballistic movement model and the random movement model, which were inertia movement and random movement.

The gas flowed perpendicular to fibrous media, electric force action, hot swimming force action and Brown force action were ignored. The diffusion movement would be taken into account when the particle size was less than 1 μm, The diffusion deposition and inertial deposition of dust particle were detail simulation studied by reference [11]. The results showed that dendrites deposition structure which was formed by diffusion movement was loose morphology structure, and dendrites deposition structure which was formed by the inertial movement
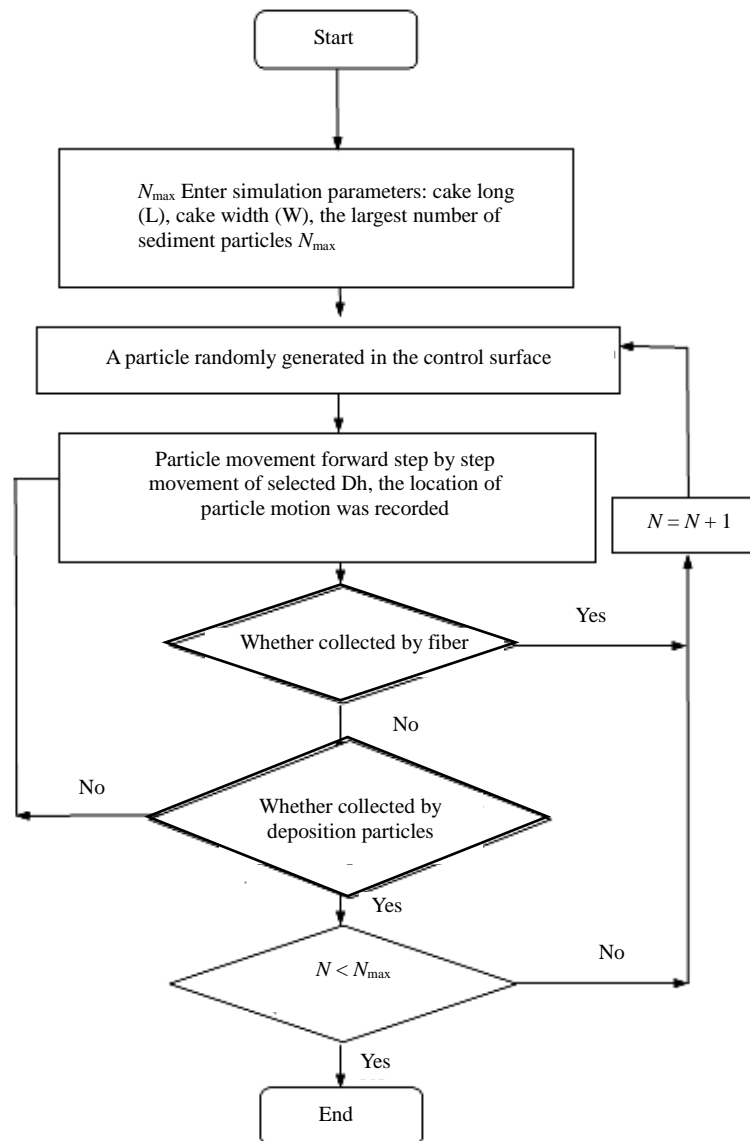
Figure 1. Flow chart of simulation program.

was close morphology structure relatively. The diffusion movement and inertia movement both exited on dust particles when dust particles diameter was less than 1 μm in the actual filtration process. As dust particle deposition which was controlled by inertial movement and diffusion movement were studied rarely, so that the proportion of inertia movement and diffusion movement affected dendrites deposition morphology, which were studied by this paper to explore the impact of particle motion mechanism on deposition morphology structure .

Dust particles were assumed to move in square grid and its moving probability was P from one point to another, P (probability) expressed the moving probability on three remainder direction, then 4P expressed diffusion movement probability, (1-4P) expressed inertial movement probability. *Pe* numbers were defined as the ratio number of inertial movement and diffusion movement [12]. The schematic diagram of particles motion was shown by **Figure 2**.

If dust particles were diffusion deposition, particles inertial movement probability was equal to zero, dust particles moving probability was equal to 0.25 for four directions. If dust particles were inertial deposition, particles diffusion movement probability was equal to infinity. The simulation results of literature [11] were special results of this paper.

Particle trajectories were showed by **Figure 3** under different *Pe* numbers, dust particle diffusion movement

trajectories were showed in **Figure 3(a)**, particle trajectories were both controlled by the diffusion movement and the inertia movement, which was shown in **Figure 3(b)**, particle inertial movement trajectories were shown in **Figure 3(c)**. Its deposition morphology structures were illustrated by **Figure 4**. Impact effect of particle motion mechanism on deposition morphology structure was obvious, which was known from **Figure 4**.

4. Simulation Results of Dust Cake Growth

Particle deposition simulation results were shown by **Figure 5** at different *Pe* numbers. It can be seen from Figure 5 that morphology of the dust layer was related with the cake structure, dust layer was looser and more open, and particles spatial distribution was more uneven when *Pe* number was smaller [13].

When *Pe* varied from 1600 to 1, morphological of the dust cake layer was not varied obviously, and morphological of the dust cake layer varied significantly when *Pe* varied from 1 to 0.025, dendritic structure of dust layer can be clearly observed. When *Pe* = 0.05 and *Pe* = 0.025, particle deposition exhibit features can be divide as two deposition stages. The first stage (it was shown below in phantom line section), the number of particles deposited increased with the height of deposited layer decreased; the second stage (it was shown above in phantom line section), the number of particles deposited increased with the height of the deposited layer increased. If number of deposition particles increased constantly and the two phases will appear alternately. Further, surface curves of dust cake became more irregular when *Pe* number was smaller.

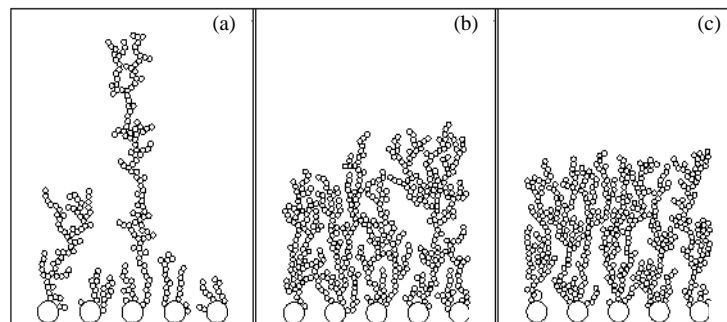## 5. Impact of Particle Size Distribution on Porosity of Dust Cake

Dust particle size distribution was assumed as the normal distribution. Median particle diameter was assumed as
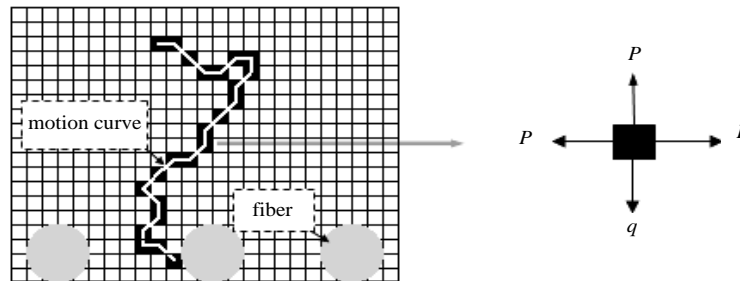
Figure 2. Schematic diagram of particle motion.
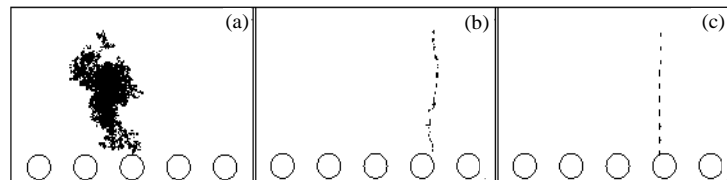
Figure 3. Particle trajectories at different *Pe* Numbers.

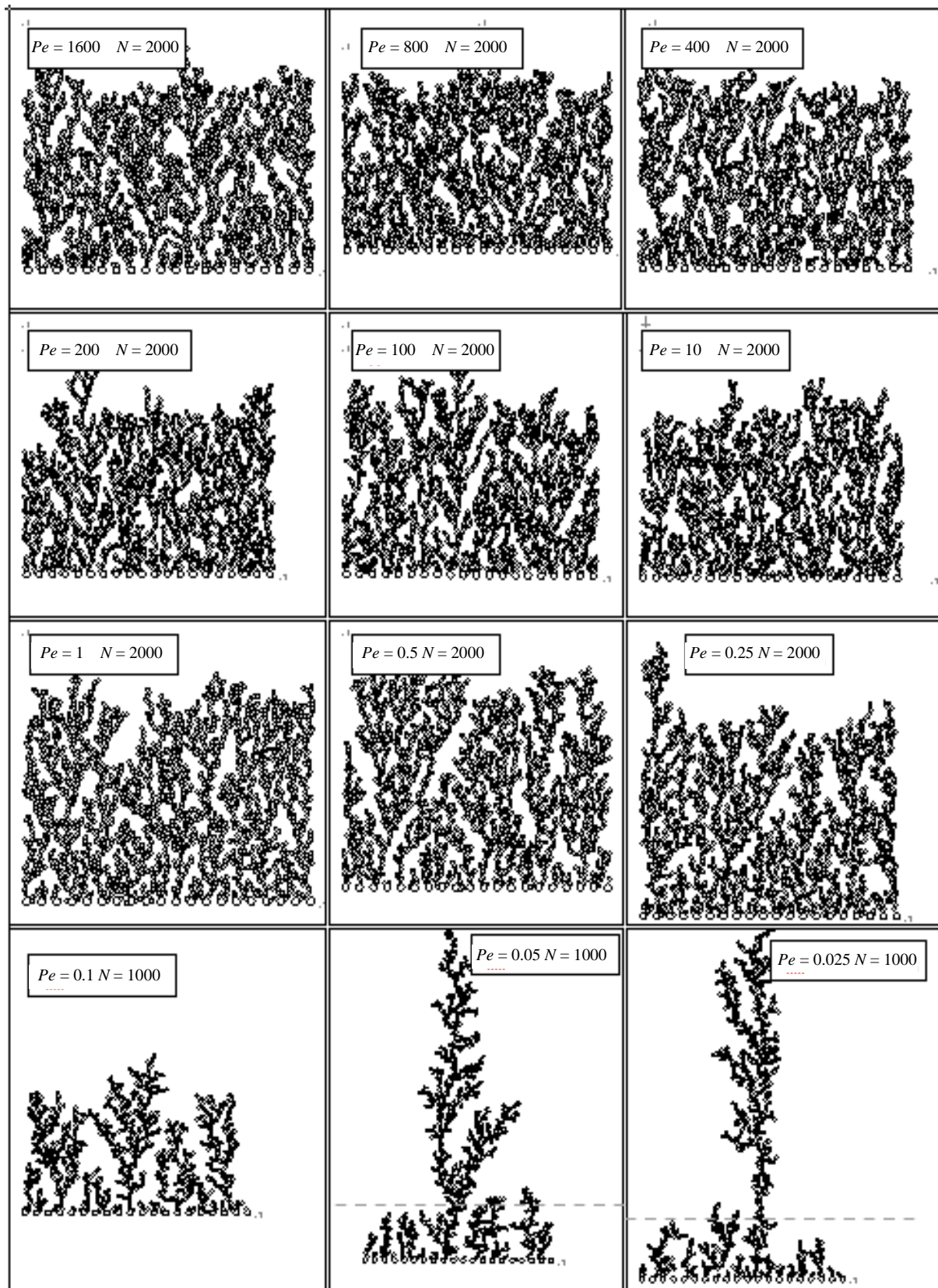**Figure 4.** Deposition morphology structure at different *Pe*.

$Pe = 1600$ $N = 2000$	$Pe = 800$ $N = 2000$	$Pe = 400$ $N = 2000$
$Pe = 200$ $N = 2000$	$Pe = 100$ $N = 2000$	$Pe = 10$ $N = 2000$
$Pe = 1$ $N = 2000$	$Pe = 0.5$ $N = 2000$	$Pe = 0.25$ $N = 2000$
$Pe = 0.1$ $N = 1000$	$Pe = 0.05$ $N = 1000$	$Pe = 0.025$ $N = 1000$

**Figure 5.** Morphological structure in different *Pe* numbers.

dp, maximum particle diameter was assumed as 2 dp, the smallest particle diameter was assumed as 0.2 dp, fiber diameter was assumed as df = 2 dp, simulation region length was assumed as L = 80 dp, the largest number of deposited particles was assumed as $N = 2000$, mean square error was assumed as $\sigma = 1, 2, 3, 4, 5, 6$, dust particle deposition was considered as inertial deposition. Dust cake morphological structures were obtained by computer simulation and its results were shown in **Figure 6**. 3D morphological structure of particles deposition was visualized by using computer simulation technology also and 3D simulation result were shown by **Figure 7**.

The simulation results were compared with simulation results of related literature to confirm the correctness of simulation model. The particle deposition typical simulation results were compared with experimental test results by **Figure 8**. The simulation results were good agreement with experimental results.

6. Conclusions

The particle deposition had been simulated by using computer technology, dust particles deposition structure was dendrite structure and simulation results were in good agreement with experimental result. It was shown that computer could help us to well understand the nature phenomenon if computer technology was better used by us.

2D and 3D dust particles simulation model were established by this paper based on the DLA evolution model. The impact of particle motion mechanism and the particle size distribution on particle deposition morphology structure were considered by this paper. The results showed that dust cake structure was depending on the particle movement mechanism; stronger particle diffusion, more uneven deposition structures; greater dust dispersion moving and greater dust cake porosity, more uneven dust cake structure. Dust cake structure depended on particle dispersion moving proportion, stronger particle dispersion moving and more uniform dust cake structure. Large particles deposition formed uniform dust cake structure, and small particles deposition formed non-uniform dust cake structure.
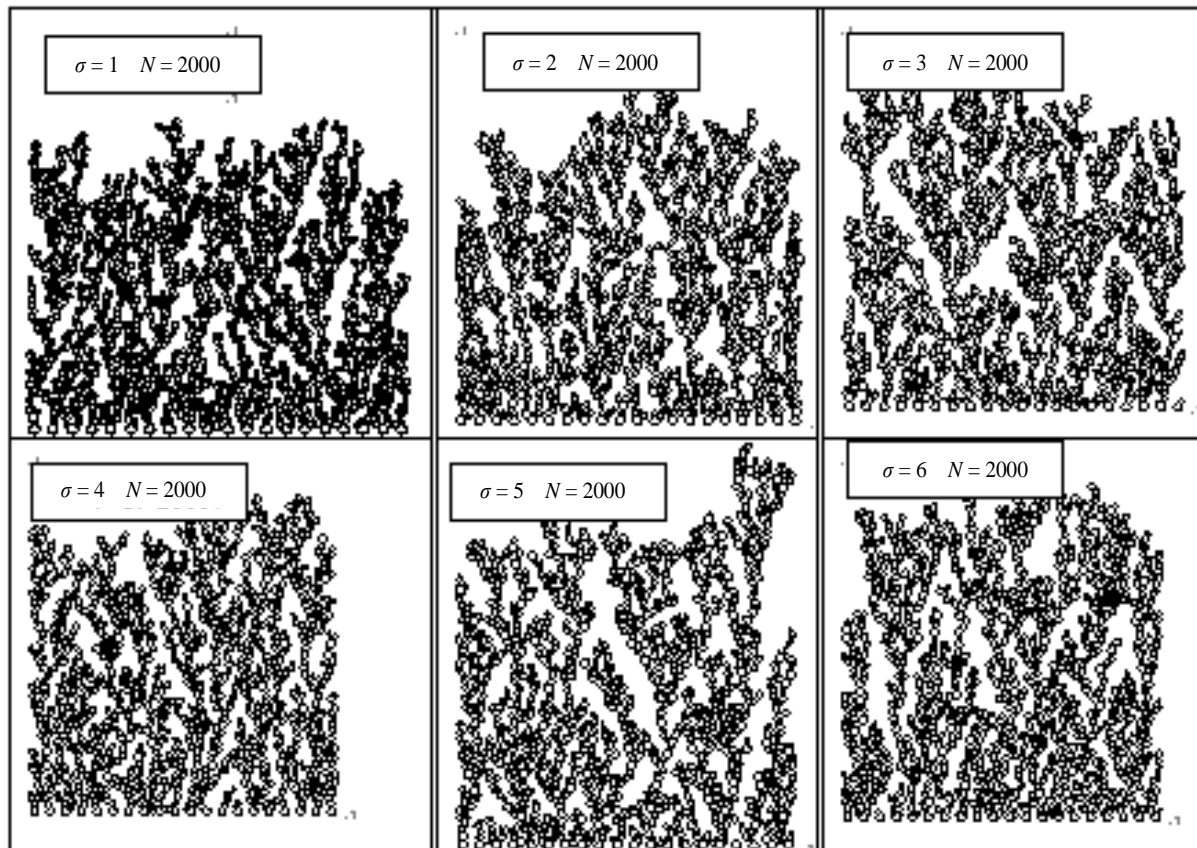
Figure 6. 2D Morphological structure of dust cake.
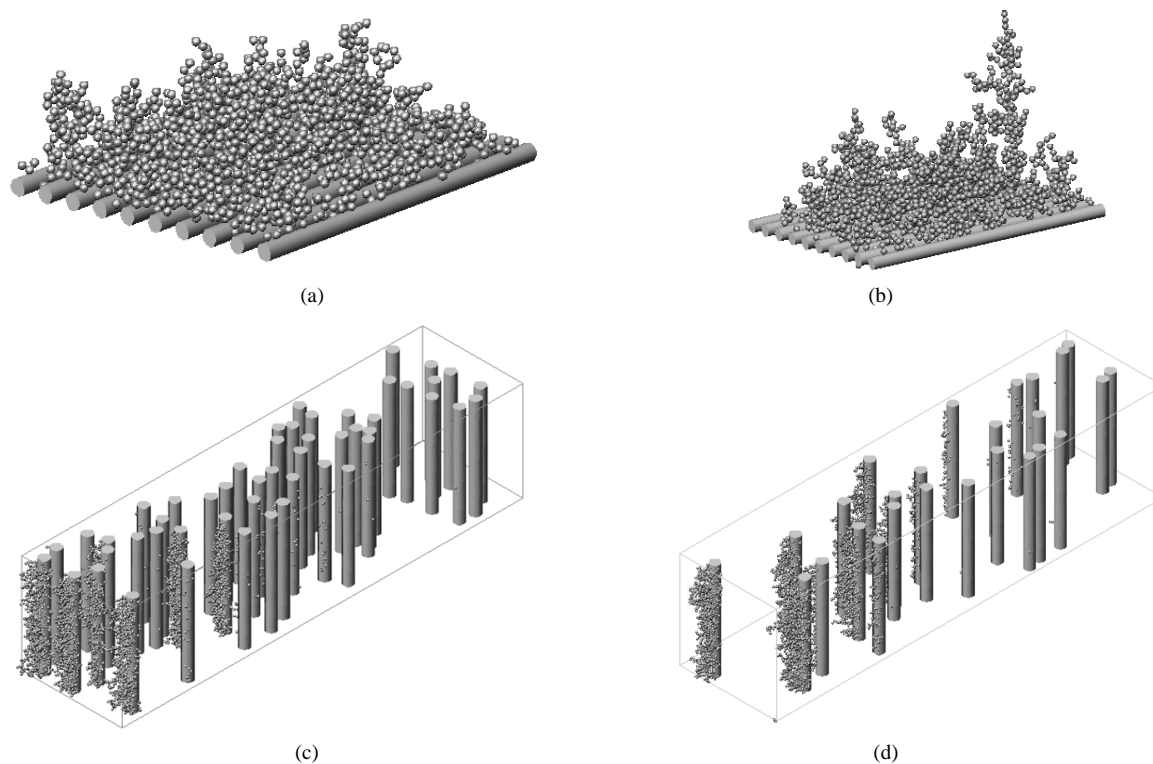
Figure 7. 3D dust cake morphological structure. (a) *Pe* = 0.25, *N* = 2000; (b) *Pe* = 0.1, *N* = 2000; (c) SVF = 0.1; (d) SVF = 0.05.
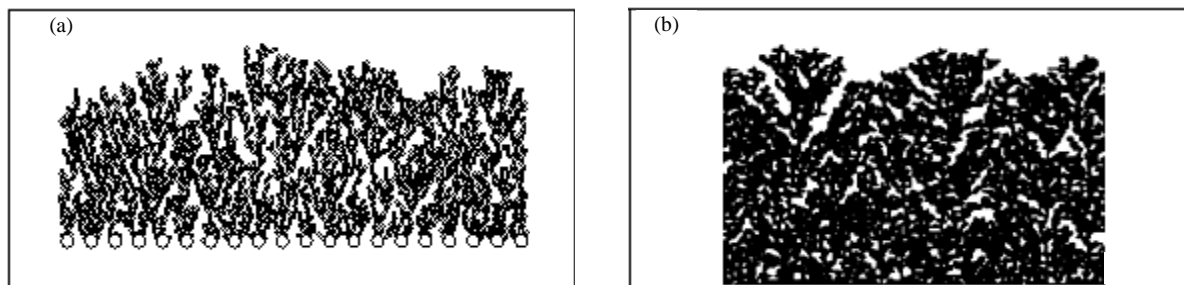
Figure 8. Simulation result comparing with experimental result. (a) Simulation results; (b) Experimental results.

Acknowledgements

References

[1] Billings, C.E. (1966) Effects of Particles Accumulation in Aerosol Filtration. California Institute of Technology, Pasadena.

[2] Payatakes, A.C. and Gradoń, L. (1980) Dendritic Deposition of Aerosol Particles in Fibrous Media by Inertial Impaction and Interception. *Chemical Engineering Science*, **35**, 1083-1096. http://dx.doi.org/10.1016/0009-2509(80)85097-4

[3] Payatakes, A.C. and Gradoń, L. (1980) Dendritic Deposition of Aerosols by Convective Brownian Motion Diffusion for Small, Intermediate and Large Knudsen Numbers. *AIChE Journal*, **26**, 443-454. http://dx.doi.org/10.1002/aic.690260316

[4] Tien, C., Wang, C.S. and Barot, D.T. (1977) Chainlike Formation of Particle Deposits in Fluid-Particle Separation. *Science*, **196**, 983-985. http://dx.doi.org/10.1126/science.196.4293.983

[5] Jung, Y.W. and Tien, C. (1993) Simulation of Aerosol Deposition in Granular Media. *Journal of Aerosol Science and*

Technology, **18**, 418-440. http://dx.doi.org/10.1080/02786829308959614

[6]   Baumgartner, M. and Löffler, F. (1987) Three-Dimensional Numerical Simulation of the Deposition of Polydisperse Aerosol Particles on Filter Fibers—Extended Concept and Preliminary Results. *Journal of Aerosol Science*, **18**, 885-888. http://dx.doi.org/10.1016/0021-8502(87)90147-9

[7]   Cai, J. (1989) Some Remarks on Efficiency Due to Dendrite Formation. *Journal of Aerosol Science*, **20**, 969-962.

[8]   Thomasa, D. and Penicot, P. (2001) Clogging of Fibrous Filters by Solid Aerosol Particles: Experimental and Modeling Study. *Chemical Engineering Science*, **56**, 3549-3561. http://dx.doi.org/10.1016/S0009-2509(01)00041-0

[9]   Kaye, B.H. (1991) Describing Filtration Dynamics from the Perspective Fractal Geometry. *KONA*, **9**, 48.

[10]   Houi, D. and Lenormand, R. (1986) Particle Accumulation at the Surface of a Filter. *Filtration and Separation*, **7/8**, 238-241.

[11]   Meakin, P. (1983) Diffusion-Controlled Deposition on Fibers and Surfaces. *Physical Review A*, **27**, 2617-2623. http://dx.doi.org/10.1103/PhysRevA.27.2616

[12]   Fu, H.M. and Zhu, H. (2009) Simulating Deposition of Aerosol Particles on Single Fiber Surface. *Journal of Donghua University* (*English Ed.*), **26**, 252-258.

[13]   Fu, H.M. and Zhu, H. (2010) Fractal Characteristics of Aerosols Deposition in the Fiber Surface. *Journal of Donghua University* (*English Ed.*), **27**, 376-384.