Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(2):401-405

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Granular flowing characteristics of tower vacuum dryer by 3D discrete element method

Zhang Zhijun[1]*, Zhang Yuekai[1], Zhao Lili[2], Zhang Shiwei[1], Xu Chenghai[1], Su Tianyi[1] and Zhao Shuangshuang[3]

[1]School of Mechanical Engineering and Automation, Northeastern University, Shenyang, P. R. China
[2]School of Mechanical Engineering, Shenyang University, Shenyang, China
[3]Shenyang Aircraft Design and Research Institute, Shenyang, P. R. China

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ABSTRACT

In China, the tower vacuum dryer has been studied and developed for a number of years. These studies have highlighted its important advantages in energy, quality and efficiency of drying process. The granular flowing characteristic has been studied in 2D method. But the 3D simulation method has not been given. Conditions to avoid blocking of the material within the inner portion of the dryer were re-determined. The retention time of the granular material was studied and a mixture characteristic across the dryer was re-determined. The simulation results makes the results of past more be creditable.

Key words: Vacuum drying, Granular flowing characteristics, Discrete element Method (DEM), Simulation

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INTRODUCTION

Vacuum drying produces good quality product, but continuous drying is very difficult, it is unable to handle the volume's product involved in maize drying. In China, the tower vacuum dryer has been studied and developed for a number of years. It has shown significant advantage in terms of saving energy, being environment friendly, handling volume's product and producing good quality dried materials [1,2] The heat transfer in tower vacuum dryer occurs mainly by heat conduction and to a lesser extent by convection and radiation. In order to guarantee the heat supply, pipes with lozenge-shaped perforations were used [3]. The maize is gravity-fed through the gap between the lozenge-shaped pipes. The blockages between the lozenge-shaped pipes must be avoided in order to guarantee the drying process.

The flow of maize in the dryer is granular flow. Given the research goals and the desired level of accuracy, two kinds of models for granular flow were adopted: the Continuum Mechanics Method, CMM and the Discrete Element Method, DEM. The former is also termed a macro-model, whereas the latter is termed a micro-model. In DEM, the medium is regarded as the discrete, independent element, and these elements have a certain geometry, including their shape, size and arrangement, as well as their physical and chemical properties. The size of element is microscopic and only affected by the border elements. The movement of the element is controlled by the traditional equation of motion, and the medium distortion and evolvement is described by other element motions at each other location. The DEM has been widely applied for granular flow in silo blowndown [4-11] but studies on the mixing characteristics of such dryers are few.

In order to improve the technology and optimize the drying process, granular flow characteristics in a tower vacuum dryer has been simulated by adopting a discrete element method and applying the PFC2D program [12]. The results show that the density, stiffness, friction coefficient of granular and friction coefficient of wall have obvious influence to the flow characteristics. The stiffness of wall has little impact. The granular is whole flow in continuous drying process; but the granular has no obvious cross-flow. For granular of the certain diameter, it can guarantee that it do not take place blockage as soon as it apply the fitful structure distance of drying room. The humidity asymmetry phenomenon of continuous drying process is the result of temperature asymmetry. The condition of material not blocking flow inside the dryer dictated the relationship between the maximum diameter of the material and the distance between the diamond pipes. The retention time characteristic of the granular material was studied and a mixture characteristic across the dryer was obtained. The guide plate was designed in order to improve the mixture characteristics.

But, the research of above is 2D simulation results. The granular is as disk or circle that is far from the real physical system. In this paper, the flowing characteristics in 3D Discrete Element Method (DEM) are studied. The results are compared with 2D simulation.

EXPERIMENTAL SECTION

The granular flow is regarded as collection of the discrete elements. The motion equations of each element were described by the Newton's 2nd Law, and the state of motion state of all elements was described. The equations are as follows [5]

$$m_i \frac{\partial v_i}{\partial t} = F_{gi} + \sum F_{ij} \tag{1}$$

$$I_i \frac{\partial \omega_i}{\partial t} = \sum (r_i \times \sum F_{ij}) \tag{2}$$

When the granular elements comes in contact with each other or the dryer wall, their shape changes as a result of the contact force, which includes spring stress and damp stress (Figure 1). The contact forces can be represented as a normal force and a tangential force, according to Hooke's Law.

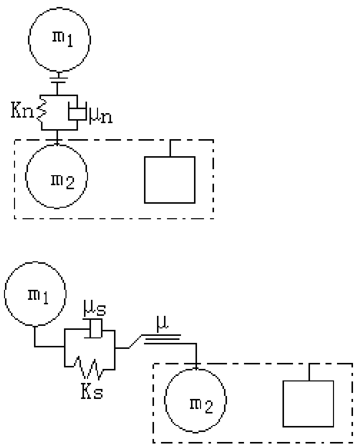

Figure 1: The model of granular contact patterns

$$F_{cij}^{n} = K_n (R_i + R_j - |l_{ij}|) - \mu_n m(v_{vel} \cdot \hat{n}_{ij}) \tag{3}$$

$$F_{cij}^{s} = -\mu_s m(v_{vel} \cdot \hat{l}_{ij}) - \mathrm{sing}(\Delta s)\min(K_s|\Delta s|, \mu|F_{cij}^{n}|) \tag{4}$$

$$m = \frac{m_i m_j}{m_i + m_j} \tag{5}$$

The model equations were solved using the PFC3D software [6]. The granular material was as the ball medium with the same physical properties. The simulation process is proceeded as follows: (a) based on the physical model 3, a model geometry was built with PFCD3D, and the bottom of half dryer was blocked by wall at first, (b) the command, was given to generate a ring of granular material with a certain diameter and density, (c) using the cycle command, granular flow from the top to the bottom, with gravity was implemented, (d) repeated (a) and (b) until the granular element filled up the dryer, in Figure 2. According the simulation requirement, the granular materials can be set to different colors. Using the command, the wall of the bottom at the dryer can be removed and the system can begin to iterate and cycle, the granular material will begin flowing out from the dryer bottom. The state of the system at any time can be stored, and the flow characteristics at the time studied. The relevant parameter set is given in Table1.In order to lower the effect, the friction is as zero.

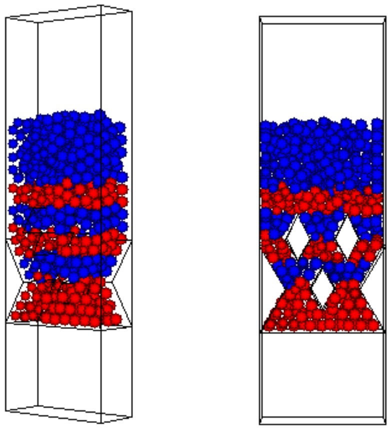

Figure 2: The simulation method of maize flow characteristic

Table 1. The geometrical parameters of the drying room

Parameter	Value	Parameter	Value
L	0.04	k_{np}	5.5×10^5
d	0.01	k_{sp}	5.5×10^5
ρ	1000	k_{nw}	3×10^6
μ_p	0.0	k_{sw}	3×10^6
μ_w	0.0	Δt	5.0×10^{-6}

RESULTS AND DISCUSSION

The flow of the granular materials occurred between the gaps of the lozenge-perforated pipes. In order to ensure the heating power and heating efficiency, the gap cannot be too big, but when it is too small, the granular material will be remain blocked between the gaps, leading to failure of the drying process. It was thus necessary to study the relationship between the gap and the diameter of the granules, and optimize the dimensions of the dryer. Some research has been shown the outlet diameter must be 4-fold larger than the granular diameter [6]. In 2D DEM simulation, the granular diameter was set at 10 mm. The L is 40 mm that is gap of pipe.

Some granular material was remained blocked in the dryer. Reducing the granular diameter to 9 mm led to no material being blocked in the dryer [12]. But in 3D simulation, even the diameter is 18 mm, the granular is not blocked. The diameter of maize grains did not exceed 10 mm, and most were in the range of 6-7 mm. So the gap of the lozenge-shaped pips was set at 40mm to ensure flow.

In a continuous drying process, the flow velocity can be controlled by the output rotary valve, since the state of flow under continuous drying is very important in the drying process. To ensures a good uniformity of moisture, and avoid poor quality drying due to an over-long retention times, the retention time of all the granular materials should be maintained close to that of the drying period.

At first, the model was built by the method as mentioned above and a part of the model is shown in Figure 2. The moving wall was set at the bottom of the dryer. It can be set for any flow velocity. So long as wall of the dryer is enough to avoid the granular material leaking out. According the experimental results that not reported, the velocity of wall was the 10^{-3}ms^{-1}. The simulation results are showed in Figure 3. The grains of different colors show obviously boundaries after flowing down. So most of granules followed the first in and first out arrangement. It is conforming well to a standard retention time. Mixture across the dryer is also important, because it can make granular materials of different moisture mix well, and the granular material would then reach the same temperature and moisture.

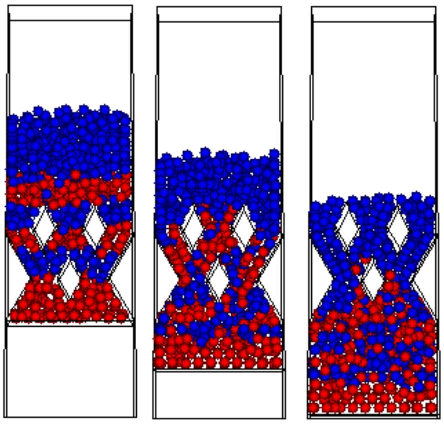

Figure 3: Level results of Granular free flow characteristic

The model was initially designed as before and a part of the model is shown in shown in Fig.4 respectively. The red-green mixing was poor under the conditions illustrated in Figure 4, and clear boundaries existed between them after flowing down. This was not a benefit to drying when the heat insulation was poor, such that the wall of the dryer was at lower temperature, than the inner portion of the dryer. The temperature difference would lead to the moisture differences. So the structure of the dryer must be changed.

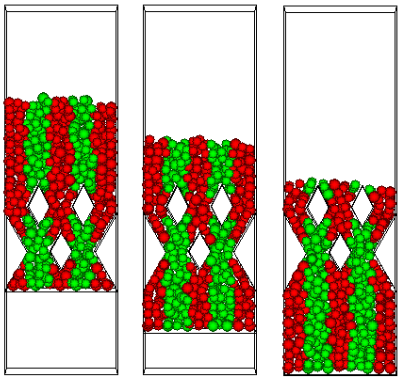

Figure 4: Level results of Granular free flow characteristic

CONCLUSION

A distance between lozenge-shaped pipes greater than 4 times of the maximum granular diameter was enough for 3D flowing; it can achieve free flow inside the vacuum dryer. During the granular flowing process from top to bottom inside the dryer, the granular is first-in first-out, guaranteeing a uniform retention time and granular uniformity. The mixture characteristics across the dryer were poor. The dryer wall's poor insulation affect moisture uniformity at the end of the drying process, but a guide plate improved mixing and product uniformity. The 3D results is similar the 2D results.

Acknowledgment
This research was supported by the National Natural Science Foundation of China (Grant Nos. 31000665, 51176027, 31371873, 31300408).

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