Powder Technology 340 (2018) 400–410

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Experimental and DEM studies on the distribution of voidage in the random filling bed of ellipsoidal particles

Xufeng Luo [a], Liang Zhao [a], Sheng Zhang [a], Hui Dong [a,*], Junsheng Feng [b]

[a] SEP Key Laboratory of Eco-industry, School of Metallurgy, Northeastern University, Shenyang, Liaoning 110819, China
[b] School of Engineering Science, University of Science and Technology of China, Hefei, Anhui 230026, China

ARTICLE INFO

Article history:
Received 4 May 2018
Received in revised form 13 September 2018
Accepted 18 September 2018
Available online 19 September 2018

Keywords:
Pellet
Discrete element method
Packed bed
Bed geometry factor
Voidage

ABSTRACT

The average voidage, radial voidage and axial voidage distribution in ellipsoidal pellets bed layer were studied by experiments and Discrete Element Method (DEM) Simulation. A series of experiments were used to determine the collision parameters of DEM model. The influence of the bed geometry factor on the average voidage and the radial voidage of the bed layer were investigated, the distribution of axial voidage in the bed was observed under different bed height conditions. The results show that the pellet diameter and cylinder diameter are the critical factor affecting the bed voidage distribution. With the bed geometry factor increasing, the average voidage of the bed gradually decreased. When $D/d_p > 50$, the average voidage of the bed approaches to a constant (0.292). The damped oscillation of the radial voidage distributes from the wall toward the center of bed, and there is a maximum value near the wall. When the total height of the bed is constant, ignoring the influence of edge effect, the axial voidage increased gradually and eventually tends to be constant. With the gradual increase of the bed height, the change rate of the voidage and the axial voidage at the same height gradually decreased.

1. Introduction

Considering the disadvantages of traditional rotary kiln [1], and learning experiences from the steel pellets shaft furnace, a kind of vertical roasting equipment - vanadium titano-magnetite roasting shaft furnace was raised [2,3]. The system has the features of high fill rate, small volume, convenient operation, and etc. In terms of structural characteristics, the vanadium titano-magnetite roasting shaft furnace is a kind of gas-solid countercurrent heat exchange device [4]. The key to determine the feasibility of the roasting shaft furnace are the gas-solid flow and heat transfer, the distribution of bed voidage is the core factor affecting the gas flow and the gas-solid heat transfer. The bulk material beds are mainly divided into two types, homogeneous and non-uniform, which belongs to the category of loose beds. The uniformity of bed voidage distribution will directly determine the roasting effect.

Up to now, Roblee et al. [5]; Thadani and Peebles [6]; Benenati and Brosilow [7]; Ridgway and Tarbuck [8]; Martin [9]; Cohen and Metzner [10]; Goodling et al. [11]; Kufner and Hofmann [12]; Govindarao et al. [13]; Mueller [14]; Sederman et al. [15]; Wang et al. [16]; And Mariani et al. [17]; Mueller [18] et al. have done a lot of research on the radial voidage distribution of the uniform filling bed by experiments or analytical calculation. Theuerkauf et al. [19] used the Discrete Element Method (DEM) to study the radial voidage distribution of spherical particles. More and more scholars have begun to study the radial voidage distribution characteristics of non-uniform random packed beds. Nguyen et al. [20] used nuclear magnetic resonance technology to measure the voidage distribution in non-uniform random packed beds. Kubie [21] investigated the voidage distribution of non-uniform particle in the wall area of randomly packed bed. Feng et al. [22] used experimental methods to study the distribution of radial voidage in sinter bed. Only Das et al. [23] obtained the distribution of the axial voidage of the fluidized bed through experiments. The fluidized bed and the randomly packed bed are quite different, so the research results are not applicable. However, it is not difficult to find that the above-mentioned studies on the distribution characteristics of bed voidage are mainly conducted on radial voidage, and the research on the axial voidage distribution characteristics of bed is rarely reported.

Zhang et al. [24] have studied the axial voidage of the sintered bed. However, there is a big difference between pellet and sinter, the surface of sinters are loose and porous. Due to the high hardness and the low smoothness of the sinters, which directly affect the coefficient of restitution and the coefficient of friction. Tao et al. [25] found that the accumulation state of particles is related to the friction coefficient. A large friction is generated between the particles during the process of sinters accumulation, the accumulation of the particles does not change with the height of the bed. Therefore, ignoring the influence of the bottom edge effect of the bed, the axial voidage is constant. It was found that the distribution of axial voidage were affected by the shape of the particles, the hardness of the particles and the smoothness of the surface. The

* Corresponding author.
E-mail address: dongh@mail.neu.edu.cn (H. Dong).

https://doi.org/10.1016/j.powtec.2018.09.042
0032-5910/

Table 1
Mainly experiments.

Particles size d_p(mm)	Diameter of cylinder(mm)			
	500	600	800	1000
20	1	2	3	4
30	5	6	7	8
40	9	10	11	12
Nature size	13	14	15	16

object in this study are ellipsoidal pellets. The volume of center part of the pellet is larger, the volume of both sides is small, and the surface is smoother than sinter. The lower roasting temperature of pellet leads to the smaller hardness, the accumulation state of the particles changes with the height of the bed. Therefore, the axial voidage changes with the height in the process of pellet accumulation, existing research does not appropriate. The pellets in this study are very different from the block materials, so the results in literatures cannot be used directly. Due to the uneven temperature distribution in the roasting process, a certain proportion of the pellets will be powdered, which results in the bed being filled ununiformly, thus the results of the voidage distribution characteristics of the uniformly packed bed cannot be used directly. The pellets move down very slowly during the roasting process and can be approximated as fixed beds. The axial voidage distribution characteristics of the bed may affect the gas flow rate and residence time at a certain height position, which directly determine the uniformity of heat exchange in the packed bed. In most of the numerical simulations, it is not reasonable to set the voidage as a constant value in the axial direction, and the result does not accord with the actual production conditions.

Therefore, the authors adopted the methods of water injection, section image and DEM to study the voidage distribution in packed bed of non-uniform ellipsoidal pellets. A series of experiments such as high collision rebound test, bevel test and balanced sliding test, stacking angle test and L-type transparent plexiglass box test were used to determine the coefficient of restitution, static friction and rolling friction. The experimental results verify the accuracy of the model. Then, the simulation results of voidage were analyzed to obtain the distribution of radial voidage and axial voidage. On this basis, the relationship between the voidage and bed geometry factor were explored. At last, a three-dimensional voidage distribution diagram of the bed was obtained through MATLAB programming.

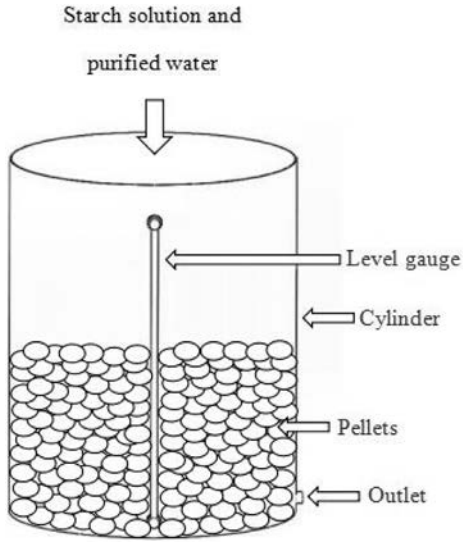

Fig. 1. Experimental setup diagram.

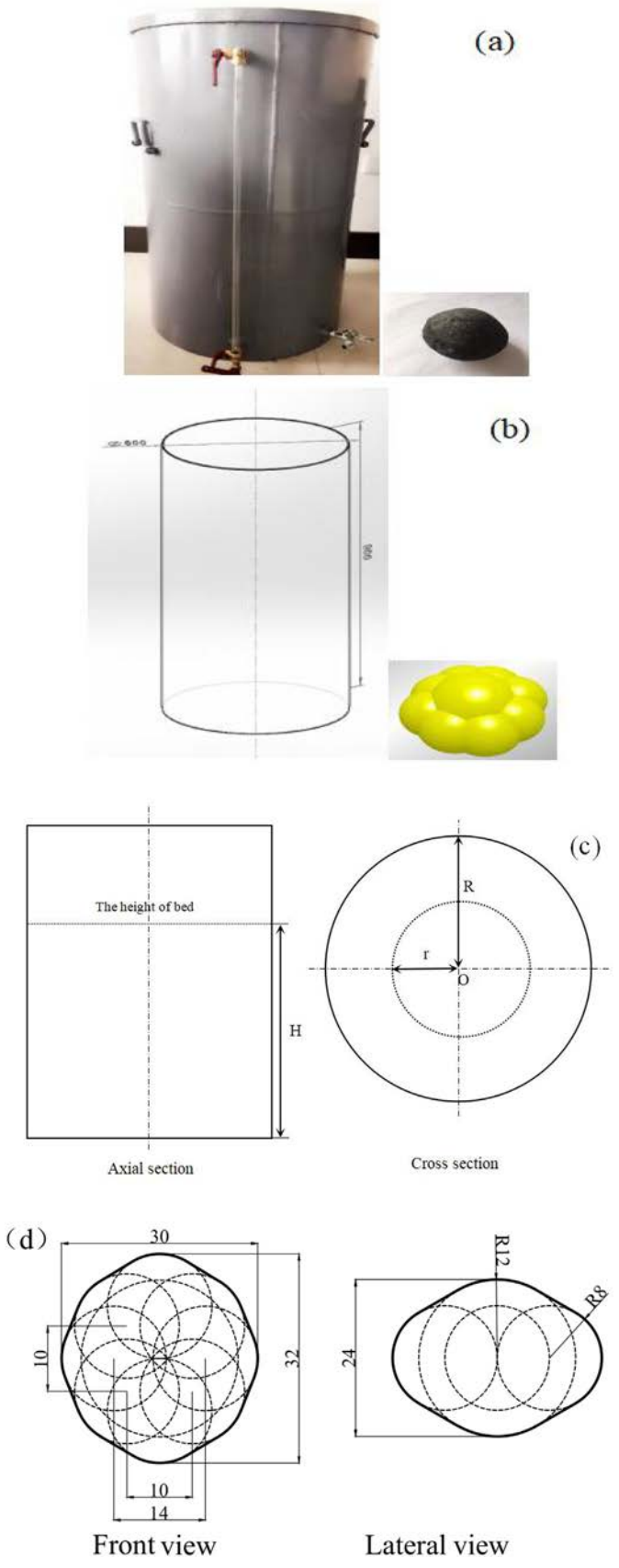

Fig. 2. (a) The pellets and cylinder in laboratory; (b) DEM model; (c)Basic parameter diagram; (d)Size of ellipsoidal particle.