Powder Technology 288 (2016) 65–75

Contents lists available at ScienceDirect

Powder Technology

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

Wear process during granular flow transportation in conveyor transfer

Liyu Xie [a], Wenqi Zhong [a,b,*], Hao Zhang [a,b], Aibing Yu [b,c], Yujun Qian [d], Yougong Situ [d]

[a] Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210096, China
[b] Centre for Simulation and Modelling of Particulate Systems, Southeast University–Monash University Joint Research Institute, Suzhou 215123, China
[c] Department of Chemical Engineering, Monash University, Clayton, Victoria 3800, Australia
[d] Datang Nanjing Power Plant, Nanjing 210011, China

ARTICLE INFO

Article history:
Received 27 June 2015
Received in revised form 5 October 2015
Accepted 26 October 2015
Available online 28 October 2015

Keywords:
Wear process
Granular flow
Conveyor transfer
Discrete element method

ABSTRACT

This paper presents a numerical study of the wear process during granular transportation in conveyor transfer systems. Discrete element method was used to calculate the interaction force between solid particles and devices which experience wear on the pipes and belts. The moving receiving belt was involved to investigate to the influence of receiving belt speed on the wear process. To investigate the relationship between the flow behavior and the wear process, the effects of particle size, feed rate, belt speed and chute structure on the granular velocity distributions and the impact force on the pipes and belts were investigated. It was revealed that the wear on the receiving belt and transfer pipe is more serious with the increase of feed rate and the decrease of particle diameter. The decrease of the receiving belt speed makes the granular layer thicker, which reduces wear on the belt.

1. Introduction

Bulk material transportation requirements have continued to press the belt conveyor industry to carry more diverse routes. Conveyor transfers are extensively adopted in conveyor belt systems due to the fact that they are irreplaceable for loading and redirecting bulk materials. However, some serious problems involved in the conveyor transfer processes have not been understood well, such as dust generation [1], wear and erosion [2] and excessive noise [3]. Generally speaking, a good design should obey the following two principal elements. Firstly, the dust emission should be controlled within a degree which is low enough and associated with the granular flow and air flow. In addition, for the sake of lengthening the life-span of the devices, wear on the chutes and conveyor belts should be fairly avoided. It is known that the flow pattern of granular materials plays an important role in affecting these factors during the transportation processes of granular materials [4,5]. So, understanding the movement characteristics of the particles is of paramount importance to the improvement in system efficiency and the reliable re-design and optimization of the actual devices. The design of the conveyor transfers at current stage has mainly been based on either trial and error or previous experience of the engineers. A critical study on the mechanism of dust generation, chute wear and excessive noise is especially needed to provide a scientific guide on the actual art. Several experimental studies have been carried out for the design of the conveyor transfers [6,7] by means of high speed video camera, PIV and so on. However, it's extremely hard to accurately measure the dust spatial distribution and the interaction forces on transfer chutes and belt conveyors by current physical measuring methods. The application of numerical simulation has been proven to be a very useful analysis and design tool for such systems. In general, there are two available models for simulating granular flows: the Eulerian model and the Lagrangian model. In the former model, the whole calculation domain is treated as continuum while the spaces that occupied by and without particles are treated as fluid with different physical properties. Inversely, the dynamic behavior of every individual particle is simulated in the Lagrangian model and thus the collision between the solid particles can be vividly described.

Over the past decades, the development of Eulerian model has been widely adopted to better understand the flow behavior of bulk materials [7–10] due to its superior computational convenience. Predicting the flow through a conveyor transfer by Eulerian model was firstly proved to be possible by Korzen [8]. Then, the frictional drag around the chute boundaries was taken into account in Roberts' continuum-based chute flow models [9]; it was found that an appropriate chute geometry could minimize the wear on the chutes and belts. A three-dimensional Eulerian simulation was carried out [7,10] to qualitatively predict the performance of six transfer chute configurations with respect to dust generation, and the simulation predictions compared favorably with experimental results. Although the numerical simulations based on the Eulerian model can produce some valuable results, the particle–particle and particle–wall interactions are hard to be accurately simulated. Moreover, the Eulerian model has trouble in modeling flows with a range of different particle types and sizes because separate

---

[*] Corresponding author at: Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210096, China.
E-mail address: wqzhong@seu.edu.cn (W. Zhong).

http://dx.doi.org/10.1016/j.powtec.2015.10.043
0032-5910/

Table 1
Force equations in the simulations.

Force	Equations
Normal contact force	$\overrightarrow{F}_{cnij}=\frac{4}{3}E_{eq}\sqrt{R_{eq}}\delta_{nij}^{3/2}$
Tangential contact force	$\overrightarrow{F}_{ctij}=S_t\delta_{tij}$
Normal damping force	$\overrightarrow{F}_{dnij}=-2\sqrt{\frac{5}{6}}\psi\sqrt{S_n m_{eq}}\overrightarrow{v}_{nij}$
Tangential damping force	$\overrightarrow{F}_{dtij}=-2\sqrt{\frac{5}{6}}\psi\sqrt{S_n m_{eq}}\overrightarrow{v}_{tij}$

Table 2
The experiment and simulation parameters [6].

Properties	Value
Particle density, ρ_p	919 kg/m^3
Experimental particle size distribution (2.36–3.35 mm)	2.90%
Experimental particle size distribution (3.35–4.00 mm)	11.73%
Experimental particle size distribution (4.00–4.75 mm)	85.37%
Simulative particle size	4 mm
Feed rate, Q_p	2 t/h, 31 t/h
Discharging belt speed, v_{dis}	2 m/s
Shear modulus	
Particle, G_p	1×10^9 N/m^2
Wall, G_w	2×10^9 N/m^2
Restitution coefficient, e	0.65
Friction coefficient	
Particle–particle, μ_p	0.222
Particle–wall, μ_w	0.282
Poisson's ratio, γ	0.3

continuity and momentum equations must be solved for each size and type which highly limits its application range.

An alternative approach is to treat the particle phase using the Lagrangian model such as the discrete element method (DEM) [11]. The DEM does not only provide the detailed material flow information, but also enables the analysis on the forces and moments acting on different elements of the equipment due to direct collisions [11]. Recently, the Lagrangian model has gained popularity in the numerical simulation of various industrial applications [12–17]. There are several numerical studies based on DEM to assist the design of conveyor transfers [6,18–20]. A DEM simulation of conveyor transfers was conducted by Hastie et al. [6] where a transfer hood and a discharging belt were contained and six simulation results including different discharging belt speed, hood position and feed rate were compared well with experimental tests. The accuracy of the reaction forces between the particles from the discharging belt and the impact-plate and the granular trajectories was quantitatively measured and qualitatively obtained using DEM simulations by Grima et al. [21], and the effects of discharging belt speed and feed rate on the impact force were investigated and they also tried to calibrate and scale-up DEM model to attain accurate predictions and results [22,23]. Cleary [24] studied the performance of a conveyor spoon transfer using more than 14 million particles with different particle sizes and feed rates in which a moving receiving belt was contained. From a survey of reference, it is shown that the DEM could be a promising scheme for the solution of conveyor transfers' design. However, usually a discharging belt and a transfer chute were contained in those simulations, only one the receiving belt speed was considered. Furthermore, the wear on the moving receiving belt caused by impact force was seldom considered.

To fill this gap, numerical simulations of the granular flow in conveyor transfer are performed using DEM in this study. Complete conveyor transfers are contained including discharging belt, top deflector, transfer chute and receiving belt. Transfer pipes are applied as they are widely used in the power plant. The purpose of the study is to figure out the problems of the interaction between the particles and devices considering moving receiving belt and offer systematic guidelines to appropriately select model parameters. The effects of particle size, feed rate, receiving belt speed and chutes' structure on the flow behavior and particle-wall interactions are investigated. The wear process is discussed based on analyzing the impact force on the transfer chutes and conveyor belts. It is worthwhile mentioning that the influence of airflow on the particle behaviors is remarkable when particle diameter is less than 100 μm. However, the wear and erosion on the wall is mainly due to the impact of particles whose radius is larger than 1 mm. Since the wear process during granular flow transportation in conveyor transfer is the main concerned issue in this paper, the influence of airflow is insignificance and thus neglected.

2. Discrete element method

In DEM, the motion of each individual particle is governed by Newton's second law of motion which can be expressed as

$$m_i\frac{d\overrightarrow{v}_i}{dt}=\overrightarrow{F}_{c,i}+m_i\overrightarrow{g}$$

$$I_i\frac{d\overrightarrow{w}_{pi}}{dt}=\sum_{j=1}^{n_i}\left(\overrightarrow{T}_{tij}+\overrightarrow{T}_{nij}\right)$$

where $\overrightarrow{v}_i$, $\overrightarrow{w}_i$, and I_i are the translational and rotation velocities, and moment of inertia of particle i, respectively. $\overrightarrow{F}_{c,i}$ is the total contact force acting on particle i and can be calculated as a combination of normal force and tangential forces. When direct collision between the elements takes place, the Hertz–Mindlin no-slip model is employed to calculate the collision force in this study. The model is based on the classical Hertz's theory [25] for the normal direction and on

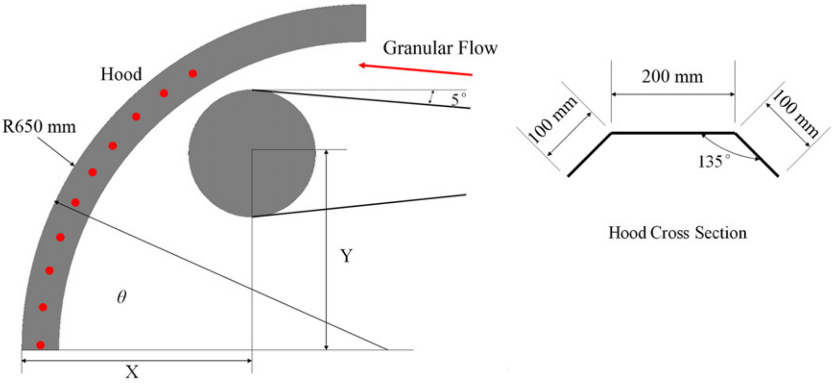

Fig. 1. Geometry of the conveyor transfer hood [6].