Case Studies in Thermal Engineering 11 (2018) 145–152

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

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

Case studies of heat conduction in rotary drums with L-shaped lifters via DEM

Qiang Xie[a,b,*], Zuobing Chen[a], Ya Mao[a], Gong Chen[a,c], Weiqiang Shen[a,c]

[a] School of Mechanical and Electronic Engineering, Wuhan University of Technology, Wuhan, China
[b] School of Materials Science and Engineering, University of New South Wales, Sydney, Australia
[c] Sinoma (Suzhou) Construction Limited Company, Kunshan, China

ARTICLE INFO

Keywords:
DEM
Rotary drums
L-shaped lifters
Heat conduction
Mixing

ABSTRACT

Rotary drums are widely used in numerous processes in industry to handle granular materials. In present work, heat transfer processes in drums with L-shaped lifters have been investigated by coupling the discrete element method (DEM) with heat transfer model. Effects of both operational and structural parameters have been analyzed. It is found that increasing rotational speed could improve heat transfer to a certain extent, however, just in relatively low speed stage. When lifter number increases, the heat transfer speed slightly decreases. An increasing lifter height could promote heat transfer first and then reduces it, but the amplitude of variation keeps small. The heat transfer rate descends with increasing lifter width. The heat transfer mechanisms have also been discussed by comparing mixing rates, total contact areas for thermal conduction, time constants (TC) indicating apparent heat transfer rate and effective heat transfer coefficients (HTC). It is concluded that dynamic conduction due to particle flow is dominated in all cases. The L-shaped lifers are turned out not a good choice when heat conduction between particles is prominent.

1. Introduction

Rotary drums have been broadly employed in industry to deal with continuous granular materials in many processes such as heating, drying, cooling and mixing. Considerable studies have been carried out to explore the granular flow behaviors and associated phenomena [1–4].

Heat transfer in rotary drums is complicated because of not only the complexity of heat transfer itself but also the interactions with particle flows. To clearly understand the heat transfer processes several ways have been developed including experiments [5,6], continuum approach [7] and discrete modeling techniques [8]. Due to development of modeling, large-scale computing and visualization techniques, the discrete element method (DEM) becomes a typical, effective and popular method to explore granular system. Sometimes it is even the only way, for example, when information of a certain particle is needed. Being coupled with heat transfer model is needed in some circumstances. For example, Gui, et al. [9,10] had coupled DEM with heat transfer model to study mixing and heat conduction of granular particles in a rotating drum. It was found that increasing rotation speeds could promote mixing.

Many efforts have been focused on heat transfer in conventional hollow rotary drums. Even so, there are still some problems unsolved such as internal heat transfer enhancement [11]. The non-conventional drums with special internals and configurations

* Corresponding author at: School of Mechanical and Electronic Engineering, Wuhan University of Technology, Wuhan, China.
E-mail addresses: johnarmstrong@whut.edu.cn, qiangxie_whut@163.com (Q. Xie).

https://doi.org/10.1016/j.csite.2018.02.001
Received 5 January 2018; Received in revised form 2 February 2018; Accepted 4 February 2018
Available online 09 February 2018

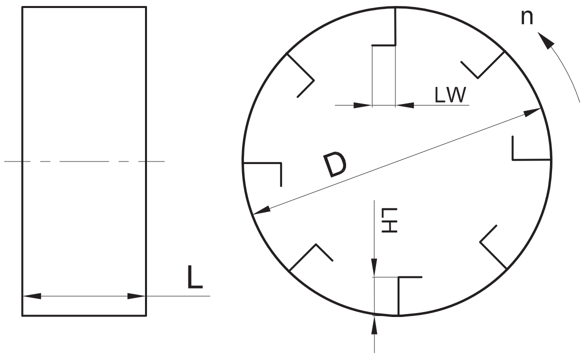

Fig. 1. Schematic diagram of a drum with L-shaped lifters. Parameters including rotating speed (*n*), lifter number (*LN*), lifter height (*LH*) and lifter width (*LW*) is considered.

have not been fully paid attention. As a fact they should have been because they show better processing efficiency [12]. Up to now few studies have focused on this topic. For example, Gui, et al. [11,13] had studied rotating wavy drums and found that the wavy drum could enhance and speed up heat conduction especially under low rotating speeds.

Our previous work [14] has compared drums with no lifters, with straight lifters and with arc lifters. It was found that drum with straight lifters show better heat conduction performance. Two heat transfer mechanisms has been identified. The heat transfer change resulted from lifter parameters comes mainly from contact area between particles and heat source. And particle flow plays a dominant role in heat transfer enhancement resulted from rotating speeds. L-shaped lifters are another important structure and they are common in practical applications especially in rotary dryers or coolers with gas flows because of their prominent volume hold up ability. As a consequence an in-house DEM code used before has been revised to analyze L-shaped lifters and the corresponding knowledge will be a significant component of understandings for rotary drums. Fig. 1 gives a schematic diagram of a drum with L-shaped lifters.

2. Numerical model description

The DEM fundamentals and the simplified Hertz-Mindlin and Deresiewicz model, developed by Hertz [15] for normal and Mindlin,et al. [16] for tangential direction, employed in present study could be found in previous work [14] for details.

Heat conduction in this work is dominated even though there are multiple heat transfer mechanisms in rotary drums [10,17]. The maximum temperature in the system is relatively low where the radiation is negligible [18]. Stagnant gas with low thermal conductivity inside the drum is considered where the conductivity ratio of particle to gas is $\lambda_p/\lambda_f \gg 1$, which results in non-prominent convective heat transfer [19], and ignorable thermal conduction through interstitial gas [20]. The applied dominating conduction model is the one proposed by Batchelor et al. [21] and modified by Cheng et al. [19], which is shown as

$$Q_{ij} = 4r_c(T_j - T_i)/(1/k_{pi} \quad +1/k_{pj}) \tag{1}$$

where Q_{ij} represents the heat flux between particle *i* and particle *j*, whose temperatures are given by T_i and T_j respectively. r_c means radius of contact area. Since the particle diameter used in this work is uniform, the radius of contact area can be calculated by

Table 1
The parameters used in the simulations.

Parameter	Symbol	Value
Particle material	*Mp*	Steel
Particle number	*Np*	10,000
Particle diameter	*dp*	2.0 mm
Particle density	ρ	7800 kg/m^3
Particle specific heat	*Cp*	460 J/Kg/K
Particle thermal conductivity	*Kp*	50 W/m/K
Particle initial temperature	*T0*	298 K
Drum wall temperature	*Tw*	698 K
Young's modulus	*E*	1.0×10^7 Pa
Poisson's ratio	γ	0.29
Time step	Δ*t*	2.8×10^{-5} s
Drum diameter	*D*	120 mm
Drum length	*L*	20 mm
Drum rotating speed	*n*	20 (10–40) rpm
Lifter number	*NL*	8 (4–10)
Lifter height	*LH*	8 (4–12) mm
Lifter width	*LW*	4 (2–6) mm