Effects of Triangle Internals on Temperature Distribution of Granular Material in Rotating Horizontal Drum

Yun-fu CHEN

College of engineering Nanjing agricultural university, Nanjing 210031, China

Keyword: Particles, Discrete element method, Triangle internal, Temperature.

Abstract. The DEM-based heat transfer model is carried out to investigate effects of triangle internals on temperature distribution of granular material in rotating horizontal drum. The model is verified by comparing with literature published previously. The effect of triangle internals on temperature distribution of granular material accounting for triangle number and rotation speed is discussed. The results show that triangle internals breaking the vortex core zone involving low-velocity and mixing dead zone in the granular bed can effectively enhance heat transfer and temperature uniformity inside the drum. Heat transfer and temperature uniformity increased with increasing triangle number and rotating speed, but slightly increased as the value is higher.

Introduction

The process of heating granular materials such as catalyst particles, plastic pellets, and food products is encountered in many industrial applications. Rotating horizontal drums are the most commonly equipment for handling and processing granular materials, and its structure design play a critical role in temperature distribution of granular material in rotating horizontal drum. Over the past decades, there has been continued interest in investigating effect of different structure design on temperature distribution of granular materials in rotating drum. Njeng and Chaudhuri et al. experimentally investigated effects of rotational speed, and lifter configuration (straight, arc and L-shape lifters) on heat transfer, which determines temperature distribution of granular materials. However, particle-surface interaction or the detailed microstructure of the granular bed cannot be captured. Scherer et al. used a DEM model to study the effect of straight baffles and L-shaped baffles on heat transfer, and discovered that L-shaped baffles lead to higher heat transfer than straight baffles due to a more even distribution of the particles across the cross-section of the drum. These studies found a vortex core zone involving low-velocity core, mixing dead zone of granular system in the rolling regime, which is not very helpful to improve the heat transfer efficiency and uniformity of temperature distribution. Therefore, attempts to directly break vortex core zone involving low-velocity core, mixing dead zone of granular system in the rolling regime have been made by using triangle internals wee set in the horizontal drum. Effects of triangle internals and rotation speed on temperature distribution of granular material in rotating horizontal drum are studied, based on coupling the DEM with a conductive heat transfer model.

Heat Transfer in Rotating Horizontal Drum Fitted with Triangle Internals

Temperature distribution of granular material in rotating horizontal drum are significantly affected by triangle internals wee set in the drum and operation condition. So the configuration of the drum, which is fitted with triangle internals, is constructed to investigate the effects of triangle internals and operation variables (rotating speed) on temperature distribution. The rotating horizontal drum being equipped with triangle internals consists of a cylindrical 120 mm diameter container with length of 20 mm, which rotates along the z-axis. Triangle internals consists of a certain number of Triangle component (C6=6) with externally circle diameter (CR=6mm). Triangle component is evenly distributed on the circle (θ=60°), which is concentric with the cylinder of the drum, and radius RC=40mm, as shown in Fig.1.
Numerical Models and Boundary Conditions

To simulate temperature distribution of granular material in rotating horizontal drum equipped with triangle internals, the three-dimensional DEM-heat transfer model is developed. DEM is applied to capture the particle motion in rotating horizontal drum in which the particle-particle and particle-wall interactions are described by a soft sphere approach \[6\]. A heat transfer model, only considering conductive heat transfer through particle-wall and particle-particle contacts, is applied to estimate the heat transfer behaviors in a drum \[7\].

At the initial time, the drum was at its static state and a certain amount of particles with initial temperature (298K) are fed in forming a packed bed with being allowed to reach mechanical equilibrium. Then, the temperature of the drum was suddenly raised to \(T_w=598K\). In the meantime, the drum started to rotate along the \(z\)-axis at \(\omega\) rpm. The drum is considered as a rigid, motion-controlled large particle with a finite radius, infinite mass walls. No-slip boundary condition is assumed on the inner wall of drum. The present numerical simulation, the corresponding parameters are listed in Table 1.

<table>
<thead>
<tr>
<th>Parameters(unit)</th>
<th>Notations</th>
<th>Base value(range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of particles</td>
<td>(N_p)</td>
<td>10100</td>
</tr>
<tr>
<td>Particle diameter(mm)</td>
<td>(d_p)</td>
<td>2</td>
</tr>
<tr>
<td>Particle density(kg/m(^3))</td>
<td>(\rho)</td>
<td>8900</td>
</tr>
<tr>
<td>Particle specific heat capacity(J/kg-K)</td>
<td>(c_p)</td>
<td>172</td>
</tr>
<tr>
<td>Particle thermal conductivity(W/(m·k))</td>
<td>(\lambda_p)</td>
<td>385</td>
</tr>
<tr>
<td>Young's modulus(MPa)</td>
<td>(E)</td>
<td>10</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>(\sigma)</td>
<td>0.29</td>
</tr>
<tr>
<td>Particle/particle restitution coefficient</td>
<td>(e_{nt})</td>
<td>0.8</td>
</tr>
<tr>
<td>Particle/wall restitution coefficient</td>
<td>(e_{nt})</td>
<td>0.5</td>
</tr>
<tr>
<td>Static friction coefficient</td>
<td>(\mu)</td>
<td>0.7</td>
</tr>
<tr>
<td>Drum rotating speed(rpm)</td>
<td>(\omega)</td>
<td>5, 15, 20</td>
</tr>
<tr>
<td>inscribed circle diameter (mm)</td>
<td>(CR)</td>
<td>6</td>
</tr>
<tr>
<td>Number of component</td>
<td>(NL)</td>
<td>6</td>
</tr>
<tr>
<td>Time step(s)</td>
<td>(t)</td>
<td>5\times10(^{-6})</td>
</tr>
</tbody>
</table>

Experimental Validation

To verify the present model, the simulation results for the particle average temperature in rotating horizontal drum have been compared with literature data \[4\]. As shown in Fig.2, the results are similar. Although it is found that there is a slight deviation between the simulation and literature, the discrepancy is within the engineering error \[8\]. Therefore, the DEM-based heat transfer model employed in the present work is proper to further investigate effects of triangle internals on temperature distribution of granular material in rotating horizontal drum.
Results and Discussion

Dynamics and Temperature of Particle Flow

Fig. 3 presented particle velocity field and axial snapshots of the granular bed in the transverse plane of the drum at 15 rpm. There are two distinct zones in the particle bed within the rotating drum, which is accord with characteristic of rolling region. As known, the two distinct zones are the passive layer in the bottom and the active layer on the top. In the passive layer, the particles rotate with the drum wall as a rigid body, indicating that the mixing rate among the particles is insignificant. The temperature distribution showed obvious temperature gradients. It is not conducive to quickly reach the uniformity of particle temperature. Moreover, there have vortex core zone involving low-velocity core, mixing dead zone near a fictitious boundary layer separating the two regions, in which form cold granular core indicating low particle temperature, as shown in Fig. 3. Although the mixture of the particles is intense and thus favoring energy transfer in the active layer, breaking the vortex core zone involving low-velocity core, mixing dead zone in the granular bed and redistributing the particles causing rapid mixing within bed is still helpful to improve heat transfer and uniformity temperature distribution.

Effect of Triangle Internals Configuration

The triangle internals configuration attaching the drum is established to interrupt core zone. Evolution of temperature in rotating drum with triangle internals attached and no triangle internals have been compared, and shown in Fig. 4. For the drum with no triangle internals, evidently, the particles in the passive layer turns in the upwards direction in a nearly solid body rotating fashion. The surface of the granular bed is almost flat. The heat is transferred from the wall to the centre of the bed, and temperature show concentric gradients. However, with the drum equipped with triangle internals, the particles near the drum wall are dragged up higher, and the surface of the granular bed is not flat. Concentric temperature gradients are changed due to break the core zone involving low-velocity core, stagnant zone. In addition, the results can be quantificationally judged from the evolutions of particle average temperatures in the granular beds. As shown in Fig. 5 (a), the particle average temperature inside the drum with the triangle internals is higher than that inside the drum.
with no column internals at the same time point. These indicate the presence of triangle internals can speed up heat transfer. Furthermore, although it is observed that the mean bed temperature increase quickly at the early stage and then gradually getting slower over time at both cases, the rate of change in the particle average temperature inside the drum with the triangle internals change faster than that inside the drum with no triangle internals. Consequently, the uniformity of the granular bed temperature can also be improved, which is estimated by the standard deviation of the particle temperature, as shown in Fig. 5 (b).

**Figure 4.** Axial snapshots of flow and temperature in the drum with no triangle internals (top) and in the drum with triangle internals (bottom) at different times ($\omega=15\text{rpm}$).

**Figure 5.** (a) The evolution of particle average temperature in the drum with no triangle internals and in the drum with triangle internals at different times ($\omega=15\text{rpm}$). (b) The standard deviation (SD) of the particle temperature in the drum with no triangle internals and in the drum with triangle internals at different times ($\omega=15\text{rpm}$).

**Effect of Rotation Speed**

Evolution of temperature of granular material in rotating horizontal drum is presented at the speed of 5, 15 and 20 rpm in Fig. 6. With increasing rotating speed, the repose angle increases and more particles are lifted and transported further. To a certain extent, the particle mixing is promoted. On the other hand, the triangle internals can push more high temperature particles into cold core per
unit of time, redistribute the particles, and then interrupt the quasi-static zone in the center of the granular bed. As a result, the cold core shrinks with time for all the cases, but it shrinks faster for drum rotated at higher speed, especially the obvious change at the speed from 5 rpm to 20 rpm. The effect of speed on temperature distribution is quantified calculating the average bed temperature as a function of time, as shown in Fig. 7 (a). It is clear that the higher rotating speed enhances the heat transfer process within the simulated range. The uniformity of the granular bed temperature is presented in Fig. 7 (b), which is estimated by standard deviation of the particle temperature. As expected, the bed rotated at higher speed reaches thermal uniformity faster.

Figure 6. Axial snapshots of flow and temperature in the drum with triangle internals at different times and rotational speed.

Figure 7. (a) The effect of rotational speed on particle average temperature at different times. (b) The evolution of standard deviation (SD) of the particle temperature versus time at different rotational speeds.
Conclusions
DEM simulations coupled with a contact heat transfer model have been conducted to study heat transfer in rotating drums equipped with triangle internals. Effects of triangle internals and rotation speed on temperature distribution of granular material in rotating horizontal drum are analyzed based on axial snapshot, particle average temperature and standard deviation of particle temperature. The results showed that triangle internals breaking the quasi-static zone in the center of the granular bed can effectively enhance heat transfer and temperature distribution uniformity inside the drum. Heat transfer and temperature distribution uniformity increased with rotating speed, but slightly increased as the value is higher. The position of triangle internals locating in the drum enhance performance of heat transfer and temperature distribution uniformity, which is dependent on number of scooping and redistribution of particles resulting in augment particle mixing and shrinking cold granular core per unit of time. Therefore, the role of triangle internals in heat transfer and temperature distribution uniformity has been identified.

Acknowledgement
This research was financially supported by “the Fundamental Research Funds for the Central Universities” (KYZ201762, Y0201900028).

References