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Simulations of dynamic properties of particles in horizontal rotating ellipsoidal drums

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ABSTRACT

Flow behavior of particles in the horizontal rotating ellipsoidal drum (RED) is predicted by means of the discrete element method (DEM). The effect of flattening of the ellipsoidal drum on flow regimes of particles is simulated because of its importance to industrial applications, and because the underlying flow of particles is not fully explained yet. Different flow regimes are produced by varying flattening. The resulting contact forces between the drum wall and particles are predicted in the horizontal RED and horizontal rotating cylinder drum (RCD). The flow of particles in the horizontal RED becomes significantly different to that in the horizontal RCD due to the increase of flattening of the ellipsoidal drum. At high rotation speed, a crescent shaped flow mode is observed at the orientation angle of 90° and a showery raining mode is observed at 120°. The results show that the resulting contact forces between the particles and the drum wall increase with the increase of flattening and rotation speed. The velocity of particles is changed with the orientation angle of the horizontal RED. The translational granular temperature and configurational temperature are calculated from simulated instantaneous translational velocity and displacement of particles, respectively. The simulated translational granular temperature and configurational temperature increase with the increase of flattening and rotation speed. The rate of energy dissipation through collisions and contact interactions of particles is predicted in the horizontal RED and RCD.

1. Introduction

Horizontal rotating drums are commonly used for processing granular materials in the mineral, cement, coal mill, metallurgical, chemical, pharmaceutical, food, and waste industries, and they are important auxiliary equipment. A horizontal rotating cylinder drum (RCD) consists of a hollow cylindrical shell rotating about its horizontal axis, and in process applications, is generally partially filled with particles [1–5]. Experimental results show that the flow of particles in the horizontal RCD depends upon Froude number which is defined as the ratio of centrifugal force to gravitational force [6,7]:

$$Fr = \frac{\omega^2 R}{g}, \tag{1}$$

where ω is the rotation speed in rad/s and R is the radius of the drum which is constant in the cylinder drum. Depending on Froude number and filling degree, flow regimes, namely: slumping, rolling, cascading, cataracting and centrifuging

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Nomenclature

A	major axis, m
B	minor axis, m
C	fluctuating velocity, m/s
d	diameter of a particle, m
D	diameter of cylinder drum, m
e	restitution coefficient
f_c	contact force, N
g_o	radial distribution
k	spring coefficient, N/m
I_p	moment of inertia of particle, kg m^2
m	mass of a particle, kg
M	total amount of sampling data
N	number of particles in the cell
r	radii of particle, m
T_p	torque, N m
v_p	linear velocity of particle, m/s
v_n	normal particle velocity, m/s
v_t	tangential particle velocity, m/s

Greek letters

η	damping coefficient, N s/m
δ_n	normal displacement, m
δ_t	tangential displacement, m
ω	angular velocity and rotation speed, rad/s
β	flattening
α	orientation angle
θ_c	configurational temperature, (m/s)^2
θ_t	translational granular temperature, (m/s)^2
ε_s	volume fraction of particles
ρ_s	density of particles, kg/m^3

Subscripts

m	mean value
n	normal direction
p	particle
t	tangential direction
w	drum wall

regimes, have been identified to describe the particle motion in horizontal RCD [1,8–9]. Yamane et al. [10] simulated the flow of particles in a horizontal RCD using the discrete element method (DEM). The different flow regimes were predicted at different rotation speeds. An agreement between DEM and magnetic resonance imaging experiments was found when the friction coefficient was adjusted in the simulations. Yang et al. used DEM to simulate the flow of particles and investigated the effect of rotation speed on the collision velocity and collision frequency in a horizontal RCD [11]. The movement and mechanical interaction of particles were simulated using DEM, and the results were compared with experimental data in the horizontal RCD [12]. The dynamic angle of repose, the thickness of the active layer and the particle velocity on the bed surface and at the wall were measured. Both the DEM simulations and the analytical model results were in agreement with the experiments. The most significant applications of DEM to rotating drums, mixers and mills, are reviewed by Zhu et al. [13] and Weerasekara et al. [14].

From Eq. (1), we find that the Froude number is constant along the periphery of the horizontal RCD at the specified rotation speed. So that it can also be called the peripheral Froude number. The investigations mentioned above indicate that the flow mode of particles depends on drum diameter because the peripheral Froude number calculated by Eq. (1) is proportional to drum size at the specified rotation speed in the horizontal RCD. In other words, the flow mode is determined at the specified drum diameter and rotation speed in the horizontal RCD. On the other hand, the peripheral Froude number varies along the periphery when a horizontal rotating ellipsoidal drum (RED) is used at the given rotation speed. The horizontal RED being considered in this paper is shown in Fig. 1; the direction of rotation is taken to be in the positive y direction using a right-hand corkscrew convention. The orientation angle α defines the angle of the drum major axis to the horizontal. The local value of Froude number using Eq. (1) varies when the horizontal RED rotates because the local positions x and z at the drum wall are varied. In the horizontal RED with a specified rotation speed, the peripheral Froude number is largest