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A preliminary study of particle separation in spiral concentrators using DEM

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ABSTRACT

Spirals are used for gravity concentration of minerals and of late these have been extensively and effectively used for iron ore processing. Their widespread use is mainly due to lower capital cost and higher efficiency to treat feed material in the size range of 3 mm to 45 μm. Although operating a spiral is quite simple its design is quite challenging for specific applications. Here we have made an attempt to develop a simulation tool based on the discrete element method (DEM) to understand the separation process in spiral and later use it for design purpose. We report preliminary results of simulation as to the splitter position on the spiral trough for maximum separation efficiency. It is observed that separation efficiency is maximum corresponding to a specific radial position and height of the splitter location.

1. Introduction

Spiral concentrator is essentially a flowing film gravity concentrator, where the combined action of gravity and hydrodynamic forces due to the circulating flowing film is brought to separate gangue from pure mineral. Spiral concentrator's full-fledged commercial use started in the early 1940s. Traditionally spiral concentrator has been used effectively in the coal and beach sand industries. Today, it is successfully used to beneficiate a number of ores like chromite, rutile, gold ore, iron ore, coal, beach sand, etc., mainly due to its operational simplicity and cost effectiveness. Recently, there has been an accelerated growth in the use of spirals for iron ore beneficiation. The demand for higher efficiency of separation is compromised by a higher capacity in the size range of 3 mm to 45 μm. For iron ore beneficiation, this size range is considered coarse to be treated by floatation and it is considered fine for other conventional gravity separators like jig which performs better for feed material above 2 mm size. Despite all its advantages, there has been an increased demand to design spiral to accommodate feed material that vary over size as well as grade. So the challenge has been to design the correct profile of the spiral.

Since its inception a lot of work has been done to understand and improve the performance of spiral (Honaker et al., 2007; Richards et al., 2000; Glass et al., 1999; Atasoy and Spottiswood, 1995; Holland-Batt, 1995; Sivamohan and Forssberg, 1985; Holland-Batt et al., 1984). However, to predict the performance of a spiral for any given application, and more importantly, to design spirals for a particular ore type to obtain a desired grade, a lot of experiments must be done. These are quite cumbersome and costly. Hence many resort to simulation of the separation process in spiral concentrators (Das et al., 2007; Matthews et al., 1998; Kapur and Meloy, 1998; Wang and Andrews, 1994). This sort of simulation requires robust mathematical models but the current situation is such that most of the mathematical models available are either quite difficult to solve or empirically derived which is only valid for a particular set of conditions. In our attempt a simple yet efficient model is developed to track the motion of particles on the spiral trough in order to predict its overall performance.

2. Simulation method

2.1. Model development

In this work the discrete element method (DEM) is used to model the dynamics of the spiral concentrator. The particles are modelled as smooth round spheres and contacts made by them with other particles and spiral surface are considered to be distinct single-point contacts. Every contact is modeled using a linear contact law, which uses a combination of a spring and a dashpot in the normal, and the shear directions. This concept is described in detail by Mishra, 2003 and exhaustively discussed in literature (Cundall and Strack, 1979; Hong, 1998; Anandarajah, 2000; Mishra et al. 2002). The main challenge in developing the spiral model within the framework of DEM is to correctly represent the spiral surface over which particles glide. For computational simplicity, we use the dynamic triangulation technique (Berg et al., 2008) to represent the spiral surface.

To study particle separation in spirals, we perform numerical simulations of 3D fluid-particle interaction problem. Particles flowing on a spiral trough experience body as well as contact forces such as gravity, drag, buoyancy, friction, centrifugal and Bagnold force. Out of

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all the forces the Bagnold force is not considered as it has effect on the separation only when slurry concentration is more than 50% (Atasoy and Spottiswood, 1995). The force on a particle depends on its location inside the spiral. Hence the geometry of the spiral must be mathematically described. We follow the approach taken by Kapur and Meloy (1998) to describe the spiral geometry which is briefly stated below.

$$x = r\sin[\theta] \quad (1)$$

$$y = r\cos[\theta];\ 0 \le \theta \le N\pi \quad (2)$$

$$z = \frac{u}{2\pi}\theta;\ 0 \le z \le H \quad (3)$$

$$s = \tan[\alpha] = \frac{u}{2\pi r} \quad (4)$$

where r is the radius, θ is the parametric representation of the coordinates, u is the pitch, H is the total height, N an even number, α is the slope angle and s being the forward tangential slope. Based on this geometry and by specifying the pitch and number of turns, the desired spiral surface is generated using a dynamic triangulation technique (Berg et al., 2008). Here the pitch refers to the distance between start of one turn of the spiral to start of the next turn. The forces of interaction between the particles and the spiral surface are represented by spring–dashpot type contact models. Furthermore, it is assumed that the net flow is steady and the velocity profile of the fluid is preserved throughout the spiral trough. The velocity profile used in the simulation follows the mathematical description of Matthews et al. (1998), who used computational fluid dynamics (CFD) to determine the velocity profile in spirals under different operating conditions. The k–ε model was used to represent the fluid flow and a Lagrangian technique was used to represent the particle flow. The forces due to the presence of fluid and other contact forces are vectorially added and the net out-of-balance force on a particle is calculated. Then Newton's second law is applied to compute the particle acceleration, velocity, and position for each time step. In this manner, the particle trajectory of all particles trickling down the spiral surface are computed and stored for further analysis to determine the extent of separation.

2.2. Simulation

Two standard spirals of five turns are considered for the purpose of simulation. The spiral mesh geometry was generated as triangular structured grid with a MATLAB code which uses a dynamic triangulation method. The use of a triangulation method simplified the contact detection problem inherent to DEM. A snapshot of the spiral so developed for simulation is shown in Fig. 1. All the simulations were performed using a total of 12,000 spherical particles of the same sizes with two different densities viz. 2400 and 4800 kg/m^3 respectively unless specified differently. The ratio of lighter to heavier particles in the mixture of particles was 1:2 by weight and heavier particles are assumed to be the valuable mineral. All parameters used for the simulations are presented in Table 1. A computer code was written in C programming language incorporating the fluid and the particle models discussed in the previous section and the simulations were carried out using an IBM workstation equipped with 2 GB RAM and 3.6 GHz Intel XEON processor. Several snapshots of a typical simulation with 12000 particles are shown in Fig. 2 where yellow (gray in black and white) colour particles are light particles and blue (black in black and white) colour particles are heavy particles. One observes from these snapshots that lighter particles are reporting to the outer periphery of spiral trough and heavier ones are reporting to the inner periphery, which is similar to what has been reported by many researchers (Das et al. 2007; Richards and Palmer, 1997; Holland-Batt 1995).

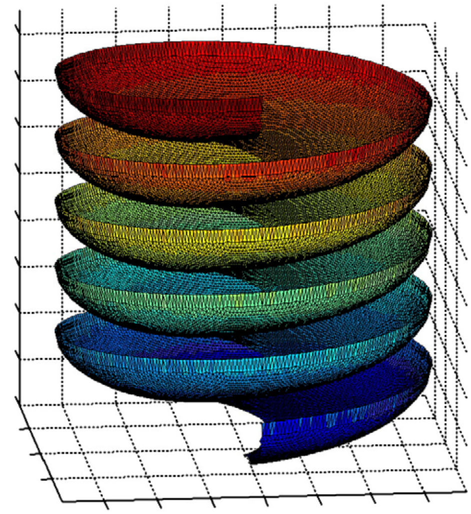

Fig. 1. Computer generated 5 turn spiral concentrator for simulation.

3. Result and discussion

In this section an attempt has been made to study the effect of splitter position on the separation efficiency of the spiral concentrator. The expression used for calculating separation efficiency (E_s) is given as (Barari et al., 1979).

$$E_s = R_v – R_g \quad (5)$$

where R_v is the recovery of valuable mineral and R_g is the recovery of gangue mineral. A splitter located on the spiral trough divides the flow into two streams as concentrate and tailing. The variation of separation efficiency at different splitter positions is shown in Fig. 3; the plot is a surface fit to the scattered data. Here the bottom end of the spiral i.e., the discharge end is considered to be the base line (height = 0.0 m) and the height increases towards the feed end. Similarly the reference point for radial position is taken to be the central axis of the spiral. It is observed that as the splitter position is moved from the inner edge to outer edge of the spiral trough and as the height decreases from the feed end to the discharge end, separation efficiency attains a maximum of 38.72% at a radial distance

Table 1
Parameters used for simulation and experiment.

Parameters	Values
Simulation	
Particle radius (mm)	5 and 2.5
Viscosity of medium (Pa s)	0.001
Temperature (K)	300
Coefficient of friction μ_f (−)	0.7
Coefficient of restitution e(−)	0.5
Number of turns in spiral (−)	5
Triangle element in mesh (−)	290,015
Diameter of trough (m)	0.7 and 0.6
Pitch of spiral (m)	0.273 and 0.435
Actual time step (s)	1.9×10^{-5} and 6.52×10^{-6}
Flow rate (lpm)	72
Experiment	
Particle radius (mm)	2.5
Feed grade (%)	44.67
Flow rate (lpm)	72
Pitch of spiral (m)	0.435
Diameter of trough (m)	0.6