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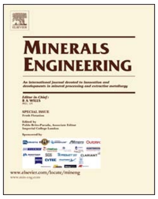

Particulate and water mixing in the feed box for a screen

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ABSTRACT

Coupled DEM/SPH flow models of rock/slurry flow are developed in order to investigate the effect of feed rate on the operation of the feed box which is used to pre-mix the solid feed with water before it is presented as slurry to the screen. For the feed box, rocks were fed into the feed box from a conveyor and travelled through a series of intermediate ledges before being combined with water from an assembly of pipe jets and spray nozzles, and then exiting to the screen. Two dispersal geometries were considered for distributing the water. Wide nozzle sprays were found to provide much more uniform delivery of water to the rock stream than jets from cylindrical pipes. The details of the feed and slurry mixture exiting the bottom chute does not appear to change significantly with conveyor feed rate.

1. Introduction

Separation and classification of bulk materials via screening is a fundamental unit operation for the mineral processing and coal industries. The manner in which material is supplied to a screen can significantly limit its performance. Feed arrangements typically consist of a feed box (sometimes called a feed distributor particularly when this feeds multiple screens) which is a type of chute often containing a number of discrete stages of flow control. Such devices are commonly used both in scalping and fine screen applications. They are used principally to reduce the impact of feed onto a screen surface as well as to provide more uniform flow onto the screen (Holt, 1978). Water is often added via pipes or spray nozzles and pre-mixed with the bulk material inside the feed box to form a slurry which is then presented to the screen. This is important for assisting uniformity of flow onto the screen, flushing fines through the screen apertures, dust suppression and to prevent build-up of fine material on the surfaces of the undersize collection chute beneath.

The design of a given feed box can significantly influence the performance of a screen. Poor design (or operation at tonnage rates outside of the range it was intended for) can result in many process issues. Size and density segregation due to flow through each of the stages within the feed box can affect the transport characteristics within the feed box and lead to compositional variations in the screen feed. Uneven distribution of material across the screen width, and the angle and speed of flow onto the screen may cause greater screen wear particularly at high tonnage rates (O'Brien et al., 2010). Also, reducing flow velocity onto the screen is important to ensure sufficient slurry residence time. Uniform distribution over the screen provides equal chance of dewatering of the feed through slurry drainage. Excessive water volume onto the screen can wash material further down the length of the screen and reduce the screening efficiency of the early screen panels.

Appropriate design choices for feed arrangements are limited due to poor understanding of particle and fluid behaviour at each of the stages within the feed box since detailed experimental measurements are usually not possible. Alternatively numerical modelling can provide predictions of flow behaviour throughout the feed box. For commercial relevance, these models need to be able to resolve a large fraction of the real particle size distribution of the feed and the fluid both at an industrial scale. There are no CFD based models in the literature of such a feed box for scalping or fine screen applications.

There has been some limited modelling for fine particle suspensions in coal distributors. Rajendran et al. (2006) and Guo et al. (2009) have published models of feed distributors used for coal washing prior to delivery to desliming screens and then cyclones. Rajendran et al. (2006) used Lagrangian particle tracking to monitor fine coal distribution inside the distributor whilst Guo et al. (2009) used a two-phase ANSYS CFX model to predict air and water flow through the distributor. Dong et al. (2008) coupled a DEM model to this two-phase air/water CFD model to study how the water flow conditions influence the coal transport through the distributor. They found that the uniformity of the solids outlet distribution could be improved using a symmetrical design of water inlets and higher water velocities. There have been a number of studies of screen classification using a Discrete Element Method (DEM) approach which resolves the coarser fractions of granular feed

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material (see Cleary et al., 2009a, 2009b; Dong et al., 2009; Jahani et al., 2015; Liu et al., 2013; Wang and Tong, 2011). Although none of these have considered the coupled two-phase behaviour of rock and slurry flow on the screen surface. Fernandez et al. (2011) used a one-way coupled DEM and SPH model to explore modelling of a wet screen.

This study investigates combined slurry and rock flow through a feed box that pre-mixes solid feed and water before presentation of the resulting mixture to a vibrating screen. Specifically, this involves the application of a two-way coupled DEM + SPH flow model (developed in Cleary (2015) and demonstrated in Cleary et al. (2016)) to predict the interactions between the solid rock feed and the fluid slurry inside the feed box. DEM is used to represent the coarser rocks in the flow and SPH to represent the coupled slurry component (which is the combination of the water added and the fine rock size fractions). We consider two representative solid feed rates (1200 t/h and 1650 t/h) and two types of water addition nozzle geometries in order to investigate the differences in rock and slurry flow and mixing within the feed box for the most important configuration and operating condition variations.

2. Computational method for coupled fluid and solids flow

2.1. Approach to the DEM + SPH coupled slurry model

The problem of fluid transport and its role in coarse particle multiphase applications requires the ability to model the particulate solids in the charge and the slurry. To do this, we couple two different computational methods to model the solid and fluid phases separately. The most suitable method for modelling the transport of bulk materials through a feed box is the Discrete Element Method (DEM), see Cleary (1998a, 2004, 2009) for details. Smoothed Particle Hydrodynamics (SPH) is a powerful method for modelling complex, splashing, free surface fluid flows that is well suited for modelling the water and slurry, (see Cleary (1998b) for details). The methodology used here for the coupled DEM particulate/SPH slurry model is an extension of the one-way coupled method proposed by Cleary et al. (2006) and has been applied to wet screening (Fernandez et al., 2011) and to slurry flow in a tower mill (Sinnott et al., 2011). This approach is a fully transient two-way coupling of the solid/fluid phases that is performed at each timestep and is described in Cleary (2015). This coupled method is also discussed and demonstrated in Cleary et al. (2016). All simulations presented here are three-dimensional.

The coupled algorithm has the following elements at each timestep of the calculation:

1. Perform a 3D SPH simulation timestep to predict the flow of water/slurry through the feed box with a drag force representing the effect of the coarser rocks.
2. Average the fluid flow data from the SPH simulation onto a Cartesian grid to obtain fluid fraction and velocity distributions that are used in the coupling force applied to the DEM particles.
3. Perform a DEM simulation timestep to predict the resultant incremental change to the flow of rocks through the feed box. This uses a drag force from the fluid phase applied to each individual particle based on the local fluid fraction and velocity distributions for the fluid phase from the last SPH step.
4. Average the particulate flow data from the DEM simulation onto a Cartesian grid to obtain solid fraction and velocity distributions that characterise the solids as a dynamic porous media. This is used in the coupling force applied to the fluid phase in step 1.

2.2. DEM modelling for the particulate solids

The Discrete Element Method (DEM) is used here to simulate the flow of rocks through a feed box. This involves modelling each collision between the particles and between the particles and their environment (such as the conveyor or the chute) and then predicting the resulting motion of every particle in the flow by integrating Newton's equations. The boundary geometry is built using a CAD package and imported as a triangular surface mesh in the DEM simulation package. This method is now well established and is described in early review articles by Barker et al. (1994), Campbell (1990) and Walton (1994) and more recently by Cleary (2004, 2009).

This is a soft particle method where particles are allowed to overlap. The amount of overlap Δx and the normal v_n and tangential v_t relative velocities are used to calculate the collisional forces via a contact force law. Here we use a linear spring-dashpot model (see Thornton et al., 2013 for details). The force in the normal direction at the contact point is:

$$F_n = -k_n \Delta x + C_n v_n \tag{1}$$

The spring term provides a repulsive force that causes the particles to rebound from each other while the dashpot dissipates a proportion of the relative kinetic energy. For specific details of the contact model, the calculation of the damping coefficient C_n from the coefficient of restitution ε and comparisons of relative performance against other collision models for inelastic particles see Thornton et al. (2013). The maximum overlap between particles is controlled by the stiffness k_n of the spring in the normal direction. This is a numerical not a material parameter and needs to be chosen to be sufficiently large that the flow predictions are independent of the particular value chosen. This has been shown to typically occur as long as the average overlaps of the particles less than 0.1–0.5% of the particle radius. For more details and examples of the DEM implementation used here see Cleary (1998a, 2004, 2009). The method has been applied to dry screening applications previously which are relevant here since this feed box mixes material for presentation to a vibrating screen (see Cleary et al., 2009a, 2009b).

The force in the tangent plane at the contact point is given by:

$$\boldsymbol{F}_t = \min\{\mu F_n, \sum k_t \boldsymbol{v}_t \Delta t + C_t \boldsymbol{v}_t\} \tag{2}$$

where both the vector force $\boldsymbol{F}_t$ and velocity $\boldsymbol{v}_t$ are defined in this tangent plane. The summation term is an incremental spring which elastically stores energy from the relative tangential motion. This models the elastic tangential deformation of the contacting surfaces as they try to move over each other. The dashpot provides dissipation for the energy in the tangential direction and models inelastic contact behaviours which can include plastic deformation of the contact or surface fracture if the material is brittle (as is typically the case for mined rock). The total tangential force $\boldsymbol{F}_t$ is limited by the Coulomb friction μF_n. When this limit is reached then bulk sliding at the contact point occurs.

In this type of application the rock particles are non-spherical. Following Cleary (2004, 2009) we represent these particles as having super-quadric shapes. This has been shown to provide good predictive capability for DEM modelling of natural (broken rock and grains) particles (Cleary, 2004, 2009, McBride and Cleary, 2009). This particle shape is defined by the equation:

$$\left(\frac{x}{a}\right)^m + \left(\frac{y}{b}\right)^m + \left(\frac{z}{c}\right)^m = 1 \tag{3}$$

Here we refer to the shape parameter m as the angularity with a, b and c being the semi-major axis lengths. For $m = 2$, Eq. (3) becomes that of an ellipsoid, while for larger values of m we obtain increasingly cubic shapes with progressively sharper edges and corners. This approach provides the DEM method with the ability to represent a broad range of particle shapes which smoothly transition through a range of surface curvatures and aspect ratios.

2.3. SPH modelling for the fluid slurry

Smoothed Particle Hydrodynamics (SPH) is a mesh-free, Lagrangian, numerical method for predicting fluid flow. The SPH particles represent volumes of fluid that carry their local state