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Modeling segregation and dispersion in jigging beds in terms of the bed porosity distribution

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ABSTRACT

A new mathematical model for the description of segregation and dispersion in jigging beds is proposed. The model relies on the dynamic simulation of the porosity distribution in the bed. It considers the influence of the main operational variables of a jig, and includes these variables as direct inputs. By combining a phenomenological model with a DEM model, it makes use of a limited number of discrete elements, which is not possible in conventional DEM codes. The model has been fitted to experimental data resulting from a series of batch jigging tests performed at different conditions. It was found that the model describes with good accuracy the experimental data. The model also gives important insights into the jigging mechanism, in particular, into the relationship between the expansion of the bed and the rate of stratification.

1. Introduction

Jigging is one of the oldest methods of gravity concentration. References to jigging can be found in the historical book by Georgius Agricola, *De Re Metalica* (XVI century). Jigging is normally used to concentrate relatively coarse material (e.g. 3–10 mm). When the specific gravity difference is large, good concentration is possible with a wider and finer size range (e.g. 0.1–1 mm). Many large jig circuits are still operated in the coal, cassiterite, tungsten, gold, barytes, and iron-ore industries (Wills and Napier-Munn, 2006).

In the jig the separation of minerals of different specific gravity is accomplished in a bed which is rendered fluid by a pulsating current of water. The aim is to dilate the bed and to control the dilation so that the heavier particles penetrate the bed. The motion can be obtained either by using a fixed screen jig, and pulsating the water, or by employing a moving screen. The heavier particles can pass through the screen or accumulate over it being discharged by some special mechanism. An example of a fixed screen jig is shown in Fig. 1 (Richardson et al., 2002). It consists of a divided box, with a top driven diaphragm on one side and a screen box on the other. The simple harmonic motion is applied by an eccentric. This particular jig incorporates a rotating valve synchronized with the diaphragm. The water addition can be set so that water enters only during the diaphragm upward stroke in order to essentially neutralize suction.

One of the first attempts to systematize the mechanisms involved in the stratification of jigging beds is the well-known theory by Gaudin (1939). Gaudin explains the stratification process as the result of the combination of hindered-settling, differential acceleration at the beginning of fall, and consolidation trickling at the end of fall. The first two mechanisms are based on the settling laws of individual particles, and for them were proposed quantitative relationships. The third mechanism describes the percolation of the fine particles between the spaces left by the coarse ones during suction. It is thus a theory based on the hydrodynamics of the process.

The next major contribution for the understanding of the jigging process is invariably attributed to Mayer (1964). Mayer developed a potential theory for jigging. A difference in potential energy exists between the un-stratified and the stratified state of a bed of grains of different density. Stratification is connected with the reduction of potential energy, this being the sole physical cause of stratification. It is not the energy supplied by the jig stroke that causes stratification. The supplied energy has only a releasing effect on the potential energy stored in the granular mixture. Unlike Gaudin's theory, Mayer's theory assumes a macroscopic perspective over the phenomena.

In spite of the identification of the mechanisms by which a jigging bed stratifies, by the middle of the 1980's, no quantitative model that could successfully predict the performance of a jig was available, apart from the traditional empirical approach based on partition curves. This is well illustrated in the book written by Burt (1984).

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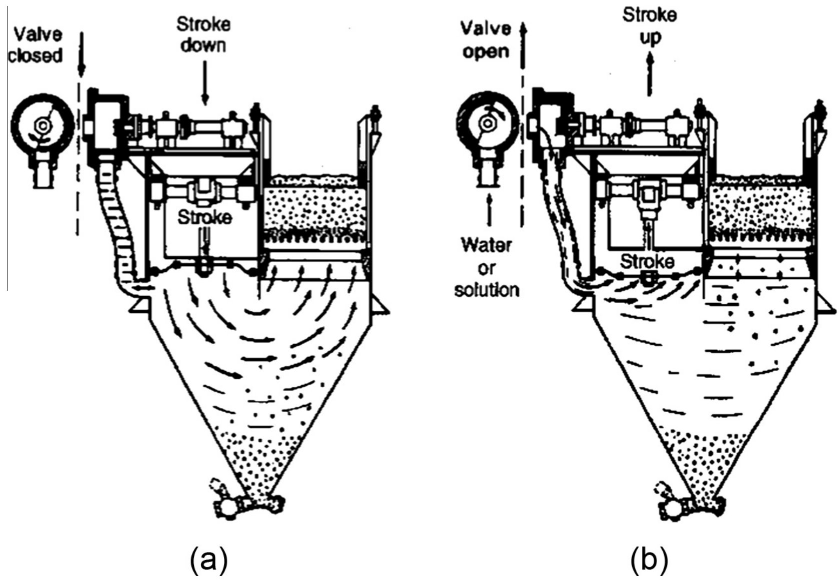

Fig. 1. Example of a fixed screen jig. (a) Downward stroke. (b) Upward stroke.

Among the first successful efforts to develop a non-empirical model that could predict the performance of a jig is the work by King (1987). In this model, it is considered that perfect stratification is never achieved (even after a very long sequence of jig strokes). The density profile of a jigging bed at steady state conditions is always the result of a dynamic equilibrium between a stratification flux and a dispersive flux.

The stratification flux is determined by the density difference between one particle and the particles that surround it. If a particle has a density superior to the surrounding particles, it will move down (lowering the potential energy of the bed). Instead, if it has a density inferior to the surrounding particles, it will move up (again, lowering the potential energy of the bed). The stratification flux is also a function of the specific mobility of the particles, a lumped parameter that accounts for bed expansion, size and shape of the particles, etc.

The dispersive flux is the result of the random motion of the particles. In practice, this type of motion flattens the concentration gradients that exist between layers of distinct densities. This process has the characteristics of a diffusive mechanism and can therefore be described by a Fickian equation.

The model developed by King (1987), originally for binary systems and later extended to multicomponent systems by Tavares and King (1995), represents a considerable improvement on Mayer's theory. It allows the computation of the steady state concentrations of the components in a jigging bed. It has been tested against experimental data from batch and continuous operations. The main limitation of the model comes from being valid only for systems of uniform size and shape. An extension of the model for particles of different size has been recently presented (Rao, 2007).

At this point it is worth mentioning the model proposed by Vetter et al. (1987). Although not considered by their authors as an extension of Mayer's theory, this model uses a physical description very similar to the one used by King (1987). The model is also limited to beds of particles of uniform size and shape. However, it has the great advantage of being a kinetic model. It allows the prediction of the evolution of the density profile in a jigging bed. This is of prime importance when addressing problems related to the residence time and the volumetric capacity of a jig.

At the beginning of the 1990's a new class of models for the stratification of jigging beds was introduced. The new modeling methodology is based on the discrete element method (DEM). According to this method, the motion of all solid particles in the bed is computed by Newton's second law of dynamics (a clear reminiscence of Gaudin's theory). All the important forces that act on the particles are accounted for. These forces describe the contacts between the particles and between the particles and the walls. The drag force and the hydrostatic impulsion are also included. Pioneer works in this field were published by Beck and Holtham (1993) and Mishra and Mehrotra (1998, 2001).

As can be easily understood, this new class of models is of a computationally intensive nature. In its first implementations, only 2D simulations of a few hundred particles were possible. In more recent works, still restricted to two dimensions but that include the simulation of the motion of the fluid by computation fluid dynamics (CFD), no more than one thousand spheres were considered (Xia et al., 2007; Xia and Peng, 2007).

In a more recent paper, which uses a CFD–DEM code, only about one thousand spheres of equal size were used (Viduka et al., 2013). In addition, in order to reduce the computational effort, the Navier–Stokes equations were solved in two dimensions, and the thickness of the bed was restricted to five particle diameters.

Among the advantages brought by DEM models, it should be mentioned the absence of adjustable parameters and, more important, the main operational variables of a jig, like the amplitude and frequency of the jig cycle, bed height, flow rate of hutch water, etc., can be easily connected with the stratification rate. This is a great improvement on the models of phenomenological nature based on Mayers's theory. However, it should be noticed that there are only a few studies in which DEM models have been tested against experimental data. It is therefore not known if these models can predict accurately the systems that they pretend to simulate.

For the usual practical needs of a metallurgist, the description of the movement of all the particles in the bed is in general an overdetailed description that could be simplified. In addition, this kind of description requires very costly computational facilities. In the models of phenomenological nature, like the model of Tavares and King (1995), the concept of class of particles greatly reduces the computational effort. However, in these models, the inclusion