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An experimental study of size segregation in a batch jig

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ABSTRACT

This paper presents the findings of an experimental investigation into size segregation in a 200 mm diameter batch jig that was conducted to provide background information for the development of a stratification model that accounts for the effects of both particle size and particle density on separation performance. The investigation focused on a simple system in which the only variable was particle size; i.e. binary systems involving 50% mixtures of two differently sized spherical glass beads from 14 mm to 4 mm diameter in 2 mm increments. The density of all beads was 2520 kg/m^3. The study revealed four different types of size segregation patterns that may occur in a jig bed, and gave some indication of the factors that determine the transition from one type to another under the specific experimental conditions of the test work carried out. It also developed a conceptual picture of the dynamics affecting size segregation in batch jigs operated under equilibrium conditions and highlighted three mechanisms: the interplay between stratification and dispersive processes; interstitial tricking of smaller particles; and convective remixing of smaller particles in the bed. Interpretation of the findings suggests a compositional regime where one segregation mechanism dominates, i.e. the stratification/dispersion interplay, and that our modelling efforts should concentrate on this mechanism and this regime.

1. Introduction

Although jigging has a long history as an effective concentration technique in mineral processing, it is only relatively recently that reasonable models of particle segregation in jig beds have been developed. Excellent reviews of these have been presented, for example, by Mehrotra and Mishra (1997) and, more recently, by Crespo (2016). These show the progression from the classical work of Gaudin (1934), who postulated hindered settling, differential acceleration and consolidation trickling as three primary segregation mechanisms operating in jig beds, to the recognition of other mechanisms – particularly the reduction of the potential energy of a bed brought about by stratification (Mayer, 1964), and dispersive processes that hinder stratification (King, 1987; Tavares and King, 1995). More recently, the use of DEM (Discrete Element Modelling) has been used in an attempt to model stratification by simulating the motions and interactions of individual particles in a bed during jigging (Mehrotra and Mishra, 1997; Beck and Holtham, 1993; Srinivasa et al., 1999; Viduka et al., 2012; Crespo, 2016). There have also been a number of essentially empirical approaches to modelling stratification and jig performance and the influence of operating variables on that performance (for example Rong and Lyman, 1991; Karantzavelos and Frangico, 1984).

The King model is perhaps the most promising and elegant phenomenological model currently available. It conceives that stratification in a jig bed is the result of a dynamic equilibrium between a stratification process driven by the reduction in the potential energy of the bed brought about by stratification, and a dispersive process driven by Fickian diffusion. Requiring only one empirical parameter, it is able to provide remarkably good fits to experimentally determined concentration profiles of multi-component systems in a variety of conditions (King, 1987; Tavares and King, 1995; Woollacott et al., 2015; Mutibura, 2015). For example, Woollacott et al. (2015) report exceptionally good fits for artificial systems involving up to seven density components, while Mutibura (2015) reports good to reasonable fits for systems involving South African coals with sizes in the range from 22.5 mm to 6.7 mm.

King's model constitutes a mathematical description of the phenomenon of particle stratification based on a set of assumptions about the physics that shape stratification behaviour in general. The empirical parameter in the model is context dependent; it caters for the specifics of the stratification context such as the size of the particles, the jigging conditions, and the physical size, shape, and nature of a jig machine. Experimental determination of the value of that parameter in a specific context therefore allows, at

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least in principle, a description or prediction of stratification behaviour in that specific context. The work reported in this paper is concerned about the ability of stratification behaviour to be modelled in general and therefore the context dependence of any parameter values is not in view.

A major problem with the King model as well as with the other models currently available is that the effect of particle size and shape on stratification is not adequately accounted for. Within the context of a larger project to develop a phenomenological model that takes particle size, shape and density into account, the work reported in this paper was a preliminary experimental study that investigated the effect of particle size alone; it studied segregation in systems where the shape and densities of all particles were the same. For the sake of simplicity and to establish the basic trends to be expected when particles of different size and different size ranges segregate, only binary systems were investigated, and only under one set of jigging conditions. Tests were conducted using spherical, soda-lime glass beads with a density of 2520 kg/m^3 and diameters in the range from 4 to 14 mm in 2 mm increments as indicated in Table 1. The information in the table is ordered according to the size range of the particles in the systems tested, as indicated by the size ratio D_{tp}/D_{bm}, where D_{tp} is the size of the larger particles in the system, i.e. the 'top size', and D_{bm} is the size of the smaller particles in the system, i.e. the 'bottom size'. The paper begins by describing the experimental set up, after which the findings are presented and discussed.

2. Experimental procedure

Tests were conducted in the batch jig represented diagrammatically in Fig. 1. To facilitate the slicing of the jig bed into horizontal fractions, the jig chamber was made up of a series of ring elements with identical cross-sections that was built up on the support screen and held in place by means of four vertical threaded rods with clamping nuts as shown. To provide some flexibility in the splitting of the bed after stratification, ring elements with heights of 15 or 20 mm were available. The internal diameter of the jig chamber was 200 mm. As shown in Fig. 2, the chamber was mounted on a pulsing unit consisting of bellows positioned below the support screen and driven pneumatically through a PLC controller to provide the required pulsion or up and down movement of water in the chamber. It also shows the overflow pipe that removed any excess water from the jig chamber and the sampling box used to collect samples removed from the jig bed. Fig. 3 indicates the shape and duration (1 s) of the jigging cycle used in all the tests which gave a bed movement of about 70 mm.

Table 1
The binary systems investigated. The systems are arranged by size ratio.

Top size D_{tp} (mm)	Bottom size D_{bm} (mm)	Size ratio (D_{tp}:D_{bm})	Approximate Size ratio
14	12	1.17:1	≈1.2:1
12	10	1.20:1	
10	8	1.25:1	≈1.3:1
8	6	1.33:1	
14	10	1.40:1	
12	8	1.50:1	≈1.5:1
6	4	1.50:1	
10	6	1.67:1	≈1.7:1
14	8	1.75:1	
12	6	2.00:1	≈2.0:1
8	4	2.00:1	
14	6	2.33:1	
10	4	2.50:1	≈3.0:1
12	4	3.00:1	
14	4	3.50:1	

To aid in the splitting of the bed into horizontal slices, a sample catch box that fitted around the outside of the jig chamber assembly was positioned appropriately to catch particles as they were scrapped from the jig bed. At the end of the jigging period, the ring elements were unclamped and were removed one at a time, and particles were carefully scraped off into the sample catch box after each ring had been removed. This 'slicing' of the bed was achieved using a 210 mm wide scraper plate, shown in Fig. 2, which was moved horizontally across the top of the assembly of the ring elements. A 'scraping' action was employed that aimed to split the bed as accurately as possible across the 'split plane' defined by the level of the top of the uppermost ring. This became more difficult with systems involving particles larger than 8 mm because many of those particles straddled the split plane significantly. Because of the experimental error associated with the splitting of the bed, all tests were done in duplicate. The concentration of each particle size component in each slice taken from the bed enabled the concentration profiles within the bed to be determined.

Tests were conducted on the 15 binary systems indicted in Table 1. Each test consisted of 6 kg of a 50% mixture (by mass) of the binary system under investigation. The duration of a test was 999 s (16.65 min or 999 cycles) which had been shown previously to be adequate for systems to reach an equilibrium state. The bed height in all tests was 130 mm.

3. Results

3.1. Types of concentration profiles

The experimental data is presented in the form of concentration profiles such as those indicated in Fig. 4. In these profiles the X axis refers to the volumetric concentration (vol/vol) of the differently sized particles in each slice taken from the jig bed while the Y axis refers to the relative bed height, $h = H/H_{bed}$, of the centre of each slice. Here H is the actual height of the centre of a slice from the bottom of the bed and H_{bed} is the height of the top of the bed.

The figure shows examples of the four different types of profile that were obtained. The data from duplicate results are shown as an indication of the degree of reproducibility obtained for the different types of concentration profile. The Type I profile, labelled '*stratified*', shows a high degree of reproducibility with the top part of the bed consisting only of smaller particles and the bottom part of the bed only of the larger particles with a 'mixed zone' in between. Type II, labelled '*stratified with trickling*' occurred with systems with a very large difference in size such that some of the smaller particles tended to trickle downwards through the interstices in the bed. This is the 'consolidation trickling' (interstitial trickling) mechanism proposed by (Gaudin, 1934). However, some trickling of this kind was also observed to occur during the bed splitting process and contributed to the experimental error. The nett result is a concentration profile that is similar in shape to the stratified pattern (Type I) except for an unexpectedly high concentration of the smaller particles towards the bottom of the bed. Duplicate tests showed a high degree of reproducibility for these profiles.

A lower degree of reproducibility was obtained for systems which developed Type III and Type IV profiles although the general shape of the profiles was reproducible. Both of these profile types were associated with systems that had only a small difference in the size of the particles. This would be expected to lead to a relatively small driving force for segregation and, consequently, a lower degree of segregation in the bed. In addition, it may be that