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Wall effects on particle separation in air jigs

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ABSTRACT

This study investigates the influence of wall effects on particle separation in an air jigging device. Tests were conducted with a ternary mixture of concrete, brick and gypsum particles in the size range from 12 to 20 mm for three different jigging times. It is shown that an unusual, remarkable segregation occurred in the direction perpendicular to the lateral walls, giving rise to a horizontal segregation pattern. In all cases, heavier particles concentrated more in the center of the particle bed while lighter particles concentrated along the side walls. Composition measurements of the stratified bed revealed that wall effects can significantly influence the composition of jig products. Linear predictions of jigging evolution suggest that stratification progress linearly after the first initial stages. Also, time evolution and analysis of local compacities indicate that stratification starts from the bottom to the upper layers of particle bed. Based on the experimental results, a mechanism for the pattern formation was proposed, which was enhanced by a geometry model of bed rearrangement. Prediction results for bed composition correlated well with experimental data and endorsed the role of lateral walls on the segregation pattern formed. The results obtained also show practical significance for the use of air jigging in the sorting of recycled aggregates.

1. Introduction

Dry processing technologies such as air jigging have received much attention over the last years due to its inherent advantage of not using process water, which offers important economic and environmental benefits. Moreover, modern air jigs have presented a significant improvement in performance compared with that of air jigs during the 20th century [1–3]. As a result of such development, the use of air jigging is no longer limited to coal and ore beneficiation but has also been investigated as a potential technique for recycling of solid wastes [4–6].

Gravity concentration processes are usually performed in the presence of water. The main reason for using water as means of separation rather than air is the separation efficiency. Taggart [7] proposed an index that combines the effects of the minerals densities and the density of the separation medium. This index is known as the "concentration criterion". The concentration criterion related to the concentration of two minerals in a gravimetric process is the ratio of the density of the denser mineral minus the density of fluid divided by the density of the less dense mineral minus the density of the fluid. This relation results in a number which is bigger for processes that use water than for processes that use air.

Jigs are versatile gravity concentrators that work efficiently with coarse particles. With the exception of jigs for fine minerals (particular discharge type of the products), all jigs operate efficiently at particle sizes above 1 to 2 mm [8,9]. The top size of the material to be concentrated is only related to operational aspects of the equipment and the mineral liberation. In coal beneficiation, there is a special jig (ROM jig) that can treat particles up to 350 mm [10].

During the 1950′s and 1960′s, water jigs were exhaustively studied and their efficiencies were greatly improved [8,9], increasing the difference in efficiency in relation to air jigs. Thus, the use of dry gravity concentration processes was restricted to regions with lack of water and to minerals that can not be wetted. From the new millennium, due to environmental problems, the cost of water usage increased greatly. Thereby, several studies were directed to the construction of modern air jigs with reasonable efficiencies.

As mentioned, the separation efficiency of air jigs is lower than that of water jigs [8,9]. However, in spite of recent efforts to investigate jigging phenomena by means of numerical simulation techniques [11, 12], water jigs remains the main focus. Little attention has been paid for peculiar phenomena that take place in air jigs. For instance, Cazacliu et al. [6] reported that purity of the air jig products could be affected by disturbing wall effects in such a way that an unequal segregation pattern can occur close to the internal jig walls. This indicates that the expected vertical stratification can be also accompanied by an unusual

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horizontal segregation in the zones close to the internal jig walls. Similarly, Windows-Yule and Parker [13] has demonstrated that the extent of density segregation in granular systems under vibration can be altered merely through the modification of the aspect ratio of the system. In the framework of air jigging, this implies that the geometry of the jig chamber can be treated as an additional factor in the separation efficiency.

Also, worthwhile studies can be performed in the scope of the time evolution of the stratification process in a jigging bed. Although previous work has demonstrated that the stratification by gravity normally occurs quickly [14], there remains a need to more fully address the local changes in composition over jigging time. For instance, Crespo [12] observed different rates of concentration of the heavy and the light components at the bottom and top of the bed, respectively. Similarly, Sampaio et al. [15] reported that the bulk of stratification of ternary mixtures of aggregates in an air jig device occurred before that a threshold of time (about 30 s) was reached, after which little gain in separation could be noted.

Furthermore, there has been extensive investigation related to segregation in dry granular systems and a variety of properties have been pointed as capable of undergoing segregation in addition to differences in particle density, size and shape. These includes frictional forces [16–18], presence of interstitial air [19,20] and differences in the packing fraction or compacity [21,22]. The synergy between these studies and particle stratification in air jigs is obvious in such way that further investigation can give rise to significant performance improvements.

The purpose of this work is to investigate a distinct stratification pattern that occurs near to the internal walls of the jig device when a granular mixture is subjected to air jigging. The composition of products obtained after several sorting tests was observed carefully. On the basis of the experimental evidences and literature data, a pattern formation mechanism together with a pattern formation model are proposed in order to better understand the role of wall effects during the stratification in air jigs. The model defines a pattern geometry of the bed stratification and a level of mixing between layers which depend on the jigging time.

2. Experimental setup

2.1. Materials

The material used in the tests was a mixture of particles in the size range of 12 to 20 mm. The components were obtained by crushing and sieving the following materials: concrete, clay bricks and gypsum. These materials were chosen in order to create conditions for a stratification based on differences in particle density and packing density (or compacity), as previously reported by Cazacliu et al. [6]. The authors showed that, despite the close particle densities of brick and concrete particles (Table 1), their separation is effective due to the significant differences in the individual compacities. Similarly, it was shown that the segregation of gypsum from the other two species (brick and concrete particles) is driven mainly by its relatively low particle density. The enveloped density was adopted as the particle density and was measured for each material by means of water displacement after waterproofing. The compacity was determined after three successive weighing of a known volume of each individual material. In this procedure, one section of the jig was fully filled with particles and, since the enveloped density was known, the particles volume was calculated and the compacity was obtained in relation to the section volume. A narrow size range was chosen to minimize the effects of size segregation.

Table 1
Skeletal, enveloped and bulk density of materials.

Material	Particle (enveloped) density (g/cm^3)	Compacity
Concrete	2.39	0.70 ± 0.00
Brick	2.26	0.49 ± 0.01
Gypsum	1.86	0.40 ± 0.00

2.2. Equipment

The tests were performed in a batch pilot-scale air jig model AllAir® S-500 from AllMineral with a capacity of approximately 50 kg per batch and a working size range of 1 to 25 mm. This laboratory jig is able to reproduce the same stratification process experienced in an industrial jig and can therefore be used to investigate the jigging process on a pilot scale. The complete jig system consists of feeding unit, separation chamber, control panel and powder filtering units as displayed in Fig. 1. The jigging cycle can be widely varied by the combined effect of bed expansion and pulse frequency. The former one is controlled by the air flow provided by a 15 kW blower (Combimac, 49,631/B1Y1), which is adjusted in the control panel in function of the percentage of the blower power (0 to 100%). The blower is able to produce an air flow up to 73 m^3/min. The air intake is controlled by a pneumatic flutter valve located in the air duct between the blower and the separation chamber. The pulse frequency is controlled in function of the valve rotation in frequencies ranging from 0 to 300 rpm.

During the tests, the mixed particles are placed into the container and subjected to vibration by two streams of air flow which enter simultaneously by the bottom plate of the jigging chamber. The first air flow is continuous and is responsible by the pre-expansion of the bed while the second one is controlled by the flutter valve and promotes the bed pulsation. The jigging chamber is assembled with different rectangular sections of Plexiglas (500 × 500 × 50 mm) fitted one over the other on a perforated plate (Ø = 1 mm). The set of rectangular sections made possible the extraction of the particles bed layer by layer.

2.3. Experimental procedure

A total of three jigging tests were conducted with three different jigging times: 15 s, 45 s and 120 s. Pulse frequency, fluidizing air rate and bed height were fixed in 160 rpm, 70% and 150 mm, respectively. This was the optimal operating point obtained by Sampaio et al. [15] for the separation of mixtures of concrete, brick and gypsum particles in an air jigging device. The operating parameters used in the tests gave a pulse duration of 0.37 s and a bed expansion of about 25 mm. For each experiment, a ternary mixture with the same bulk volume of aggregates was prepared, which corresponded to a mass fraction of 48% of concrete, 31% of brick and 21% of gypsum. The total amount of materials used in each test was of 43,000 g (±1%). In order to quantify the particles stratification, the bed was divided into six sampling zones. Three vertical layers (top, middle and bottom) were divided

Fig. 1. Air jig model AllAir® S-500 from AllMineral. (1) Feeding unit; (2) control panel; (3) separation chamber; (4) powder filtering unit.