Segregation Effects in Rectangular Piles Built Up by a Moving Injection Device

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Abstract. An experimental study of granular segregation is reported on rectangular grain piles built by dropping simultaneously grains of two different species from a funnel moving back and forth sinusoidally parallel to the length of the pile. Our experimental set-up allows us to control the following variables during the build-up of the pile: height of the injection point above the top, amplitude and velocity of its displacement and injection flow rate for each kind of grains. Glass beads of different diameters are used in the experiment. Preliminary experimental results demonstrate that the distance of the injection point from the top of the pile and the amplitude of the motion have the largest influence on the segregation.

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INTRODUCTION

In recent years, many industries like cement, paper, coal, fertilizers, etc. seek to improve quality through a better use of the raw materials and an optimization of the processing plants. Greater and greater fluctuations in the properties of raw materials, such as ores, limestone require that blending equipment provides a high-quality end product [1].

In cement production, raw material is stored as pyramidal heaps and, although empirical homogeneization techniques are used with good results, segregation is observed due to the broad distribution of grain sizes. Actually, segregation takes place every time this dry material is handled [2-4].

Ideally, the stockpiles of raw material are build up by a belt stacker in the form of as many thin layers of identical volume as possible. As a result of this large number of layers, variable material properties in superposed layers are offset by the cutting process of machines in operation. The number of layers is determined by the cross section of the pile, the handling capacity and the traveling speed of the stacking machine.

Depending on the industrial process considered, the arrangement of homogeneizing yards respectively blending beds can be classified in longitudinal and circular beds. The stacking mode is selected in function of the duty and of the type of reclaimer to be used.·For longitudinal beds, two of the most commonly used stacking methods are the Chevron and Windrow ones. Basically these methods consist of stacking a large number of layers on top of each other in the longitudinal direction of the pile. In the Chevron method material is deposited by an injection point that moves along its axis with an alternative motion and at a constant speed. The injection point is raised following the growth in height of the stockpile. This method induces segregation with the larger grains at the bottom and at the surface of the pile while the finest ones are in the central part [2]. If reclaiming takes place cross-wise by a bridge scraper reclaimer higher homogenization efficiency can be achieved.

In the Windrow method material is deposited by the stacker which moves in the direction of the axis of the heap and in the transverse direction. This mode prevents segregation and compensates the unfavorable effect of Chevron mode stacking.

On the other hand, there are other problems related to the fact that the range of sizes of the grains in these heaps is very broad. The relative amount of particles of a given size in the mixture is strongly related to the grinding process, and, particularly, to the degree of wear of the hammers used in the mills. The chemical composition of the grains was found to be correlated

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with their geometry; also, their aspect ratio does not influence the stability of the piles characterized by the critical angles which depend mostly on the relative amount of fine grains in the granular mixture and on the dispersion of the sizes [5].

In this work we present preliminary qualitative results obtained in piles controled built up with a dicharge point which can oscillates and move up from the top in order to understand segregation mechanisms.

EXPERIMENTAL SETUP

The designed device allows one to create piles of, at most, two different species of grains inside a quasi bi dimensional transparent cell (length: 400 mm, height: 150 mm, thickness: 10 mm).

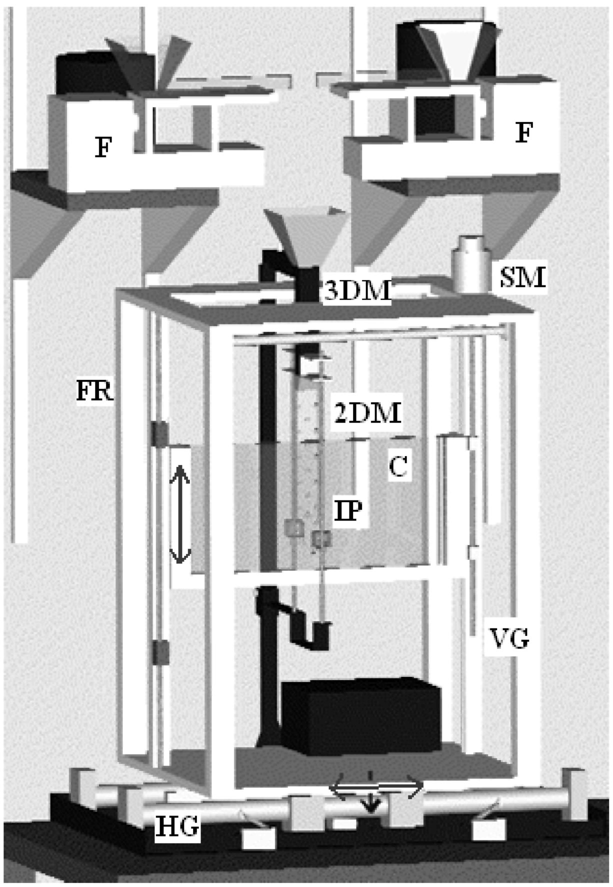

FIGURE 1. Experimental device scheme. F: feeder, 3DM: 3D mixer, 2DM: 2D mixer, IP: injection point, C: cell, VG: vertical guide, SM: stepper motor, FR: frame, HG: horizontal guide.

The piles can be constructed with a controlled vertical and horizontal relative motion between the grains' injection point and the pile in formation.

The device consists of a grain feeding system, which is fixed in space and has its outlet at the injection point (IP in Fig. 1), and the cell where the pile is constructed (C), that features the mentioned horizontal and vertical movements.

The grain feeding system is formed by two vibration feeders (F) and a tandem of a 3D and 2D static mixers [6,7] (3DM and 2DM). Each feeder contains only one kind of grain which mass rate can be controlled by the tension applied to the feeder. The mixers assurance that the segregation seen in the pile is due to the construction process and that the kinetic energy at which the grains reach the pile is the one gained by grains during their trajectories between the injection point and the top of the pile.

The cell moves along two vertical guides (VG) and its motion is produced by a stepper motor (SM) through a screw and nut mechanism. Besides, the vertical guides are fixed to a frame (FR) that moves along two horizontal guides (HG) driven by a DC motor and a rack and pinion mechanism. In this way it is obtained the coupled vertical and horizontal motion of the cell that, beyond its function of controlling experimental variables, allows one to position the cell for the photography that is taken after each experience.

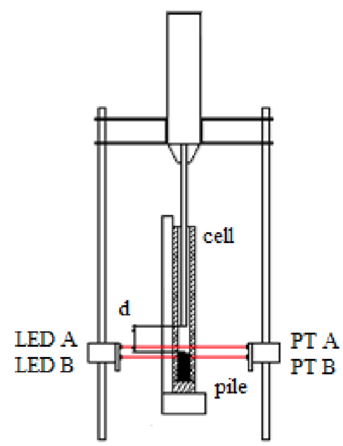

FIGURE 2. Vertical movement's control system. PT: phototransistor, d: distance between the injection point and the top of the pile.

The control system of the vertical motion allows fixing the distance between the injection point and the top of the pile during the construction process (d in Fig. 2). The system consists of two infrared detectors formed by two LEDs (LED A and LED B in Fig. 2) and two phototransistors (PT A and PT B in Fig. 2).

When the top of the pile moves below the barrier formed by LED B and PT B, the stepper motor rotates counterclockwise to make the cell ascend. Similarly, when the top of the pile moves above the barrier formed by LED A and PT A, the stepper motor rotates clockwise to make the cell descend.

Regarding the horizontal motion, a control system allows one to make it alternative with fixed amplitude and velocity. The amplitude is controlled by two movable switches that inverse the movement while the velocity control is done by the input tension of the DC motor. Although the velocity control is an open loop one, it counts with the measure of the rotational velocity of the DC motor through an encoder for verification. The discharge point horizontal speed can be varied from 2 to 13 mm/s.

EXPERIMENTS AND RESULTS

In order to study the segregation phenomenon present in the formation of piles we have performed experiments with the device depicted above, wondering about the influence of the following control parameters: size relation of grain species, injection flow, height of the injection point and the extent of the longitudinal displacement for the case of dynamic experiments.

We worked with three different sizes of glass beads (3, 2 and 1mm diameter) using two size relations, 3:1 and 3:2. The injection flow for granular materials were 0.2 g/s and 0.4 g/s; and the relations of flows were 1:1, 1:2 and 2:1. We used a heigth of 10 and 50 mm for the injection point, mesureded from the top of the pile. For dynamic experiments, the horizontal speed of the injection point was fixed at (10.0$\pm$0.3) mm/s, and the amplitudes of the movement were 100 and 200 mm.

In order to analyze the influence of the injection flow, we have built piles with grains with diameter 2 and 3 mm, for a height of the injection point H = 10 mm and different masses relations. In experiments with a lower discharged mass of coarse grains (relationship of 0.6 between coarse and fine particles mass) we observe a strong segregation, i.e., we have obtained piles with a low presence of large grains in the central region of them as reported by Williams [8]. Fig. 3 shows a photograph of a typical pile built up with this parameters.

Let us notice, that the influence of the mass flow of each component is no significant on the segregation patterns: the relative volumes occupied by the different species are in direct relation to the mass ratio and does not change the structure.

For piles built with grains of 1 and 3 mm and H= 10 mm for the injection point we observe bands of large and small grains. A typical pile showing stratification [9] can be seen in Fig. 4. Let us remember that Makse *et al* argue that stratification phenomenon is associated to the competition of two segregation mechanisms: segregation due to the grain geometry and segregation due to difference in size. In the case of our experiments, the grains are quite spherical and we observe that stratification vanishes for higher coarse mass flow rate compared to fine ones taking place stronger segregation.

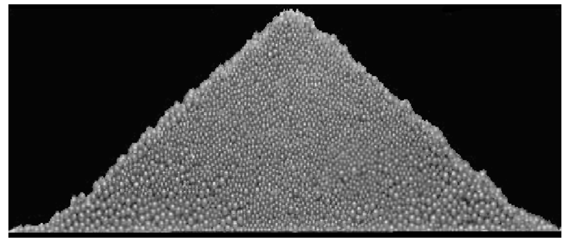

FIGURE 3. Pile with size relation 3:2, for a height H = 10 mm and a greater mass of small grains. Mass relation between both sizes 0.6.

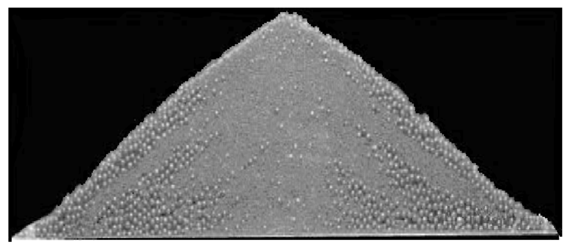

FIGURE 4. Pile with size relation 3:1, for a height H = 10 mm and a greater mass of small grains. Mass relation between both sizes 0.6.

In order to study the influence of the height of the discharge point we have performed experiments with H = 50 mm. Figs. 5 and 6 show piles for size relations 3:2 and 3:1, respectively, with a height of 50 mm and mass ratio of 0,6 (coarse/fin particles relationship). Comparing to Figs. 3 and 4, we observe a higher degree of mixing in piles built with the same size and mass relation but H = 50 mm. In fact, grains arrive at the piling up with greater kinetic energy: in this case, the grains "jump" throughout the slope and its distribution in the piling up will depend on the properties of the collision between grains. For an injection close to the top of the pile as in Figs. 3 and 4, grains roll down the surface. Then, segregation takes place and the dominant mechanism is the interaction between the grains and the layer of grains just below which depends on the size of the rolling grains [10-11].

We have carried out dynamic experiments with different amplitudes of the oscillating motion of the discharge point.. In Fig. 7 and 8 we show piles obtained for an amplitude of 100 mm and 200 mm, H = 10 mm.

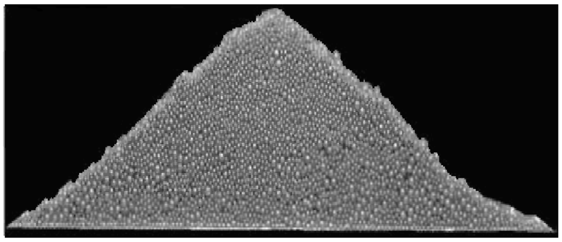

FIGURE 5. Pile with size relation 3:2, 50 mm for height of the injection point and mass relation between both sizes 0.6.

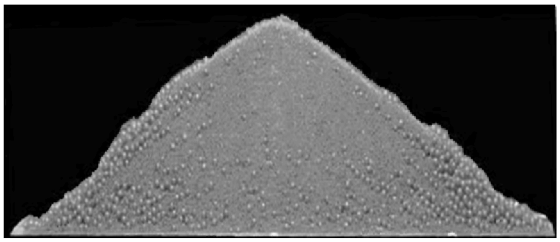

FIGURE 6. Pile with size relation 3:1, 50 mm for height of the injection point and mass relation between both sizes 0.6.

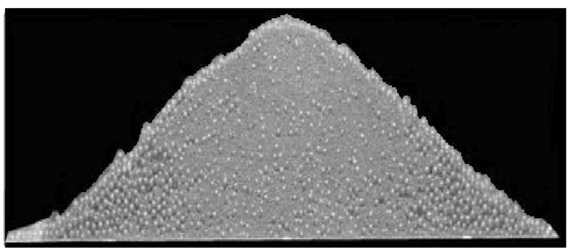

FIGURE 7. Pile with size relation 3:1, H = 10 mm, amplitude of 100 mm and approximately equal mass of both grain species.

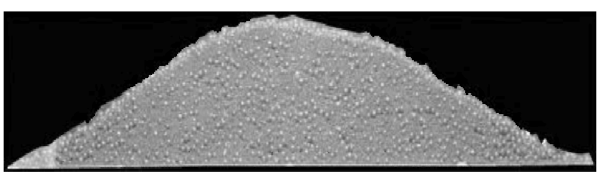

FIGURE 8. Pile with size relation 3:1, H = 10 mm, amplitude of 200 mm and approximately equal mass of both grain species.

We can observe that when we increased the amplitude, the top of the pile becomes more rounded and the mixture of grains was improved, as shown in Fig. 8.

CONCLUSIONS

We have reported preliminar experimental observations of the influence of different parameters of building piles on the segregation. The influence of the ratio of sizes on segregation was studied many years ago and is well known to be very significant. Nevertheless, we have seen that for certain conditions, we observed bands corresponding to striae that may be due to the combined effect: grain bearings and the outbreak of small avalanches. This competition between segregation and stratification in these experiments needs to be explore in detail. If the injection is placed far from the top of the pile, the grains arrive at the piling up with greater kinetic energy: in this case, the distribution in the piling up will depend on the collision properties between grains. This mechanism reduces the segregation, independent of the relation of sizes. The displacement of the injection point also reduces the segregation phenomenon. A possible explanation is that the horizontal movement allows the percolation of grains in different layers while rolling.

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REFERENCES

1 F. M. Wolpers. “Homogenization of bulk material in longitudinal and circular stockpile arrangements” in *BELTCON 8.18* (1995). The South African Institute of Materials Handling (http://www.saimh.co.za/)
2 Williams, J. C. *Powder Technol.*, 15, 245–251 (1976).
3 G F Salter, R J Farnish, M S A Bradley and A J Burnett. “Segregation of binary mixtures of particles during the filling of a two-dimensional representation of a hopper”. Proc. IMechE, Part E: *Journal of Process Mechanical,* 214, 3 197-208 (2000).
4 H. Matthée. *Powder Technol.*, 8, 1, 265–271 (1967)
5 A. M. Vidales, I. Ippolito, O. A. Benegas, F. Aguirre, O. C. Nocera and M. R. Baudino, *Powder Technol.,* 163 184–189 (2006)
6 L Bruno, A. Calvo and I. Ippolito. *Eur. Phys. J. E.* 11, 131-140 (2003)
7 L. Bruno, A. Calvo and I. Ippolito. *Int Journal of Heat & Technology*, 21, 1 (2003)
8 Williams, J.C., *Chem. Proces. Supplement*, April, (1965).
9 H. A. Makse, P. Cizeau, and H. E. Stanley. Phys. Rev. Lett. 78, 3298-3301 (1997).
10 M. A. Aguirre, I. Ippolito, A. Calvo, C. Henrique and D. Bideau. *Powder Technol.* **92,** 75-80 (1997)
11 C. Henrique, M. A. Aguirre, A. Calvo, I. Ippolito, S. Dippel, G. G. Batrouni and D. Bideau. *Phys Rev E*, **57**, 4 4743-4750 (1998).