SEGREGATION OF BINARY GRANULAR MIXTURES DURING HEAP FORMATION IN A SIMPLIFIED MODEL OF BLAST FURNACE

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Abstract Granular materials segregate during flow due to their different physical properties. Segregation of granular mixtures during heap formation has been studied in a quasi two-dimensional rectangular bin. Results presented here are for binary mixtures with different size and equal density particles. Parameters varied in the experiment to obtained different segregation pattern at equilibrium are volume (mass) of pouring and the height of the divider from the bottom. Profiles of number fraction of big particles along the flow direction across the depth in the flowing layers are plotted for the different cases. The extent of segregation is found to increase with increase in height of the divider but is independent of the mass of pouring. Each experiment is repeated eight times to get an average data.

1 INTRODUCTION

Granular materials are a collection of solid particles in a size range of a few millimeters to a few centimeters. They are present everywhere in nature and are the second most manipulated material after water [1]. Commonly used granular materials are salt, sugar, coffee, rice in day to day life and sand, gravel, coal, powders, fertilizers, and pharmaceutical pills in various industries. This paper is mainly interested in the above mentioned size range as most of the materials used in the industry are in this range. Electrostatic charges and surface forces are negligible for such particles. The flow of granular material is encountered in various industries during transportation of materials, mixing of rotary kiln, storage of materials in hopper and silos, crushing and grinding, mechanical separations etc. It is also encountered in nature during transportation at river bed, during formation of sand dunes, in lava flows, in avalanches. The properties of granular materials during flow are different which gives problems in various industries.

A number of researchers have studied segregation mechanisms experimentally [2-5, 13-14] as well as by simulations [6-8]. Particle Dynamics [9-10] or discrete element method [11] and Monte Carlo simulations [1, 3, 12] are used as a computational techniques. Several previous studies of segregation in granular mixtures have focused on rotating cylinder [2, 4, and 9] and chute flows [3, 13]. This paper perform experiments of segregation in granular flows during heap formation.

The objective of the present work is to study the segregation of a binary mixture of granular materials in a quasi-2 dimensional rectangular bin (two vertical glass plate separated by a gap of 10 mm) during heap formation. The intensity of segregation is calculated in terms of number fraction of big particles present in the mixture. The variation in number fraction of big particles is plotted along the flow direction across the depth in the flowing layer by changing height and volume of pouring.

2 EXPERIMENTAL

Experiments are carried out in quasi-two-dimensional rectangular bin (two vertical glass plate separated by a gap of 10 mm). Stainless steel (SS 316) balls of different size of diameters (1, and 2 mm) are used as model granular materials. The images taken are analyzed using computer code to detect the particles. Image analysis technique is used to detect the position and size of the particles. Profiles of number fraction of big (2 mm) particles along the flow direction across the depth in the layers are plotted separately for top and bottom region of the heap. Flowing layer decreases towards the end. We have assume flowing depth constant for simplicity. Schematic view of heap formation is shown in figure 1.

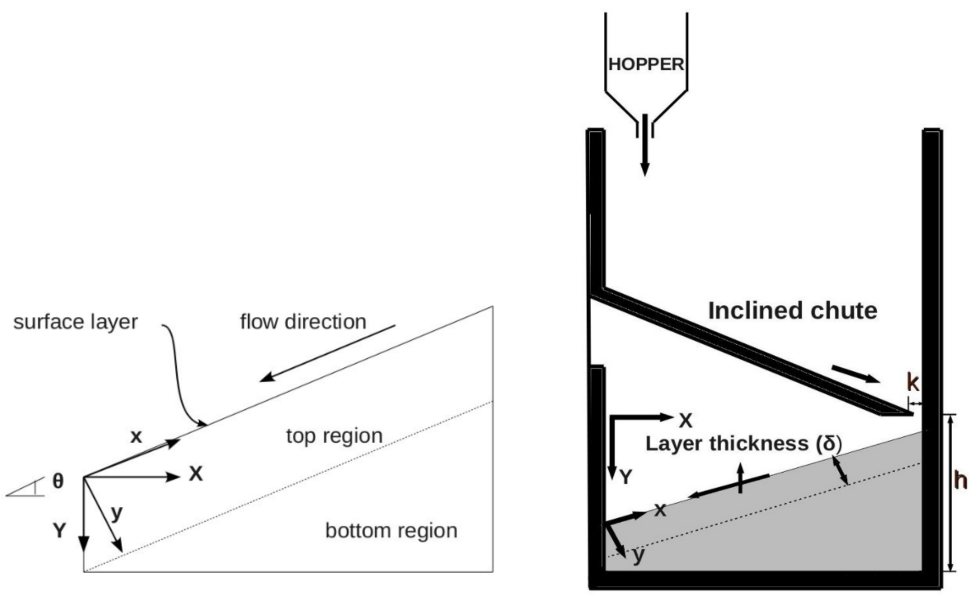

Figure 1: Schematic view of heap formation, comprising top and bottom region (left) along with setup used (right). Coordinate system shows x= 0, y= 0 at the low end of the top surface of the pile. The coordinate system employed in the analysis is shown (left).

Experimental setup consists of two glass plates (52 cm x 29 cm), L shaped aluminum divider and an auxiliary hopper. The side walls (glass plates) are transparent to facilitate imaging. The gap between two vertical glass plates is 1 cm and the L shaped aluminum spacer is placed. L shape divider is chute used in the blast furnace with angle of chute close to 40 degrees. Aluminium divider forms an inclined chute so that materials will easily flow and then settles at the bottom to form a heap. The auxiliary hopper is placed on the top of the bin for supply of granular material as a feed. The exit of the chute is designed so as to provide minimum disturbance to the flow. The tip of the chute is smoothen by reducing the sharpness of the exit (the point at which materials fall from the gap k and then fall on to the heap), which in turn reduces the disturbance to the flow. A black paper is placed at the back of the glass plate so as to ensure good quality images after experiments. The position of the aluminum divider can be adjusted to control the flow rate and the height of fall to the top of the heap. Halogen lamp (1000 watt) is used as light source for better image analysis. The setup is leveled properly to ensure that side walls are vertical and the base is horizontal. The distance between divider exit and heap (forms at the bottom after experiments) is sufficient so that material will flow easily and get enough time to settle at the bottom.

3 IMAGE ANALYSIS TECHNIQUE

3.1 Detection of particles

Image analysis technique is used to detect the position and size of the particles from captured images. The images (4608 x 3072 pixels) are captured using a digital camera (Nikon D3100). In all images particles appear as tiny bright spots on a black background. A typical captured image is shown in figure 2. These data is used to plot profiles of number fraction of big particles along the flow direction across the depth in the flowing layer.

4 RESULTS AND DISCUSSION

The parameters varied in the experiments are the volume (mass) of mixture and height of the divider from the bottom for fixed gap (k = 5 mm) between the plate and the divider. Therefore results presented below are based on these parameters. The profiles of number fraction of big (2mm) particles along the flow direction across the depth in the flowing layer for top and bottom region are shown below. Each flowing layer is divided into bin of size (layer thickness x 10 mm). Layer thickness is depends upon amount of volume poured in each step. Layer thickness is calculated experimentally as well as theoretically for known volume (mass) of mixture which is explained below. In practical, thickness of layer reduces with distance but here assume as same from initial (pouring point) to the end point. Experimentally it is measured before and after pouring using Image J software in terms of pixels and then converted to mm. Theoretical calculations is done as follows. Initially amount of material poured (i.e. mass) converted into volume using

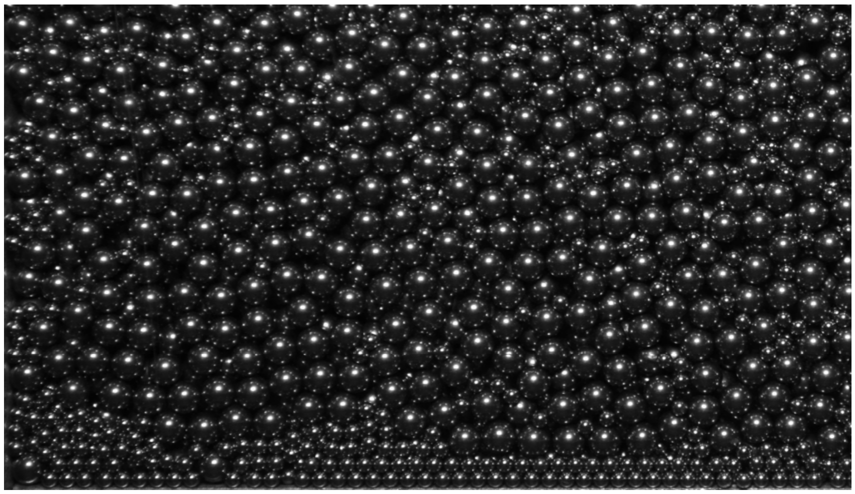

Figure 2: Typical captured image: The particles are seen as bright spots.

density of material. Then using setup geometry, the distance of one layer in x- direction (flow direction) is known which is typically distance of surface profile. The gap between two glass plates is known as 10 mm (1cm). Finally using the formula, Volume of material (mm3) = layer thickness (mm) x gap (mm x distance in flow direction (mm), I have calculated layer thickness which is compared with the experimental value. In figure (3), 10 mm is the layer thickness for 150 gm of mixture and average layer thickness taken for each layer is 5 mm and similar calculation is done for subsequent layers. In all cases studied top layer (surface layer) is neglected. The error bars denote the standard deviation over eight experiments

Effect of mass of pouring

Figure 3 shows the profile for 50% mixture of small (1 mm) and big (2 mm) particles with equal density for different volume of pouring for top region (3 (a), (b), and (c)) and bottom region (3 (d), (e) and (f)). The number fraction profiles of big particles for bottom region are overlap with each other and almost identical for all the cases of volume of pouring (3 (d), (e) and (f)). The profiles of top region 3 (a), (b) and (c) does not shows significant variation in the number fraction across the depth in flowing layer and it indicates that segregation in flowing layer is independent of volume of pouring. The data indicate segregation (partial) with big particles at the far end of the heap and small particles settle near the heap.

Effect of height variation

Fig. 4 shows profiles of 50% by volume of mixture of small and big particles with equal density for different height of the divider from the bottom. Top region (4 (a) and (b)) as well as bottom region (4 (c) and (d)) shows large variation in number fraction profile plotted for different layer thickness. This indicates that mixing is more in flowing layer if height of the divider from the bottom is increases. Also increase in height creates more energy for particles during flow due to which small particles may bounce and settle at the far end of heap.

5 ACKNOWLEDGEMENT

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6 CONCLUSIONS

Segregation of different sized particles of equal density has been studied to understand the dependence of mass of pouring and variation in height (h) of the divider from the bottom. Data obtained from image analysis is used to determine number fraction of big particles along the flow direction across the depth in the flowing layers. Data shows large particles travel more distance than small particles as smaller ones can easily fit into void spaces created during flow of materials. Increase in height of the divider from the bottom, decreases the number fraction of big particles. Mass of pouring does not have significant effect on number fraction of particles.

REFERENCES

[1] Patrick, R., Nicodemi M., Delannay R., Ribiere P., and Bideau D. (2005). Slow relaxation and compaction of granular systems. *Nat. Mater.* 4, 121–128.

[2] Ding, Y. L., Forster R., Seville J. P. K., and Parker D. J. (2002). Segregation of granular flow in the transverse plane of a rolling mode rotating drum. *Int. J. Multiphase Flow* 28, 635–663.

[3] Khakhar, D. V., Orpe A. V., and Hajra S. K. (2003). Segregation of granular materials in rotating cylinders. *Physica A* 318, 129–136.

[4] Makse, H. A., Havlin S., King P. R., and Stanley H. E. (1997). Spontaneous stratification in granular mixtures. *Nature* 386.

[5] Ottino, J. M. and Khakhar D. V. (2001). Fundamental research in heaping, mixing, and segregation of granular materials: challenges and perspectives. *Powder Tech.* 121, 117–122.

[6] Shinbrot, T., Zeggio M., and Muzzio F. J. (2001). Computational approaches to granular segregation in tumbling blenders. *Powder Tech.* 116, 224–231.

[7] Tripathi, A. and Khakhar D. V. (2011) Rheology of binary granular mixtures in the dense flow regime. *Phys. Fluids* 23, 113302

[8] Yaowei, Y., Saxen H. (2010) Experimental and dem study of segregation of ternary size particles in a blast furnace top bunker model *Chem. Eng. Sci.* 65, 5237–5250.

[9] Khakhar, D. V., McCarthy J. J., and Ottino J. M. (1997) Radial segregation of granular mixtures in rotating cylinders. *Phys. Fluids* 9, 3600–3614.

[10] Vargas, W. L., Hajra S. K., Shi D., and McCarthy J. J. (2008) Suppressing the segregation of granular mixtures in rotating tumblers. *AIChE* 54, 3124–3132.

[11] William, R. K., Curtis J. S., Wassgren C. R., and Hancock B. C. (2008) Modeling granular segregation in flow from quasi-three-dimensional, wedge-shaped hoppers. *Powder Technol.* 179, 126–143.

[12] Rosato, A. and Prinz F. (1986) Monte carlo simulation of particulate matter segregation. *Powder Technol.* 49, 59–69.

[13] Savage, S. B. and Lun C. K. K. (1988) Particle size segregation in inclined chute flows of dry cohesionless granular solids. *J. FLuid Mech.* 189, 311–335

[14] Gharat, S. H. (2017) Dynamics of granular segregation in quasi 2D system. *EPJ web of conf.* 140, 03039.

[15] Gharat, S. H. and Khakhar D. V. (2013). Granular segregation in quasi 2d rectangular bin. *AIP Conf. Proc.*, Powders and Grains, 1542, 755–758

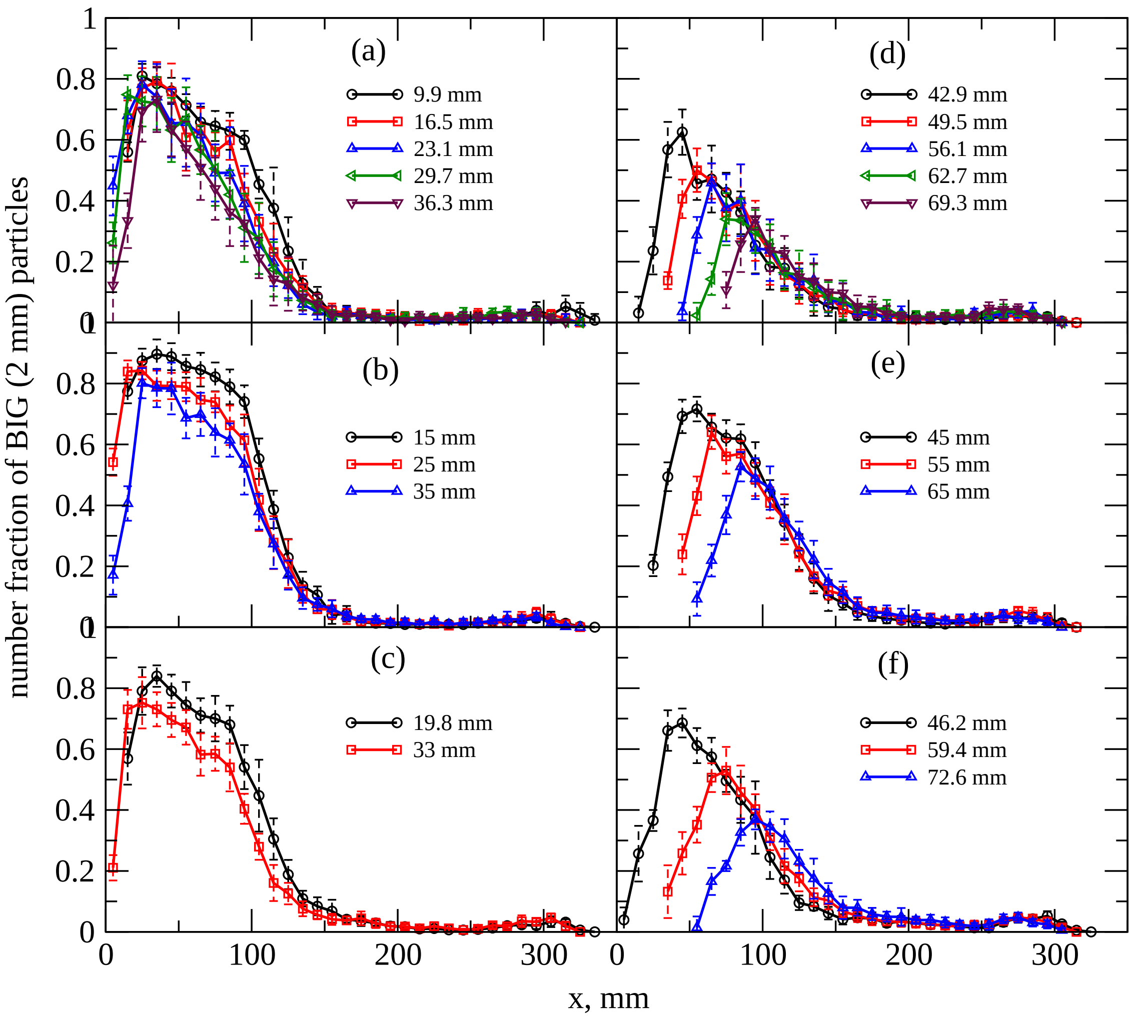

Figure 3: Profiles of number fraction of big (2 mm) particles along the flow direction, x (mm) across the depth in the flowing layer, y (mm), for equal % of mixture. Volume of pouring (a) 100 gm (b) 150 gm and (c) 200 gm for top region and similarly for bottom region (d), (e) and (f). Height of the divider from the bottom (h): 22 cm. Error bars show the standard deviation over eight experiments.

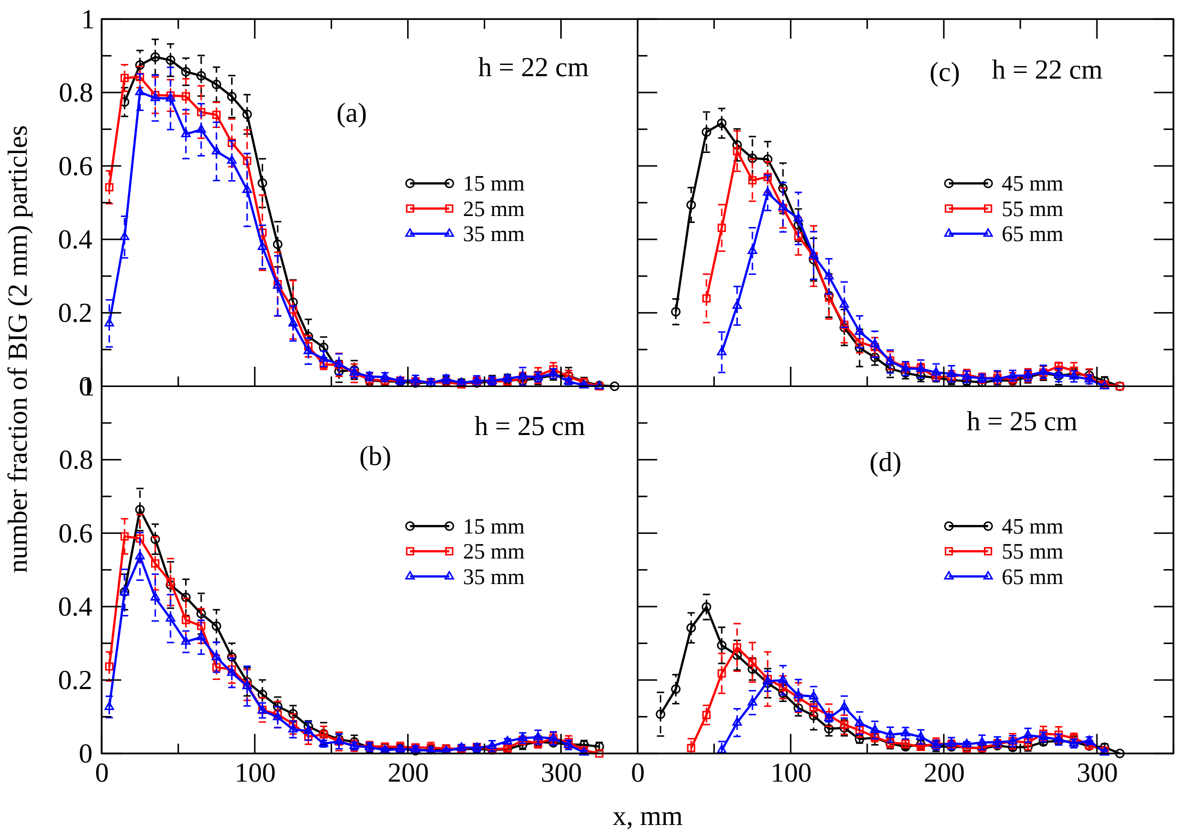

Figure 4: Profiles of number fraction of big (2 mm) particles along the flow direction, x (mm) across the depth in the flowing layer, y (mm) for equal % of mixture. Height of the divider from the bottom (a) 22 cm, and (b) 25 cm for top region and similarly for bottom region (c), and (d). Volume of pouring: 150 gm. Error bars show the standard deviation over eight experiments.