Study of Behaviors of Single Large Intruders in Bulk Flow

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Introduction

- Understanding the fundamentals of granular flow is crucial to industrial applications. Good examples are found in processing pharmaceutical pills and ceramic powders. Mixing granular materials is a major concern for engineers who process granular materials.
- Developing sensor particles to track the flow of granular materials is a good way to understand the characteristics of granular flow.
- In order to facilitate the development of sensor particles, it is crucial to understand how the sensor particles behave in bulk granular flow. This research was to study how a single intruder's (sensor) movement might be different than that of the bulk particles. In other words, this research is to understand the segregation process, so that details of this disparate movement could be used to predict the bulk behavior.
- Most of the segregation occurs in the vertical direction so that most parts of this research is focused on exploring the vertical segregation between intruders and matrix particles.

Methods

- A split-bottom cell (Fig 1) already built in Prof. Hill's laboratory was used for this study. When particles fill the cylinder partway and the center of the base is rotating, it will generate a bulk flow.
- Two types of particles were used in my experiment, glass particles 2 mm in diameter acting as matrix particles, and larger particles acting as intruder particles 20 mm or 25 mm in diameter and with various densities the density ratios between intruders and matrix ranges from 0.1 to 1.3.
- The filling height of matrix particles in the split bottom cell varies from 35 mm to 55 mm so that the intruder particles' travel distances in the vertical direction can be studied.
- Most of the intruder particles have lower density compared to matrix particles, thus they are expected to rise in the matrix. As a result, the intruder particles were buried at the bottom of the split cell and their average vertical rising time *t* were measured. From this, the vertical velocity *v* were evaluated, because v is a significant indicator of vertical segregation effects.

Data and Graph

Fig 1a

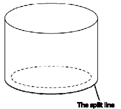

Fig 1b

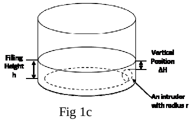

Fig 1c

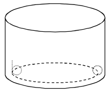

Fig 1d

Figure 1a: photo of split-bottom cell. Figure 1b: schematics of split bottom cell. The inner bottom is split and is able to rotate. Figure 1c: schematics of placement of intruders at the center of split. *h* represents the total filling height. ΔH is the travel distance: $\Delta H = h - 2r_{\text{intruder}}$. Figure 1d: different burial locations. The intruder on the left is placed inside the split line while the right one is place at the split line.

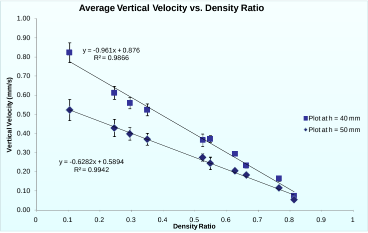

Fig 2: plots of "average vertical velocity vs. density ratio" for 25 mm diameter intruder particles at rotation frequency 0.01 revolution/s. The square spots represent results of filling height H = 40 mm. The diamond spots represent results of filling height H = 50 mm.

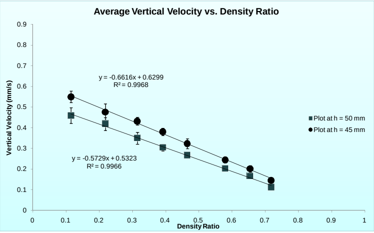

Fig 3: plots of "average vertical velocity vs. density ratio" for 20 mm diameter intruder particles at rotation frequency 0.01 revolution/s. The dots represent results of filling height H = 45 mm. The square spots represent results of filling height H = 50 mm.

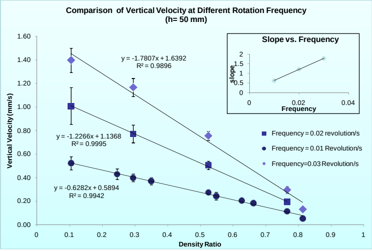

Fig 4: comparison plots of "average vertical velocity vs. density ratio" for 25 mm diameter intruder particles under different rotation frequencies. The dots represent results at f = 0.01 revolution/s, the square spots represent results at f = 0.02 revolution/s and the diamond spots represent results at f = 0.03 revolution/s. Note that the slopes of best fit trendlines changes linearly with rotation frequencies.

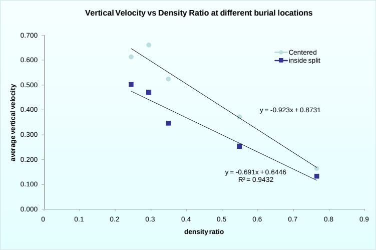

Fig 5: comparison plots of "average vertical velocity vs. density ratio " for 25 diameters at h = 40 mm at the two burial locations. The dots represents velocity results that intruder particles' burial location is at the split line and the square spots represents results buried inside the split line.

Future works

- More tests on various sizes of intruders are needed to determine the impact of size ratio on segregation effects.
- Computer simulations are quite helpful to explore the intruders' vertical velocity profile inside the matrix.
- Segregation effect the radial direction will be studied as another important aspect of intruder segregations.

Results and Discussion

- *Linearly decreasing trend.* – The key result of my research is that the density ratio has a linear impact on vertical segregation effects of intruder particles. Fig2 to Fig4 all exhibit the trend that the average rising velocity is decreasing as density ratio increases. It is reasonable because with density ratio increasing, the effects of density segregation become weaker so that the vertical velocity will be getting smaller. A linear trendline fits each group of data extremely well indicating that the average vertical velocities are actually decreasing linearly:

In Fig2: for 25 mm intruders filling height at 40 mm:

$$y = -0.961x + 0.876 \tag{1}$$

For 25 mm intruders filling height at 50 mm

$$y = -0.6282x + 0.5894 \tag{2}$$

In fig 3: for 20 mm intruders filling height at 45 mm:

$$y = -0.6616x + 0.6299 \tag{3}$$

For 20 mm intruders filling height at 50 mm:

$$y = -0.5729x + 0.5323 \tag{4}$$

- *Impact of increasing filling height.* – By comparing the two equations of the same group of intruder particles, It is apparent that the magnitude of slope at larger filling height is noticeably smaller. In Eq. (1) and Eq. (2), 0.961 > 0.6282. In Eq. (3) and Eq. (4), 0.6616 > 0.5729. This indicates that the average vertical velocity *v* for every intruder is significantly lower for larger filling heights. A lower velocity indicates a lower average net upward segregation effect for larger filling heights.

- *Impact of rotation frequency.*– The rotation frequency might be an important factor involved in exploring the behaviors of intruder particles. In microscopic scale, as the rotation frequency increases, the collisions between matrix and intruder will increase accordingly. Fig 4 compares the trend of average vertical velocities of 25 mm diameter intruders at *h* = 50 mm under three different rotation frequencies. As expected, all the plots show the linearly decreasing trend. The higher frequency, the higher average vertical velocity the intruders have. Furthermore, The slopes are almost directly proportional to rotation frequency. As a result, a linear increase of slope has proved that the segregation effect, due to the collision among matrix particles, will have the same order of increase with rotation frequency.

Impact of burial locations.–Since the shear zone starts from the split line, intruders will always have the largest amount of segregation force as they are initially placed at the split line. However, if the burial locations of intruder particles are off from the split line, they might have less segregation force at the beginning, thus having longer rising time. Therefore, I varied the burial position and measured the time difference. (See Fig. 1d) Fig 5 shows the comparison plots of average vertical velocity for 25 diameters at *h* = 40 mm at the two horizontal burial locations. As expected, seen from the plot, Intruder particles that buried were at the split line have higher average vertical velocities. Intruder particles that are not initially buried right at the shear zone area will take longer time to rise to the top because of a reduced segregation force.

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