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 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 ratio 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.

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. Eq2 to Eq4 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 well extremely indicating that the average vertical velocities are actually decreasing linearly.
- In Eq2, for 25 mm intruders filling height at 40 mm:
  \[ y = -0.961x + 0.876 \]  
  \[ y = -0.5729x + 0.5323 \]

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.

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