STUDY OF SEGREGATION OF NON-SPHERICAL PARTICLES IN A FLUIDISED BED USING LIGGGHTS AND OpenFOAM

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INTRODUCTION

What are granular particles?

- A **granular** material is a collection of distinct macroscopic **particles.**
- Some examples of granular materials are snow, sand, coal, rice, fertilizers, detergent powder, nuts.
- Due to their small size, they are more cohesive and more easily suspended in a gas.

SEGREGATION

- The lighter and/or smaller-sized component will tend to accumulate at the top of the bed and the heavier and/or larger-sized component will sink to the bottom.

- Reason behind segregation:
  - Action of bubbles in fluidized beds.
  - Difference in shape, size, orientation, density of particles.
  - Percolation

- Results into unacceptable product in many process of industries.

SOFTWARE OVERVIEW

- **CFDEM** (Computational Fluidized Dynamics / Discrete Element Method)
  - Couple the OpenFOAM (CFD) and LIGGGHTS (DEM).
  - Based on solving the naiver stokes equation with a solid phase present.
  - Its MPI parallelization enables to use it at large scale.

- **LIGGGHTS** (LAMMPS improved for general granular and granular heat transfer simulations)
  - Used as a simulator for DEM.
  - Generation of particles and setting the wall properties.
  - Calculates position, drag forces, kinetic energy etc. of the particles at each timestep of the particle.

- **OpenFOAM** (Open Source Field Operation and Manipulation)
  - Act as a CFD toolbox.
  - Used to pass fluid of specified parameter in the bed.
  - Generates mesh and compute parallel calculations of pressure drop, inlet and outlet velocity, normal forces on wall.

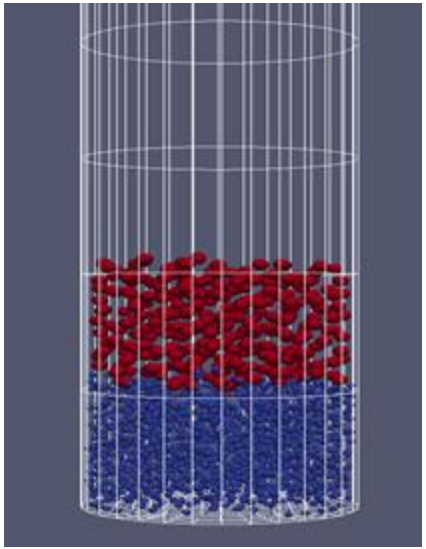
- **Paraview**
  - Visualization tool for the logged data.
  - Python is combined with it to convert the binary data to csv and generate the desired plot.

SIMULATION PROTOTYPE

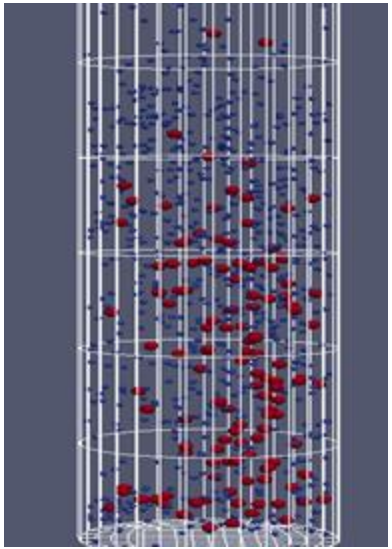
- Scaled the fluidization column to the dimension of column present in lab.
- Performed coupling of binary mixture having two different particles size and shapes in cylindrical and rectangular column.
- No slip condition is assumed between the particles and wall of the bed.
- Some other important parameters are shown in below table:

Properties	Values
Young's Modulus (Pa)	10^{-8}
Poisson's ratio	0.24
Density of the air (kg/m^3)	1.3
Density of particles	2500 kg/m^3
Friction Coefficient	0.6
Cylindrical Column specifications	d = 10 cm , h = 60 cm
Rectangular Column specification	l = 10 cm, b = 8 cm, h = 100 cm

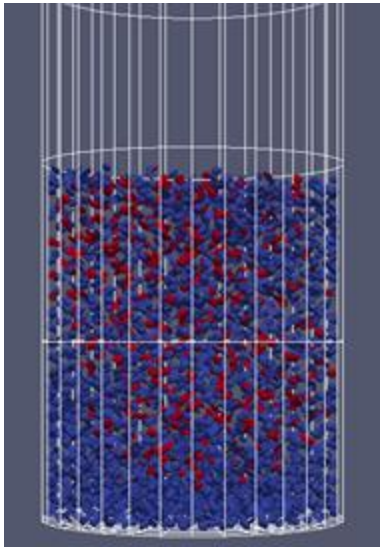
SIMULATION PROTOTYPE (cylindrical)



Initial state

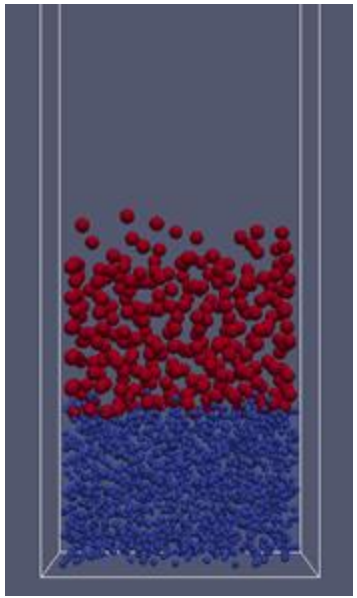


Intermediate

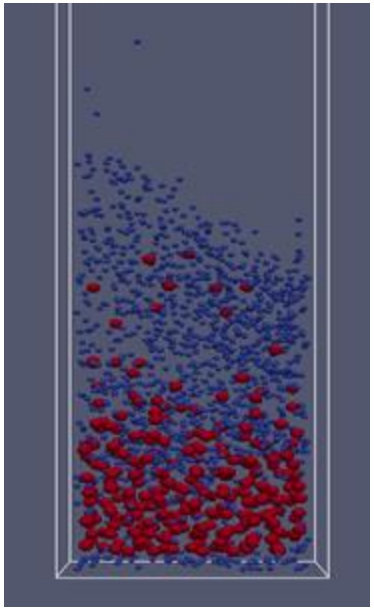


Mixed state

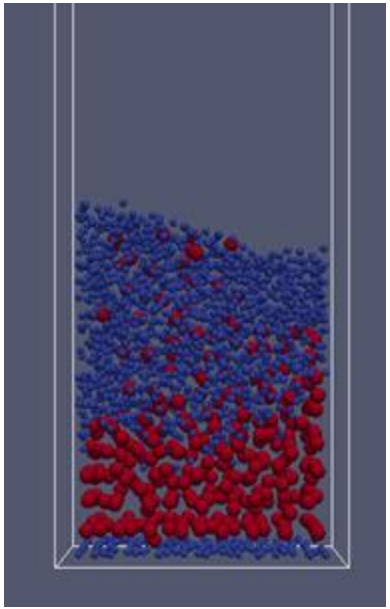
SIMULATION PROTOTYPE (rectangular)



Initial state

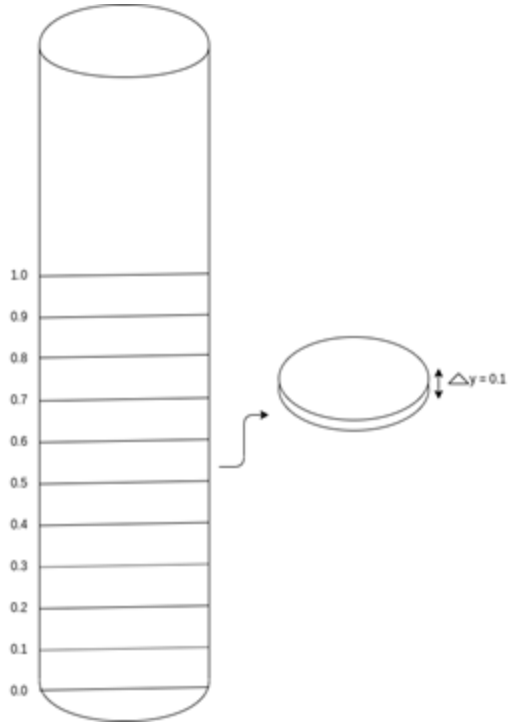


Intermediate



Mixed state

Results and Discussion

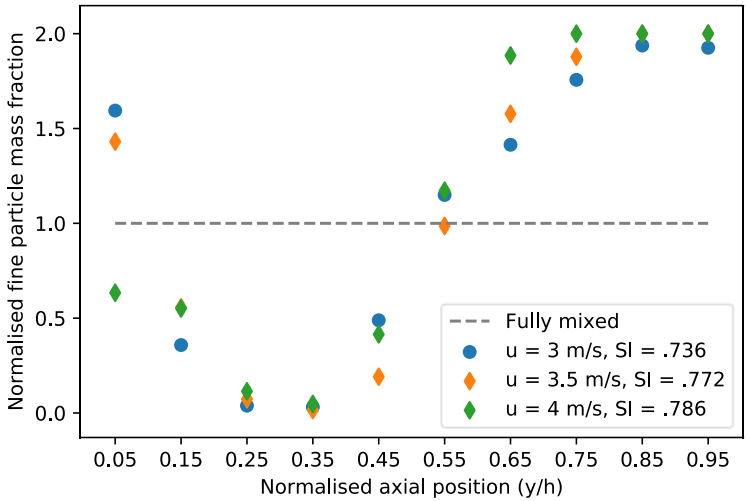


Overall segregation Index (SI)

$$SI = \sqrt{\frac{1}{P}\sum_{p=1}^{P}\left(\left(\frac{x_i}{x_f}\right)_p - \left(\frac{x_i}{x_f}\right)_{\text{mean}}\right)^2}$$

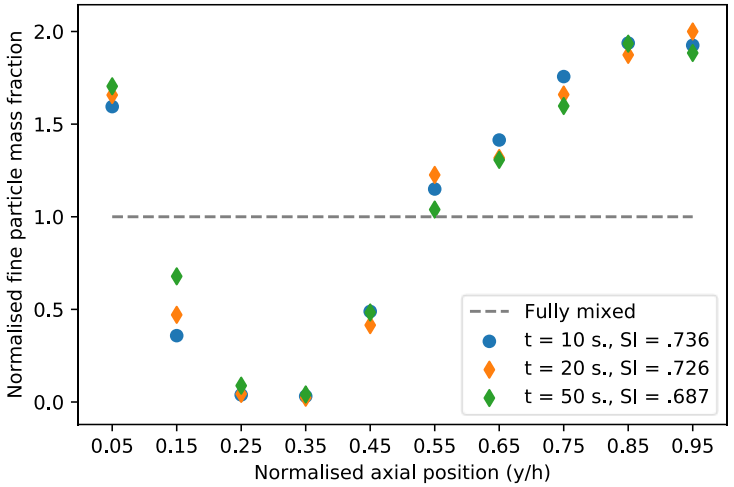
where $\left(\frac{x_i}{x_f}\right)_{\text{mean}} = 1$

Results and Discussion



Segregation at different velocities

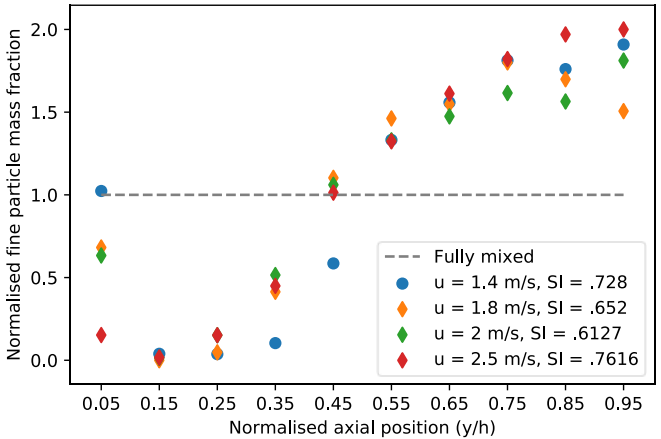
Particles size(3 mm – 6mm), Cylindrical Column



Segregation at different time interval

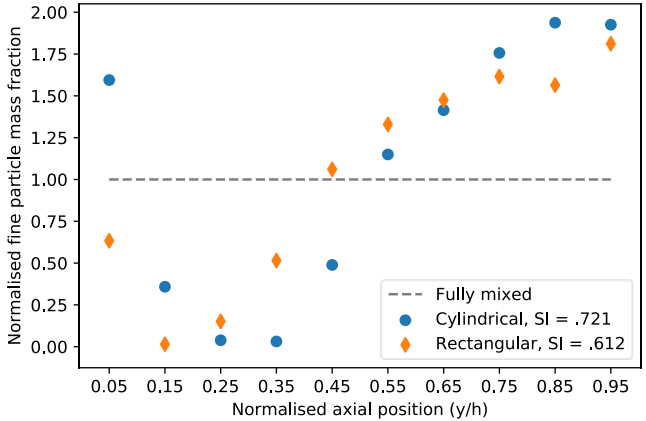
Particles size(3 mm – 6mm), Cylindrical Column

Results and Discussion



Segregation at different velocities

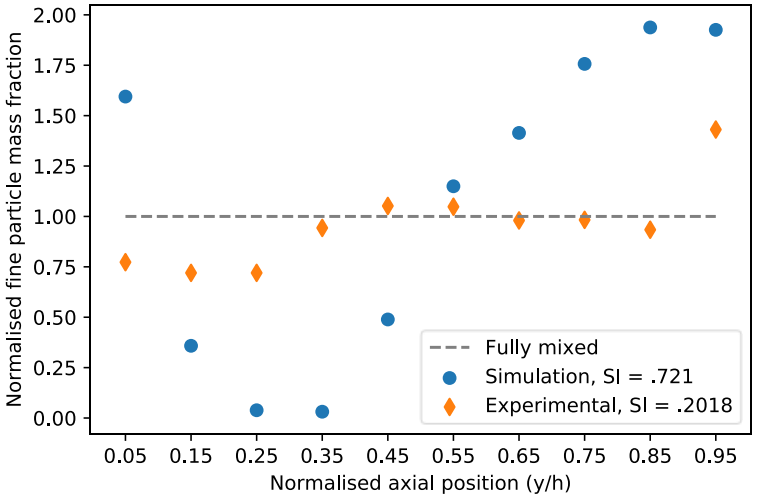
Particles size(3 mm – 6mm), Rectangular Column



Segregation in different shape of fluidised bed

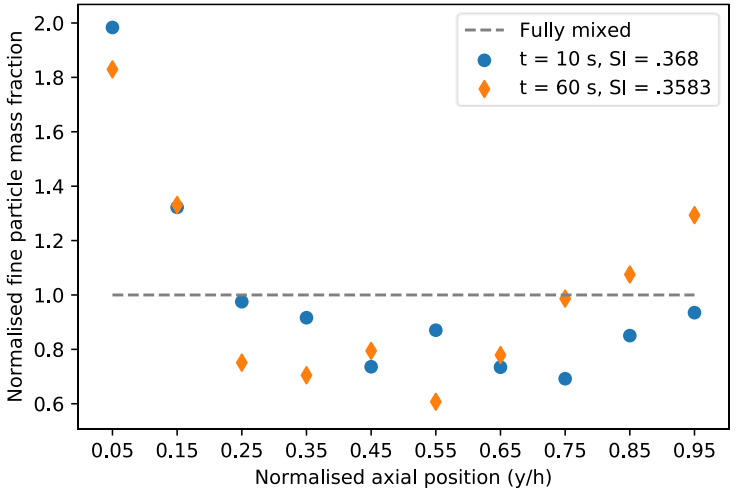
Particles size(3 mm – 6mm)

Results and Discussion



Comaprison of Simulation and experimental results

Particles size(3 mm – 6mm)



Segregation of spherical and prolate particles at different time

Particles size(spherical: 3 mm – prolate: 6-6-3mm)

FUTURE GOALS

- Analyzing the trends of simulation results with the experimental data extracted in the lab.
- Implementing the super quadric (non-spherical) particles for CFDEM and extracting results of it.
- Perform coupling by changing shape of fluidized bed:
    - Pyramidal

REFERENCES

- Experimental and numerical study of fluidization and pressure drop of spherical and non-spherical particles in a model scale fluidized bed, K. Vollmari a, R. Jasevičius , H. Kruggel-Emden
- Predicting the flow mode from hoppers using the discrete element method, William R. Ketterhagen, Jennifer S. Curtis , Carl R. Wassgren , Bruno C. Hancock
- M. A. Gilbertson, I.Eames, Segregation patterns in gas-fluidized systems, Journal of Fluid Mechanics 433 (2001) 347–356.
- Gibilaro, L. G.; Hossain, I.; Waldram, S. P. On the Kennedy and Bretton Model for Mixing and Segregation in Liquid Fluidized Beds. Chem. Eng. Sci. 1985, 40, 2333.
- Rowe, P. N., and A. W. Nienow. 1976. “Particle Mixing and Segregation in Gas Fluidised Beds. A Review.” *Powder Technology* 15.
- https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=2653&context=etd
- https://www.victoria.ac.nz/scps/research/research-groups/raman-lab/eric-le-ru/publications/2009-PCCP-SERS-on-spheroids-from-T-matrix-.pdf