Shear Flows of Dense Suspensions

Meital Carmi, Bernhard Vowinckel, Edward Biegert, Eckart Meiburg
Mechanical Engineering Department, UCSB

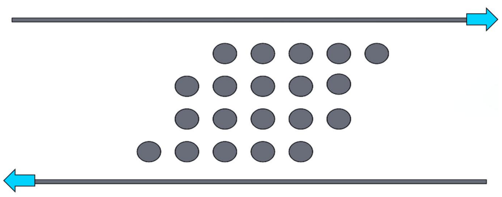
Gorman Scholar Program

Introduction

Understanding the behavior of a dense suspension that is being sheared has a wide variety of applications. For example, we could be able to predict and control debris flows and mudslides. In fluids with large amounts of suspended particles, a very small increase in the shear force often causes an abrupt increase in the mixture's viscosity. This effect, called discontinuous shear thickening (DST), occurs only in flows with dense suspensions and does not occur in clear water flows. This suggests that DST is caused by some element of the particles' behavior, particularly their clustering and mixing. The goal of this project is to analyze the clustering of particles in a dense suspension, experiencing shear force, to understand its relationship to DST.

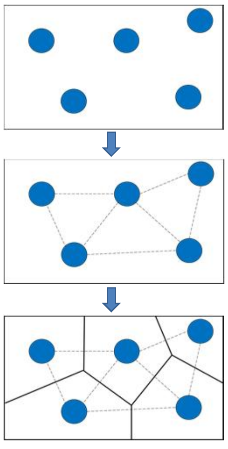
Method

We use numerical simulations to model the flow of a dense suspension being sheared in a channel, with walls moving in opposite directions.

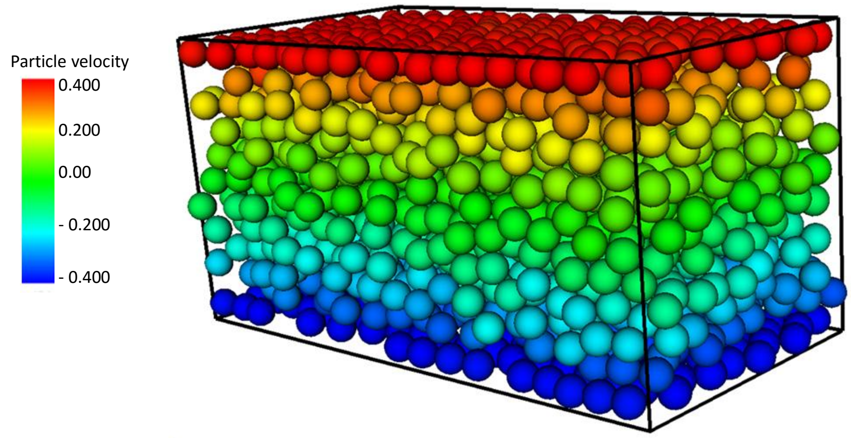


The simulation models 1,000 to 2,000 particles over several hundred time steps and outputs the position of every particle at each time step. We use Matlab to analyze this position data and quantitatively measure the particles' clustering.

Our main tool is the Voronoi diagram, which we use to organize the position data and perform calculations to measure the particles' clustering. A Voronoi diagram is the collection of boundaries drawn around the volume closer to each particle than to any other. For example, to create the Voronoi diagram of the points below, draw lines connecting the points. Then, draw the perpendicular bisector of each line. These bisectors form the boundaries of the Voronoi cells. We apply this concept to the three dimensional particles in the simulation above.

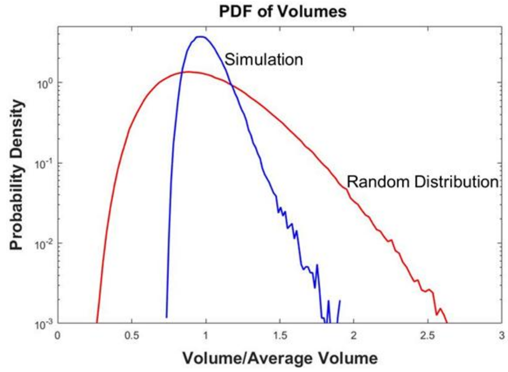


The simulation of a dense suspension in a channel with upper and lower walls moving in opposite directions.

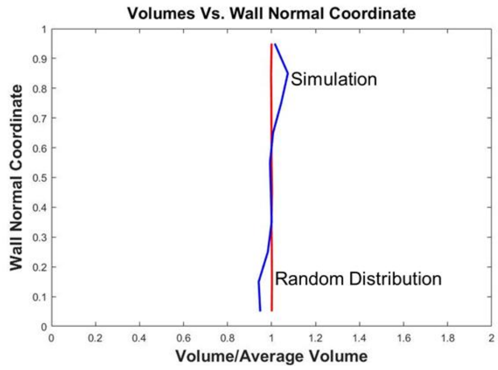


Volume of Voronoi Cells

Small volumes of the Voronoi cells mean that the particles are tightly clustered, while large volumes mean that the particles are farther apart. In the probability density function (PDF) graphed below, the simulation data is compared to a random distribution, used as our control.



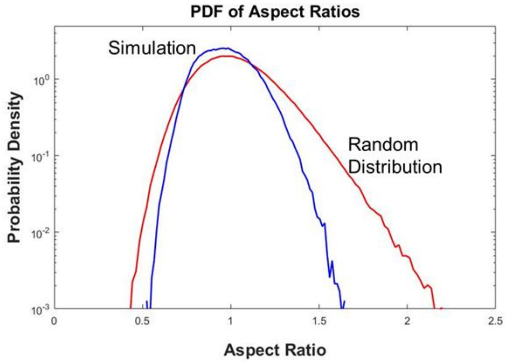
The volumes of the simulation data are closer to the average than the random distribution, due to the even dispersion of the simulated particles. This suggests that the particles are densely clustered, forcing them to pack evenly.



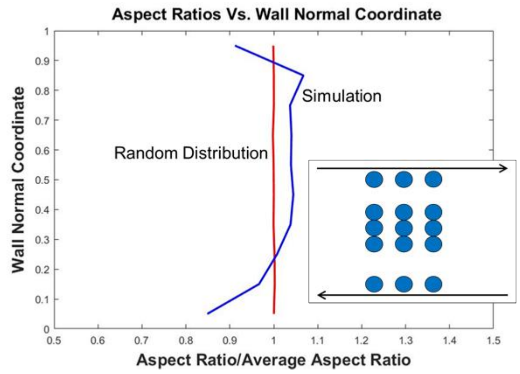
The volumes of the simulation data are fairly constant, vertically, throughout the channel, further implying that the particles are evenly dispersed.

Aspect Ratio of Voronoi Cells

The ratios of the largest horizontal dimensions to the largest vertical dimensions of the Voronoi cells measure shape of the particle clusters. Small aspect ratios mean that the vertical distance between particles is greater, while large aspect ratios mean that the horizontal distance is greater.



The simulation data is closer to and more symmetrically centered on one, than the random distribution. This means that the horizontal and vertical distances between particles are about equal, suggesting an even packing.



This graph suggests that the particles are widely dispersed at the channel walls where the flow speed is greater, and densely packed in the center where the speed is lower.

Conclusion and Future Research

These results suggests that there is a layer of clear fluid flowing quickly near the channel walls and a high concentration of particles flowing slowly in the center of the channel. The dense clustering at the channel's center forces the particles to pack evenly, as shown by the volume data.

Our next step is to perform calculations, similar to the ones discussed above, to measure the particles' mixing. Then, we will run more simulations varying the velocity of the channel walls and the number of particles, to find the threshold where DST occurs. We will run the simulation on either side of this threshold and compare the clustering and mixing of the particles, to determine the behavior that causes DST.

Thank you to Dean Pierre Wiltzius and Office of the Dean, Math, Life & Physical Sciences for organizing the Gorman funding
This work used the Extreme Science and Engineering Discovery Environment (XSEDE), which is supported by National Science Foundation grant number ACI-1053575