Pacific Northwest NATIONAL LABORATORY

PNNL-29736

# Particle Size and Density Measurement

April 2020

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U.S. DEPARTMENT OF ENERGY

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Richland, Washington 99354

# Particle Size and Density Measurement

*PA Gauglitz, CLH Bottenus, MR Powell, CA Burns, GK Boeringa, TG Veldman, and DR Bottenus*

### ◆ Project Summary

This project has developed a miniature gravity settling classifier (flow cell) and flow system that separates slurry particles by settling rate into six different Cuts. The settling rates for particles in each Cut were determined from COMSOL computational fluid dynamics (CFD) modeling of the flow in the flow cell together with particle tracking for particles of differing settling rates. For particles collected in each Cut, the particle concentration and size distribution were measured. The effective particle densities from each Cut are calculated from their respective CFD modeled settling rates using a relationship between the unhindered settling rate, particle size distribution (PSD), and effective density. The particle size and density distribution (PSDD) of the slurry sample is then calculated by combining the size and density distributions determined for the particles collected in each of the settling rate Cuts. ◆

### Introduction and Project Description

A central challenge in processing high-level radioactive waste slurries is dealing with settling particles and predicting the behavior of settling particles in processing operations such as pipeline transport, bulk settling, and waste mobilization. While the measurement of the size distribution and average density of slurry particles are established methods, current methods to measure the PSDD in a slurry with a mixture of particles are inadequate.

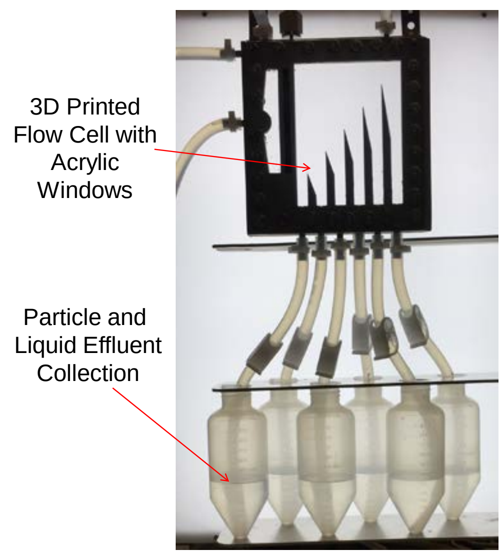
Wells et al. (2007) were the first to emphasize the importance of knowing the PSDD of particles in waste slurries for understanding the behavior of settling particles in slurry processing applications. This need was further clarified by Wells et al. (2011) and several studies of simulant selection for process testing have further emphasized the importance of knowing the PSDD in processing applications (Lee et al. 2012; Gauglitz et al. 2012; Meyer et al. 2012; and Peterson et al. 2016).

Based on the need to measure the PSDD of a slurry, a previous effort was undertaken to develop a method that used video microscopy to measure the size and terminal settling rate of individual particles, and calculate the particle density for multiple individual particles in a slurry using a relationship between particle terminal settling velocity, diameter, and density for ideal spheres (Fountain et al. 2012). The general approach was successful, but the settling velocity measurement was complicated by small thermal convection currents that adversely affected the terminal settling velocity away from ideal behavior. This was particularly apparent for slower settling particles where the terminal settling velocity became comparable or less than the thermal convection currents, while at the same time the non-spherical nature of the particles complicated size measurements.

The objective of the current study is to develop an alternate method of measuring the PSDD of a slurry that minimizes the experimental difficulties observed in the previous study by Fountain et al. (2012).

### Results and Accomplishments

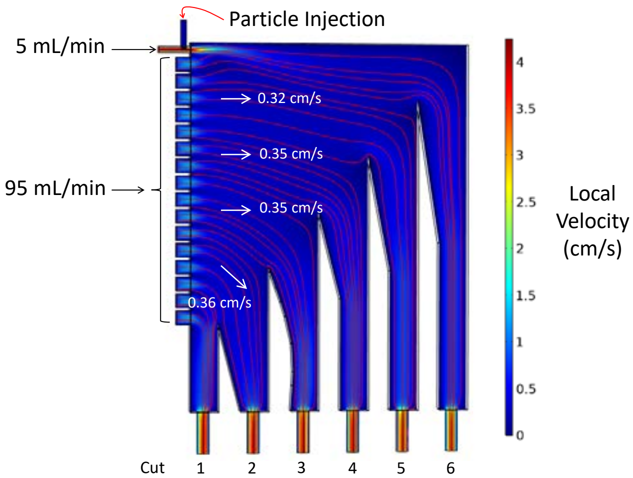
A miniature gravity settling classifier (flow cell) and flow system was developed for separating particles by settling rate into six different Cuts that were collected in individual sample bottles. The flow cell was fabricated with plastic using 3D printing (Hatchbox PLA using a Prusa i3 MK2) and had front and back acrylic windows to allow visual observation of particle trajectories.




**Flow Cell and Particle Collection Bottles**

The settling rate ranges for each Cut were determined from COMSOL modeling of fluid velocity in the flow cell, shown in the figure and table below, together with particle tracking for particles of differing unhindered settling rates. The theoretical results serve as a basis for assessing the performance of the device.

Flow cell tests were conducted with each of five different particles, which had known densities and PSDs. The settling velocities for the particles are shown in the table below. Particles were injected as slurries, using both individual particles and a mixture of all five particles.



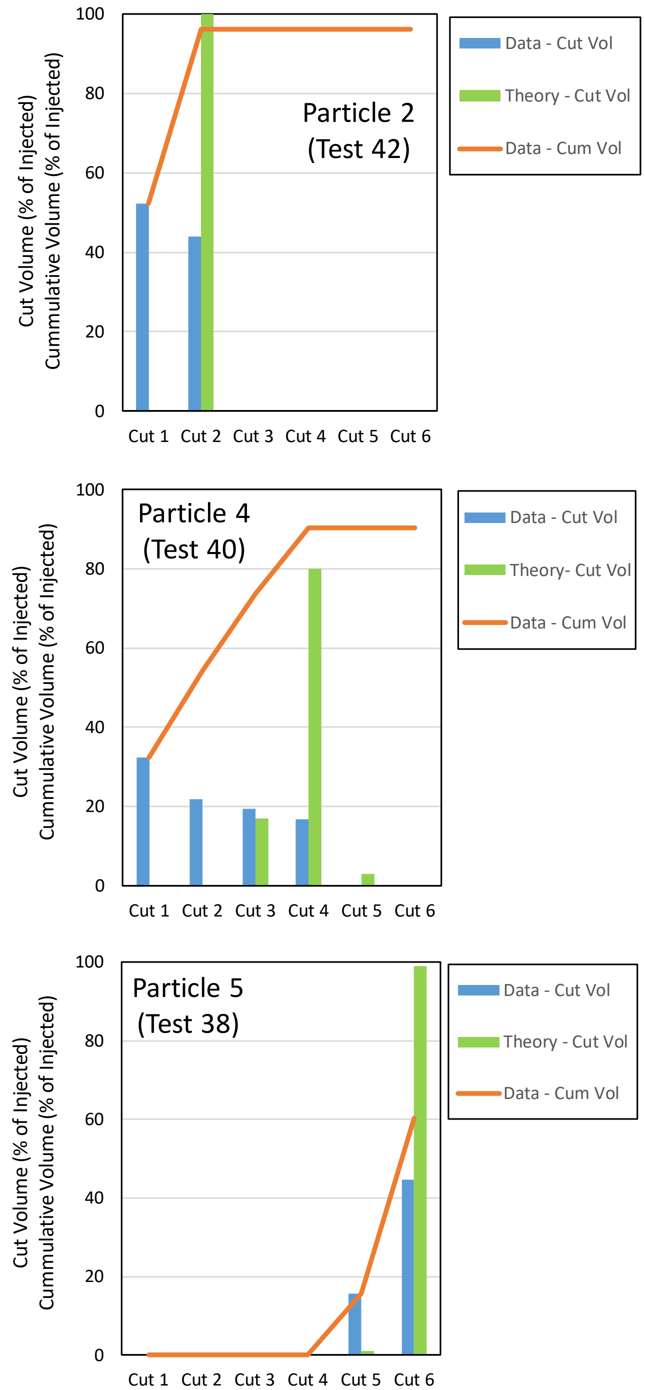

**COMSOL Predicted Streamlines and Centerline Velocities in the Flow Cell for a Flow of 100 mL/min**

| Cut | COMSOL Settling Velocity (cm/s) | Tested Particles $d_{50}$ Settling Velocity (cm/s) |
|---|---|---|
| 1 | > 3.4 | |
| 2 | 0.65 to 3.4 | 3.05 (Particle 1)<br>1.69 (Particle 2)<br>0.740 (Particle 3) |
| 3 | 0.30 to 0.65 | |
| 4 | 0.17 to 0.30 | 0.250 (Particle 4) |
| 5 | 0.054 to 0.17 | |
| 6 | < 0.054 | 0.0118 (Particle 5) |

**COMSOL Predicted Settling Velocities for each Cut and Predicted Cut for each Particle Tested for a Flow of 100 mL/min in the Flow Cell**

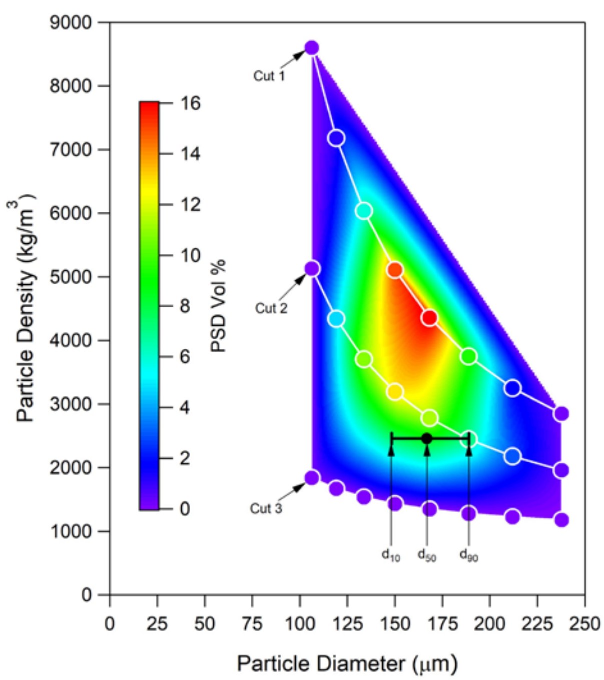
Results of these tests clearly show separation of particles of different settling rates into the different Cuts with faster settling particles being collected in Cuts 1 and 2 and slower settling particles being collected in Cuts 5 and 6. Unfortunately, the particles would typically settle faster (collected in smaller numbered Cuts) than predicted by COMSOL and the particles also spread into multiple Cuts when they were predicted to collect in only one or, at most, two Cuts.

Results for typical particle separation experiments, for individual particles, are shown below with comparisons to the Cuts for these particles predicted by COMSOL. These results demonstrate separation of particles by settling rate and the undesirable results of settling too fast (lower Cut number than theory) and spreading into multiple Cuts (particularly apparent for particle 4). The effective particle densities from each Cut are calculated from their respective CFD modeled settling rates using a relationship between the unhindered settling rate, PSD, and particle density.




**Three Particles with Different Settling Rates Separating and being Collected in Different Cuts and Comparison to Theoretical Predictions**

Because the individual particles are collected in multiple Cuts, and specifically Cuts having faster settling rates, the densities calculated from these results are inaccurate and too high. The three particles shown as examples each had a density of ~ 2.5 kg/m$^3$ but the calculated densities determined from the analysis of the flow cell separation and predicted settling behavior were much higher than the known density. The figure below shows an example of the calculated PSDD for Particle 2 from a flow cell test and comparison to the known particle density and size. The peak in the PSDD occurs at a density of ~ 4.5 kg/m$^3$ The most significant inaccuracy in calculated density occurred for Particle 4, which was predicted to collect primarily in Cut 4, but instead was distributed in Cuts 1 through 4. The calculated density from the flow cell results for Particle 4 ranged from 1.5 to 52.5 kg/m$^3$. The largest inaccuracy occurred for the fraction of Particle 4 that was collected in Cut 1, where the calculated density was 12.5 to 52.5 kg/m$^3$. These results are quite inaccurate compared to the known density of 2.5 kg/m$^3$. Visual observations of the particle behavior in the flow cell showed that the particles, when introduced as a slurry, settled as a dense slurry plume, and more quickly than predicted for individual particles. The injection of particles with horizontal flow showed that the particles would sometimes move too quickly, as a horizontal jet, which contributed to spreading into multiple Cuts. Efforts were made to minimize these particle introduction problems, but they were not overcome.




**Measured PSDD for Particle 2 from Flow Cell Test where Particles were Collected in Cuts 1-3 and Comparison to known Particle Density and Size (black line showing $d_{10}$, $d_{50}$, and $d_{90}$ at 2460 kg/m$^3$)**

## Conclusions

Results showed that the miniature gravity settling classifier did separate particles of different settling rates, but problems with the introduction of particles caused spreading of particles into three or four Cuts, when they should have been collected in one or two Cuts. Also, the particles tended to settle more quickly than predicted based on CFD modeling of particle settling in the flow cell. The key particle introduction problems were: 1) when the particles were introduced as slurries, they would settle more quickly than predicted for individual particles in dense slurry plumes; and 2) when introducing the particles as a slurry with a horizontal flow direction, the slurry would sometimes flow too quickly, as a jet, and the particles moved farther horizontally than they should.

## References


Fountain MS, J Blanchard, RL Erickson, DE Kurath and DT Howe. 2012. *Design of a Particle Shadowgraph Velocimetry and Size (PSVS) System to Determine Particle Size and Density Distributions in Hanford Nuclear Tank Wastes.* Paper 12280, Waste Management 2012, February 26 – March 1, 2012, Phoenix, AZ.

Gauglitz PA, DN Tran, and WC Buchmiller. 2012. *Simulant Development for Hanford Double-Shell Tank Mixing and Waste Feed Delivery Testing.* PNNL-21791, Rev 0, Pacific Northwest National Laboratory, Richland, WA.

Lee, KP, BE Wells, PA Gauglitz, and RA Sexton. 2012. *Waste Feed Delivery Mixing and Sampling Program Simulant Definition for Tank Farm Performance Testing.* RPP-PLAN-51625, Rev 0, Washington River Protection Solutions, Richland, WA.

Meyer PA, JA Bamberger, CW Enderlin, JA Fort, BE Wells, SK Sundaram, PA Scott, MJ Minette, GL Smith, CA Burns, MS Greenwood, GP Morgen, EBK Baer, SF Snyder, M White, GF Piepel, BG Amidan, and A Heredia-Langner. 2012. *Pulse Jet Mixing Tests with Noncohesive Solids.* PNNL-18098, Rev. 1 (WTP-RPT-182, Rev. 1), Pacific Northwest National Laboratory, Richland, WA.

Peterson RA, RC Daniel, SK Fiskum, PA Gauglitz, SR Suffield, and BE Wells. 2016. *Simulant Basis for the Standard High Solids Vessel Design,* PNNL-24476, Rev 0 (WTP-RPT-241 Rev 0), Pacific Northwest National Laboratory, Richland, WA.

Wells BE, MA Knight, EC Buck, SK Cooley, RC Daniel, LA Mahoney, PA Meyer, AP Poloski, JM Tingey, WS Callaway III, GA Cooke, ME Johnson, MG Thien, DJ Washenfelder, JJ Davis, MN Hall, GL Smith, SL Thomson, and Y Onishi. 2007. *Estimate of Hanford Waste Insoluble Solid Particle Size and Density Distribution.* PNWD-3824 (WTP-RPT-153, Rev. 0), Battelle—Pacific Northwest Division, Richland, WA.

Wells BE, DE Kurath, LA Mahoney, Y Onishi, JL Huckaby, SK Cooley, CA Burns, EC Buck, JM Tingey, RC Daniel, and KK Anderson. 2011. *Hanford Waste Physical and Rheological Properties: Data and Gaps.* PNNL-20646. Pacific Northwest National Laboratory, Richland, WA.

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