Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy.

Disclaimer:

Modeling and Simulation of Solid Fluidization in a Resin Column

Si Y. Lee
Savannah River National Laboratory
Aiken, SC 29808
si.lee@srnl.doe.gov

INTRODUCTION

There are many of the fluidization and sedimentation phenomena of practical applications such as fluid mixing, solid mixing, and removal of solids from the bed. Because of the complexity of fluid-solid hydrodynamics, most theoretical studies and prediction models on solid motions have been idealized. Recently, availability of both high-speed computer hardware and advanced numerical codes can make the simulations of realistic fluid-solid behaviors possible.

The objective of the present work is to model the resin particles within the column during fluidization and sedimentation processes using computation fluid dynamics (CFD) approach. The calculated results will help interpret experimental results, and they will assist in providing guidance on specific details of testing design and establishing a basic understanding of particle's hydraulic characteristics within the column. The model is benchmarked against the literature data and the test data (2003) conducted at Savannah River Site (SRS). The paper presents the benchmarking results and the modeling predictions of the SRS resin column using the improved literature correlations applicable for liquid-solid granular flow.

DESCRIPTION OF THE ACTUAL WORK

A fluidized system consists of the liquid phase and granular solids representative of a mean diameter, d_s, and density, ρ_s. In this system the porosity ε represents the fraction of the volume occupied by the liquid phase. The basic equations governing the liquid and granular solid phases within the column have mass and momentum balance equations for each phase in order to describe, mathematically, the motions of the solids in a fluidized system.

The fluid-soild interfacial drag term, F_{fs}, in momentum equation was originally developed by Syamlal-O'Brien (1989) using the literature correlations for the air bubble-solid system. Their correlation overpredicted the interfacial drag by about 25% for the present liquid-solid system. A modified correlation for the interfacial drag was used for the present work. That is

$$F_{fs} = 0.75 C_D \left(\frac{\varepsilon_f \varepsilon_s \rho_f}{d_s u_t^2} \right) \left| \vec{V}_s - \vec{V}_f \right| \tag{1}$$

In Eq (1) particle drag term C_D was given by terminal velocity u_t when Reynolds number is defined as $d_s \rho_f \left| \vec{V}_s - \vec{V}_f \right| / \mu_f$.

$$C_D = \left\{ 0.63 + 4.8 \left(\frac{u_t}{\mathrm{Re}} \right)^{0.5} \right\}^2 \tag{2}$$

The terminal velocity for solid particle u_t was given in terms of Reynolds number.

$$u_t = 0.5 \varepsilon_f^{4.14} - 0.03\,\mathrm{Re} + \sqrt{0.0036\,\mathrm{Re}^2 - \left(0.12\,\mathrm{Re} - \varepsilon_f^{4.14}\right) \varepsilon_f^{4.14} + 0.24 \lambda} \tag{3}$$

In Eq (3) λ was fitted by the literature data in terms of Reynolds Re number and porosity ε_f.

$$\lambda = A\,\mathrm{Re}\,\varepsilon_f^{B} \tag{4}$$

A transient two-dimensional axisymmetric approach was taken to analyze the resin fluidized system for different operating conditions. Computational fluid dynamics method was applied for the numerical simulations of the fluidized system using a commercial CFD code, FLUENT.

RESULTS

The solution method described above was developed for the primary goal of simulating the resin particle motions within the column during the particle fluidization and sedimentation processes and understanding hydraulic behavior for particles within column during the resin fluidization and sedimentation processes.

Some experimental work has been done previously by Hoffman et al. (1960) dealing with fluidized bed with different glass particles in water. The fluidization apparatus consisted of a glass fluidizing column, a pump, a water reservoir, and rotameters. In their experiment, each uniform size of glass beads was fluidized separately to determine the individual batch expansion curves. A given weight of beads was fluidized in the column until the bed had expanded to the full height of the column. Then, the water flowrate was decreased incrementally, with the height of the fluidized bed and the fluid rate being measured after each increment. Numerical simulations were performed by following the experimental procedure described above. Two different sizes of the glass beads, close to typical solid sizes representative of the SRS resins, were chosen for the validation of the present model. Detailed modeling conditions are shown in Fig. 1 and the material properties of fluid and solid sizes are summarized in Table 1.

Table 1: Supernate fluid properties used in the work

Tank fluid	Density, gm/ml	Kinematic Viscosity (Centipoise)
Supernate + Inhibited water (Deionized water + NaOH)	1.00	1.00
Supernate, NaOH + $NaNO_2$ + Deionized water	1.26	2.35
Supernate, NaOH + $NaNO_3$ + Deionized water	1.32	2.26

Using the two-dimensional axi-symmetric multi-phase Eulerian modeling approach, the calculations of the bed expansion were made for various water flow rates and the operating conditions in Table 1. Figure 1 presents the comparison of the predictions with the experimental results.

The results show that the interfacial drag model developed by Syamlal and O'Brien overpredicts the test results by about 25%. The present modeling predictions with the improved correlation agree with the test results for different particle sizes. The modeling results for two typical sizes of solids, close to the SRS resin diameters, are compared in Fig. 2.

Table 1. Material properties and particle sizes used for the present benchmarking against the test results done by Hoffman et al. (1960)

Particle size	Material	Density	Fluid
0.465 mm	glass	2.525 gm/cc	water
0.269 mm	glass	2.486 gm/cc	water

Figure 3 shows the minimum fluidization velocities corresponding to various glass volume fractions. The improved correlations for the interfacial drag parameters A and B of equation (7) are given by equation (8).

$$A = 0.5,\ B = 1.28 \quad \text{for} \quad \varepsilon_f \le 0.85$$

$$A = 1.0,\ B = 4.50 \quad \text{for} \quad \varepsilon_f > 0.85 \qquad (8)$$

Hydraulic test of the resin column was conducted at SRS to study the resin suspension and expansion behavior during the bed expansion period. The column consisted of the 0.3 to 0.78-mm resin particles within the test column. The resin particles of 1.24 gm/cc density were suspended by water in 5.5-in diameter column. Using the same model as benchmarked earlier, the modeling calculations were made to verify hydraulic behavior of the SRS test column. In this case three different particle diameters were used with equal volume fraction of each size for the hydraulic test of the resin particles. The resin diameters are 0.290mm, 0.555mm, and 0.775mm. Figure 4 compares the prediction results against the test data. The results show that the bed expansion behavior follows the test data during the resin suspension period.

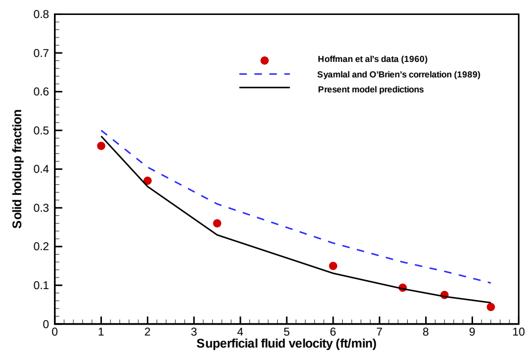

Figure 1. Comparison of the modeling predictions and test results.

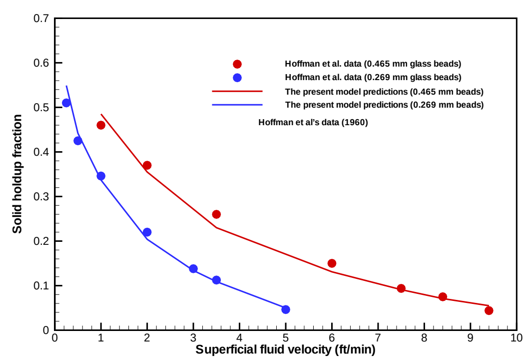

Figure 2. Benchmarking results of the present model predictions against the test results.

The validated model as demonstrated above was used to predict the hydraulic performance of the original full-scale column test. The axi-symmetric full-scale geometry as modeled for the present work is shown in Fig. 5. Flow inlet is located at the bottom and flow exit at the top with fine-mesh screen during the suspension period. For the drainage simulation of the resin column, fluid flow exits the column at the bottom after the resin suspension period. The mesh screen region was modeled as porous medium region. Detailed physical parameters used for the full-scale model are summarized in Table 2.

Based on the improved drag correlations the modeling calculations were performed under transient conditions to understand hydraulic behavior for particles within the full-scale column during the resin fluidization and sedimentation processes. As shown in Fig. 6, the transient modeling results demonstrated that it takes about 16 minutes for the test column to be fluidized with resin particles when 6 cm/min water flows upward at the bottom of the 48-in column.

When the resin particles are suspended in the column at the transit time of 16 minutes, the predicted solid volume fractions for three different resin sizes are shown in Fig. 7. The results demonstrated that the smallest resin particles have the largest population near the top of the column when water flows upward from the bottom of the column during the suspension period. Figure 8 shows fluid and solid volume fractions along the central region of the column from the bottom to the top. The figure shows that about 65% of the total column volume is occupied by water at the central annular region of the column.

As shown in the previous figure, large size of the resin particles is present near the bottom of the column, and the smallest one near the top region of the column. In this case the water flow patterns near the bottom of the column were investigated for different water flowrates during the bed suspension period. Figure 9 shows water flow patterns for 6 cm/min water upflow at bed inlet under full-scale column. Flow patterns for the larger flowrate (10 cm/min) are shown in Fig. 10. The results for the lower flowrate show that flow rotations are generated and the fluid momentum is dissipated rapidly near the bottom corner regions of the column during the suspension period.

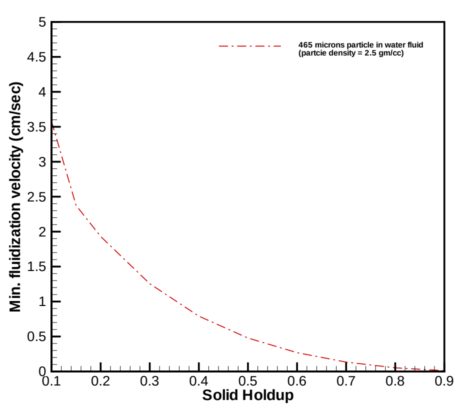

Figure 3. Minimum fluidization velocities for various solid volume fractions

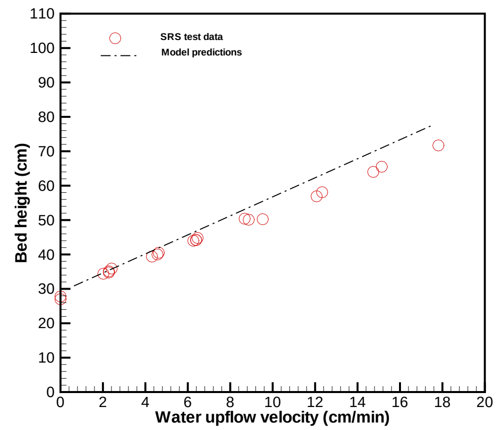

Figure 4. Comparison of the modeling predictions and SRS test results for the column expansion during the resin suspension period.

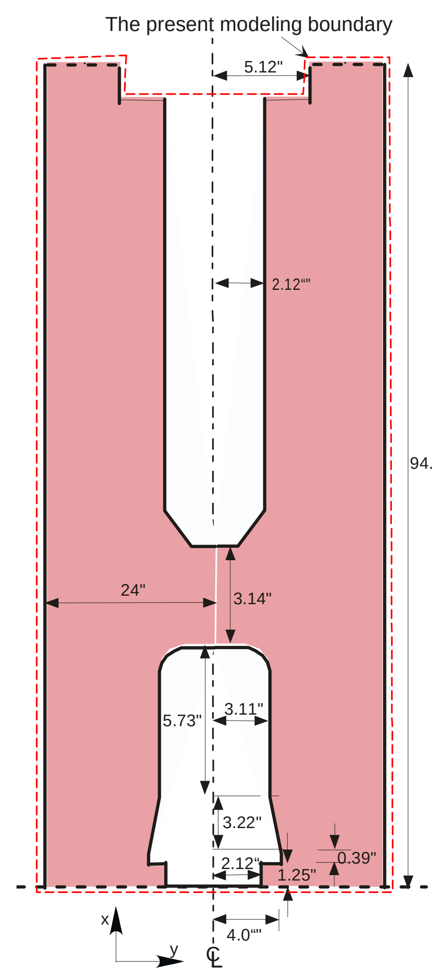

Figure 5. Axi-symmetric model for the full-scale resin column test.

Table 2. Physical parameters used for the full-scale column model

Physical parameters	Data
Column size (height x diameter) (inches)	94 x 48 (as shown in Fig. 5)
Effective resin density (gm/cc)	1.24
Average resin diameter (mm)	0.29, 0.43, 0.555, 0.65, 0.775
Initial height of packed bed (inches)	54
Resin volume fractions at initial bed condition	12% for each resin size
Range of superficial water velocities at inlet (cm/min)	3.6 to 12.24
Fluid in column	water

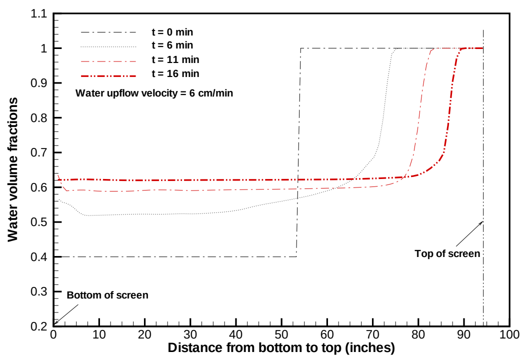

Figure 6. Predicted transient water volume fractions during the bed expansion period for 6 cm/min water upflow velocity at the column bottom.

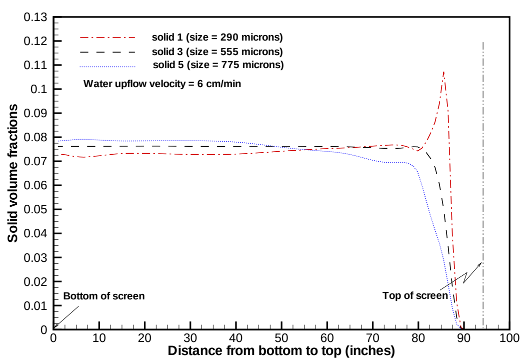

Figure 7. Predicted resin volume fractions at the transient time of 16 min. during the bed expansion period for 6 cm/min water upflow velocity at the column bottom.

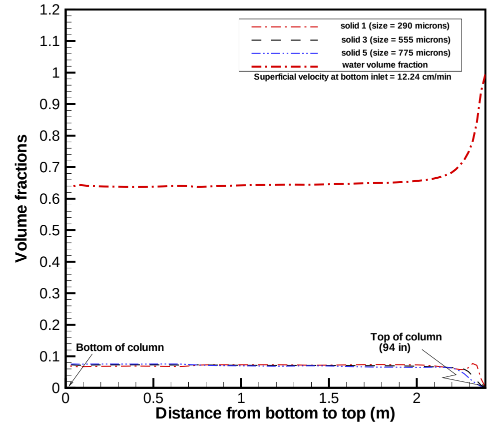

Figure 8. Fluid and solid volume fractions along the central region of the column from the bottom to the top

After the expansion and suspension period of the resin column is completed, bed removal was simulated to study flow patterns and fundamental behavior of resin particles. When water is drained through the underneath hole of the bell shape on the bottom of the column, the results show that most solids are kept lower position due to the gravity and more water is drained through the central region of the column during the drainage period after fluidization. It is noted that the larger particle is drained faster than the smaller one.

The present numerical model was benchmarked against the literature data and the onsite test results. The validated model was used for predicting the addition and removal performance of the full-scale test. The modeling results also assisted in providing operational guidance on the resin column testing under the full scale.

REFERENCES

1. S. Y. Lee, "Two-Phase Flow and Heat Transfer in Porous Media, MS Thesis, Massachusetts Institute of Technology, 1983.
2. D. Gidaspow, *Multiphase Flow and Fluidization*, Academic Press, New York, 1994.
3. M. Syamlal and T. J. O'Brien, "Computer Simulation of Bubbles in a Fluidized Bed", AIChE Symposium Series, Vol. 85, pp. 22-31, 1989.
4. R. F. Hoffman, L. Lapidus, and J. C. Elgin, "The Mechanic of Vertical Moving Fluidized Systems: IV. Application to Batch-Fluidized Systems with Mixed Particle Sizes", A.I.Ch.E. Journal, Vol. 6, No. 2, 1960.