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Axial Pressure Drop Measurements during Pilot-Scale Testing of a Mott Crossflow Filter

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SUMMARY

The Department of Energy selected caustic side solvent extraction (CSSX) as the preferred cesium removal technology for Savannah River Site (SRS) waste. As a pretreatment step for the CSSX flowsheet, personnel contact the incoming salt solution that contains entrained sludge with monosodium titanate (MST) to adsorb strontium and select actinides. They filter the resulting slurry to remove the sludge and MST. We conducted pilot-scale crossflow filter testing with simulated SRS high level waste to evaluate the impact of operating parameters on the crossflow filtration process. During the tests, we measured the axial pressure drop as a function of axial velocity, feed slurry [i.e., sludge plus MST (5.6 M sodium), sludge plus MST (6.4 M sodium), sludge only, and sludge plus manganese oxide], and insoluble solids concentration. Personnel employed 0.5 micron and 0.1 micron filters in the tests.

The conclusions from this work follow.

- The axial pressure drop varies with velocity raised to the 1.75 power, which agrees with theory.
- At an axial velocity of 12 ft/s, the maximum measured pressure drop was 16 psi.
- The axial pressure drop depends on the feed slurry, but the effect is less than observed for axial velocity. The sludge plus MST slurry with the 0.1 micron filter and the sludge plus manganese oxide slurry with the 0.5 micron filter produced the highest axial pressure drop. The sludge plus MST slurry with the 0.5 micron filter produced the lowest axial pressure drop.
- The effect of insoluble solids concentration is statistically insignificant when the insoluble solids loading is at or below 4.5 wt %. However, when the insoluble solids loading increased to 12.2 wt %, concentration had a significant effect on axial pressure drop. The likely cause of the effect is the slurry becoming non-Newtonian.
- The measured axial pressure drops are approximately 2X the value predicted based on pipe flow models. This observation agrees with similar data provided by a crossflow filter manufacturer.

INTRODUCTION

The Department of Energy selected CSSX as the preferred cesium removal technology for Savannah River Site waste. As a pretreatment step for the CSSX flowsheet, personnel contact the incoming salt solution that contains entrained sludge with MST to adsorb strontium and select actinides. They filter the resulting slurry to remove the sludge and MST. The filtrate receives further treatment to remove cesium in the solvent extraction system. The baseline filtration technology uses a Mott crossflow filter.

We conducted pilot-scale crossflow filter testing with simulated SRS high level waste to evaluate the impact of operating parameters on the crossflow filtration process.[1,2,3,4] The tests employed 0.5 micron and 0.1 micron filters. The feed slurries for these tests included simulated sludge plus MST, simulated sludge only, and simulated sludge plus manganese oxide solids. The supernate for these tests consisted of 5.6 – 6.4 M sodium, average salt solution. During the tests, we measured the axial pressure drop as a function of axial velocity, feed slurry, and insoluble solids concentration. This report documents the axial pressure drop data.

TESTING

The testing occurred at the Filtration Research Engineering Demonstration (FRED) facility at the University of South Carolina shown in Figure 1. The FRED facility contains a filter element with seven Mott filter tubes. Each tube is made from sintered stainless steel, 0.75 inches OD, 0.625 inches ID, 10 feet long, and nominal 0.5 or 0.1 micron pore size.

Figure 1. Filtration Research Engineering Demonstration

A 225 gpm Hazelton centrifugal pump feeds the filter system. The feed slurry that enters the filter is distributed among the seven tubes. The transmembrane pressure forces supernate from the inside of the tubes into the shell. The filter media prevents solid particles from entering the shell side of the unit. The axial velocity sweeps the particles away from the filter surface and transports them back to the feed tank. A differential pressure transducer, with ports located upstream and downstream of the filter housing, measures the axial pressure drop.

The simulated waste slurry contained nominally "average" Savannah River Site salt solution (5.6 – 6.4 M sodium). Table 1 shows the feed slurries along with the insoluble solids loadings.

Personnel set the tank temperature to 35 ± 3 °C, and added feed solids to reach the target concentration. They circulated the feed solution through the system to mix it.

Details of the filter test protocol are described in the individual test reports.[1-5] In some tests, personnel backpulsed the filter at the beginning of each test. The duration of the tests varied. These differences would affect the relationship between filter operating parameters and filter flux, but should have minimal impact on the relationship between filter axial velocity and axial pressure drop.

Table 1. Feed Slurries and Insoluble Solids Loadings

Feed Slurry	Pore Size	Na (M)	Insoluble Solids (wt %)
Purex Sludge + MST	0.5 μ	6.4	0.05
Purex Sludge + MST	0.5 μ	6.4	0.74
Purex Sludge + MST	0.5 μ	6.4	0.05
Purex Sludge + MST	0.5 μ	6.4	0.10
Purex Sludge + MST	0.5 μ	6.4	0.20
Purex Sludge + MST	0.5 μ	6.4	0.39
Tank 40H/8F Sludge + MST	0.5 μ	5.6	0.033
Tank 40H/8F Sludge + MST	0.5 μ	5.6	0.25
Tank 40H/8F Sludge + MST	0.5 μ	5.6	1.1
Tank 40H/8F Sludge + MST	0.5 μ	5.6	4.2
Tank 8F Sludge	0.5 μ	5.6	0.044
Tank 8F Sludge	0.5 μ	5.6	0.21
Tank 8F Sludge	0.5 μ	5.6	0.88
Tank 8F Sludge	0.5 μ	5.6	4.8
Tank 40H Sludge + Manganese Oxide	0.5 μ	5.6	0.09
Tank 40H Sludge + Manganese Oxide	0.5 μ	5.6	0.34
Tank 40H Sludge + Manganese Oxide	0.5 μ	5.6	1.5
Tank 40H Sludge + Manganese Oxide	0.5 μ	5.6	3.0
Tank 40H/8F/SB2 Sludge + MST	0.1 μ	5.6	0.06
Tank 40H/8F/SB2 Sludge + MST	0.1 μ	5.6	4.5
Tank 40H/8F/SB2 Sludge + MST	0.1 μ	5.6	12.2

RESULTS

Figure 2 shows the axial pressure drop as a function of axial velocity in the tests with 6.4 M sodium supernate, Purex sludge, and MST. (Appendix A contains the raw data.) The data shows no effect of solids loading on axial pressure drop, and a nonlinear relationship between axial velocity and axial pressure drop.

Figure 3 shows the axial pressure drop as a function of axial velocity in the tests with 5.6 M sodium supernate, Tank 40H sludge, Tank 8F sludge and MST. The data shows no effect of solids loading on axial pressure drop, and a nonlinear relationship between axial velocity and axial pressure drop.

Figure 4 shows the axial pressure drop as a function of axial velocity in the tests with 5.6 M sodium supernate and Tank 8F sludge. The data shows no effect of solids loading on axial pressure drop, and a nonlinear relationship between axial velocity and axial pressure drop.

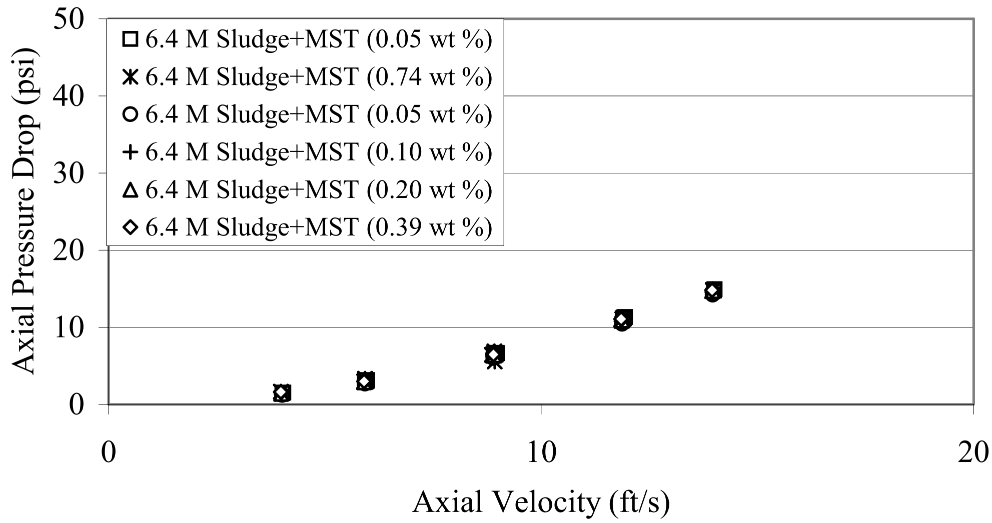

Figure 2. Axial Pressure Drop during Test with 6.4 M Sodium Supernate, Purex Sludge, and MST (0.5 μ filter)

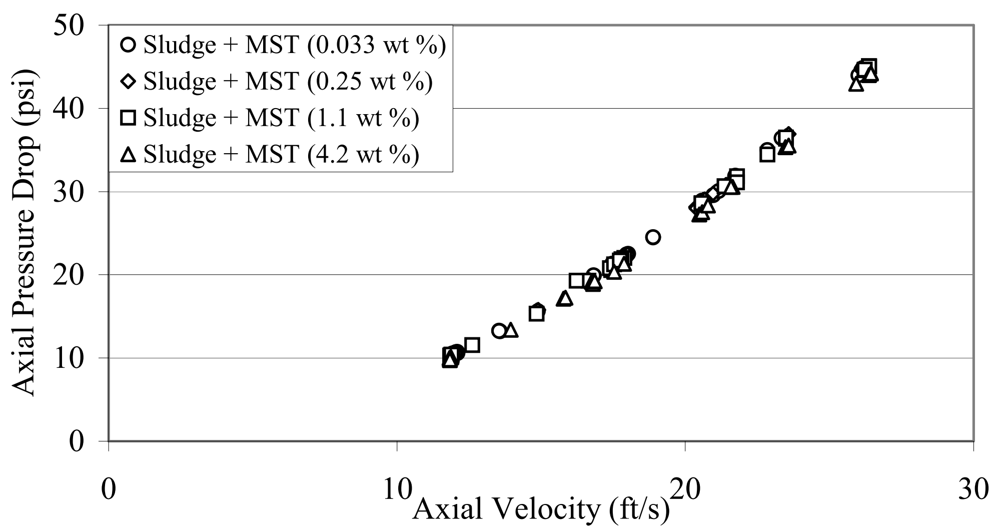

Figure 3. Axial Pressure Drop during Test with 5.6 M Sodium Supernate, Tank 40H Sludge, Tank 8F Sludge, and MST (0.5 μ filter)

Figure 5 shows the axial pressure drop as a function of axial velocity in the tests with 5.6 M sodium supernate, Tank 40H sludge, and manganese oxide solids. The data shows no effect of solids loading on axial pressure drop, and a nonlinear relationship between axial velocity and axial pressure drop.

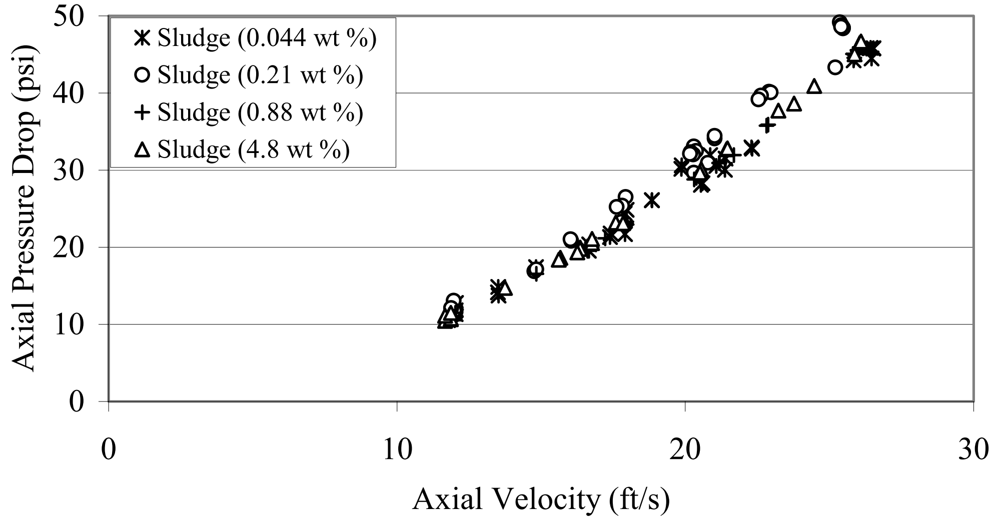

Figure 4. Axial Pressure Drop during Test with 5.6 M Sodium Supernate and Tank 8F Sludge (0.5 μ filter)

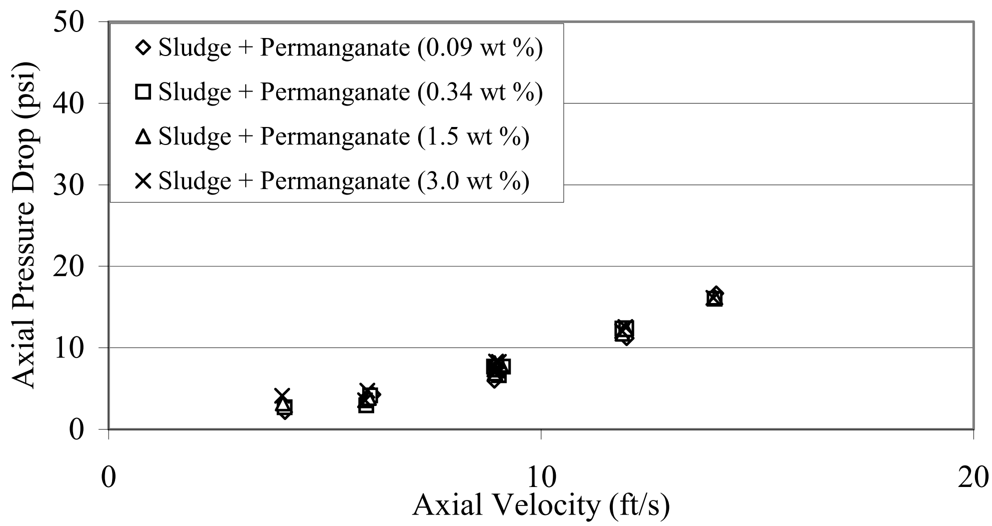

Figure 5. Axial Pressure Drop during Test with 5.6 M Sodium Supernate and Tank 40H Sludge, and Manganese Oxide Solids (0.5 μ filter)

Figure 6 shows the axial pressure drop as a function of axial velocity in the tests with 5.6 M sodium supernate, Tank 40H sludge, Tank 8F sludge, sludge batch 2, and MST solids. The figure shows good agreement between the measured pressure drop with 0.06 and 4.5 wt % solids, but the pressure drop appears to increase as the solids loading increases to 12.2 wt %. We will discuss this effect later. The relationship between axial velocity and axial pressure drop is nonlinear.

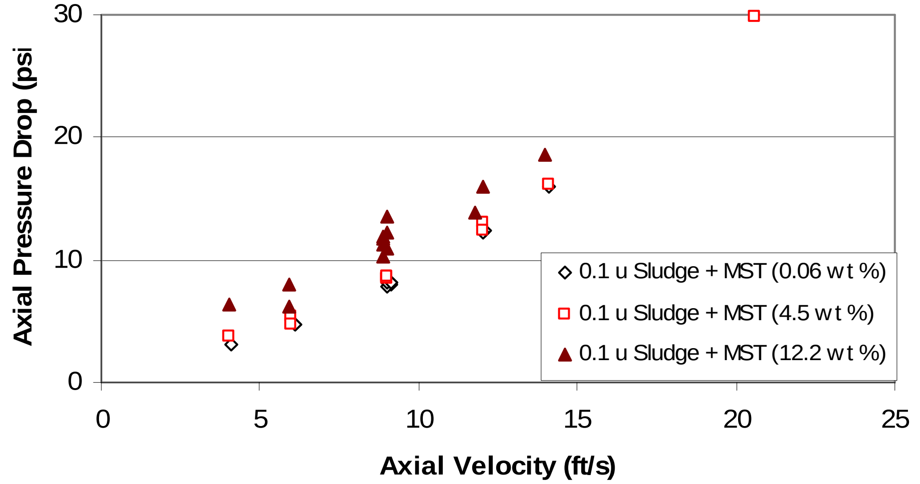

Figure 6. Axial Pressure Drop during Test with 5.6 M Sodium Supernate and Tank 40H Sludge, Tank 8F Sludge, Sludge Batch 2, and MST Solids (0.1 μ filter)

Figure 7 shows the data from the five tests plotted together along with a theoretical prediction. One may calculate the axial velocity for turbulent pipe flow with equation [1]

$$-\Delta P = \frac{0.158 v^{1.75} \rho^{0.75} L \mu^{0.25}}{D^{1.25}} \qquad \text{for Re} > 10{,}000 \qquad [1]$$

where v is axial velocity, ρ is fluid density, L is tube length, μ is viscosity, D is tube diameter, and Re is the Reynolds number.[6] With the pilot-scale filter unit (D=0.625 in) and the SRS supernate (ρ=1.26 g/mL and μ =2.42 cp), an axial velocity of 4 ft/s produces a Reynolds number of 10,000. Since the minimum axial velocity tested equaled 4 ft/s, equation [1] applies.

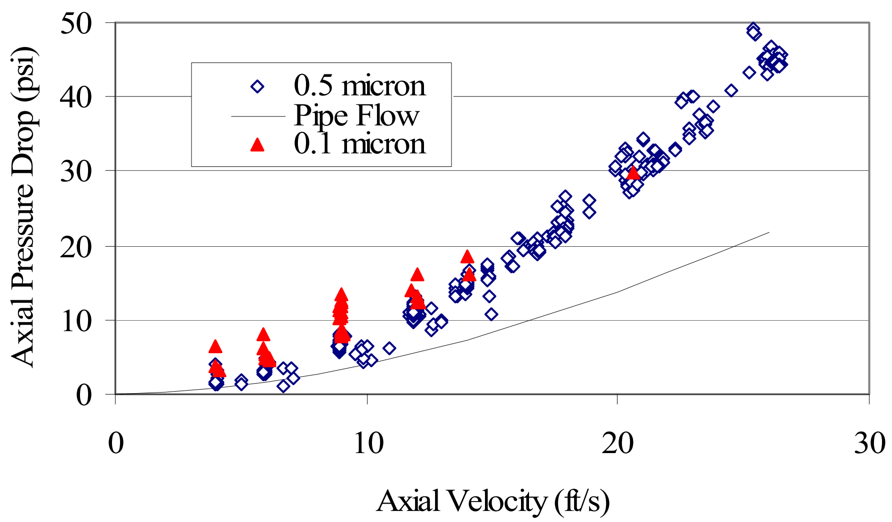

Figure 7. Axial Pressure Drop of Five Tests Compared with Prediction

The pressure drops measured with the pilot-scale filter are approximately 2X the value predicted by equation [1]. This observation agrees with data in the User's Manual for SCT Membranes produced by Membralox®, a manufacturer of crossflow filters.[7]

We conducted a statistical analysis of the data collected using the JMP® statistical software to determine which operating parameters influence the axial pressure drop. We regressed the data with a model described by equations [2] and [3]

$$-\Delta P = f(\text{feed})\, C\, v^{1.75} \qquad [2]$$

$$\ln[-\Delta P] = a_0 + a_1 \ln[f(\text{feed})] + a_2 \ln[C] + a_3 \ln(v^{1.75}) \qquad [3]$$

where f is a function describing the effect of the variation in feed solution, C is the insoluble solids concentration, v is axial velocity, and a_0, a_1, a_2, and a_3 are constants. The feed variable includes differences in supernate solution, solid particles, and filter pore size. Table 2 shows the results of the statistical analysis from tests with a solids loading of 4.5 wt % or less. Table 3 shows the statistical analysis using all of the data.

Table 2. Statistical Analysis of Axial Pressure Drop Data with Solids Loading ≤ 4.5 wt %

Source	# parameters	Degrees freedom	Sum Squares	F-ratio	Prob.>F
Feed	4	4	2.66620	98.5600	<.0001
ln(conc)	1	1	0.00365	0.5404	0.4626
$\ln(v^{1.75})$	1	1	132.40816	19578.7	0.0000

Table 3. Statistical Analysis of Axial Pressure Drop Data with All Solids Loadings

Source	# parameters	Degrees freedom	Sum Squares	F-ratio	Prob.>F
Feed	4	4	4.53222	104.044	<.0001
ln(conc)	1	1	0.10371	9.5229	0.0022
$\ln(v^{1.75})$	1	1	132.40718	12158.5	0.0000

The F-ratio is the ratio of the mean square from the model to the mean square from the error. From the F-ratio, one can calculate the probability that the variation observed is due to error rather than to the parameter being investigated. If the probability is less than 0.05, the variation is due to the parameter and the effect of the parameter is statistically significant. The effect of feed slurry and axial velocity are statistically significant, with the axial velocity having the strongest effect.

Concentration does not have a significant effect on pressure drop when the solids loading is at or below 4.5 wt %. When the insoluble solids concentration increases to 12.2 wt %, and the slurry becomes non-Newtonian (i.e., Bingham Plastic), increasing concentration increases the axial pressure drop.

Table 4 shows the estimates of the coefficients in equation [3]. The purpose of estimating the coefficients is not to develop an empirical correlation describing the axial pressure drop in the FRED facility, but rather to determine which feed slurries produce the largest axial pressure drop and to verify that the exponents describing the concentration and axial velocity effects are good approximations. The results show $v^{1.75}$ describes the effect of axial velocity on axial pressure drop well and that the effect of concentration on axial pressure drop is very small. The data also show that sludge plus MST slurry (0.1 micron filter) and sludge plus manganese oxide slurry (0.5 micron filter) will produce the largest pressure drop followed by sludge only slurries, sludge plus MST (@ 6.4 M sodium) slurries, and sludge plus MST (@ 5.6 M sodium) slurries.

Table 4. Coefficients for Axial Pressure Drop Model

Term	Parameter	Estimate (≤ 4.5 wt %)	Estimate (≤ 12.2 wt %)
Intercept	a_0	-1.9	-1.8
Feed (0.1 micron)	a_1	0.17	0.24
Feed(6.4 M Sludge + MST)	a_1	-0.11	-0.13
Feed (Sludge + MST)	a_1	-0.11	-0.12
Feed (Sludge + MnO2)	a_1	0.08	0.044
Ln[C}	a_2	0.002	0.009
$Ln[v^{1.75}]$	a_3	1.0	0.99

Because the statistical analysis showed insoluble solids concentration affects the axial pressure drop when it is greater than 4.5 wt %, the authors plotted the relationship between solids loading and axial pressure drop in Figure 8. All of the data is at 9 ft/s axial velocity. The data show an increase in axial pressure drop as the solids loading is increased from 4.5 to 12.2 wt %.

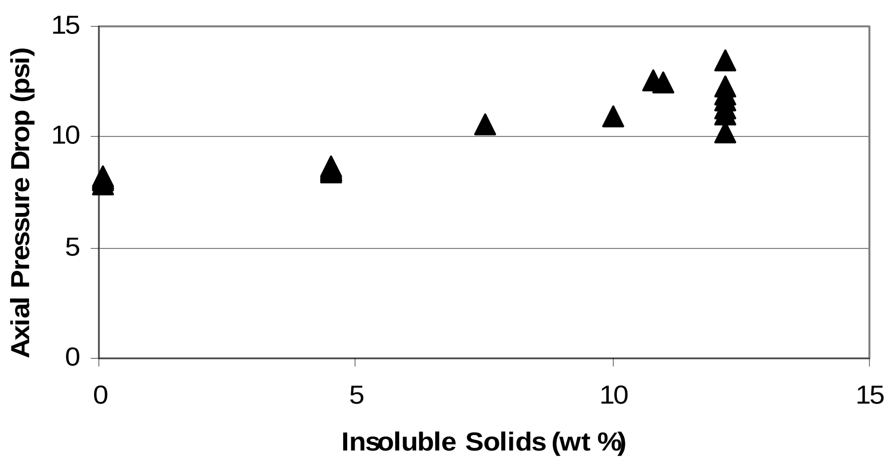

Figure 8. Axial Pressure Drop as a Function of Solids Loading (with 9 ft/s axial velocity)

CONCLUSIONS

The conclusions from this work follow.

- The axial pressure drop varies with velocity raised to the 1.75 power, which agrees with theory.
- At an axial velocity of 12 ft/s, the maximum measured pressure drop was 16 psi.
- The axial pressure drop depends on the feed slurry, but the effect is less than observed for axial velocity. The sludge plus MST slurry with the 0.1 micron filter and the sludge plus manganese oxide slurry with the 0.5 micron filter produced the highest axial pressure drop.

The sludge plus MST slurry with the 0.5 micron filter produced the lowest axial pressure drop.
- The effect of insoluble solids concentration is statistically insignificant when the insoluble solids loading is at or below 4.5 wt %. However, when the insoluble solids loading increased to 12.2 wt %, concentration had a significant effect on axial pressure drop. The likely cause of the effect is the slurry becoming non-Newtonian.
- The measured axial pressure drops are approximately 2X the value predicted based on pipe flow models. This observation agrees with similar data provided by a crossflow filter manufacturer.

REFERENCES

1. Ralph Haggard, Travis Deal, Carol Stork, and Vince Van Brunt, "Final Report on the Crossflow Filter Testing for the Salt Disposition Alternative", USC-FRED-PSP-RPT-09-0-010, Rev. 0, December 4, 1998.
2. M. R. Poirier, "FY2000 FRED Test Report,"WSRC-TR-2001-00035, Rev. 0, January 11, 2001 and included report "Final Report on the Crossflow Filter Optimization with 5.6 M Sodium Salt Solution" (V. Van Brunt, C. Stork, T. Deal, and R. Haggard, USC-FRED-PSP-RPT-09-0-015, December 20, 2000).
3. V. Van Brunt, R. Haggard, T. Deal, C. Stork, M. R. Poirier, and S. D. Fink, "Cross-Flow Filtration of Simulated High-Level Waste Sludge (Tank 8F)", WSRC-TR-2001-00195, April 20, 2001.
4. M. R. Poirier, S. D. Fink, V. Van Brunt, R. Haggard, T. Deal, and C. Stork, "Comparison of Crossflow Filtration Performance for Manganese Oxide/Sludge Mixtures and Monosodium Titanate/Sludge Mixtures", WSRC-TR-2002-00194, Rev. 0, April 19, 2002.
5. M. R. Poirier, J. L. Siler, S. D. Fink, R. Haggard, T. Deal, C. Stork, and V. Van Brunt, "Pilot-Scale Testing of a 0.1 Micron Filter with SRS Simulated High Level Waste", WSRC-TR-2003-00469, Rev. 0, October 8, 2003.
6. C. O. Bennett and J. E. Myers, Momentum, Heat, and Mass Transfer, 3rd Ed., McGraw-Hill New York, 1982, p.168,198.
7. User's Manual, SCT Membranes, Membralox®, March 1987.

Appendix A
Crossflow Filter Axial Pressure Drop Data

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
66	Sludge+manganese oxide	0.5 µ	35	3.04	8.93	6.94
65	Sludge+manganese oxide	0.5 µ	35	3.04	5.93	3.59
64	Sludge+manganese oxide	0.5 µ	35	3.04	13.98	16.13
63	Sludge+manganese oxide	0.5 µ	35	3.04	9.02	8.29
62	Sludge+manganese oxide	0.5 µ	35	3.04	5.98	4.76
61	Sludge+manganese oxide	0.5 µ	35	3.04	8.94	7.28
60	Sludge+manganese oxide	0.5 µ	35	3.04	11.87	12.05
59	Sludge+manganese oxide	0.5 µ	35	3.04	8.96	8.33
58	Sludge+manganese oxide	0.5 µ	35	3.04	4.01	4.11
57	Sludge+manganese oxide	0.5 µ	35	3.04	11.95	12.56
56	Sludge+manganese oxide	0.5 µ	35	3.04	8.96	7.45
55	Sludge+manganese oxide	0.5 µ	35	1.52	9.01	7.23
54	Sludge+manganese oxide	0.5 µ	35	1.52	5.94	3.56
53	Sludge+manganese oxide	0.5 µ	35	1.52	14.03	16.16
52	Sludge+manganese oxide	0.5 µ	35	1.52	9.07	7.91
51	Sludge+manganese oxide	0.5 µ	35	1.52	6.02	3.83
50	Sludge+manganese oxide	0.5 µ	35	1.52	8.94	6.86
49	Sludge+manganese oxide	0.5 µ	35	1.52	11.88	11.74
48	Sludge+manganese oxide	0.5 µ	35	1.52	8.93	8.11
47	Sludge+manganese oxide	0.5 µ	35	1.52	4.03	3.16
46	Sludge+manganese oxide	0.5 µ	35	1.52	11.96	12.29
45	Sludge+manganese oxide	0.5 µ	35	1.52	8.92	7.35
44	Sludge+manganese oxide	0.5 µ	35	0.34	9.02	6.64
43	Sludge+manganese oxide	0.5 µ	35	0.34	5.96	2.96
42	Sludge+manganese oxide	0.5 µ	35	0.34	14.01	16.00
41	Sludge+manganese oxide	0.5 µ	35	0.34	9.12	7.68
40	Sludge+manganese oxide	0.5 µ	35	0.34	6.05	4.16
39	Sludge+manganese oxide	0.5 µ	35	0.34	8.96	7.49
38	Sludge+manganese oxide	0.5 µ	35	0.34	11.88	12.36
37	Sludge+manganese oxide	0.5 µ	35	0.34	8.91	7.68
36	Sludge+manganese oxide	0.5 µ	35	0.34	4.07	2.71
35	Sludge+manganese oxide	0.5 µ	35	0.34	11.97	12.42
34	Sludge+manganese oxide	0.5 µ	35	0.34	8.97	7.43
33	Sludge+manganese oxide	0.5 µ	35	0.07	9.07	7.94
32	Sludge+manganese oxide	0.5 µ	35	0.07	5.99	4.02
31	Sludge+manganese oxide	0.5 µ	35	0.07	14.05	16.69
30	Sludge+manganese oxide	0.5 µ	35	0.07	9.10	7.84
29	Sludge+manganese oxide	0.5 µ	35	0.07	6.12	4.27
28	Sludge+manganese oxide	0.5 µ	35	0.07	9.00	7.41
27	Sludge+manganese oxide	0.5 µ	35	0.07	11.91	12.09
26	Sludge+manganese oxide	0.5 µ	35	0.07	8.93	7.33
25	Sludge+manganese oxide	0.5 µ	35	0.07	4.08	2.12
24	Sludge+manganese oxide	0.5 µ	35	0.07	11.98	11.20
23	Sludge+manganese oxide	0.5 µ	35	0.07	8.92	5.98
22	water	0.5 µ	50	0	9.88	4.28
21	water	0.5 µ	50	0	6.72	1.11
20	water	0.5 µ	50	0	14.95	10.64
19	water	0.5 µ	50	0	10.15	4.50

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
18	water	0.5 μ	50	0	7.11	2.22
17	water	0.5 μ	50	0	9.85	4.97
16	water	0.5 μ	50	0	12.61	8.55
15	water	0.5 μ	50	0	9.54	5.27
14	water	0.5 μ	50	0	5.00	1.99
13	water	0.5 μ	50	0	12.95	9.83
12	water	0.5 μ	50	0	9.80	6.11
11	water	0.5 μ	30	0	9.79	6.44
10	water	0.5 μ	30	0	6.66	3.37
9	water	0.5 μ	30	0	14.88	13.28
8	water	0.5 μ	30	0	10.03	6.55
7	water	0.5 μ	30	0	7.04	3.43
6	water	0.5 μ	30	0	9.80	5.95
5	water	0.5 μ	30	0	12.66	9.31
4	water	0.5 μ	30	0	9.54	5.35
3	water	0.5 μ	30	0	5.04	1.41
2	water	0.5 μ	30	0	13.01	9.74
1	water	0.5 μ	30	0	10.87	6.17
150	sludge only	0.5 μ	35	4.8	15.67	18.65
149	sludge only	0.5 μ	35	4.8	15.61	18.40
148	sludge only	0.5 μ	35	4.8	16.36	19.94
147	sludge only	0.5 μ	35	4.8	24.47	40.92
146	sludge only	0.5 μ	35	4.8	16.36	19.80
145	sludge only	0.5 μ	35	4.8	11.83	11.25
144	sludge only	0.5 μ	35	4.8	11.81	10.90
143	sludge only	0.5 μ	35	4.8	11.67	10.46
142	sludge only	0.5 μ	35	4.8	11.87	10.68
141	sludge only	0.5 μ	35	4.8	11.87	10.76
140	sludge only	0.5 μ	35	4.8	16.25	19.32
139	sludge only	0.5 μ	35	4.8	13.75	14.71
138	sludge only	0.5 μ	35	4.8	11.67	11.12
137	sludge only	0.5 μ	35	4.8	17.59	23.21
136	sludge only	0.5 μ	35	4.8	26.05	46.49
135	sludge only	0.5 μ	35	4.8	21.43	32.68
134	sludge only	0.5 μ	35	4.8	16.76	20.55
133	sludge only	0.5 μ	35	4.8	11.87	11.48
132	sludge only	0.5 μ	35	4.8	16.76	21.09
131	sludge only	0.5 μ	35	4.8	21.46	32.84
130	sludge only	0.5 μ	35	4.8	26.09	46.66
129	sludge only	0.5 μ	35	4.8	23.23	37.73
128	sludge only	0.5 μ	35	4.8	20.55	30.14
127	sludge only	0.5 μ	35	4.8	17.84	23.12
126	sludge only	0.5 μ	35	4.8	20.51	29.65
125	sludge only	0.5 μ	35	4.8	23.77	38.65
124	sludge only	0.5 μ	35	4.8	25.87	45.04
122	sludge only	0.5 μ	35	0.88	17.95	23.32
121	sludge only	0.5 μ	35	0.88	17.96	22.93
120	sludge only	0.5 μ	35	0.88	17.94	23.17
118	sludge only	0.5 μ	35	0.88	12.03	11.03
117	sludge only	0.5 μ	35	0.88	12.00	10.54

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
116	sludge only	0.5 µ	35	0.88	21.68	31.95
115	sludge only	0.5 µ	35	0.88	17.90	22.59
114	sludge only	0.5 µ	35	0.88	12.03	11.04
113	sludge only	0.5 µ	35	0.88	12.00	10.78
112	sludge only	0.5 µ	35	0.88	17.22	21.17
111	sludge only	0.5 µ	35	0.88	11.99	10.95
110	sludge only	0.5 µ	35	0.88	25.81	45.06
109	sludge only	0.5 µ	35	0.88	16.61	20.12
108	sludge only	0.5 µ	35	0.88	12.02	11.50
107	sludge only	0.5 µ	35	0.88	14.83	16.54
106	sludge only	0.5 µ	35	0.88	16.53	19.78
104	sludge only	0.5 µ	35	0.88	25.97	45.55
103	sludge only	0.5 µ	35	0.88	26.16	45.82
102	sludge only	0.5 µ	35	0.88	25.86	44.57
101	sludge only	0.5 µ	35	0.88	21.18	30.96
100	sludge only	0.5 µ	35	0.88	16.61	19.62
99	sludge only	0.5 µ	35	0.88	11.87	10.46
98	sludge only	0.5 µ	35	0.88	16.61	19.54
97	sludge only	0.5 µ	35	0.88	21.17	30.93
96	sludge only	0.5 µ	35	0.88	25.89	45.07
95	sludge only	0.5 µ	35	0.88	22.82	35.77
94	sludge only	0.5 µ	35	0.88	20.39	29.02
93	sludge only	0.5 µ	35	0.88	17.85	22.71
92	sludge only	0.5 µ	35	0.88	20.31	28.81
91	sludge only	0.5 µ	35	0.88	22.87	35.88
90	sludge only	0.5 µ	35	0.88	25.98	45.40
87	sludge only	0.5 µ	35	0.21	17.93	23.06
86	sludge only	0.5 µ	35	0.21	11.90	11.15
85	sludge only	0.5 µ	35	0.21	11.99	11.44
84	sludge only	0.5 µ	35	0.21	12.03	11.62
83	sludge only	0.5 µ	35	0.21	25.20	43.31
82	sludge only	0.5 µ	35	0.21	11.90	11.42
81	sludge only	0.5 µ	35	0.21	11.98	11.69
80	sludge only	0.5 µ	35	0.21	20.30	29.66
79	sludge only	0.5 µ	35	0.21	20.78	30.94
78	sludge only	0.5 µ	35	0.21	14.77	16.90
77	sludge only	0.5 µ	35	0.21	14.83	17.13
76	sludge only	0.5 µ	35	0.21	12.04	12.08
75	sludge only	0.5 µ	35	0.21	17.78	23.26
74	sludge only	0.5 µ	35	0.21	11.99	11.77
73	sludge only	0.5 µ	35	0.21	11.88	12.08
72	sludge only	0.5 µ	35	0.21	11.97	13.06
71	sludge only	0.5 µ	35	0.21	20.30	33.08
70	sludge only	0.5 µ	35	0.21	17.93	26.52
69	sludge only	0.5 µ	35	0.21	25.36	49.17
68	sludge only	0.5 µ	35	0.21	22.90	40.17
67	sludge only	0.5 µ	35	0.21	20.37	32.50
66	sludge only	0.5 µ	35	0.21	17.81	25.39
65	sludge only	0.5 µ	35	0.21	20.27	32.04
64	sludge only	0.5 µ	35	0.21	22.96	40.07
63	sludge only	0.5 µ	35	0.21	25.47	48.46

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
62	sludge only	0.5 µ	35	0.21	25.47	48.38
61	sludge only	0.5 µ	35	0.21	21.02	34.12
60	sludge only	0.5 µ	35	0.21	16.04	20.84
59	sludge only	0.5 µ	35	0.21	11.88	12.13
58	sludge only	0.5 µ	35	0.21	16.02	21.04
57	sludge only	0.5 µ	35	0.21	21.02	34.43
56	sludge only	0.5 µ	35	0.21	25.41	48.78
55	sludge only	0.5 µ	35	0.21	22.63	39.66
54	sludge only	0.5 µ	35	0.21	20.19	32.33
53	sludge only	0.5 µ	35	0.21	17.62	25.21
52	sludge only	0.5 µ	35	0.21	20.16	32.10
51	sludge only	0.5 µ	35	0.21	22.54	39.18
50	sludge only	0.5 µ	35	0.21	25.40	48.60
42	sludge only	0.5 µ	35	0.044	19.86	30.15
41	sludge only	0.5 µ	35	0.044	19.87	30.63
40	sludge only	0.5 µ	35	0.044	14.82	17.44
39	sludge only	0.5 µ	35	0.044	17.97	24.85
38	sludge only	0.5 µ	35	0.044	17.90	24.38
37	sludge only	0.5 µ	35	0.044	20.86	31.93
36	sludge only	0.5 µ	35	0.044	18.84	26.12
35	sludge only	0.5 µ	35	0.044	18.84	26.08
34	sludge only	0.5 µ	35	0.044	13.50	14.15
33	sludge only	0.5 µ	35	0.044	12.04	11.81
32	sludge only	0.5 µ	35	0.044	13.51	14.87
31	sludge only	0.5 µ	35	0.044	12.05	12.76
30	sludge only	0.5 µ	35	0.044	17.41	21.77
29	sludge only	0.5 µ	35	0.044	25.84	44.25
28	sludge only	0.5 µ	35	0.044	21.07	30.54
27	sludge only	0.5 µ	35	0.044	12.03	11.31
26	sludge only	0.5 µ	35	0.044	13.52	13.73
25	sludge only	0.5 µ	35	0.044	17.39	21.31
24	sludge only	0.5 µ	35	0.044	26.53	45.81
23	sludge only	0.5 µ	35	0.044	21.37	30.04
22	sludge only	0.5 µ	35	0.044	16.65	19.56
21	sludge only	0.5 µ	35	0.044	11.90	11.52
20	sludge only	0.5 µ	35	0.044	16.67	20.36
19	sludge only	0.5 µ	35	0.044	21.40	31.50
18	sludge only	0.5 µ	35	0.044	26.51	45.78
17	sludge only	0.5 µ	35	0.044	22.30	32.96
16	sludge only	0.5 µ	35	0.044	20.54	28.09
15	sludge only	0.5 µ	35	0.044	17.91	21.71
14	sludge only	0.5 µ	35	0.044	20.60	28.31
13	sludge only	0.5 µ	35	0.044	22.32	32.76
12	sludge only	0.5 µ	35	0.044	26.46	44.48
11	sludge only	0.5 µ	35	0.044	26.42	45.87
30	Sludge+MST	0.5 µ	35	0.033	26.10	44.53
31	Sludge+MST	0.5 µ	35	0.033	22.85	34.97
32	Sludge+MST	0.5 µ	35	0.033	20.59	28.91
33	Sludge+MST	0.5 µ	35	0.033	17.96	22.28
34	Sludge+MST	0.5 µ	35	0.033	20.69	28.99

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
35	Sludge+MST	0.5 µ	35	0.033	23.34	36.40
36	Sludge+MST	0.5 µ	35	0.033	26.16	44.84
37	Sludge+MST	0.5 µ	35	0.033	21.74	31.92
38	Sludge+MST	0.5 µ	35	0.033	16.83	19.90
39	Sludge+MST	0.5 µ	35	0.033	11.93	10.54
40	Sludge+MST	0.5 µ	35	0.033	16.82	19.95
41	Sludge+MST	0.5 µ	35	0.033	21.73	31.82
42	Sludge+MST	0.5 µ	35	0.033	26.15	44.67
43	Sludge+MST	0.5 µ	35	0.033	16.67	19.24
44	Sludge+MST	0.5 µ	35	0.033	13.58	13.22
45	Sludge+MST	0.5 µ	35	0.033	14.89	15.64
46	Sludge+MST	0.5 µ	35	0.033	12.09	10.75
47	Sludge+MST	0.5 µ	35	0.033	13.55	13.29
48	Sludge+MST	0.5 µ	35	0.033	17.48	21.32
49	Sludge+MST	0.5 µ	35	0.033	18.89	24.49
50	Sludge+MST	0.5 µ	35	0.033	17.47	21.31
51	Sludge+MST	0.5 µ	35	0.033	18.89	24.52
52	Sludge+MST	0.5 µ	35	0.033	12.05	10.70
53	Sludge+MST	0.5 µ	35	0.033	13.55	13.24
54	Sludge+MST	0.5 µ	35	0.033	18.02	22.52
55	Sludge+MST	0.5 µ	35	0.033	17.97	22.43
56	Sludge+MST	0.5 µ	35	0.033	20.97	29.57
57	Sludge+MST	0.5 µ	35	0.033	26.00	43.97
58	Sludge+MST	0.5 µ	35	0.033	12.10	10.58
59	Sludge+MST	0.5 µ	35	0.033	21.16	30.07
60	Sludge+MST	0.5 µ	35	0.25	18.00	22.48
61	Sludge+MST	0.5 µ	35	0.25	26.27	45.02
62	Sludge+MST	0.5 µ	35	0.25	23.48	36.66
63	Sludge+MST	0.5 µ	35	0.25	20.63	29.01
64	Sludge+MST	0.5 µ	35	0.25	17.83	22.22
65	Sludge+MST	0.5 µ	35	0.25	20.67	29.08
66	Sludge+MST	0.5 µ	35	0.25	23.58	36.91
67	Sludge+MST	0.5 µ	35	0.25	26.25	44.93
68	Sludge+MST	0.5 µ	35	0.25	21.42	30.78
69	Sludge+MST	0.5 µ	35	0.25	16.68	19.36
70	Sludge+MST	0.5 µ	35	0.25	11.93	10.38
71	Sludge+MST	0.5 µ	35	0.25	12.09	10.62
72	Sludge+MST	0.5 µ	35	0.25	21.43	30.78
73	Sludge+MST	0.5 µ	35	0.25	26.27	44.79
74	Sludge+MST	0.5 µ	35	0.25	21.41	30.80
75	Sludge+MST	0.5 µ	35	0.25	20.40	28.10
76	Sludge+MST	0.5 µ	35	0.25	12.04	10.54
77	Sludge+MST	0.5 µ	35	0.25	11.97	10.24
78	Sludge+MST	0.5 µ	35	0.25	12.05	10.54
79	Sludge+MST	0.5 µ	35	0.25	17.80	21.87
80	Sludge+MST	0.5 µ	35	0.25	12.08	10.62
81	Sludge+MST	0.5 µ	35	0.25	14.90	15.77
82	Sludge+MST	0.5 µ	35	0.25	14.84	15.72
83	Sludge+MST	0.5 µ	35	0.25	20.96	29.74
84	Sludge+MST	0.5 µ	35	0.25	20.37	28.14
85	Sludge+MST	0.5 µ	35	0.25	12.03	10.62

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
86	Sludge+MST	0.5 μ	35	0.25	11.98	10.48
87	Sludge+MST	0.5 μ	35	0.25	26.13	44.59
88	Sludge+MST	0.5 μ	35	0.25	12.07	10.71
89	Sludge+MST	0.5 μ	35	0.25	12.04	10.56
90	Sludge+MST	0.5 μ	35	0.25	11.97	10.34
91	Sludge+MST	0.5 μ	35	0.25	17.81	21.85
92	Sludge+MST	0.5 μ	35	0.25	14.89	15.74
93	Sludge+MST	0.5 μ	35	0.25	20.38	27.98
94	Sludge+MST	0.5 μ	35	1.1	26.30	44.64
95	Sludge+MST	0.5 μ	35	1.1	23.49	36.34
96	Sludge+MST	0.5 μ	35	1.1	20.56	28.49
97	Sludge+MST	0.5 μ	35	1.1	17.89	22.01
98	Sludge+MST	0.5 μ	35	1.1	20.56	28.58
99	Sludge+MST	0.5 μ	35	1.1	23.49	36.48
100	Sludge+MST	0.5 μ	35	1.1	26.37	45.09
101	Sludge+MST	0.5 μ	35	1.1	21.38	30.60
102	Sludge+MST	0.5 μ	35	1.1	16.64	19.28
103	Sludge+MST	0.5 μ	35	1.1	11.90	10.40
104	Sludge+MST	0.5 μ	35	1.1	16.23	19.27
105	Sludge+MST	0.5 μ	35	1.1	21.36	30.64
106	Sludge+MST	0.5 μ	35	1.1	26.38	45.03
107	Sludge+MST	0.5 μ	35	1.1	22.85	34.45
108	Sludge+MST	0.5 μ	35	1.1	12.61	11.54
109	Sludge+MST	0.5 μ	35	1.1	26.21	44.59
110	Sludge+MST	0.5 μ	35	1.1	11.85	10.10
111	Sludge+MST	0.5 μ	35	1.1	17.43	20.57
112	Sludge+MST	0.5 μ	35	1.1	14.84	15.32
113	Sludge+MST	0.5 μ	35	1.1	11.89	10.16
114	Sludge+MST	0.5 μ	35	1.1	17.39	20.80
115	Sludge+MST	0.5 μ	35	1.1	26.23	44.64
116	Sludge+MST	0.5 μ	35	1.1	11.85	10.22
117	Sludge+MST	0.5 μ	35	1.1	17.53	21.23
118	Sludge+MST	0.5 μ	35	1.1	11.85	10.28
119	Sludge+MST	0.5 μ	35	1.1	11.88	10.37
120	Sludge+MST	0.5 μ	35	1.1	17.79	21.86
121	Sludge+MST	0.5 μ	35	1.1	21.79	31.85
122	Sludge+MST	0.5 μ	35	1.1	11.85	10.29
123	Sludge+MST	0.5 μ	35	1.1	11.89	10.39
124	Sludge+MST	0.5 μ	35	1.1	17.73	21.69
125	Sludge+MST	0.5 μ	35	1.1	21.79	31.11
126	Sludge+MST	0.5 μ	35	4.2	26.37	43.99
127	Sludge+MST	0.5 μ	35	4.2	23.47	35.32
128	Sludge+MST	0.5 μ	35	4.2	20.48	27.27
129	Sludge+MST	0.5 μ	35	4.2	17.53	20.36
130	Sludge+MST	0.5 μ	35	4.2	20.59	27.53
131	Sludge+MST	0.5 μ	35	4.2	23.58	35.53
132	Sludge+MST	0.5 μ	35	4.2	26.44	44.25
133	Sludge+MST	0.5 μ	35	4.2	21.64	30.58
134	Sludge+MST	0.5 μ	35	4.2	16.76	19.13
135	Sludge+MST	0.5 μ	35	4.2	11.87	10.06
136	Sludge+MST	0.5 μ	35	4.2	16.75	19.16

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
137	Sludge+MST	0.5 μ	35	4.2	21.58	30.56
138	Sludge+MST	0.5 μ	35	4.2	26.44	44.19
139	Sludge+MST	0.5 μ	35	4.2	20.79	28.32
140	Sludge+MST	0.5 μ	35	4.2	17.88	21.34
141	Sludge+MST	0.5 μ	35	4.2	11.84	9.72
142	Sludge+MST	0.5 μ	35	4.2	13.94	13.40
143	Sludge+MST	0.5 μ	35	4.2	16.80	18.89
144	Sludge+MST	0.5 μ	35	4.2	11.87	10.05
145	Sludge+MST	0.5 μ	35	4.2	11.87	10.08
146	Sludge+MST	0.5 μ	35	4.2	11.83	9.95
147	Sludge+MST	0.5 μ	35	4.2	11.83	9.99
148	Sludge+MST	0.5 μ	35	4.2	11.87	10.14
149	Sludge+MST	0.5 μ	35	4.2	16.85	19.22
150	Sludge+MST	0.5 μ	35	4.2	25.93	42.94
151	Sludge+MST	0.5 μ	35	4.2	16.85	19.25
152	Sludge+MST	0.5 μ	35	4.2	15.78	17.11
153	Sludge+MST	0.5 μ	35	4.2	15.84	17.24
154	Sludge+MST	0.5 μ	35	4.2	11.84	9.82
37	6.4 M Sludge+MST	0.5 μ	35	0.05	8.97	6.69
38	6.4 M Sludge+MST	0.5 μ	35	0.05	11.94	11.33
39	6.4 M Sludge+MST	0.5 μ	35	0.05	4.04	1.54
40	6.4 M Sludge+MST	0.5 μ	35	0.05	8.93	6.59
41	6.4 M Sludge+MST	0.5 μ	35	0.05	11.90	11.15
42	6.4 M Sludge+MST	0.5 μ	35	0.05	8.96	6.61
43	6.4 M Sludge+MST	0.5 μ	35	0.05	5.98	3.16
44	6.4 M Sludge+MST	0.5 μ	35	0.05	8.98	6.64
45	6.4 M Sludge+MST	0.5 μ	35	0.05	14.01	14.92
46	6.4 M Sludge+MST	0.5 μ	35	0.05	5.96	2.97
47	6.4 M Sludge+MST	0.5 μ	35	0.05	8.95	6.49
52	6.4 M Sludge+MST	0.5 μ	35	0.05	8.94	6.58
53	6.4 M Sludge+MST	0.5 μ	35	0.05	11.92	11.16
54	6.4 M Sludge+MST	0.5 μ	35	0.05	4.02	1.47
55	6.4 M Sludge+MST	0.5 μ	35	0.05	8.91	6.51
56	6.4 M Sludge+MST	0.5 μ	35	0.05	11.89	11.02
57	6.4 M Sludge+MST	0.5 μ	35	0.05	8.94	6.50
58	6.4 M Sludge+MST	0.5 μ	35	0.05	5.97	3.06
59	6.4 M Sludge+MST	0.5 μ	35	0.05	8.95	6.54
60	6.4 M Sludge+MST	0.5 μ	35	0.05	14.00	14.78
61	6.4 M Sludge+MST	0.5 μ	35	0.05	5.93	2.92
62	6.4 M Sludge+MST	0.5 μ	35	0.05	8.93	6.44
66	6.4 M Sludge+MST	0.5 μ	35	0.74	8.93	6.71
67	6.4 M Sludge+MST	0.5 μ	35	0.74	11.90	11.22
68	6.4 M Sludge+MST	0.5 μ	35	0.74	3.99	1.61
69	6.4 M Sludge+MST	0.5 μ	35	0.74	8.86	6.42
70	6.4 M Sludge+MST	0.5 μ	35	0.74	11.88	11.03
71	6.4 M Sludge+MST	0.5 μ	35	0.74	8.93	5.58
72	6.4 M Sludge+MST	0.5 μ	35	0.74	5.93	3.31
73	6.4 M Sludge+MST	0.5 μ	35	0.74	8.92	6.89
74	6.4 M Sludge+MST	0.5 μ	35	0.74	13.98	14.90
75	6.4 M Sludge+MST	0.5 μ	35	0.74	5.92	3.06

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
76	6.4 M Sludge+MST	0.5 μ	35	0.74	8.92	6.66
81	6.4 M Sludge+MST	0.5 μ	35	0.74	8.92	6.70
82	6.4 M Sludge+MST	0.5 μ	35	0.74	11.90	11.29
83	6.4 M Sludge+MST	0.5 μ	35	0.74	3.98	1.66
84	6.4 M Sludge+MST	0.5 μ	35	0.74	8.90	6.59
85	6.4 M Sludge+MST	0.5 μ	35	0.74	11.88	11.07
86	6.4 M Sludge+MST	0.5 μ	35	0.74	8.92	6.63
87	6.4 M Sludge+MST	0.5 μ	35	0.74	5.93	3.32
88	6.4 M Sludge+MST	0.5 μ	35	0.74	8.92	6.76
89	6.4 M Sludge+MST	0.5 μ	35	0.74	13.97	14.83
90	6.4 M Sludge+MST	0.5 μ	35	0.74	5.91	2.97
91	6.4 M Sludge+MST	0.5 μ	35	0.74	8.91	6.53
95	6.4 M Sludge+MST	0.5 μ	35	0.05	8.93	6.13
96	6.4 M Sludge+MST	0.5 μ	35	0.05	11.94	10.79
97	6.4 M Sludge+MST	0.5 μ	35	0.05	4.01	1.25
98	6.4 M Sludge+MST	0.5 μ	35	0.05	8.90	6.00
99	6.4 M Sludge+MST	0.5 μ	35	0.05	11.87	10.44
100	6.4 M Sludge+MST	0.5 μ	35	0.05	8.93	6.21
101	6.4 M Sludge+MST	0.5 μ	35	0.05	5.96	2.87
102	6.4 M Sludge+MST	0.5 μ	35	0.05	8.94	6.27
103	6.4 M Sludge+MST	0.5 μ	35	0.05	13.97	14.24
104	6.4 M Sludge+MST	0.5 μ	35	0.05	5.93	2.69
105	6.4 M Sludge+MST	0.5 μ	35	0.05	8.93	6.22
110	6.4 M Sludge+MST	0.5 μ	35	0.05	8.93	6.34
111	6.4 M Sludge+MST	0.5 μ	35	0.05	11.89	10.90
112	6.4 M Sludge+MST	0.5 μ	35	0.05	4.02	1.26
113	6.4 M Sludge+MST	0.5 μ	35	0.05	8.90	6.25
114	6.4 M Sludge+MST	0.5 μ	35	0.05	11.87	10.74
115	6.4 M Sludge+MST	0.5 μ	35	0.05	8.92	6.28
116	6.4 M Sludge+MST	0.5 μ	35	0.05	5.95	2.88
117	6.4 M Sludge+MST	0.5 μ	35	0.05	8.94	6.31
118	6.4 M Sludge+MST	0.5 μ	35	0.05	13.97	14.52
119	6.4 M Sludge+MST	0.5 μ	35	0.05	5.92	2.78
120	6.4 M Sludge+MST	0.5 μ	35	0.05	8.92	6.27
124	6.4 M Sludge+MST	0.5 μ	35	0.1	8.92	6.40
125	6.4 M Sludge+MST	0.5 μ	35	0.1	11.90	10.93
126	6.4 M Sludge+MST	0.5 μ	35	0.1	4.01	1.32
127	6.4 M Sludge+MST	0.5 μ	35	0.1	8.90	6.32
128	6.4 M Sludge+MST	0.5 μ	35	0.1	11.87	10.85
129	6.4 M Sludge+MST	0.5 μ	35	0.1	8.92	6.36
130	6.4 M Sludge+MST	0.5 μ	35	0.1	5.95	2.97
131	6.4 M Sludge+MST	0.5 μ	35	0.1	8.94	6.40
132	6.4 M Sludge+MST	0.5 μ	35	0.1	13.97	14.60
133	6.4 M Sludge+MST	0.5 μ	35	0.1	5.92	2.86
134	6.4 M Sludge+MST	0.5 μ	35	0.1	8.92	6.34
139	6.4 M Sludge+MST	0.5 μ	35	0.1	8.93	6.46
140	6.4 M Sludge+MST	0.5 μ	35	0.1	11.89	11.00
141	6.4 M Sludge+MST	0.5 μ	35	0.1	4.00	1.38
142	6.4 M Sludge+MST	0.5 μ	35	0.1	8.90	6.27
143	6.4 M Sludge+MST	0.5 μ	35	0.1	11.86	10.78
144	6.4 M Sludge+MST	0.5 μ	35	0.1	8.92	6.33

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
145	6.4 M Sludge+MST	0.5 µ	35	0.1	5.94	2.95
146	6.4 M Sludge+MST	0.5 µ	35	0.1	8.94	6.37
147	6.4 M Sludge+MST	0.5 µ	35	0.1	13.96	14.55
148	6.4 M Sludge+MST	0.5 µ	35	0.1	5.92	2.82
149	6.4 M Sludge+MST	0.5 µ	35	0.1	8.92	6.31
153	6.4 M Sludge+MST	0.5 µ	35	0.2	8.92	6.50
154	6.4 M Sludge+MST	0.5 µ	35	0.2	11.89	11.07
155	6.4 M Sludge+MST	0.5 µ	35	0.2	4.00	1.45
156	6.4 M Sludge+MST	0.5 µ	35	0.2	8.90	6.31
157	6.4 M Sludge+MST	0.5 µ	35	0.2	11.86	10.84
158	6.4 M Sludge+MST	0.5 µ	35	0.2	8.91	6.38
159	6.4 M Sludge+MST	0.5 µ	35	0.2	5.94	2.98
160	6.4 M Sludge+MST	0.5 µ	35	0.2	8.93	6.41
161	6.4 M Sludge+MST	0.5 µ	35	0.2	13.95	14.67
162	6.4 M Sludge+MST	0.5 µ	35	0.2	5.92	2.89
163	6.4 M Sludge+MST	0.5 µ	35	0.2	8.92	6.35
168	6.4 M Sludge+MST	0.5 µ	35	0.2	8.91	6.48
169	6.4 M Sludge+MST	0.5 µ	35	0.2	11.85	10.99
170	6.4 M Sludge+MST	0.5 µ	35	0.2	3.99	1.38
171	6.4 M Sludge+MST	0.5 µ	35	0.2	8.88	6.34
172	6.4 M Sludge+MST	0.5 µ	35	0.2	11.87	10.89
173	6.4 M Sludge+MST	0.5 µ	35	0.2	8.91	6.38
174	6.4 M Sludge+MST	0.5 µ	35	0.2	5.95	3.00
175	6.4 M Sludge+MST	0.5 µ	35	0.2	8.93	6.42
176	6.4 M Sludge+MST	0.5 µ	35	0.2	13.97	14.69
177	6.4 M Sludge+MST	0.5 µ	35	0.2	5.91	2.87
178	6.4 M Sludge+MST	0.5 µ	35	0.2	8.91	6.36
182	6.4 M Sludge+MST	0.5 µ	35	0.39	8.90	6.62
183	6.4 M Sludge+MST	0.5 µ	35	0.39	11.88	11.21
184	6.4 M Sludge+MST	0.5 µ	35	0.39	3.99	1.58
185	6.4 M Sludge+MST	0.5 µ	35	0.39	8.89	6.48
186	6.4 M Sludge+MST	0.5 µ	35	0.39	11.86	11.05
187	6.4 M Sludge+MST	0.5 µ	35	0.39	8.90	6.54
188	6.4 M Sludge+MST	0.5 µ	35	0.39	5.92	3.18
189	6.4 M Sludge+MST	0.5 µ	35	0.39	8.92	6.62
190	6.4 M Sludge+MST	0.5 µ	35	0.39	13.97	14.94
191	6.4 M Sludge+MST	0.5 µ	35	0.39	5.93	3.07
192	6.4 M Sludge+MST	0.5 µ	35	0.39	8.88	6.51
197	6.4 M Sludge+MST	0.5 µ	35	0.39	8.90	6.75
198	6.4 M Sludge+MST	0.5 µ	35	0.39	11.87	11.33
199	6.4 M Sludge+MST	0.5 µ	35	0.39	3.98	1.61
200	6.4 M Sludge+MST	0.5 µ	35	0.39	8.92	6.55
201	6.4 M Sludge+MST	0.5 µ	35	0.39	11.85	11.07
202	6.4 M Sludge+MST	0.5 µ	35	0.39	8.90	6.53
203	6.4 M Sludge+MST	0.5 µ	35	0.39	5.92	3.14
204	6.4 M Sludge+MST	0.5 µ	35	0.39	8.91	6.55
205	6.4 M Sludge+MST	0.5 µ	35	0.39	13.95	14.81
206	6.4 M Sludge+MST	0.5 µ	35	0.39	5.91	2.99
207	6.4 M Sludge+MST	0.5 µ	35	0.39	8.90	6.49

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
1	water	0.1 µ	35	0	10.20	7.00
2	Water	0.1 µ	35	0	13.10	10.40
3	Water	0.1 µ	35	0	5.00	2.80
4	water	0.1 µ	35	0	9.40	6.30
5	water	0.1 µ	35	0	12.70	9.90
6	water	0.1 µ	35	0	10.00	6.80
7	water	0.1 µ	35	0	7.30	4.40
8	Water	0.1 µ	35	0	10.20	7.00
9	Water	0.1 µ	35	0	14.80	12.90
10	Water	0.1 µ	35	0	6.60	4.00
11	Water	0.1 µ	35	0	9.90	6.80
12	Water	0.1 µ	35	0	10.10	7.10
13	Sludge + MST	0.1 µ	35	0.06	9.10	8.00
14	Sludge + MST	0.1 µ	35	0.06	12.10	12.40
15	Sludge + MST	0.1 µ	35	0.06	4.10	3.10
16	Sludge + MST	0.1 µ	35	0.06	9.00	7.90
17	Sludge + MST	0.1 µ	35	0.06	12.00	12.30
18	Sludge + MST	0.1 µ	35	0.06	9.10	8.10
19	Sludge + MST	0.1 µ	35	0.06	6.10	4.80
20	Sludge + MST	0.1 µ	35	0.06	9.10	8.20
21	Sludge + MST	0.1 µ	35	0.06	14.10	16.00
22	Sludge + MST	0.1 µ	35	0.06	6.10	4.70
23	Sludge + MST	0.1 µ	35	0.06	9.00	8.10
24	Sludge + MST	0.1 µ	35	0.06	9.10	8.10
25	Sludge + MST	0.1 µ	35	4.5	20.60	29.80
26	Sludge + MST	0.1 µ	35	4.5	9.00	8.50
27	Sludge + MST	0.1 µ	35	4.5	12.00	13.10
28	Sludge + MST	0.1 µ	35	4.5	4.00	3.80
29	Sludge + MST	0.1 µ	35	4.5	9.00	8.50
30	Sludge + MST	0.1 µ	35	4.5	12.00	12.40
31	Sludge + MST	0.1 µ	35	4.5	9.00	8.40
32	Sludge + MST	0.1 µ	35	4.5	6.00	5.40
33	Sludge + MST	0.1 µ	35	4.5	9.00	8.70
34	Sludge + MST	0.1 µ	35	4.5	14.10	16.10
35	Sludge + MST	0.1 µ	35	4.5	6.00	4.80
36	Sludge + MST	0.1 µ	35	4.5	9.00	8.50
37	Sludge + MST	0.1 µ	35	4.5	9.00	8.60
38	Sludge + MST	0.1 µ	35	10	9.00	10.90
39	Sludge + MST	0.1 µ	35	10.8	9.00	12.60
40	Sludge + MST	0.1 µ	35	11	9.00	12.50
41	Sludge + MST	0.1 µ	35	12.2	9.00	12.30
42	Sludge + MST	0.1 µ	35	12.2	8.90	11.70
43	Sludge + MST	0.1 µ	35	12.2	12.00	16.00
44	Sludge + MST	0.1 µ	35	12.2	4.00	6.40
45	Sludge + MST	0.1 µ	35	12.2	8.90	11.30
46	Sludge + MST	0.1 µ	35	12.2	11.80	13.90
47	Sludge + MST	0.1 µ	35	12.2	8.90	10.20
48	Sludge + MST	0.1 µ	35	12.2	5.90	8.00
49	Sludge + MST	0.1 µ	35	12.2	8.90	11.90
50	Sludge + MST	0.1 µ	35	12.2	14.00	18.60
51	Sludge + MST	0.1 µ	35	12.2	5.90	6.20

Test	Feed	Pore Size	Temp	Conc (wt %)	Vel (ft/s)	DP (psi)
52	Sludge + MST	0.1 µ	35	12.2	9.00	11.00
53	Sludge + MST	0.1 µ	35	12.2	9.00	13.50
54	Sludge + MST	0.1 µ	35	7.5	9.00	11.90
55	Sludge + MST	0.1 µ	35	7.5	9.00	10.60
56	water	0.1 µ	35	0	9.00	5.70
57	water	0.1 µ	35	0	12.00	9.00
58	water	0.1 µ	35	0	4.10	1.90
59	water	0.1 µ	35	0	9.00	5.50
60	water	0.1 µ	35	0	12.00	8.70
65	water	0.1 µ	35	0	6.00	3.00
66	water	0.1 µ	35	0	9.00	5.50
67	water	0.1 µ	35	0	9.00	5.50

Appendix B
Statistical Analysis

Influence of Operating Parameters on Axial Pressure Drop at Solids Loading at or below 4.5 wt %

Response ln(DP)
Whole Model
Summary of Fit

RSquare	0.99041
RSquare Adj	0.990281
Root Mean Square Error	0.082237
Mean of Response	2.547415
Observations (or Sum Wgts)	454

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	312.20067	52.0334	7693.97
Error	447	3.02301	0.0068	Prob > F
C. Total	453	315.22368		0.0000

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	354	2.9396408	0.008304	9.2633
Pure Error	93	0.0833693	0.000896	Prob > F
Total Error	447	3.0230102		<.0001
				Max RSq
				0.9997

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.878455	0.031066	-60.47	<.0001
Feed[0.1 micron]	0.1662687	0.014018	11.86	<.0001
Feed[6.4 M Sludge+MS]	-0.110795	0.008631	-12.84	<.0001
Feed[Sludge+MST]	-0.105629	0.00916	-11.53	<.0001
Feed[Sludge+MnO_2]	0.076695	0.011421	6.72	<.0001
ln(conc)	0.001834	0.002495	0.74	0.4626
ln(v1.75)	1.0046212	0.00718	139.92	0.0000

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Feed	4	4	2.66620	98.5600	<.0001
ln(conc)	1	1	0.00365	0.5404	0.4626
ln(v1.75)	1	1	132.40816	19578.65	0.0000

Influence of Operating Parameters on Axial Pressure Drop at Solids Loading at all Solids Loadings

Response ln(DP)

Whole Model

Summary of Fit

RSquare	0.984184
RSquare Adj	0.983978
Root Mean Square Error	0.104356
Mean of Response	2.543486
Observations (or Sum Wgts)	467

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	311.73046	51.9551	4770.841
Error	460	5.00946	0.0109	Prob > F
C. Total	466	316.73992		0.0000

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	361	4.8582650	0.013458	8.8120
Pure Error	99	0.1511948	0.001527	Prob > F
Total Error	460	5.0094598		<.0001
				Max RSq
				0.9995

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.783967	0.038679	-46.12	<.0001
Feed[0.1 micron]	0.244448	0.015292	15.99	<.0001
Feed[6.4 M Sludge+MS]	-0.134088	0.010792	-12.43	<.0001
Feed[Sludge+MST]	-0.117202	0.011318	-10.36	<.0001
Feed[Sludge+MnO_2]	0.0436777	0.014208	3.07	0.0022
ln(conc)	0.009427	0.003055	3.09	0.0022
ln(v1.75)	0.9893365	0.008972	110.27	0.0000

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Feed	4	4	4.53222	104.0442	<.0001
ln(conc)	1	1	0.10371	9.5229	0.0022
ln(v1.75)	1	1	132.40718	12158.46	0.0000