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Evaluating the Effects of Tri-Butyl Phosphate and Normal Paraffin Hydrocarbon in Simulated Low-Activity Waste Solution on Ultrafiltration

by

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SAVANNAH RIVER TECHNOLOGY CENTER

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April 25, 2002

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List of Acronyms

ADS	Analytical Development Section
DI	deionized
DBP	dibutylphosphate
fps	feet per second
HLW	high level waste
IC	ion chromatography
ICPES	inductively coupled plasma emission spectroscopy
ITS	Immobilization Technology Section
NPH	normal paraffin hydrocarbon (dodecane)
QA	Quality Assurance
QC	Quality Control
SpGr	specific gravity
SRS	Savannah River Site
SRTC	Savannah River Technology Center
TBP	tributyl phosphate
TC	total carbon
TIC	total inorganic carbon
TOC	total organic carbon
TS	total solids
TSS	total suspended solids
WPT	Waste Processing Technology (Section)
WSRC	Westinghouse Savannah River Company

1.0 Executive Summary

The effect on the filter flux of tributyl phosphate (TBP) and normal paraffin hydrocarbon (dodecane) in a simulated AZ-101 3.5 wt% insoluble, 28-30 wt% total solids slurry was studied. A 0.1 μm sintered metal Mott filter element was used for this work. The operating parameters used were specified by the customer to be within the range applicable to the full-scale plant. Specifically, transmembrane pressures of 20-60 psi and linear velocities of 7-15 fps were tested.

With TBP and dodecane at up to 2500 mg/L each, no effect on the filter flux was found. Therefore, the de minimis concentration of separable organics, if one exists, must be greater than 2500 mg/L.

All measured fluxes exceeded the customer's minimum of 0.014 gpm/ft^2. Simulants with no organics, 25 mg/L each, and 2500 mg/L each were concentrated by a factor of one to produce permeate for ion exchange tests.

Cleaning of the system after use with the organics proved difficult using only water and nitric acid. It should be noted that the concentrations of separable organics were much higher than should actually be seen in the WTP. We recommend that the effect of TBP and NPH be studied further during filter cleaning tests.

2.0 Background and Introduction

Detailed background on the origin of this task is given in the customer's (RPP-WTP) specifying document: TSP-W375-00-00036, Rev. 1.[1] This work is specified in the RPP-WTP R/T Plan (PL-W375-TE00007, Rev. 0).

2.1 Objectives

2.1.1 General Objectives

The effects of trace quantities of separable organics (tri-butyl phosphate {TBP} and normal paraffin hydrocarbon{NPH}, herein also called "organics") in the tank waste liquid feed to the Hanford River Protection Project Waste Treatment Plant (RPP-WTP) and the fate of the separable organics within the system shall be evaluated. Bulk average concentrations of ~25 ppm (or mg/L) are expected, but instantaneous concentrations could be higher. Each potentially affected unit operation, including ultrafiltration, ion exchange, and evaporation shall be examined for process, safety, and permitting implications. Based upon the results of these tests, the SRTC shall propose a de minimis concentration level for separable organics that could be sent to the WTP without adversely affecting the WTP. Specifically, the effects of insoluble TBP and NPH on ultrafiltration filter flux rate with a simulated AZ-10l solution are to be evaluated in this task.

The products from these filtration tests will be used as the feed for cesium and technetium ion exchange studies, which will be covered by a separate Task Technical & Quality Assurance Plan. Evaporation studies are described in a separate customer request.[2]

2.1.2 Specific Objectives

1. Determine the effect on filter flux rate, for a 0.1 μm sintered metal Mott filter element, of processing a simulated waste solution containing approximately 25 ppm (mg/L) TBP and 25 ppm NPH each above their solubility limit. The solubility limit for TBP is approximately 1.1 mg/L. Although the solubility limit for NPH in the salt solution is not exactly known, it should be much less than that for TBP since NPH is more non-polar.

2. Determine the effect on filter flux rate, for a 0.1 μm sintered metal Mott filter element, of processing a simulated waste solution containing incrementally higher levels of TBP and NPH each above their solubility limit. Organic levels up to 2500 mg/L each are to be studied.

3. For the simulant without TBP/NPH and simulant with two levels of TBP and NPH, produce at least 2.0-2.5 liters of permeate solution of each for use in ion exchange tests.

2.2 Experimental System & Operation

Figure 2.1 shows a photograph of the system. A schematic of the experimental system is shown in Figure 2.2. The experimental crossflow filter, or Cold Cells Unit Filter (CUF) contains a single crossflow filter tube. A 5-stage centrifugal pump is used to feed the slurry into the filter. Some liquid permeates through the filter wall (permeate) and the remainder passes through the filter axially (concentrate). As solids accumulate on the filter wall, backpulsing can be used to remove accumulation. The filter in this work was a 3/8-inch internal diameter, 2-foot long Mott Metallurgical sintered stainless steel filter. The nominal pore size was 0.1 μm. The single filter tube was mounted horizontally in a stainless steel housing of welded construction.

Filtrate flowrate was measured with a graduated collection glass and stopwatch. The simple backpulse system is manually operated. The backpulse chamber is first charged with filtrate followed by compressed air. Quickly opening a toggle valve below the chamber forces reverse flow of filtrate upon the filter medium. Standard Bourdon tube type pressure gauges on both the inlet and exit of the filter indicate pressure. A thermocouple mounted near the bottom of the reservoir measures slurry temperature directly. A heat exchanger and chiller unit provide temperature control. All experiments were performed at 25 ± 5°C.

Slurry is recirculated through a heat exchanger and the filter element. A magnetic flow meter measures the volumetric flow in the system, which is displayed on a digital read out along with the feed vessel temperature. The filter is back-pulsed before the start each experiment by pressurizing the backpulse tank to 45 psig. The toggle valve is then open repeatedly at no flow conditions. When air is observed returning to the feed vessel, back-pulsing is stopped. Each set of experimental conditions are set by adjusting the flow of air to the feed pump and adjusting the slurry flow control valve until the desired flow and transmembrane pressures are achieved. The system was operated per an approved operating procedure.[3]

2.2.1 Cross-flow Filter Conditioning

The equipment internals were first rinsed with flush solutions or DI water per the steps below. The filter cleaning fluids were pre-filtered with 0.22 μm nylon filters before use. The laboratory de-ionizing unit uses a 0.22 μm filter on the discharge.

A previously used filter element was used. It was first drained of any previous fluid, then filled with deionized water. This water was filtered through a 0.22 μm nylon filter, which was located on the deionizer. This water was then recirculated through the filter concentrate side for at least 15 minutes. The filtrate generated was recycled back to the feed tank. The system was then drained, filled with ~1 M nitric acid, and recirculated for at least one hour. The filtrate generated was again recycled back to the reservoir. At least 2 backpulses were done in this period to clean the backpulse system as well as the filter. The system was then drained and the backpulse chamber is purged to empty it. A solution of 0.01 M NaOH was then added and recirculated for at least 15 minutes. At least 2 backpulses were done in this period to clean the backpulse system as well as the filter. The entire system and backpulse chamber were then drained and then refilled with fresh DI water (the system is laid up with DI water).

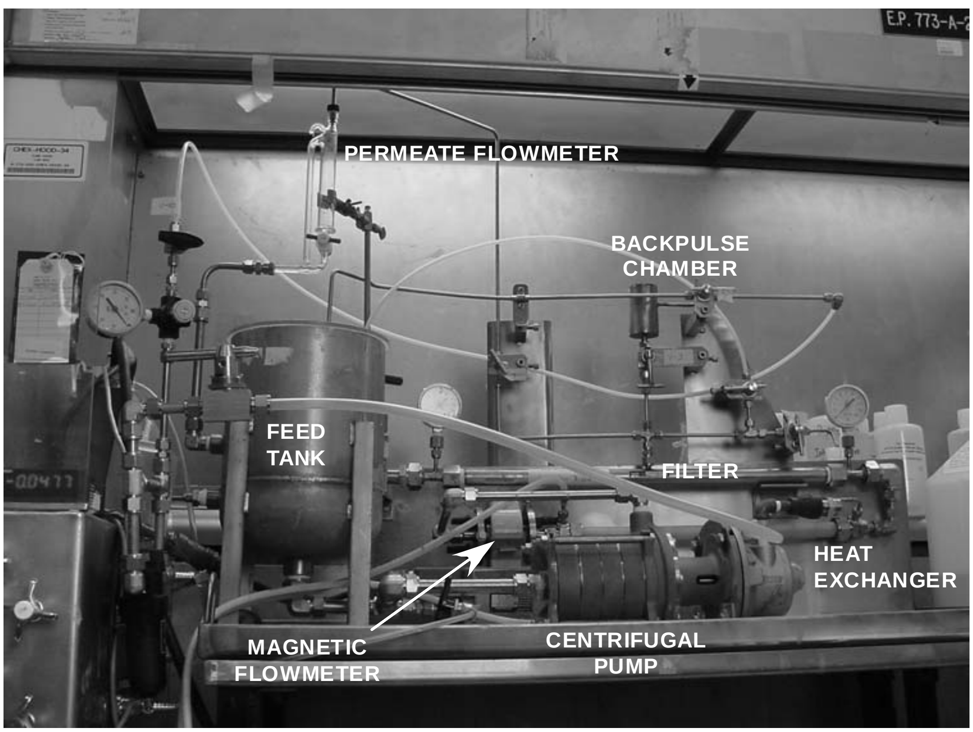


Figure 2.1 Crossflow Ultrafilter System

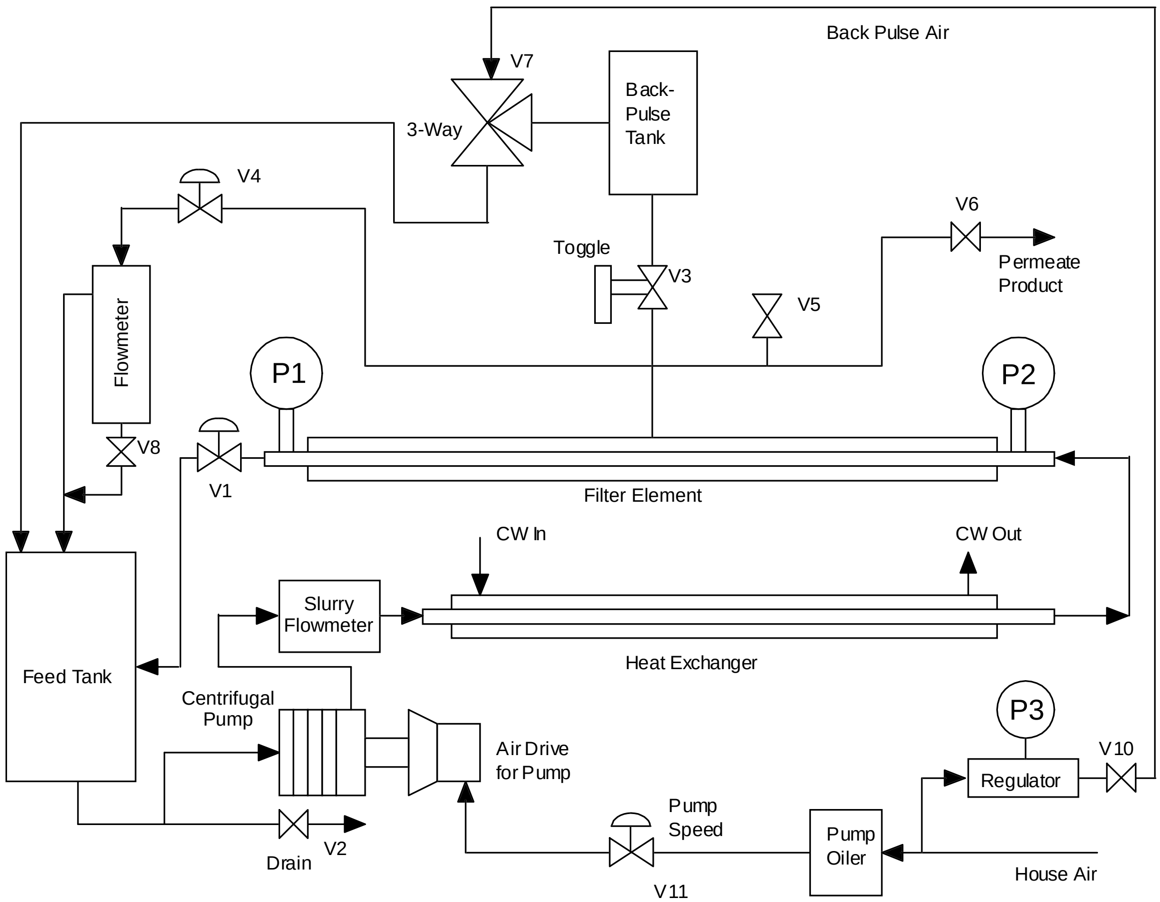


Figure 2.2 Cross-flow Filtration Schematic

2.3 Experimental Methods & Materials

Initially, this work was specified to be performed with no insoluble solids, then respecified to include 0.1 wt% insoluble solids, then again respecified to use 3 wt% insoluble solids. Given these changes, to complete this work on a reasonable schedule, it was decided that the best way to proceed was to use the already made supernate simulant, some existing Envelope D solids simulant, and trim chemicals.

The simulant used for these experiments was made from a supernate simulant and a solids simulant. A simulated Tank 241-AZ-101 supernate solution that was ~5M Na concentration was prepared using a slight modification of the Envelope B simulant recipe.[4] The details of the recipe are given in Appendix 5.1. The solids used were an Envelope D simulant.[4] The supernate simulant and the solids simulant were each analyzed prior to use to verify correct makeup. The solids simulant used was actually from three different bottles of previously made materials that were at different insoluble solids concentrations (8.03-14.8 wt%). Note that concentration of these solids simulants to greater than 15 wt% insoluble solids by dead end filtration and centrifugation had been tried previously with no success, so they were used as is. The supernate simulant was mixed with calculated amounts of the solids simulants to achieve a total insoluble solids content of nominally 3.0 wt%. Additional trim chemicals needed to be added to adjust the soluble solids concentrations to the correct values since the solids simulant had been washed to remove soluble components (e.g., Na, nitrite, nitrate, etc.). The amounts of each simulant material and chemicals used are shown in Table 2.1. The compositions of the simulant materials are shown in Appendix 5.2.

Table 2.1 Amounts of Simulants and Chemicals Used

Material	Insoluble Solids wt%	Amount Used
Supernate simulant	0	4.0 L
Solids simulant	11.2	1.84 L
Solids simulant	14.8	0.25
Trim chemicals	0	513 g
Final Simulant	~ 3	6.3 L

The supernate simulant was prepared to give an Al concentration of approximately 10700 mg/L, but precipitation of aluminum as alumina occurred immediately. The pH was about 11.3 and the total hydroxide concentration was greater than 1.0M. Small amounts of Si and Li also appear to have precipitated. Analysis of precipitate from a previous attempt to prepare this simulant showed that the solids were predominantly gibbsite [$Al(OH)_3$], $NaNO_2$, $NaNO_3$, and a trace amount of hydrogen aluminum silicate [$H(AlSi_2O_6)$]. The actual supernate simulant Al concentration was 5070 mg/L. Although aluminum precipitation could not be avoided, it was decided to continue with the experiments since the concentration of soluble aluminum in the simulant was deemed to have little effect on filtration. The supernate simulant was filtered prior to mixing with the solids simulants. Upon mixing the supernate simulant with the solids simulants and trim chemicals, the final composition shown in Table 2.2 was achieved. Note that the Al concentration is less than the original simulant. Aluminum was not added as a trim chemical, since it was suspected that additional precipitation would occur.

Table 2.2 Measured Initial Composition of Simulant from Supernate, Solids, & Trim Chemicals

Treatment:	Filtrate Filtered		Filtered Solids Aqua Regia Dissolution		Total Sample Microwave Dissolution			
	mg/L	mg/L	mg/kg	mg/kg	mg/L	mg/L	mg/L	mg/L
ICPES: Al	1970	2100	7289	7257	2694	2662	2678	2691
B	20.2	28.1	544	461	NA	NA	NA	NA
Ba	<0.12	<0.12	873	874	66.3	65.6	65.0	65.7
Ca	0.404	0.812	2371	2342	185	182	179	177
Cd	0.490	0.745	11120	11155	820	823	824	826
Co	<0.44	<0.44	1425	1449	107	107	105	108
Cr	443	454	1660	1684	551	562	559	564
Cu	<0.5	<0.5	482	475	35.7	32.5	29.9	28.0
Fe	0.560	0.952	142543	142434	10845	10898	10915	10895
Li	<1	<1	<43	<43	<30	<30	<28	<28
Mg	<0.84	<0.84	245	226	<25	<25	<23	<23
Mn	<0.09	<0.09	3452	3452	287	289	261	261
Mo	5.00	5.25	<43	<43	30.4	30.4	27.7	27.7
Na	99600	105000	181250	176188	109955	106667	108417	107407
Ni	<0.62	<0.62	8616	8691	682	681	690	688
P	711	735	1240	1016	1031	1018	1052	1022
Pb	<6.9	<6.9	1552	1585	<210	<210	<191	<222
Si	3.70	4.40	3196	3064	6077	6115	5653	5366
Sn	<2.6	<2.6	<112	<112	<79	<79	<72	<72
Sr	0.165	0.170	428	422	97.6	97.0	31.7	32.1
Ti	<1.4	<1.4	216	215	<42	<42	<39	<39
V	<1.3	<1.3	<56	<56	<40	<40	<36	<36
Zn	<3.7	<3.7	480	482	<112	<112	<102	<102
Zr	0.997	2.15	42243	42785	3677	3669	3479	3496
La	<7	<7	5578	5563	358	337	230	263
K	3650	3920	5753	5864	3547	3509	3786	3451
Re	33.2	34.4	52.7	62.3	<61	<61	64	64
S	6190	6230	9429	9513	6572	6682	6719	6623
Ag	<3	<3	599	841	<91	<91	<83	<83
Ce	<7.7	<7.7	1243	1300	<234	<234	<213	<213
Nd	<2.6	<2.6	3952	3992	390	316	300	319
IC: chloride	194				231		200	
fluoride	1738				2011		1694	
nitrate	67107				75686		63905	
nitrite	54366				50080		61437	
sulfate	18123				20532		17019	
phosphate	2547				2358		2358	
TC	NA				4000			
TIC	NA				4000			
TOC	NA				<200			
Total Solids (wt%)	26.5				28.0			
Insoluble Solids (wt%)					2.95			
Specific Gravity	1.22				1.25			

Numbers in red with < indicate values below detection limit

Samples of the slurry simulant and permeate were taken throughout the experiments. Some samples were analyzed completely, while others were analyzed only for total solids, insoluble solids, and specific gravity. Sample results from throughout the experiments are discussed in Section 3.1. The TBP and NPH used were 99.9+ % pure. The NPH used was actually dodecane. The TBP and NPH were first mixed to a 50:50 wt% mixture and then the mixture was added to the simulant in the necessary quantities.

2.4 Experimental Runs Matrix

The experimental runs were divided into four sections:

1. No organics. Factorial design. Permeate flux versus transmembrane pressure (TMP) and linear velocity. (Called “Level Z” herein.)

2. TBP and NPH both at 25 mg/L above the solubility limit. Factorial design as in #1. (Called “Level L” herein.)

3. Increase TBP and NPH to as high as 2500 mg/L each to determine concentration (impact level) that adversely affects the filter flux. This is the “de minimis” concentration determination. (Called “Level M” herein.)

4. Organics at impact level. Factorial design as in #1. (Called “Level H” herein.)

The factorial design for the no organics level is shown in Figure 2.3. Three clean water flux determination points are also shown in this Figure. The clean water flux was determined prior to the first runs with simulant sludge. The level L and level H designs are shown in Figure 2.4-Figure 2.5. The clean water flux was again determined after level H was completed. The numbers on each experimental point indicate the order in which the experiments were conducted; this order was randomly chosen for each level prior to the start of the experiments. Details of these experimental designs are given in Appendix 5.3.

Between each level, approximately two liters of permeate was collected for further use in ion exchange and evaporation experiments. For all three collection periods, the permeate was collected at a velocity of 13.4-15.9 fps, TMP of 32-39 psi, and a permeate flux of 0.061-0.095 gpm/ft^2. The Test Specification called for these production runs to be conducted at the optimum conditions of flow and pressure. The results of this work showed that the highest permeate flowrate was achieved at the highest attainable velocity and any pressure (above 20 psi, since lower pressures were not tested).

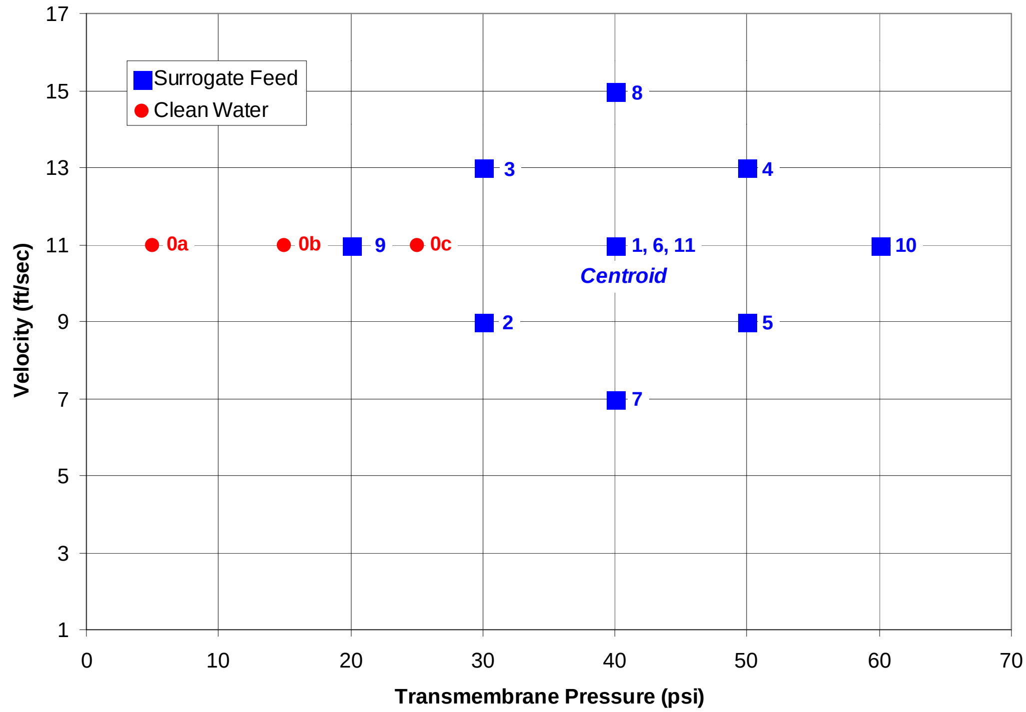


Figure 2.3 Level Z (No Organics) Factorial Design

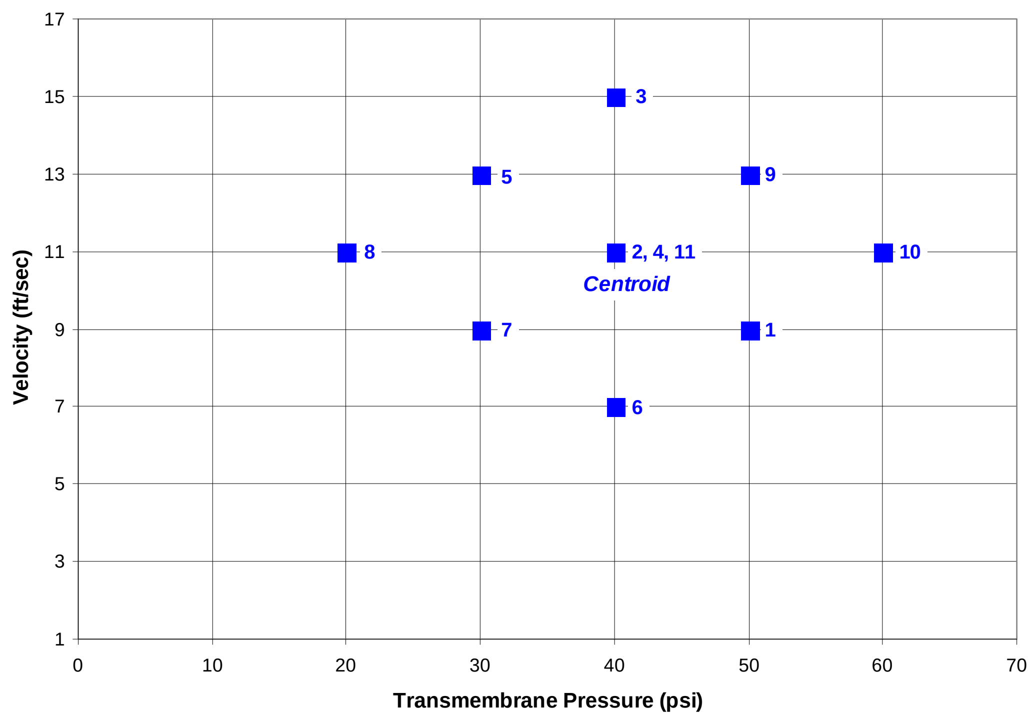


Figure 2.4 Level L (25 mg/L Each TBP & NPH) Factorial Design

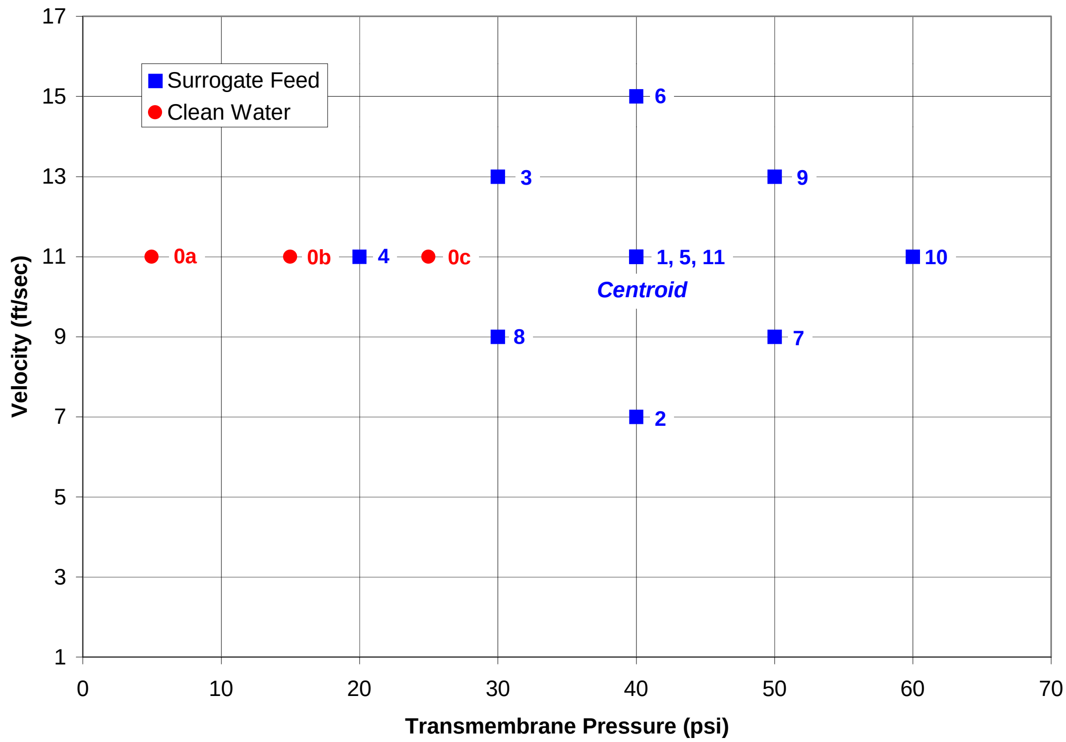


Figure 2.5 Level H (2500 mg/L Each TBP & NPH) Factorial Design

3.0 Results and Discussion

3.1 Experimental Data

3.1.1 Clean Water Flux

Clean water fluxes were taken after the system was flushed with cleaning fluids as described in section 2.2.1. Transmembrane pressures were between 5 and 20 psi and fluxes were measured after initial backpulsing. The purpose for obtaining the clean water flux measurements is to ensure the equipment is cleaned and to establish a baseline filter flux to determine if filter fouling occurs during tests with the waste simulant sample. The high filtrate flux observed for water made it necessary to collect filtrate in a 500 ml graduated cylinder instead of the 40 ml graduated collection vessel used in slurry operation. Figure 3.1 presents the measured clean water flux prior to and after the experimentation. The clean water flux prior to the filtration of the Sr/TRU precipitate of Envelope C waste, on a similar ultrafilter, is also shown.[5]

The post-test clean water flux data was taken after the system had been cleaned as described in section 2.2.1, with the exceptions that the 0.01M NaOH flush was not done and a flush with a low-foaming detergent (Alconox™) was performed. Soaking with ~1M nitric acid for several days did not return the flux back to the original values, so the detergent was used on the assumption that the organics had affected the filter (although not adversely for slurry filtration). Both TBP and NPH are relatively stable in nitric acid (they are used in solvent extraction), so the apparent ineffectiveness of the nitric acid is not surprising since little organic degradation should occur.

After soaking with detergent, the system was flushed with water and then re-cleaned with nitric acid. At this time, significant foaming occurred, so the acid was left in the system for several weeks. After the additional soaking, the foaming stopped and the fluxes returned to values similar to before the run. There is no comparative cleaning data with an AZ-101 simulant without organics present to determine if the same difficulty in cleaning would have occurred.

Also note that the final feed used, at 2500 mg/L each of TBP and NPH, was much higher than would ever be expected in the WTP, so the effect of these organics may have been much more severe that will actually occur in the WTP. We recommend that the effect of separable organics on cleaning be investigated during filter cleaning tests.

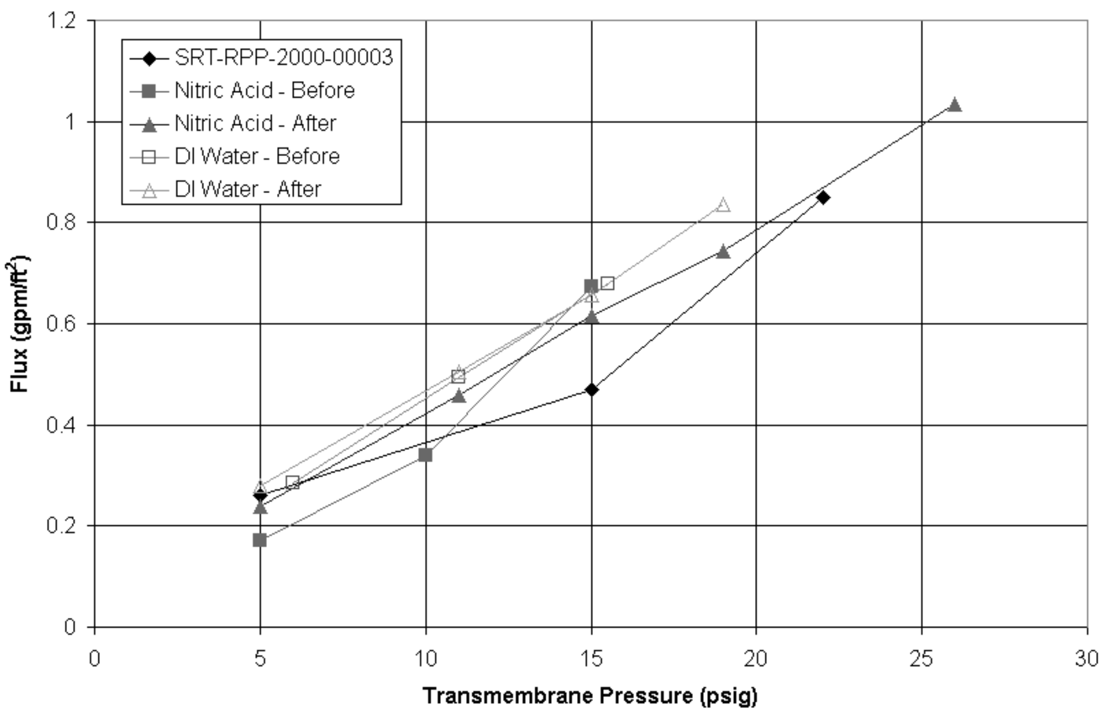


Figure 3.1 Clean Water Flux Prior to Experimentation

3.1.2 Experimental Runs

The no organics (Level Z) and the 25 mg/L each of TBP & NPH experiments (Level L) were run in succession per the designs shown in Figure 2.3 and Figure 2.4. Upon completing level L, the organics content was incrementally increased from 25 mg/L each of TBP & NPH to 2500 mg/L of each. The organics content was increased each time by adding the additional organics on top of the feed in the feed tank. The pump was then started and run for several minutes at ~15 fps velocity to mix the organics.

The Test Plan specified that addition of organics cease when the "impact level" was found. However, no significant impact of the organics up to 2500 mg/L appeared to be found. The high organics (Level H) factorial experiment, with both TBP and NPH at 2500 mg/L, was then performed per the design shown in Figure 2.5.

The experimental fluxes measured for all levels of the factorial and impact level experiments are shown in Appendix 5.4. Plots of these same data are also shown in this Appendix. Figure 3.2 shows the factorial experiment arrangement with the actual variable values. The inability to achieve the highest flow/pressure combinations had no effect on the outcome of these tests. It should be noted that the multi-stage centrifugal pump should have been a six stage, rather than five stage pump.

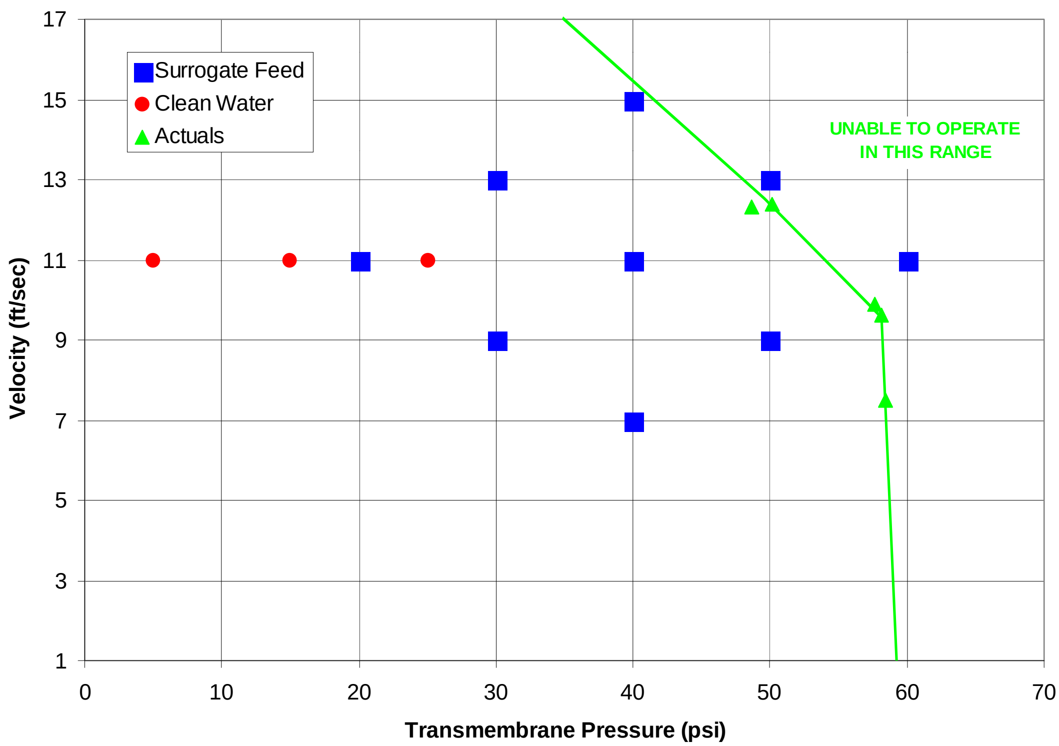


Figure 3.2 Factorial Data Points for All Levels

Because the factorial experiment used various combinations of TMP and velocity, direct graphical comparison of the data is somewhat difficult except where these variables are at the same values. Figure 3.3 shows the measured fluxes versus run number for the centroid point of the factorial experiments; this plot also includes the impact level determination data, which was also taken at the centroid. The minimum flux for Envelope B/D is 0.014 gpm/ft^2.[6] During the Level L factorial experiment, the centrifugal pump began to leak from the mechanical seal. By the end of this level, the leak was too great to continue without repairs. To repair the pump, the system had to be drained and flushed. The flushing of the system resulted in a step change increase of about 0.006 gpm/ft^2 in the steady state flux. Note the two data points that were run at the same conditions. To account for this change in flux, all of the flux data after the pump repair was decreased by 0.006 gpm/ft^2 to put this data on the same basis as the initial data.

The steady state flux decreased approximately linearly until the beginning of the impact level (M) determination runs. This type of behavior has been seen in other ultrafiltration work at SRTC.[7] The cause for this type of trend has been attributed to either irreversible (except with cleaning) changes in the filter membrane or particle degradation to an ultimate particle size distribution.[8] Both of these proposed phenomena are functions primarily of run time.

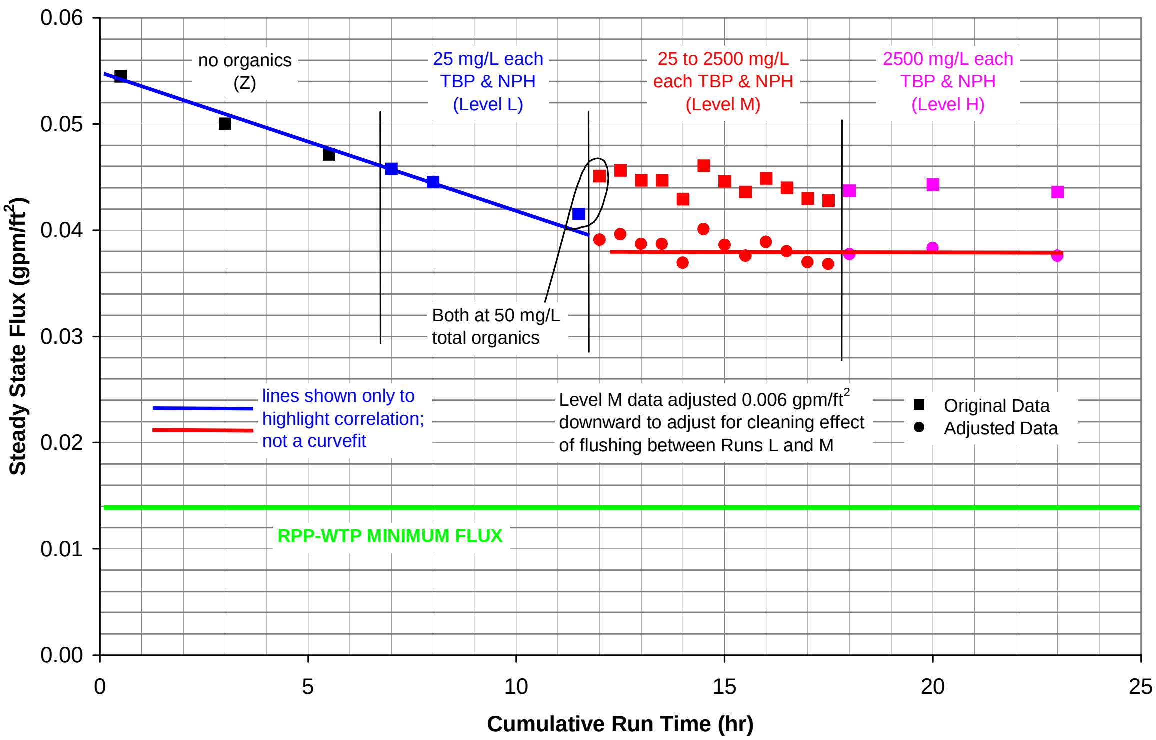


Figure 3.3 All Centroid Flux Data

3.2 Simulant and Permeate Composition Versus Time

The total solids and suspended (insoluble) solids contents and the specific gravity of the simulant sludge and permeate was measured periodically. More complete analyses of the composition of the simulant were made between each level of experiment. Figure 3.4 shows the total solids, suspended solids, and specific gravity of the slurry throughout the experiments. The total solids content ranged from about 27.5 to 29.0 wt% during the factorial experiments, and increased during the concentration steps. These data are also summarized in Figure 3.5. Overall, there was a slight increase in all three quantities from level to level. These differences are due to the way each level was started. Upon completion of the concentration step from the previous level, supernate simulant was re-added to the feed tank in the approximate amount that had been removed. The variation in the amounts of these additions is the reason for the different solids and specific gravity measurements.

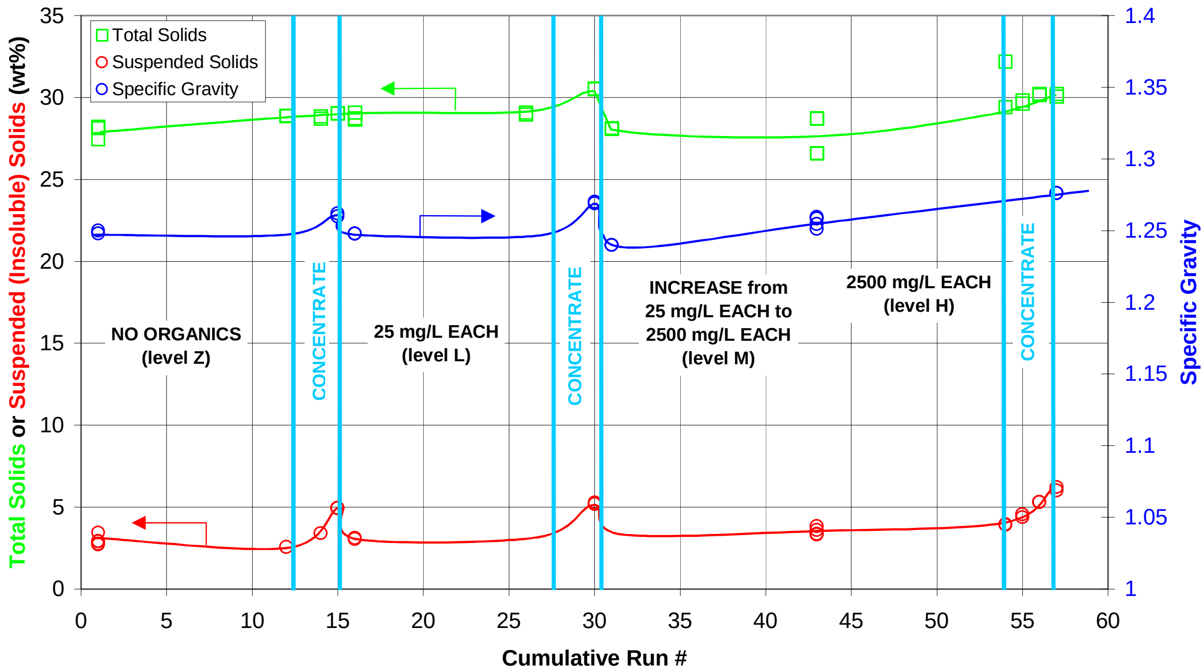


Figure 3.4 Total Solids, Suspended Solids, and Specific Gravity versus Run

The composition of the slurry, permeate (or filtrate from slurry samples), and the filtered solids are shown in Table 3.1. Most of the analyses of the slurry from level to level are consistent and generally within 20%. Different types of dissolutions were sometimes necessary for the elemental analyses to dissolve the entire sample. The microwave dissolution was usually used, but the peroxide fusion and aqua regia dissolutions were also used.

Since the main purpose of this work was to determine if the presence of the TBP and NPH have any effect on the filtrate flux, it was important to eliminate other possible causes for the data behavior. Dissolution or precipitation of selected species could have a significant effect on the filterability of the slurry. Figure 3.6-Figure 3.8 show the slurry and permeate IC and carbon analyses plotted versus cumulative run number. Note that some of the variation seen is due to slightly different solids concentrations that existed during the different levels. There were several unexpected trends. The phosphate concentration in both the slurry and permeate appears to have dropped off during the high organics runs. An increase in phosphorus was expected with the addition of the TBP; however, the difficulty in getting a representative sample containing the organic phase contributed to this trend (see discussion in Section 3.3). The hydroxide concentration also dropped off during the experiments, starting at about 0.97M and dropping to about 0.8M. In Figure 3.9-Figure 3.10, the IC and TIC/TOC data is shown in mg/L and Molar, respectively, where all concentrations have been normalized to a constant nitrate concentration. Nitrate concentration was not expected to change except for dilution effects. These figures show that when normalized to nitrate, the concentrations of sulfate, chloride, and fluoride stay essentially constant. The graph of Molar concentration shows that the decrease in the hydroxide concentration is, to within the analytical accuracy, balanced by the increase in the carbonate concentration. Therefore, absorption of carbon dioxide appears to account for the hydroxide decrease.

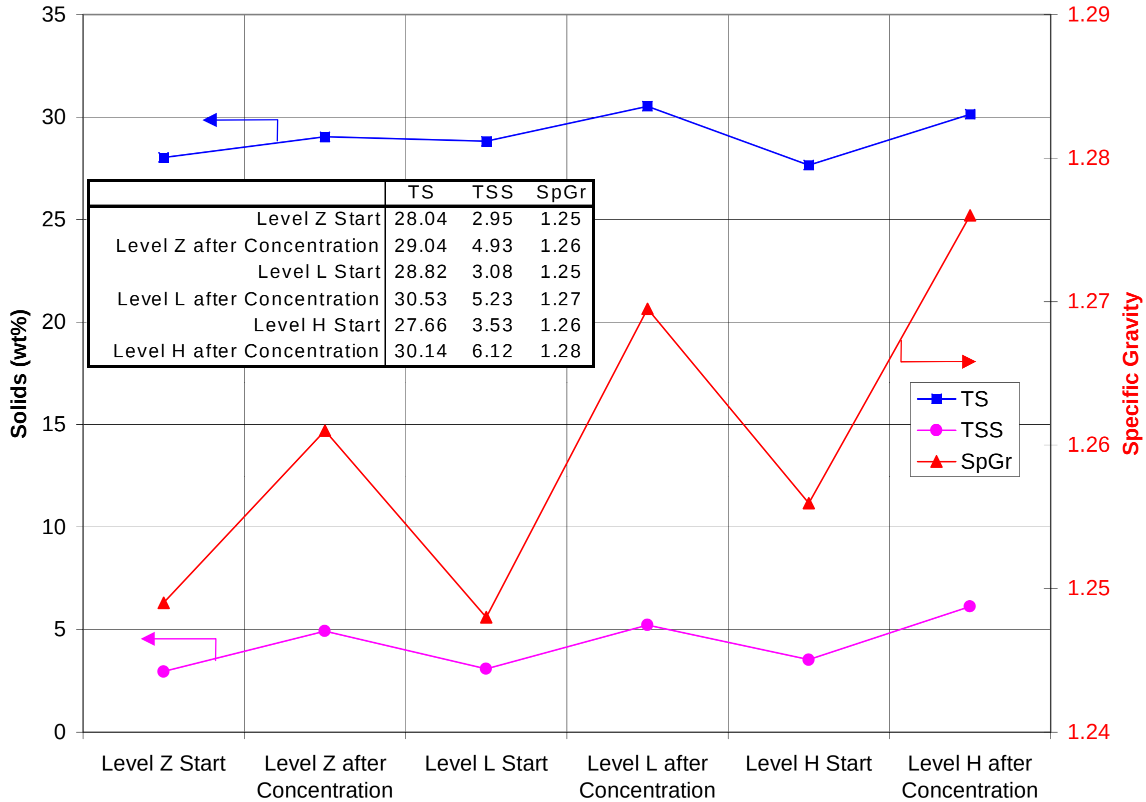
The data in Figure 3.11 show that the iron concentration was relatively constant during the factorial experiments and that it increased during the concentration, as expected. Iron was the major insoluble species in the slurry. The other significant insoluble species were Zr, and Si; the data for both of these is inconclusive. The dissolution of Zr by the microwave and aqua regia methods gave inconsistent results, whereas there was significant scatter in the Si data. The soluble species Na, Al, Cr, and K all stayed relatively constant as expected.

Since Zr and Fe were mostly insoluble, their concentrations in the slurry should parallel the suspended solids concentration. The ratio of these elements to the TSS is shown in Figure 3.12. The ratios, within experimental variation, are constant.

Figure 3.8 shows the carbon analyses during the experiments. There is good agreement between the TIC and carbonate analyses (although a constant offset) and also between the TOC analyses and the TOC calculated from the organics added (except for the last data point). The TOC calculated from the organics measured by GC-MS was generally about 1/3 of the actual amount added. This discrepancy can be explained by the difficulty in getting a representative sample of the slurry/organic phase mixture, which is discussed in Section 3.3. The average analyses of filtrate from slurry and permeate were shown in Figure 3.2. The composition of the permeate varied little during the experiments, as shown in Table 3.2. The first two columns and the last column are data for dead-end filtered slurry.

Table 3.1 Average Compositions of Slurry, Permeate, and Solids

	Filtrate or Permeate mg/L	Sludge Solids mg/L	Slurry – Level Z Start mg/L	Slurry - Level Z Concentrated mg/L	Slurry - Level L Start mg/L	Slurry – Level L Concentrated mg/L	Slurry - Level H Start mg/L	Slurry – Level H Concentrated mg/L
Al	2339	7273	2681	2862	3038	3356	2782	NA
B	21.4	503	NA	NA	NA	NA	<29.6	621
Ba	0.23	931	66	94	70.8	103	297	149
Ca	<0.47	3131	181	256	196	277	180	1054
Cd	0.87	11128	823	1189	887	1300	831	1664
Co	<0.44	1459	106	156	118	167	108	219
Cr	525	1803	559	589	649	710	624	737
Cu	<0.50	378	32	44	42.8	43.8	30.0	<18.8
Fe	3.58	144878	10888	15394	11548	17076	10852	21717
Li	<1.00	<71	<29	<29	<30.8	<30.1	<14.1	<37.5
Mg	<0.84	248	<24	<25	<25.9	<25.3	<17.1	<73.8
Mn	<0.13	3592	274	380	289	411	272	541
Mo	4.51	<71	<29	<31	<32.5	<30.1	<14.1	<37.5
Na	110622	178719	108112	108213	112206	114892	112549	NA
Ni	<0.71	8809	685	960	732	1058	665	1364
P	742	2343	1031	1069	968	991	395	862
Pb	<6.90	1717	<208	207	<213	217	163	270
Si	3.55	5247	5803	3838	5292	5421	NA	5801
Sn	<2.60	<184	<76	<75	<80.2	<78.2	<36.6	<97.5
Sr	<0.12	444	65	60	46.8	48.6	40	NA
Ti	<1.40	259	<41	<43	<43.2	<42.1	<20.2	<191
V	<1.30	<92	<38	<37	<40.1	<39.1	<18.3	<48.8
Zn	<3.70	513	<107	<106	<114	<111	<52.1	<139
Zr	3.45	42514	3580	4970	3786	5494	2999	NA
La	<7.00	5510	297	361	324	498	440	893
K	4141	5809	3573	3534	3619	3842	3768	NA
Re	38.0	127	<63	<58	<62.0	<81.0	<70.4	<37.5
S	6386	9405	6649	6557	6654	6635	7105	6991
Ag	<3.00	1226	<87	<144	<92.5	<150	<73.8	<313
Ce	<7.70	1326	<224	<222	<237	<232	<119	<289
Nd	<2.60	3921	331	380	365	476	288	603
chloride	164	NA	215	221	207	221	161	155
fluoride	1629	NA	1852	1888	1866	1973	1793	1705
nitrate	62749	NA	69795	70394	73099	77174	69285	66567
nitrite	49750	NA	55758	55171	57827	61918	58525	59140
sulfate	16286	NA	18776	17332	18714	19701	17207	16302
phosphate	2108	NA	2358	2424	2167	2276	1655	1325
carbonate	NA	NA	22302	24105	24432	29403	27588	27690
hydroxide	NA	NA	17061	16426	16394	14799	13782	13336
TS (wt%)	27.25	NA	28.04	29.04	28.8	30.5	27.7	30.1
TSS (wt%)	NA	NA	2.95	4.93	3.08	5.23	3.53	6.12
SpGr	1.235	NA	1.249	1.261	1.25	1.27	1.26	1.28



	TS	TSS	SpGr
Level Z Start	28.04	2.95	1.25
Level Z after Concentration	29.04	4.93	1.26
Level L Start	28.82	3.08	1.25
Level L after Concentration	30.53	5.23	1.27
Level H Start	27.66	3.53	1.26
Level H after Concentration	30.14	6.12	1.28

Figure 3.5 Total Solids, Suspended Solids, and Specific Gravity versus Level

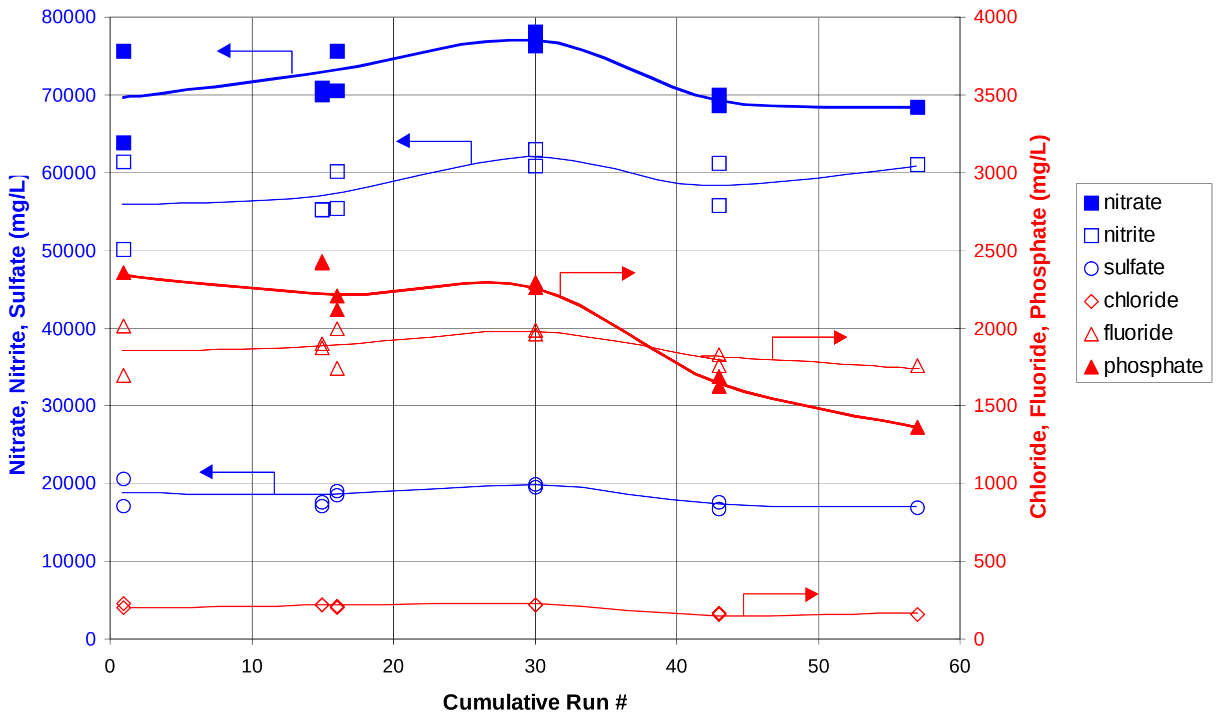


Figure 3.6 Ion Chromatography Data for Slurry Samples

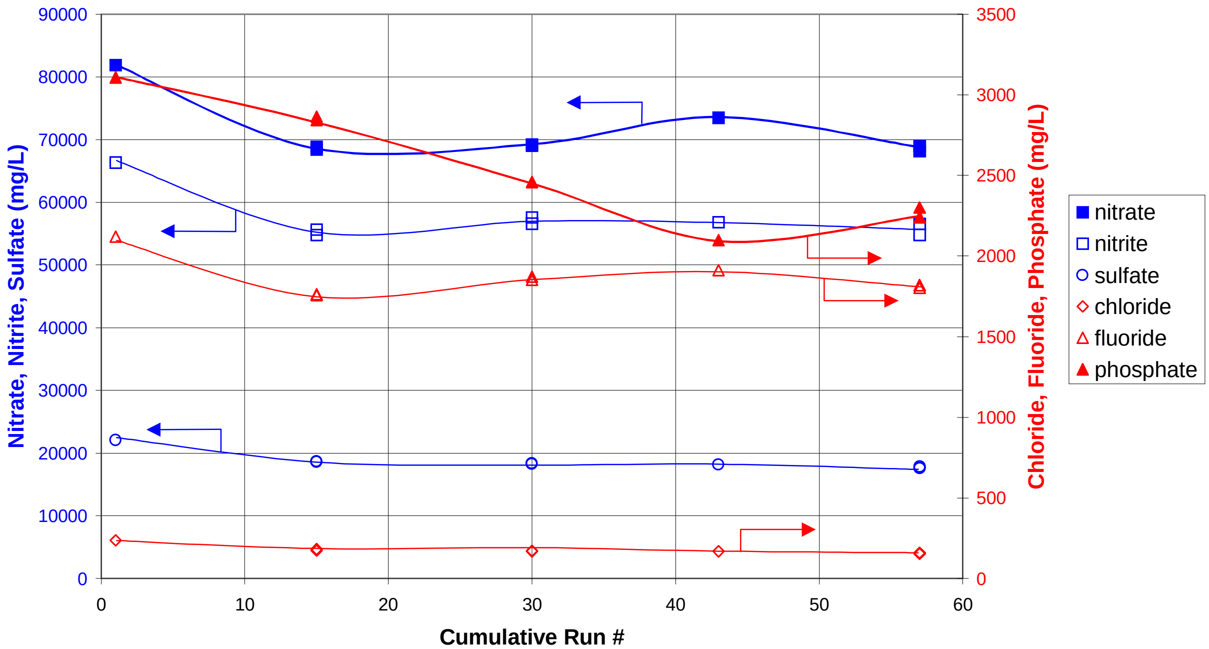


Figure 3.7 Ion Chromatography Data for Permeate

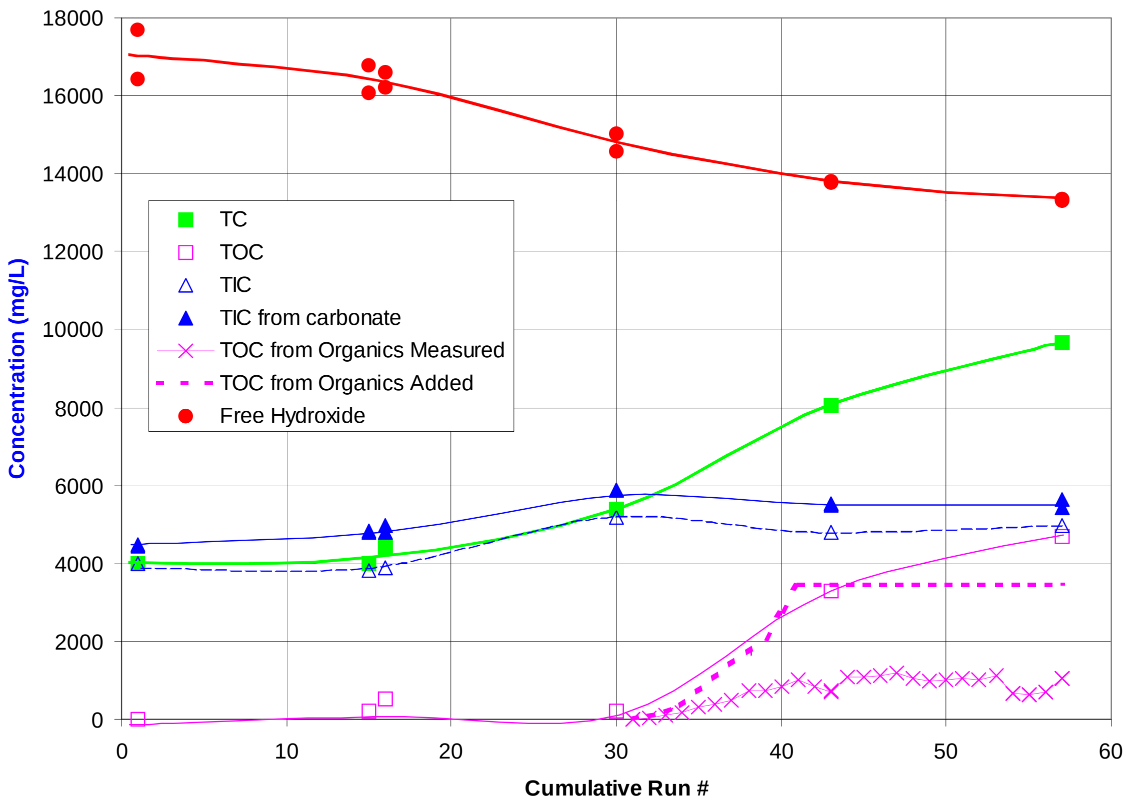


Figure 3.8 Slurry Carbon and Free Hydroxide Analyses

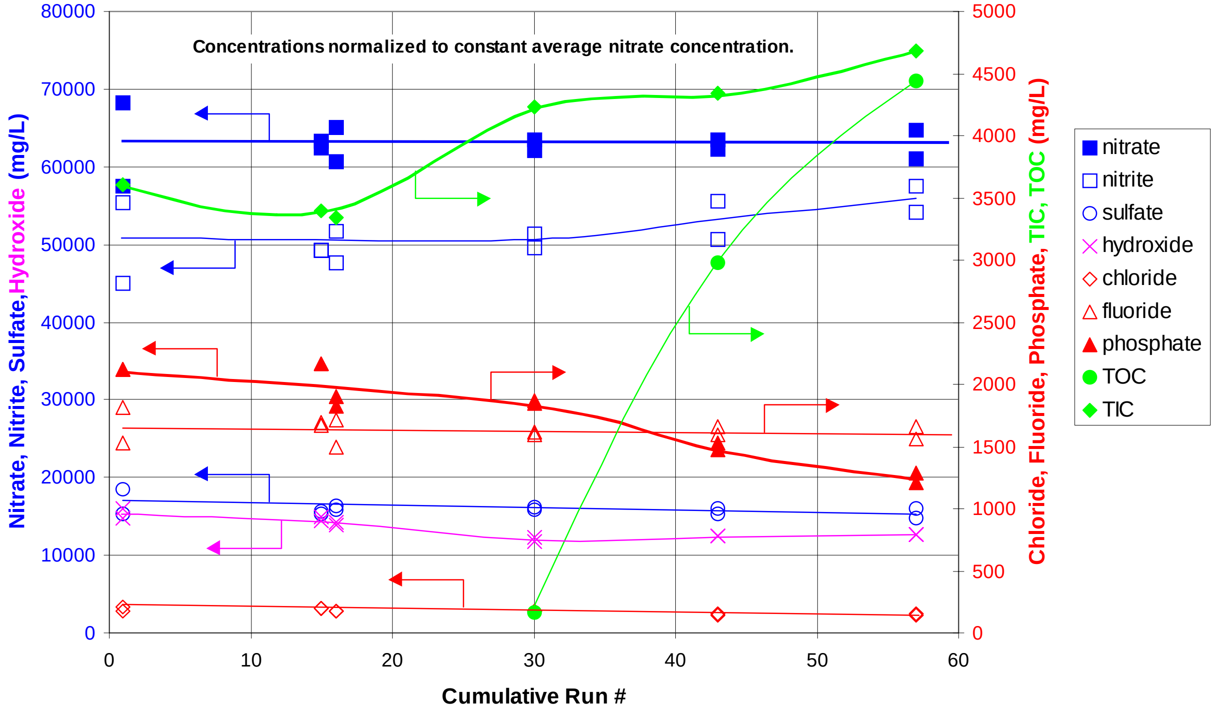


Figure 3.9 IC, Hydroxide, and TIC/TOC mg/L Data Normalized to Constant Average Nitrate

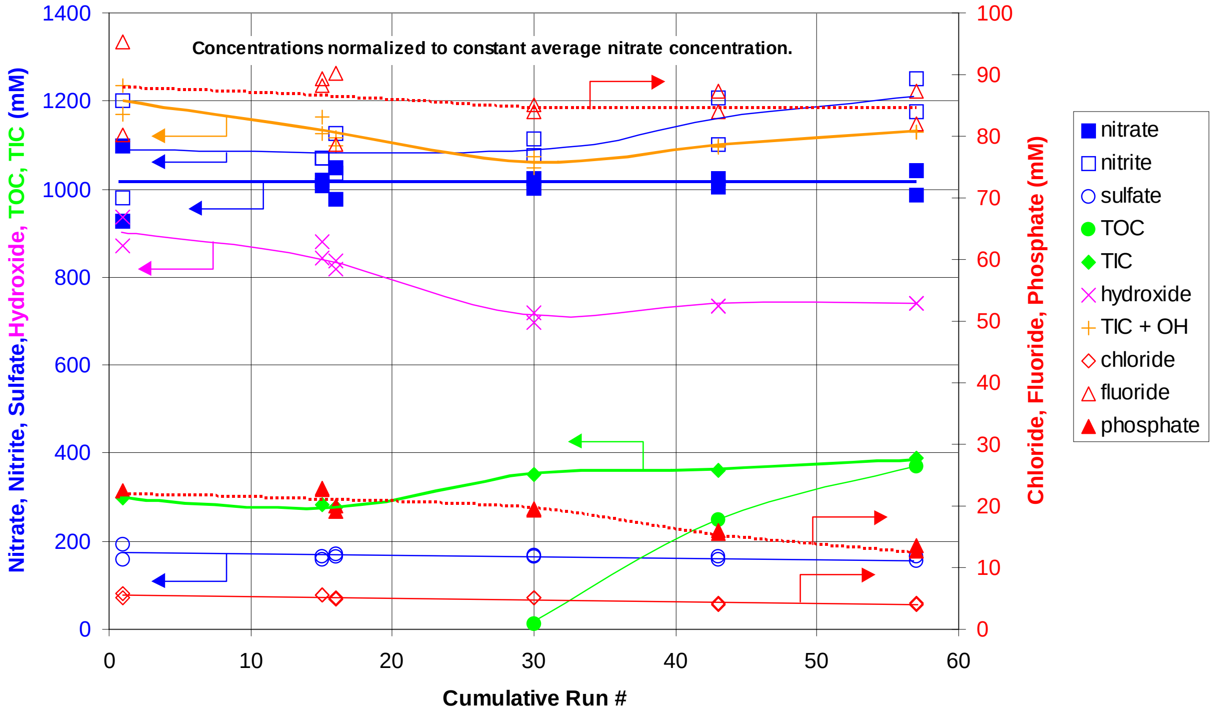


Figure 3.10 IC, Hydroxide, and TIC/TOC Molar Data Normalized to Constant Average Nitrate

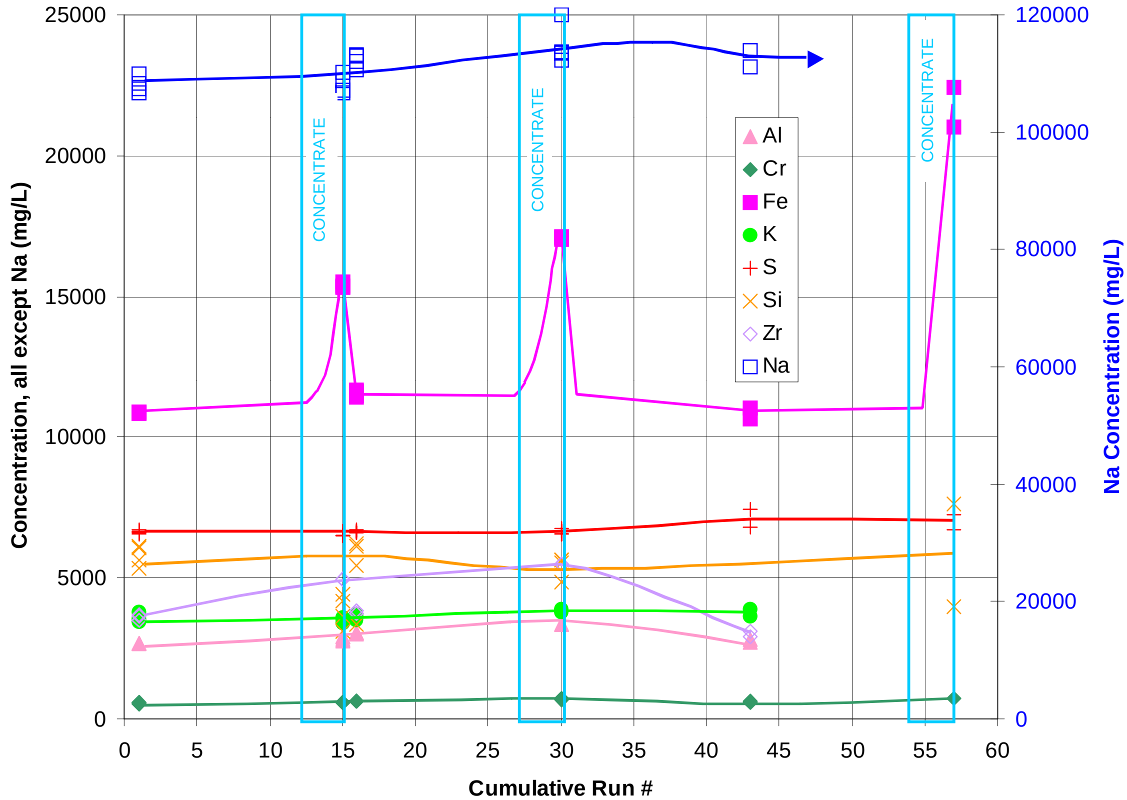


Figure 3.11 Elemental Analyses (by ICPES) for Major Metals

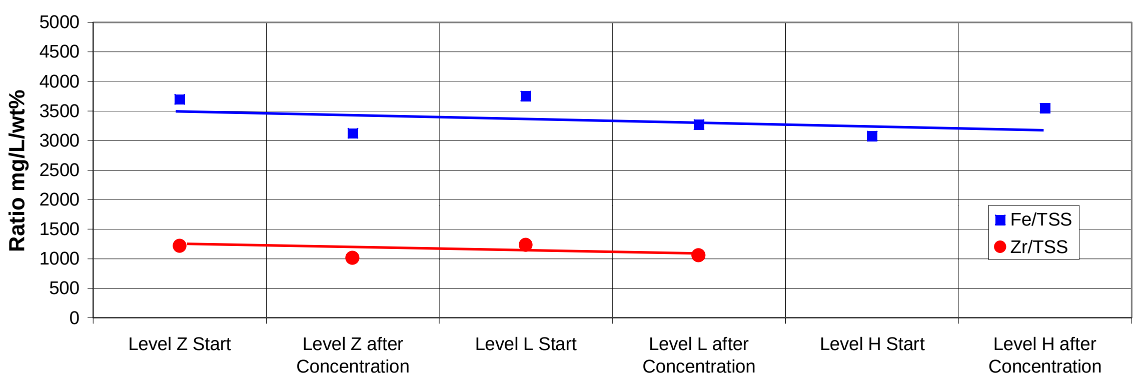


Figure 3.12 Ratio of Iron and Zirconium to Suspended Solids

Table 3.2 Composition of Permeate

	Filtered Slurry Initial		Permeate Level Z		Permeate Level L		Permeate Level H		Filtered Slurry Level H
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Al	1970	2100	2280	2290	2280	2290	2630	2620	2590
B	20.2	28.1	26.0	24.9	26.0	24.9	15.2	14.7	12.1
Ba	<0.12	<0.12	0.33	0.39	0.33	0.39	<0.12	<0.12	0.19
Ca	0.40	0.81	<0.4	<0.4	<0.4	<0.4	0.40	0.53	0.51
Cd	0.49	0.75	0.79	0.77	0.79	0.77	0.56	0.53	2.41
Co	<0.44	<0.44	<0.44	<0.44	<0.44	<0.44	<0.44	<0.44	<0.44
Cr	443	454	497	500	497	500	611	610	612
Cu	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.50
Fe	0.56	0.95	1.31	1.20	1.31	1.20	0.60	0.65	24.4
Li	<1	<1	<1	<1	<1	<1	<1	<1	<1
Mg	<0.84	<0.84	<0.84	<0.84	<0.84	<0.84	<0.84	<0.84	0.84
Mn	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	0.47
Mo	5.00	5.25	5.73	5.21	5.73	5.21	2.81	2.82	2.81
Na	99600	105000	117000	114000	117000	114000	109000	109000	111000
Ni	<0.62	<0.62	<0.62	<0.62	<0.62	<0.62	<0.62	<0.62	1.44
P	711	735	794	762	794	762	695	694	730
Pb	<6.9	<6.9	<6.9	<6.9	<6.9	<6.9	<6.9	<6.9	<6.9
Si	3.70	4.40	2.61	2.32	2.61	2.32	5.40	6.28	2.28
Sn	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6
Sr	0.17	0.17	<0.1	<0.1	<0.1	<0.1	0.0631	0.14	0.12
Ti	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4
V	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
Zn	<3.7	<3.7	<3.7	<3.7	<3.7	<3.7	<3.7	<3.7	<3.7
Zr	1.00	2.15	1.72	1.64	1.72	1.64	0.99	0.97	19.2
La	<7	<7	<7	<7	<7	<7	<7	<7	<7
K	3650	3920	4300	4340	4300	4340	4130	4170	4120
Re	33.2	34.4	40.2	38.2	40.2	38.2	39.1	38.9	39.6
S	6190	6230	6700	6410	6700	6410	6310	6290	6230
Ag	<3	<3	<3	<3	<3	<3	<3	<3	<3
Ce	<7.7	<7.7	<7.7	<7.7	<7.7	<7.7	<7.7	<7.7	<7.7
Nd	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6

Table 3.2 Composition of Permeate (continued)

	Filtered Slurry Initial		Permeate Level Z		Permeate Level L		Permeate Level H		Filtered Slurry Level H
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Total Solids (wt%)	26.5		27.6		27.2		27.0		28.0
Sp Gr	1.22		1.23		1.23		1.24		1.26
Cl	194								134
F	1738								1519
NO3	67107								58391
NO2	54366								45134
SO4	18123								14448
PO4	2547								1668

3.3 Organics in Slurry and Permeate

The concentrations of TBP and dodecane are plotted versus run number in Figure 3.15. As these organics were added during Level M, the measured concentrations in the slurry were generally about 1/3 of what the actual additions were.

The low measured concentration of organics would, at least initially, tend to indicate that the entire amount of organics did not pass through the filter system. If this were true, the filter would not have been challenged as much as planned. Visual observation of the top of the feed tank showed that, although the organic phase tended to float on top of the aqueous phase, it was periodically (on the order of several seconds) pulled down into the aqueous phase and fed to the filter. Figure 3.13 shows photos of slurry samples that show the presence of organics. No accumulation of organic phase above the liquid level, which would have been effectively excluded from processing, was seen. There also was no evidence of sticking elsewhere in the system.

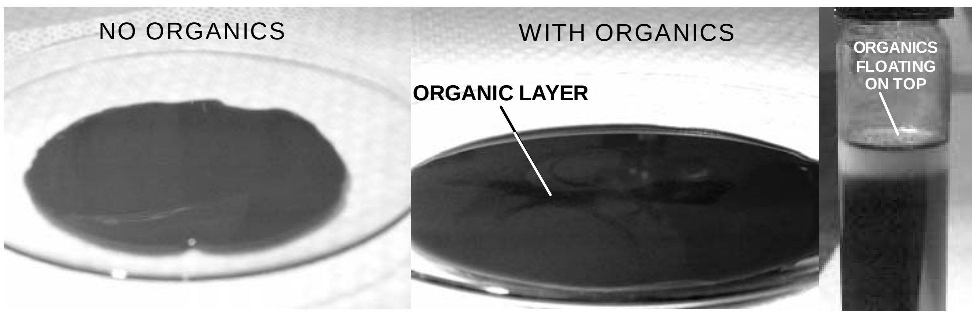


Figure 3.13 Photos of Slurry Samples

The lower than expected concentrations can be explained by the difficulty in getting a representative sample of the three phase (aqueous, solid, organic) mixture. Any given sample could contain different proportions of organics and slurry. The presence of organics in the samples taken from the piping at the pump inlet is verified by these analyses and also by visual examination of the samples. Figure 3.14 shows how the slurry samples were taken.

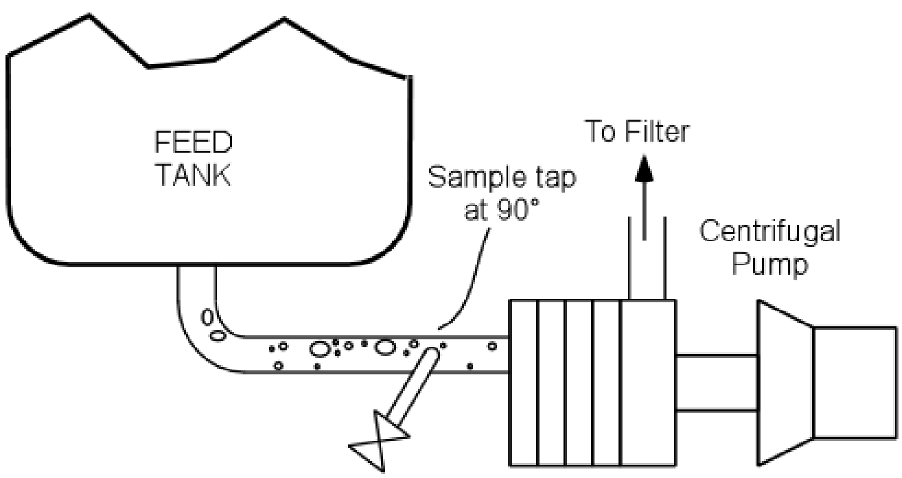


Figure 3.14 Possible Organic Phase Separation in Piping

Due to the density difference, the organic phase will tend to float to top of pipe even in turbulent flow. The axial distribution of organic phase along the pipe will also be not uniform. Therefore, samples taken at the sample tap would be expected to have lower average organic concentration than the average material in the pipe. (However, this sample tap configuration should result in good samples for the slurry consisting of small particles.)

The permeate measurements show that the dodecane was always below the detection limit, which was approximately 0.12 mg/L. The TBP concentrations in the permeate ranged from the detection limit of 0.12 mg/L to about 0.7 mg/L. The approximate solubility of TBP in high Na^+ solutions is 1.1 mg/L.[9] The concentrations of dibutylphosphate and 1-butanol (n-butanol) were measured in two samples. A trace amount of 1-butanol was found in the permeate samples; the DBP was below the detection limit. Slurry sample results for DBP & n-butanol were all below the detection limit. These data are summarized in Table 3.3.

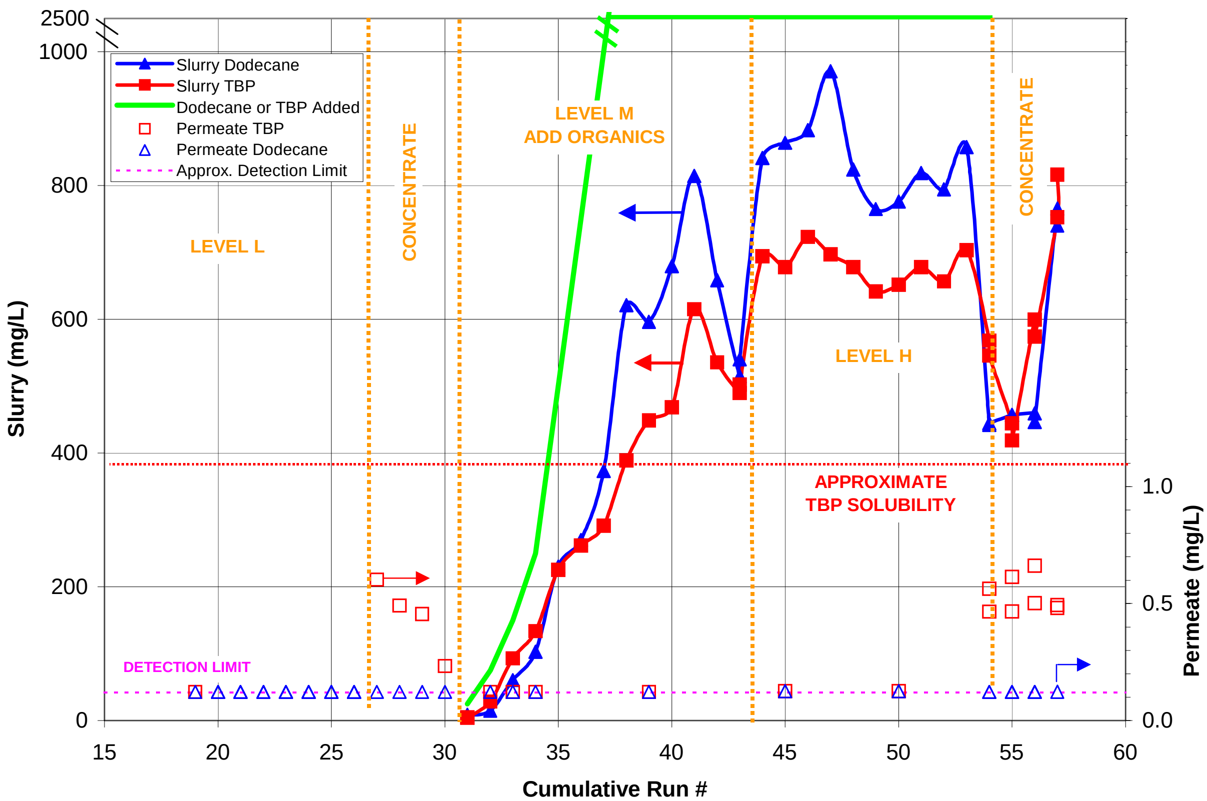


Figure 3.15 Organics Concentrations in Slurry and Permeate

Table 3.3 Dibutylphosphate and 1-Butanol in Samples

Sample	dibutylphosphate (DBP) mg/L	1-butanol (n-butanol) mg/L
sludge (2 samples)	<10	<25
permeate	<10	0.98
permeate	<10	2.0

3.4 Statistical Analysis of Data

The filtrate flux for ultrafiltration can depend on several factors. To determine if the effects of TBP and NPH, transmembrane pressure, velocity, and run time (or approximately, number of runs) were significant, several potential models were examined. A number of models have been proposed for modeling the behavior of filters. Listed below are some of these models.

Kozeny-Carman $J \propto \Delta P$

Brownian Diffusion $J \propto V^{0.503} C^{\frac{1}{3}}$

Shear Induced Diffusion $J \propto V^{1.75} C^{\frac{1}{3}}$

Inertial Lift $J \propto V^{3.5}$

Surface Transport $J \propto V^{1.75}$

Lift Velocity $J \propto V^{2.625}$

Boundary Layer $J \propto V^{1.75} \ln\left(\frac{1}{C}\right)$ or $V^{1.75}\left(\frac{1}{C}\right)$

where J = transmembrane flux (gpm/ft^2)
V = velocity (ft/sec)
ΔP = transmembrane pressure (psi)
C = solids (insoluble) concentration (wt%)

In addition to the variables given above, the total organics concentration and total run time were added as variables to a generalized model that was proposed:

Generalized Model $J = aV^v C^c \Delta P^p Q^q (1 - bt_{adj})$

where Q = organics concentration + 1 (mg/L)
t_{adj} = cumulative run time (hr) up to 13.5 hr, then = 13.5 thereafter
a, v, c, p, q, b = parameters (constants)

The cumulative run time term was added to account for the leveling off behavior shown in Figure 3.3. The linear drop occurs until about 13.5 hours, then the flux is essentially independent of time. The form of the organics concentration term was arbitrary since there was no theoretical basis for adding this term. The "concentration + 1" was used to make the baseline at zero organics have a contribution of "1" to the equation. The statistical analyses and curve fitting was performed using a statistical software package.[10]

The solids concentration term was immediately removed from the model because the solids concentration only varied from 2.95 to 3.53 wt%, which is too small a range to reliably fit a model. (Actual fitting with this variable gave a stair-step predicted flux, as expect, which is not what was seen.) Fitting of the model without the effect of solids is summarized in Table 3.4.

Table 3.4 Parameter Estimates for Model with Velocity, Adjusted Time, Pressure, and Organics Content

		Approximate 95% Confidence Limit	
Parameter	Estimate	Lower	Upper
a	0.002642	0.001728	0.004016
v	1.350	1.234	1.467
b	*0.008222*	*-0.004988*	*0.019929*
q	*-0.01972*	*-0.03813*	*0.00058*
p	*-0.07914*	*-0.15746*	*0.00129*

Correlation of Estimates

	a	v	b	q	p
a	1.0000	-0.7219	0.1902	0.1711	-0.7145
v	-0.7219	1.0000	-0.1340	-0.1209	0.0461
b	0.1902	-0.1340	1.0000	**0.9503**	-0.0074
q	0.1711	-0.1209	**0.9503**	1.0000	-0.0244
p	-0.7145	0.0461	-0.0074	-0.0244	1.0000

The effect of pressure (p) is statistically insignificant since the confidence region includes zero. Both time “b” and organics “q” are also insignificant, although both parameters barely include zero. Moreover, they are highly correlated, so they tend to describe the same effect. Leaving out the effect of organics, since leaving this out makes more physical sense than leaving out time, gives the parameters in Table 3.5.

Table 3.5 Parameter Estimates for Model with Velocity and Adjusted Time

		Approximate 95% Confidence Limit	
Parameter	Estimate	Lower	Upper
a	0.002091	0.001543	0.002821
v	1.342	1.221	1.464
b	0.01942	0.01631	0.02233

Correlation of Estimates

	a	v	b
a	1.0000	-0.9914	0.1717
v	-0.9914	1.0000	-0.0597
b	0.1717	-0.0597	1.0000

With only time as a variable, the parameter "b" is significant. Parameters "a" and "v" are highly correlated as is common with exponential models. The best model is then:

$$J = 0.002091 V^{1.342} (1 - 0.01942\, t_{adj})$$

The predicted values for this model for all of the data is shown in Figure 3.16. The offset from each curve to the data points is due to the effect of pressure on flux. If a subset of the data is taken, the effect of pressure can be found to be statistically significant, but the scatter in the overall data hides this effect. In reality, higher pressures appear to result in slightly higher fluxes. Note the circled points in the Figure; if these are eliminated, the fit of the V=11 fps data is quite good.

Models with all parameters in most of the possible combinations were examined to thoroughly eliminate the possible models. Models without the time factor and with either the solids or organics gave statistically equivalent curve fits, but the shape of the curves were unrealistic. Figure 3.17 shows the fit of flux versus velocity, time, and organics concentration. Similar curves result from fitting versus velocity and just organics or solids. Figure 3.17 also shows that the adjusted time and organics concentration are highly correlated. A summary of the curve fits performed is given in Appendix 5.5.

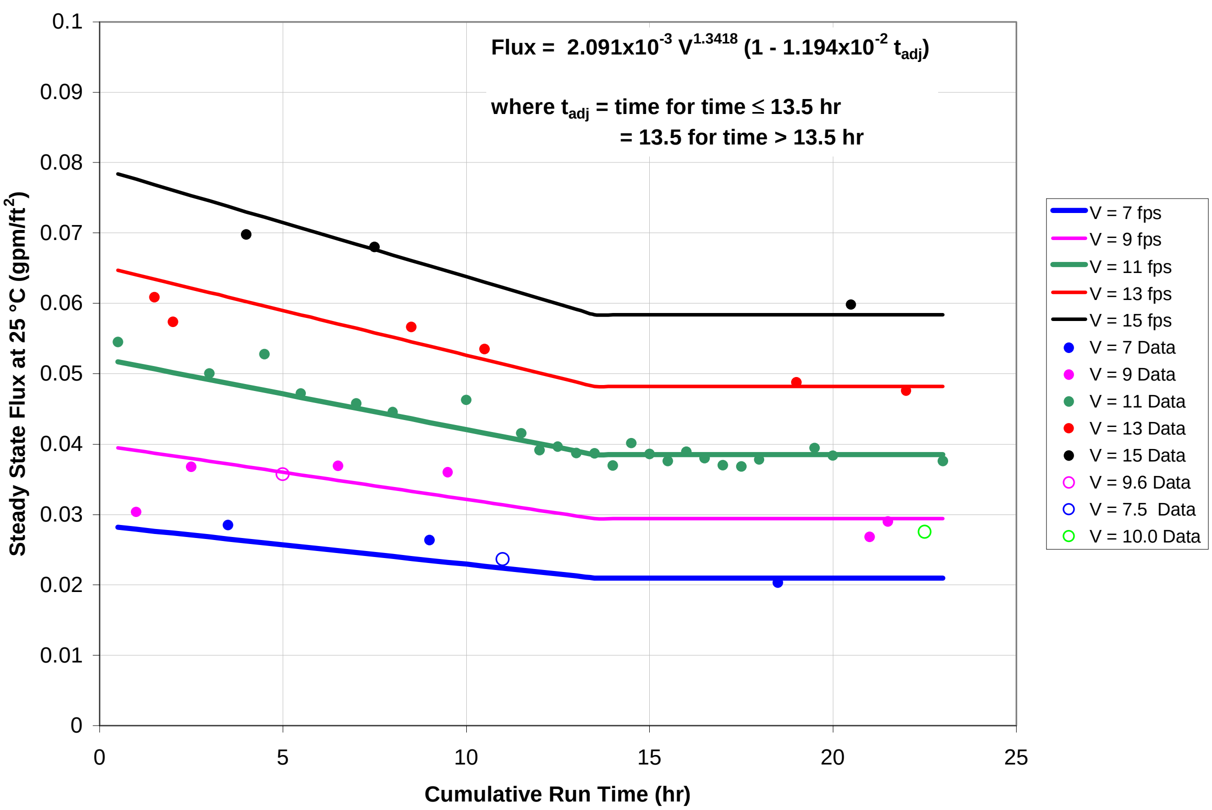


Figure 3.16 Fitted Data for Flux versus Velocity and Time

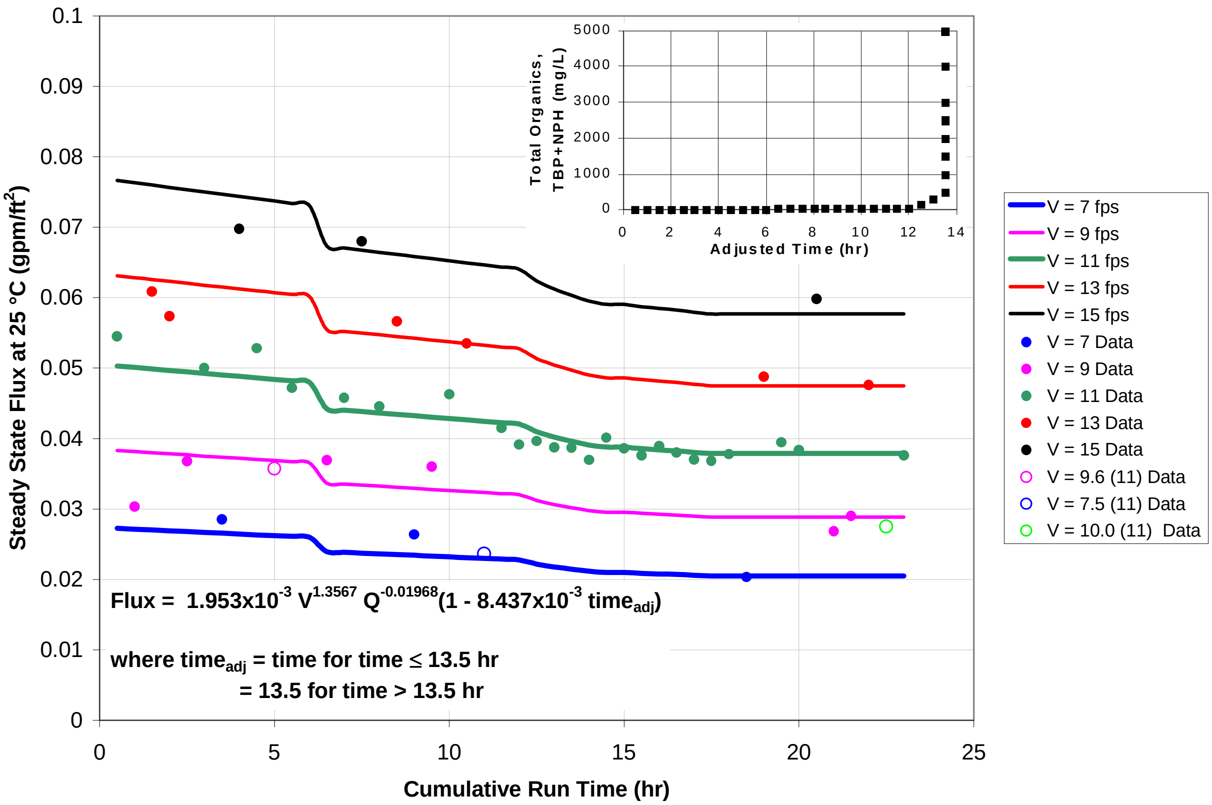


Figure 3.17 Fitted Data for Flux versus Velocity, Time, and Organics

3.5 Quality Assurance

This task was conducted per the requirements of a Task Technical & Quality Assurance Plan that was approved by both SRTC and RPP-WTP personnel (technical & QA manager).[11] These tests were not HLW form affecting. Therefore, the Quality Assurance Requirements and Description (DOE/RW-0333P), the principle quality assurance requirements for the Civilian Radioactive Waste Management Program, did not apply to this work. All data was recorded in a Laboratory Notebook.[12]

4.0 Conclusions

1. The presence of tributyl phosphate and normal paraffin hydrocarbon (dodecane) at concentrations up to approximately 2500 mg/L of each has no effect on flux rate for filtration of an AZ-101 3.5 wt% slurry simulant for a 0.1 μm sintered metal Mott filter element.

2. If a concentration exists wherein the flux is affected (de minimis), it is above the tested levels.

3. The AZ-101 slurry simulant was filtered to an insoluble solids content of up to 6 wt% without the flux deteriorating below the lower limit of 0.014 gpm/ft^2.

4. The permeate concentration of TBP was always less than 1 mg/L and the dodecane was always less than the detection limit of ~0.12 mg/L. Neither of these passed through the filter at a level higher than its solubility and so were concentrated in the slurry.

5. Cleaning of the system after use with the organics proved difficult using only water and nitric acid. It should be noted that the concentrations of separable organics were much higher than should actually be seen in the WTP. We recommend that the effect of TBP and NPH be studied further during filter cleaning tests.

5.0 Appendices

5.1 Appendix – Supernate Recipe

Volume of Feed Made from this Recipe	8	Liters	
Weigh a LARGE MIXING VESSEL of	at least 8000	ml capacity	
ADD THE FOLLOWING COMPOUNDS:			
Transition Metals and Complexing Agents	Formula	Mass Needed (g)	Actual Wt (g)
Alumimum Nitrate	Al(NO3)3•9H2O	1186.521	1186.52
Ammonium Nitrate	NH4NO3	11.759	11.76
Cesium Nitrate	CsNO3	0.438	0.438
Zirconyl Nitrate	ZrO(NO3)2•xH2O	0.067	0.067
Sodium Chloride	NaCl	2.631	2.633
Sodium Fluoride	NaF	32.06	32.064
Sodium Chromate	Na2CrO4	18.189	18.1912
Sodium Sulfate	Na2SO4	209.021	209.02
Sodium Perrhenate	NaReO4	0.468	0.4619
ADD	Formula	Mass Needed (g)	Actual Wt (g)
Water	H2O	1600	1600.00
MIX THOROUGHLY TO DISSOLVE THE SALTS.			
IN A SEPARATE CONTAINER MIX THE FOLLOWING:			
	Formula	Mass Needed (g)	Actual Wt (g)
Sodium Hydroxide	NaOH	639.284	639.26
Potassium Hydroxide	KOH	53.085	53.09
Water	H2O	800	800.00
MIX THOROUGHLY TO DISSOLVE THE SODIUM HYDROXIDE AND POTASSIUM HYDROXIDE.			
ADD		Mass Needed (g)	Actual Wt (g)
Sodium Phosphate	Na3PO4•12H2O	48.117	48.12
Water	H2O	1600	1600.00
MIX THOROUGHLY. THEN ADD THIS SOLUTION SLOWLY TO THE MIXING VESSEL WHILE MAINTAINING AGITATION.			
ADD	Formula	Mass Needed (g)	Actual Wt (g)
Sodium Carbonate	Na2CO3	326.057	326.06
MIX THOROUGHLY.			
ADD	Formula	Mass Needed (g)	Actual Wt (g)
Sodium Nitrate	NaNO3	10.162	10.16
Sodium Nitrite	NaNO2	780.663	780.66
MIX THOROUGHLY.			
NEXT ADD THE FINAL WATER ADDITION	Formula	Mass Needed (g)	Actual Wt (g)
Water	H2O	2371.31	2371.30

5.2 Appendix – Simulant Compositions

The final simulant was made up from 4.0 liters of supernate simulant, 1.84 liters of solids simulant #1 and 0.25 liters of solids simulant #3. Trim chemicals, in amounts shown below, were then added to replace the washed sodium and anions. The final volume was approximately 6.3 liters.

Table 5.1 Supernate Simulant Samples

		First Supernate Sample			Second Supernate Sample			Overall
	LIMS #300-	167560	167560	Average	169527	169527-D	Average	Average*
ICPES (mg/L)	*Al*	*5860*	*5740*	*5800*	*5060*	*5080*	*5070*	*5070*
	B	<2.1	<2.1		<2.1	<2.1		
	Ba	<0.12	<0.12		<0.12	<0.12		
	Ca	0.547	0.459	0.503	<0.4	<0.4		
	Cd	<0.14	<0.14		<0.14	<0.14		
	Co	<0.44	<0.44		<0.44	<0.44		
	Cr	720	721	720	727	727	727	724
	Cu	<0.8	<0.8		<0.5	<0.5		
	Fe	<0.44	<0.44		<0.44	<0.44		
	Li	1.99	1.97	1.98	<1	<1		
	Mg	<0.84	<0.84		<0.84	<0.84		
	Mn	<0.09	<0.09		<0.09	<0.09		
	Mo	<1	<1		<1	<1		
	Na	101000	100000	100500	114000	112000	113000	106750
	Ni	<0.62	<0.62		<0.62	<0.62		
	P	528	539	533	516	505	511	522
	Pb	<6.9	<6.9		<6.9	<6.9		
	Si	*8.83*	*10.4*	*9.61*	*4.35*	*4.76*	*4.56*	*4.56*
	Sn	<2.6	<2.6		<2.6	<2.6		
	Sr	<0.04	<0.04		<0.02	<0.02		
	Ti	<1.4	<1.4		<1.4	<1.4		
	V	<1.3	<1.3		<1.3	<1.3		
	Zn	<3.7	<3.7		<3.7	<3.7		
	Zr	<0.6	<0.6		<0.48	<0.48		
	La	<7	<7		<7	<7		
	K	3840	3860	3850	3910	3920	3915	3883
	Re	40.0	40.3	40.2	39.5	39.3	39.4	39.8
	S	6380	6330	6355	6180	6130	6155	6255
	Ag	<3	<3					
	Ce	<7.7	<7.7					
	Nd	<3.0	<3.0					

Supernate Simulant Samples (continued)

		First Supernate Sample			Second Supernate Sample			Overall
	LIMS #300-	167560	167560	Average	169527	169527-D	Average	Average*
IC (mg/L)	F	1570	1574	1572	NA	NA	1572	1572
	formate	<100	<100	<100	NA	NA		
	Cl	139	141	140	NA	NA	140	140
	NO2-	60805	61724	61265	NA	NA	61265	61265
	NO3-	61724	62704	62214	NA	NA	62214	62214
	PO4(-3)	1292	1385	1339	NA	NA	1339	1339
	SO4(-2)	21402	21385	21394	NA	NA	21394	21394
	oxalate	<100	<101		NA	NA	0	
Carbon (mg/L)	TOC	4.60	4.60	4.60	NA	NA	4.60	4.60
	TIC	<1	<1	<1	NA	NA	<1	
	TC	5.03	5.03	5.03	NA	NA	5.03	5.03
	Free OH	NA	NA	NA	NA	NA	NA	
Solids	Total	27.5	27.6	27.5	NA	NA	27.5	27.5
Specific	Gravity	1.244	1.241	1.243	NA	NA	1.243	1.24
Estimated	Sp Gr	1.198	1.200					

** Average for Al, Li, Si from second sample only due to drop (precipitation).*
Values < detection limit not shown in averages.

Table 5.2 Sludge Solids Sample #1: Composition of solids filtered from sample.

	LIMS #300-	167562	167564	Mean
ICPES (mg/kg)	Ag	351	349	350
	Al	791	799	795
	B	NA	NA	NA
	Ba	257	254	255
	Ca	669	737	703
	Cd	3210	3160	3185
	Ce	341	306	323
	Co	415	413	414
	Cr	329	327	328
	Cu	139	144	141
	Fe	41700	40900	41300
	K	673	759	716
	La	1610	1580	1595
	Li	<10	<10	
	Mg	63.1	62.8	63.0
	Mn	989	981	985
	Mo	<20	<20	
	Na	8000	8090	8045
	Nd	1110	1080	1095
	Ni	2520	2490	2505
	P	1130	1050	1090
	Pb	486	475	480
	Re	17.4	18.6	18.0
	S	335	347	341
	Si	2680	4090	3385
	Sn	<50	<50	
	Sr	122	120	121
	Ti	78.8	75.7	77.3
	V	<15	<15	
	Zn	140	139	140
	Zr	13400	13300	13350
Original Sample (prior to filtration)				
Solids	Total	14.9	14.8	14.8
	Insoluble	13.7	13.1	13.4
	Soluble (calculated)	1.18	1.61	1.40

Table 5.3 Sludge Solids Sample #2: Composition of solids filtered from sample.

	LIMS #300-	167566	167568	Mean
ICPES (mg/kg)	Ag	186	182	184
	Al	400	385	393
	B	NA	NA	NA
	Ba	135	133	134
	Ca	777	771	774
	Cd	1680	1650	1665
	Ce	176	180	178
	Co	221	217	219
	Cr	176	171	174
	Cu	73.2	74.4	73.8
	Fe	21900	21800	21850
	K	395	433	414
	La	848	854	851
	Li	<10	<10	NA
	Mg	42.2	36.8	39.5
	Mn	523	520	521
	Mo	<20	<20	NA
	Na	3950	3890	3920
	Nd	555	537	546
	Ni	1320	1290	1305
	P	316	234	275
	Pb	270	253	262
	Re	7.91	6.30	7.10
	S	173	153	163
	Si	3240	3290	3265
	Sn	<50	<50	NA
	Sr	64.0	64.0	64.0
	Ti	42.3	39.7	41.0
	V	<15	<15	NA
	Zn	73.7	72.3	73.0
	Zr	6970	6930	6950
Original Sample (prior to filtration)				
Solids	Total	8.05	8.00	8.03
	Insoluble	7.25	7.19	7.22
	Soluble (calculated)	0.80	0.81	0.81

Table 5.4 Sludge Solids Sample #3: Composition of solids filtered from sample.

	LIMS #300-	169717a	169717b	Calculated
ICPES (mg/kg)	Ag			263
	Al			597
	B			
	Ba			192
	Ca			528
	Cd			2392
	Ce			243
	Co			311
	Cr	Composition same as Sample #2, but more concentrated.		246
	Cu			106
	Fe			31017
	K			538
	La			1198
	Li			
	Mg	Calculated composition based on ratioing total solids.		47.3
	Mn			740
	Mo			
	Na			6042
	Nd			822
	Ni			1881
	P			819
	Pb			361
	Re			13.5
	S			256
	Si			2542
	Sn			
	Sr			91.2
	Ti			58.0
	V			
	Zn			105
	Zr			10026
Original Sample (prior to filtration)				
Solids (wt%)	Total	11.2	11.1	11.1
	Insoluble	9.97	9.73	9.85
	Soluble (calculated)	1.21	1.32	1.27

Table 5.5 Sludge Sample #1: Composition of filtrate from sample.

	LIMS #300-	167561 mg/L	167563 mg/L	Average mg/L
ICPES	Ag	<3	<3	<3
	Al	5.08	<2.4	5.08
	B	16.4	26.9	21.6
	Ba	<0.12	<0.12	<0.12
	Ca	15.2	11.9	13.6
	Cd	<0.14	<0.14	<0.14
	Ce	<7.7	<7.7	<7.7
	Co	<0.44	<0.44	<0.44
	Cr	4.52	6.66	5.59
	Cu	<0.6	<0.6	<0.6
	Fe	<0.44	<0.44	<0.44
	K	313	444	378
	La	<7	<7	<7
	Li	NA	NA	NA
	Mg	3.71	3.98	3.84
	Mn	<0.09	<0.09	<0.09
	Mo	9.83	15.4	12.6
	Na	4190	6150	5170
	Nd	<2.6	<2.6	<2.6
	Ni	<0.62	<0.62	<0.62
	P	<6.8	<6.8	<6.8
	Pb	<6.9	<6.9	<6.9
	Re	12.0	18.0	15.0
	S	254	363	308
	Si	<1.3	<1.3	<1.3
	Sn	NA	NA	NA
	Sr	<0.15	<0.15	<0.15
	Ti	<1.4	<1.4	<1.4
	V	NA	NA	NA
	Zn	<3.7	<3.7	<3.7
	Zr	<0.48	<0.48	<0.48
IC	fluoride	47.0	69.0	58.0
	formate	<100	<100	<100
	chloride	85.0	108	96.5
	nitrite	2916	4166	3541
	nitrate	2655	3916	3286
	phosphate	<100	<100	<100
	sulfate	572	837	705
	oxalate	<100	<100	<100

Table 5.6 Sludge Sample #2: Composition of filtrate from sample.

	LIMS #300-	167565 mg/L	167567 mg/L	Average mg/L
ICPES	Ag	<3	<3	<3
	Al	<2.4	<2.4	<2.4
	B	15.0	14.8	14.9
	Ba	<0.12	<0.12	<0.12
	Ca	8.90	10.1	9.52
	Cd	<0.14	<0.14	<0.14
	Ce	<7.7	<7.7	<7.7
	Co	<0.44	<0.44	<0.44
	Cr	2.98	3.00	2.99
	Cu	<0.6	<0.6	<0.6
	Fe	<0.44	<0.44	<0.44
	K	216	227	222
	La	<7	<7	<7
	Li	NA	NA	NA
	Mg	1.59	2.03	1.81
	Mn	<0.09	<0.09	<0.09
	Mo	6.90	6.48	6.69
	Na	2910	2790	2850
	Nd	<2.6	<2.6	<2.6
	Ni	<0.62	<0.62	<0.62
	P	<6.8	<6.8	<6.8
	Pb	<6.9	<6.9	<6.9
	Re	7.81	7.78	7.79
	S	160	162	161
	Si	<1.3	<1.3	<1.3
	Sn	NA	NA	NA
	Sr	<0.15	<0.15	<0.15
	Ti	<1.4	<1.4	<1.4
	V	NA	NA	NA
	Zn	<3.7	<3.7	<3.7
	Zr	<0.48	<0.48	<0.48
IC	fluoride	38.0	37.0	37.5
	formate	<100	<100	<100
	chloride	69.0	67.0	68.0
	nitrite	1871	1833	1852
	nitrate	1627	1595	1611
	phosphate	<100	<100	<100
	sulfate	382	378	380
	oxalate	<100	<100	<100

Table 5.7 Sludge Sample #3: Composition of filtrate calculated from composition of Sample #2 by ratio.

	Calculated (mg/L)
Ag	0
Al	4.42
B	18.9
Ba	0
Ca	11.8
Cd	0
Ce	0
Co	0
Cr	4.87
Cu	0
Fe	0
K	330
La	0
Li	0
Mg	3.35
Mn	0
Mo	11.0
Na	4506
Nd	0
Ni	0
P	0
Pb	0
Re	13.1
S	269
Si	0
Sn	0
Sr	0
Ti	0
V	0
Zn	0
Zr	0
fluoride	50.5
formate	0
chloride	84.1
nitrite	3086
nitrate	2863
phosphate	0
sulfate	614
oxalate	0

Table 5.8 Overall Compositions of Samples #1-3 Calculated from Solids and Filtrate Analyses.

		Sample #1 mg/L	Sample #2 mg/L	Sample #3 mg/L
Metals	Ag	345	172	247
	Al	788	368	565
	B	20.3	14.4	18.0
	Ba	252	125	180
	Ca	705	734	508
	Cd	3137	1559	2249
	Ce	319	166	228
	Co	408	205	292
	Cr	328	165	236
	Cu	139	69.1	99.9
	Fe	40681	20462	29166
	K	1060	601	820
	La	1571	797	1126
	Li	0	0	0
	Mg	65.6	38.8	47.7
	Mn	970	488	696
	Mo	11.8	6.45	10.5
	Na	12770	6420	9975
	Nd	1079	511	773
	Ni	2467	1222	1769
	P	1074	258	770
	Pb	473	245	339
	Re	31.8	14.2	25.2
	S	625	308	497
	Si	3334	3058	2390
	Sn	0	0	0
	Sr	120	59.9	85.7
	Ti	76.1	38.4	54.6
	V	0	0	0
	Zn	138	68.4	98.6
	Zr	13150	6509	9428
Anions	fluoride	54.4	36.2	48.2
	formate	0	0	0
	chloride	90.4	65.6	80.1
	nitrite	3318	1786	2941
	nitrate	3079	1554	2728
	phosphate	0	0	0
	sulfate	660	367	585
	oxalate	0	0	0
Solids (wt%)	Insoluble	13.4	7.22	9.85
	Soluble	1.40	0.805	1.27
	Total	14.8	8.03	11.1
	Specific gravity	1.09	1.04	1.06

Table 5.9 Trim Chemicals Added

Chemical	Amount (g)
NaOH	141.01
NaCl	0.25
NaF	7.79
$NaNO_2$	204.04
$NaNO_3$	190.06
$Na_3PO_4*12H_2O$	12.45
Na_2SO_4	71.60
KNO_3	18.14
$NaReO_4$	0.0548

5.3 Appendix – Experimental Design

Table 5.10 Experimental Design Table

Test Phase	TBP/NPH Level (each) (mg/L)	Run Name	Run Order (randomized)	Factorial Design Std Order	Factorial Design Level	Pressure (psid)	Velocity (ft/s)	Volumetric Flowrate (gpm)	Sample Time
Clean water flux	water	Z-0a	0a			5	11	3.79	-
	water	Z-0b	0b			15	11	3.79	-
	water	Z-0c	0c			25	11	3.79	-
NO ORGANICS EXPERIMENTAL DESIGN									
	0	Z-1	1	9	00	40	11	3.79	SS flux
	"	Z-2	2	1	- -	30	9	3.10	SS flux
	"	Z-3	3	2	- +	30	13	4.47	SS flux
	"	Z-4	4	4	+ +	50	13	4.47	SS flux
	"	Z-5	5	3	+ -	50	9	3.10	SS flux
	"	Z-6	6	10	00	40	11	3.79	SS flux
	"	Z-7	7	7	0a	40	7	2.41	SS flux
	"	Z-8	8	8	0A	40	15	5.16	SS flux
	"	Z-9	9	5	a0	20	11	3.79	SS flux
	"	Z-10	10	6	A0	60	11	3.79	SS flux
	"	Z-11	11	11	00	40	11	3.79	SS flux
Collect 2 liters permeate in 500 ml fractions									every 500 ml permeate
Add 2 liters new feed									
LOW TBP/NPH LEVEL EXPERIMENTAL DESIGN: 25 ppm each TBP & NPH added									
	25	L-1	1	3	+ -	50	9	3.10	SS flux
	"	L-2	2	9	00	40	11	3.79	SS flux
	"	L-3	3	8	0A	40	15	5.16	SS flux
	"	L-4	4	10	00	40	11	3.79	SS flux
	"	L-5	5	2	- +	30	13	4.47	SS flux
	"	L-6	6	7	0a	40	7	2.41	SS flux
	"	L-7	7	1	- -	30	9	3.10	SS flux
	"	L-8	8	5	a0	20	11	3.79	SS flux
	"	L-9	9	4	+ +	50	13	4.47	SS flux
	"	L-10	10	6	A0	60	11	3.79	SS flux
	"	L-11	11	11	00	40	11	3.79	SS flux
Collect 2 liters permeate in 500 ml fractions	"	-	-						every 500 ml permeate

Table 5.10 Experimental Design Table (continued)

Test Phase	TBP/NPH Level (each) (mg/L)	Run Name	Run Order (randomized)	Factorial Design Std Order	Factorial Design Level	Pressure (psid)	Velocity (ft/s)	Volumetric Flowrate (gpm)	Sample Time
Add 2 liters new feed Add TBP/NPH back to ~25 ppm each									
DETERMINE IMPACT LEVEL	25	M-1	1			40	11	3.79	SS flux
	75	M-2	2			40	11	3.79	SS flux
	150	M-3	3			40	11	3.79	SS flux
	250	M-4	4			40	11	3.79	SS flux
	500	M-5	5			40	11	3.79	SS flux
	750	M-6	6			40	11	3.79	SS flux
	1000	M-7	7			40	11	3.79	SS flux
	1250	M-8	8			40	11	3.79	SS flux
	1500	M-9	9			40	11	3.79	SS flux
	2000	M-10	10			40	11	3.79	SS flux
	2500	M-11	11			40	11	3.79	SS flux
IMPACT LEVEL EXPERIMENTAL DESIGN	2500	H-1	1	9	00	40	11	3.79	SS flux
	"	H-2	2	7	0a	40	7	2.41	SS flux
	"	H-3	3	2	- +	30	13	4.47	SS flux
	"	H-4	4	5	a0	20	11	3.79	SS flux
	"	H-5	5	10	00	40	11	3.79	SS flux
	"	H-6	6	8	0A	40	15	5.16	SS flux
	"	H-7	7	3	+ -	50	9	3.10	SS flux
	"	H-8	8	1	- -	30	9	3.10	SS flux
	"	H-9	9	4	+ +	50	13	4.47	SS flux
	"	H-10	10	6	A0	60	11	3.79	SS flux
	"	H-11	11	11	00	40	11	3.79	SS flux
Collect 2 liters permeate IN 500 ml increments									every 500 ml permeate
Clean water flux	water	H-0a	0a			5	11	3.79	-
	water	H-0b	0b			15	11	3.79	-
	water	H-0c	0c			25	11	3.79	-

5.4 Appendix – Experimental Results

Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
Z-1			0	3.84	11.15	43	40	53.16	0	0.0607	22	1.08906	0.0662
			5	3.94	11.45	42	39	59.89	5	0.0539	23	1.058322	0.0571
			10	3.80	11.04	43	40	57.98	10	0.0557	23	1.058322	0.0589
			15	3.85	11.18	44	40	59.1	15	0.0546	24	1.028649	0.0562
			20	3.89	11.30	43	40	60.29	20	0.0536	24	1.028649	0.0551
			25	3.66	10.63	43	40	61.13	25	0.0528	24	1.028649	0.0543
			30	3.77	10.95	41	38	63.46	30	0.0509	24	1.028649	0.0523
	11	**40**	**Mean:**	**3.82**	**11.10**	**42.71**	**39.57**					**Mean Steady State:**	**0.0539**
						41.14							
Z-2			0	3.06	8.89	32	30	98.14	0	0.0329	24	1.028649	0.0338
			5	3.04	8.83	32	29	98.97	5	0.0326	24	1.028649	0.0336
			10	3.10	9.01	34	31	98.67	10	0.0327	24	1.028649	0.0337
			15	3.13	9.09	34	31	104.96	15	0.0308	25	1	0.0308
			20	3.30	9.59	31	28	111.38	20	0.0290	23	1.058322	0.0307
			25	3.06	8.89	30	27	113.7	25	0.0284	23	1.058322	0.0301
			30	3.08	8.95	30	27	114.75	30	0.0281	23	1.058322	0.0298
	9	**30**	**Mean:**	**3.11**	**9.03**	**31.86**	**29.00**					**Mean Steady State:**	**0.0303**
						30.43							
Z-3			0	4.47	12.98	35	27	48.53	0	0.0665	23	1.058322	0.0704
			5	4.50	13.07	32	31	52.72	5	0.0613	23	1.058322	0.0648
			10	4.48	13.01	32	28	53.98	10	0.0598	24	1.028649	0.0615
			15	4.40	12.78	33	29	53.87	15	0.0599	24	1.028649	0.0617
			20	4.59	13.33	33	29	54	20	0.0598	24	1.028649	0.0615
			25	4.49	13.04	33	30	52.94	25	0.0610	24	1.028649	0.0627
			30	4.55	13.22	33	29	56.17	30	0.0575	25	1	0.0575
	13	**30**	**Mean:**	**4.50**	**13.06**	**33.00**	**29.00**					**Mean Steady State:**	**0.0609**
						31.00							
Z-4			0	4.01	11.65	49	47	46.34	0	0.0697	27	0.945607	0.0659
			5	4.18	12.14	52	48	47.84	5	0.0675	28	0.919786	0.0621
			10	4.34	12.61	51	47	51.29	10	0.0630	28	0.919786	0.0579
			15	4.34	12.61	53	48	52.23	15	0.0618	28	0.919786	0.0569

Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
			20	4.34	12.61	53	50	52.91	20	0.0610	27	0.945607	0.0577
			25	4.37	12.69	53	49	52.05	25	0.0620	27	0.945607	0.0587
			30	4.32	12.55	53	50	52.8	30	0.0612	28	0.919786	0.0563
	13	**50**	**Mean:**	**4.27**	**12.41**	**52.00**	**48.43**					**Mean Steady State:**	**0.0574**
						50.21							
Z-5			0	3.08	8.95	50	48	71.53	0	0.0451	26	0.972332	0.0439
			5	3.00	8.71	49	47	79.06	5	0.0408	26	0.972332	0.0397
			10	2.98	8.66	52	49	81.06	10	0.0398	26	0.972332	0.0387
			15	3.03	8.80	52	50	83.23	15	0.0388	25	1	0.0388
			20	3.20	9.30	51	48	87.53	20	0.0369	26	0.972332	0.0359
			25	3.22	9.35	51	48	90.13	25	0.0358	26	0.972332	0.0348
			30	3.08	8.95	52	50	83.49	30	0.0387	26	0.972332	0.0376
	9	**50**	**Mean:**	**3.08**	**8.96**	**51.00**	**48.57**					**Mean Steady State:**	**0.0368**
						49.79							
Z-6			0	3.78	10.98	41	38	63.54	0	0.0508	20	1.153916	0.0586
			5	3.79	11.01	42	39	64.42	5	0.0501	20	1.153916	0.0578
			10	3.79	11.01	43	40	67.66	10	0.0477	21	1.120909	0.0535
			15	3.77	10.95	41	38	68.68	15	0.0470	22	1.08906	0.0512
			20	3.78	10.98	42	38	69.25	20	0.0466	22	1.08906	0.0508
			25	3.75	10.89	42	39	69.02	25	0.0468	23	1.058322	0.0495
			30	3.75	10.89	42	39	68.43	30	0.0472	24	1.028649	0.0485
	11	**40**	**Mean:**	**3.77**	**10.96**	**41.86**	**38.71**					**Mean Steady State:**	**0.0496**
						40.29							
Z-7			0	2.40	6.97	41	39	97.52	0	0.0331	25	1	0.0331
			5	2.37	6.88	41	39	100.21	5	0.0322	25	1	0.0322
			10	2.47	7.18	42	40	106.14	10	0.0304	25	1	0.0304
			15	2.42	7.03	42	40	108.91	15	0.0297	26	0.972332	0.0288
			20	2.41	7.00	42	40	111.24	20	0.0290	25	1	0.0290
			25	2.40	6.97	42	40	114.4	25	0.0282	25	1	0.0282
			30	2.40	6.97	42	40	115.77	30	0.0279	25	1	0.0279
	7	**40**	**Mean:**	**2.41**	**7.00**	**41.71**	**39.71**					**Mean Steady State:**	**0.0285**
						40.71							
Z-8			0	5.07	14.73	43	38	36.89	0	0.0875	24	1.028649	0.0900

Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
			5	5.17	15.02	43	38	43.11	5	0.0749	25	1	0.0749
			10	5.13	14.90	42	39	44.2	10	0.0731	24	1.028649	0.0752
			15	5.24	15.22	43	38	45.48	15	0.0710	25	1	0.0710
			20	5.14	14.93	43	39	45.41	20	0.0711	25	1	0.0711
			25	5.08	14.76	43	39	45.43	25	0.0711	26	0.972332	0.0691
			30	5.06	14.70	43	39	46.27	30	0.0698	26	0.972332	0.0679
	15	**40**	**Mean:**	**5.13**	**14.89**	**42.86**	**38.57**					**Mean Steady State:**	**0.0698**
						40.71							
Z-9			0	3.78	10.98	22	19	57.2	0	0.0565	23	1.058322	0.0597
			5	3.69	10.72	20	17	68.4	5	0.0472	21	1.120909	0.0529
			10	3.73	10.84	20	17	72.45	10	0.0446	21	1.120909	0.0500
			15	3.69	10.72	20	17	71.56	15	0.0451	21	1.120909	0.0506
			20	3.75	10.89	20	17	69.43	20	0.0465	22	1.08906	0.0507
			25	3.90	11.33	21	18	62.2	25	0.0519	23	1.058322	0.0549
			30	3.91	11.36	22	19	63.99	30	0.0505	22	1.08906	0.0550
	11	**20**	**Mean:**	**3.78**	**10.98**	**20.71**	**17.71**					**Mean Steady State:**	**0.0528**
						19.21							
Z-10			0	3.10	9.01	58	56	71.55	0	0.0451	23	1.058322	0.0478
			5	3.22	9.35	60	57	81.14	5	0.0398	23	1.058322	0.0421
			10	3.33	9.67	60	58	86.81	10	0.0372	24	1.028649	0.0383
			15	3.22	9.35	60	57	87.14	15	0.0371	24	1.028649	0.0381
			20	2.90	8.42	60	57	89.87	20	0.0359	25	1	0.0359
			25	3.74	10.86	60	56	93.71	25	0.0345	25	1	0.0345
			30	3.60	10.46	59	55	94.04	30	0.0343	25	1	0.0343
	11	**60**	**Mean:**	**3.30**	**9.59**	**59.57**	**56.57**					**Mean Steady State:**	**0.0357**
						58.07							
Z-11			0	3.70	10.75	42	39	66.28	0	0.0487	20	1.153916	0.0562
			5	3.55	10.31	41	38	72.37	5	0.0446	21	1.120909	0.0500
			10	3.75	10.89	41	38	74.54	10	0.0433	22	1.08906	0.0472
			15	3.83	11.13	41	37	73.5	15	0.0439	23	1.058322	0.0465
			20	3.85	11.18	42	39	69.74	20	0.0463	24	1.028649	0.0476
			25	3.80	11.04	42	39	70.95	25	0.0455	24	1.028649	0.0468
			30	3.82	11.10	43	40	71.8	30	0.0450	23	1.058322	0.0476

Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft²)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft²)
	11	**40**	**Mean:**	**3.76**	**10.91**	**41.71**	**38.57**			**Mean Steady State:**			**0.0471**
						40.14							
L-1			0	3.01	8.74	52	49	64.79	0	0.0498	26	0.972332	0.0485
			5	2.86	8.31	50	48	79.11	5	0.0408	26	0.972332	0.0397
			10	3.00	8.71	49	47	84.95	10	0.0380	25	1	0.0380
			15	2.99	8.69	50	48	87.73	15	0.0368	25	1	0.0368
			20	2.97	8.63	51	48	89.58	20	0.0360	24	1.028649	0.0371
			25	2.96	8.60	53	50	87.67	25	0.0368	24	1.028649	0.0379
			30	3.22	9.35	51	48	90.01	30	0.0359	25	1	0.0359
	9	**50**	**Mean:**	**3.00**	**8.72**	**50.86**	**48.29**			**Mean Steady State:**			**0.0369**
						49.57							
L-2			0	3.60	10.46	42	39	55.96	0	0.0577	26	0.972332	0.0561
			5	3.64	10.57	41	38	65.21	5	0.0495	24	1.028649	0.0509
			10	3.64	10.57	40	37	71.18	10	0.0454	23	1.058322	0.0480
			15	3.59	10.43	40	37	73.67	15	0.0438	23	1.058322	0.0464
			20	3.64	10.57	41	38	70.93	20	0.0455	24	1.028649	0.0468
			25	3.63	10.54	40	37	70.43	25	0.0459	25	1	0.0459
			30	3.79	11.01	41	38	73.26	30	0.0441	25	1	0.0441
	11	**40**	**Mean:**	**3.65**	**10.59**	**40.71**	**37.71**			**Mean Steady State:**			**0.0458**
						39.21							
L-3			0	5.22	15.16	43	38	36.68	0	0.0880	25	1	0.0880
			5	5.07	14.73	43	39	39.15	5	0.0825	27	0.945607	0.0780
			10	5.04	14.64	41	37	42.85	10	0.0754	27	0.945607	0.0713
			15	5.08	14.76	40	35	46.22	15	0.0699	26	0.972332	0.0679
			20	5.07	14.73	41	36	48.33	20	0.0668	25	1	0.0668
			25	5.21	15.13	43	38	48.34	25	0.0668	25	1	0.0668
			30	5.20	15.11	44	40	45.86	30	0.0704	25	1	0.0704
	15	**40**	**Mean:**	**5.13**	**14.89**	**42.14**	**37.57**			**Mean Steady State:**			**0.0680**
						39.86							
L-4			0	3.82	11.10	41	38	60.83	0	0.0531	25	1	0.0531
			5	3.64	10.57	42	39	65.08	5	0.0496	24	1.028649	0.0510
			10	3.73	10.84	39	36	71.07	10	0.0454	24	1.028649	0.0467
			15	3.84	11.15	41	39	71.85	15	0.0449	26	0.972332	0.0437

Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
			20	3.82	11.10	41	39	72.42	20	0.0446	25	1	0.0446
			25	3.82	11.10	41	39	73.05	25	0.0442	25	1	0.0442
			30	3.87	11.24	42	40	70.67	30	0.0457	25	1	0.0457
	11	**40**	**Mean:**	**3.79**	**11.01**	**41.00**	**38.57**					**Mean Steady State:**	**0.0445**
						39.79							
L-5			0	4.38	12.72	32	28	44.51	0	0.0726	26	0.972332	0.0705
			5	4.58	13.30	33	29	52.49	5	0.0615	26	0.972332	0.0598
			10	4.47	12.98	32	28	56.82	10	0.0568	25	1	0.0568
			15	4.45	12.93	32	28	59.4	15	0.0544	25	1	0.0544
			20	4.60	13.36	33	29	56.23	20	0.0574	25	1	0.0574
			25	4.58	13.30	33	29	55.51	25	0.0582	26	0.972332	0.0566
			30	4.64	13.48	34	30	54.07	30	0.0597	26	0.972332	0.0581
	13	**30**	**Mean:**	**4.53**	**13.15**	**32.71**	**28.71**					**Mean Steady State:**	**0.0566**
						30.71							
L-6			0	2.32	6.74	41	39	97.41	0	0.0332	23	1.058322	0.0351
			5	2.32	6.74	42	40	105.48	5	0.0306	24	1.028649	0.0315
			10	2.46	7.15	41	39	114.36	10	0.0282	25	1	0.0282
			15	2.44	7.09	41	39	116.96	15	0.0276	25	1	0.0276
			20	2.40	6.97	42	40	117.63	20	0.0275	26	0.972332	0.0267
			25	2.40	6.97	42	40	124.94	25	0.0258	25	1	0.0258
			30	2.36	6.86	42	40	131.37	30	0.0246	24	1.028649	0.0253
	7	**40**	**Mean:**	**2.39**	**6.93**	**41.57**	**39.57**					**Mean Steady State:**	**0.0264**
						40.57							
L-7			0	3.18	9.24	32	30	76.38	0	0.0423	25	1	0.0423
			5	3.09	8.98	33	31	79.61	5	0.0406	25	1	0.0406
			10	3.09	8.98	34	32	81.17	10	0.0398	25	1	0.0398
			15	3.12	9.06	34	31	83.27	15	0.0388	26	0.972332	0.0377
			20	3.14	9.12	34	32	92.7	20	0.0348	24	1.028649	0.0358
			25	3.08	8.95	33	31	94.36	25	0.0342	23	1.058322	0.0362
			30	3.13	9.09	32	30	96.95	30	0.0333	24	1.028649	0.0343
	9	**30**	**Mean:**	**3.12**	**9.06**	**33.14**	**31.00**					**Mean Steady State:**	**0.0360**
						32.07							
L-8			0	3.86	11.21	23	19	59.82	0	0.0540	25	1	0.0540

Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
			5	3.71	10.78	20	17	63.7	5	0.0507	25	1	0.0507
			10	3.74	10.86	23	19	66.36	10	0.0487	25	1	0.0487
			15	3.72	10.81	22	19	67.35	15	0.0479	25	1	0.0479
			20	3.62	10.52	21	18	69.09	20	0.0467	26	0.972332	0.0454
			25	3.61	10.49	21	17	70.39	25	0.0459	25	1	0.0459
			30	3.67	10.66	21	18	70.62	30	0.0457	25	1	0.0457
	11	**20**	**Mean:**	**3.70**	**10.76**	**21.57**	**18.14**					**Mean Steady State:**	**0.0463**
						19.86							
L-9			0	4.32	12.55	53	50	46.44	0	0.0695	25	1	0.0695
			5	4.23	12.29	51	47	51.66	5	0.0625	26	0.972332	0.0608
			10	4.17	12.11	51	48	53.91	10	0.0599	26	0.972332	0.0582
			15	4.26	12.37	50	47	58.42	15	0.0553	25	1	0.0553
			20	4.24	12.32	51	47	60.9	20	0.0530	25	1	0.0530
			25	4.25	12.35	49	46	62.07	25	0.0520	24	1.028649	0.0535
			30	4.10	11.91	48	44	61.86	30	0.0522	25	1	0.0522
	13	**50**	**Mean:**	**4.22**	**12.27**	**50.43**	**47.00**					**Mean Steady State:**	**0.0535**
						48.71							
L-10			0	2.35	6.83	59	57	90.09	0	0.0358	26	0.972332	0.0349
			5	2.44	7.09	59	56	122.24	5	0.0264	25	1	0.0264
			10	2.83	8.22	60	57	130.2	10	0.0248	25	1	0.0248
			15	2.70	7.84	60	58	134.59	15	0.0240	25	1	0.0240
			20	2.61	7.58	60	57	136	20	0.0237	25	1	0.0237
			25	2.56	7.44	60	57	138.64	25	0.0233	25	1	0.0233
			30	2.58	7.49	60	57	141.8	30	0.0228	24	1.028649	0.0234
	11	**60**	**Mean:**	**2.58**	**7.50**	**59.71**	**57.00**					**Mean Steady State:**	**0.0236**
						58.36							
L-11			0	3.56	10.34	40	37	62.07	0	0.0520	25	1	0.0520
			5	3.80	11.04	43	40	68.7	5	0.0470	24	1.028649	0.0484
			10	3.73	10.84	42	39	73.32	10	0.0440	24	1.028649	0.0453
			15	3.76	10.92	38	35	81.21	15	0.0398	24	1.028649	0.0409
			20	3.96	11.50	42	39	78.31	20	0.0412	24	1.028649	0.0424
			25	3.99	11.59	43	40	74.09	25	0.0436	26	0.972332	0.0424
			30	3.83	11.13	40	37	77.78	30	0.0415	26	0.972332	0.0404

Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
	11	**40**	**Mean:**	**3.80**	**11.05**	**41.14**	**38.14**					**Mean Steady State:**	**0.0415**
						39.64							
M-1			0	3.82	11.10	43	39	57.6	0	0.0561	23	1.058322	0.0593
			5	3.86	11.21	41	37	64.83	5	0.0498	23	1.058322	0.0527
50 mg/L			10	3.84	11.15	42	38	63.38	10	0.0510	25	1	0.0510
			15	3.81	11.07	41	37	66.25	15	0.0487	26	0.972332	0.0474
			20	3.78	10.98	41	37	66.04	20	0.0489	27	0.945607	0.0462
			25	3.81	11.07	40	36	66.64	25	0.0485	26	0.972332	0.0471
			30	3.72	10.81	41	37	70.19	30	0.0460	26	0.972332	0.0447
			35	3.77	10.95	41	37	69.04	35	0.0468	26	0.972332	0.0455
	11	**40**	**Mean:**	**3.80**	**11.04**	**41.25**	**37.25**					**Mean Steady State:**	**0.0451**
						39.25							
M-2			0	3.80	11.04	40	38	56.91	0	0.0567	26	0.972332	0.0552
			5	3.86	11.21	42	39	59.46	5	0.0543	27	0.945607	0.0514
150 mg/L			10	3.83	11.13	41	38	67.43	10	0.0479	26	0.972332	0.0466
			15	3.84	11.15	43	40	63.48	15	0.0509	26	0.972332	0.0495
			20	3.77	10.95	43	40	63.78	20	0.0506	27	0.945607	0.0479
			25	3.84	11.15	41	37	67.93	25	0.0475	27	0.945607	0.0450
			30	3.74	10.86	43	40	67.82	30	0.0476	26	0.972332	0.0463
	11	**40**	**Mean:**	**3.81**	**11.07**	**41.86**	**38.86**					**Mean Steady State:**	**0.0456**
						40.36							
M-3			0	3.92	11.39	42	38	56.94	0	0.0567	25	1	0.0567
			5	3.76	10.92	41	38	62.12	5	0.0520	26	0.972332	0.0505
300 mg/L			10	3.82	11.10	43	40	67.72	10	0.0477	26	0.972332	0.0464
			15	3.80	11.04	42	39	65.87	15	0.0490	25	1	0.0490
			20	3.81	11.07	41	38	67.31	20	0.0480	25	1	0.0480
			25	3.82	11.10	41	39	68.66	25	0.0470	26	0.972332	0.0457
			30	3.80	11.04	41	38	72.22	30	0.0447	25	1	0.0447
			35	3.83		43	40	71.95	35	0.0449	26	0.972332	0.0436
	11	**40**	**Mean:**	**3.82**	**11.09**	**41.75**	**38.75**					**Mean Steady State:**	**0.0447**
						40.25							
M-4			0	3.80	11.04	42	38	57.99	0	0.0557	24	1.028649	0.0573
			5	3.75	10.89	41	39	67.87	5	0.0476	24	1.028649	0.0489

Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
500 mg/L			10	3.80	11.04	42	38	71.06	10	0.0454	24	1.028649	0.0467
			15	3.75	10.89	41	41	70.53	15	0.0458	25	1	0.0458
			20	3.86	11.21	44	39	69.16	20	0.0467	25	1	0.0467
			25	3.85	11.18	42	40	74.66	25	0.0433	24	1.028649	0.0445
			30	3.86	11.21	43	39	74.02	30	0.0436	24	1.028649	0.0449
	11	**40**	**Mean:**	**3.81**	**11.07**	**42.14**	**39.14**					**Mean Steady State:**	**0.0447**
						40.64							
M-5			0	3.78	10.98	42	39	62.88	0	0.0514	23	1.058322	0.0544
			5	3.83	11.13	43	40	68.93	5	0.0468	23	1.058322	0.0496
1000 mg/L			10	3.86	11.21	41	38	74.73	10	0.0432	23	1.058322	0.0457
			15	3.84	11.15	41	38	79.66	15	0.0405	23	1.058322	0.0429
			20	3.85	11.18	41	38	77.02	20	0.0419	24	1.028649	0.0431
			25	3.88	11.27	42	39	76.78	25	0.0421	25	1	0.0421
			30	3.89	11.30	42	39	74.05	30	0.0436	25	1	0.0436
	11	**40**	**Mean:**	**3.85**	**11.18**	**41.71**	**38.71**					**Mean Steady State:**	**0.0429**
						40.21							
M-5b			0	3.87	11.24	41	38	63.43	0	0.0509	21	1.120909	0.0571
			5	3.84	11.15	41	38	68.82	5	0.0469	22	1.08906	0.0511
1000 mg/L			10	3.77	10.95	41	38	71.64	10	0.0451	23	1.058322	0.0477
			15	3.87	11.24	43	40	71.89	15	0.0449	23	1.058322	0.0475
			20	3.75	10.89	41	38	73.25	20	0.0441	24	1.028649	0.0453
			25	3.87	11.24	43	40	69.78	25	0.0463	25	1	0.0463
			30	3.79	11.01	42	39	71.58	30	0.0451	25	1	0.0451
			35	3.72	10.81	40	37	74.31	35	0.0435	26	0.972332	0.0423
	11	**40**	**Mean:**	**3.81**	**11.07**	**41.50**	**38.50**					**Mean Steady State:**	**0.0461**
						40.00							
M-6			0	3.68	10.69	41	38	61.96	0	0.0521	25	1	0.0521
			5	3.86	11.21	42	39	64.69	5	0.0499	24	1.028649	0.0514
1500 mg/L			10	3.82	11.10	42	39	69.94	10	0.0462	24	1.028649	0.0475
			15	3.81	11.07	42	39	71.05	15	0.0455	25	1	0.0455
			20	3.81	11.07	42	39	70.04	20	0.0461	25	1	0.0461
			25	3.83	11.13	42	39	70.36	25	0.0459	26	0.972332	0.0446
			30	3.83	11.13	42	39	72.29	30	0.0447	25	1	0.0447

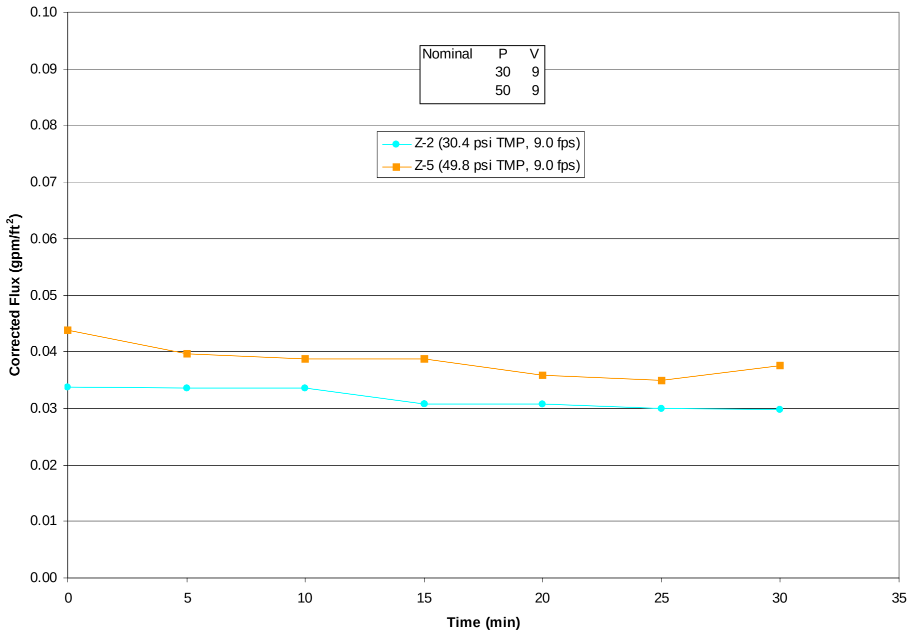
Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
	11	**40**	**Mean:**	**3.81**	**11.06**	**41.86**	**38.86**					**Mean Steady State:**	**0.0446**
						40.36							
M-7			0	3.80	11.04	42	39	61.05	0	0.0529	24	1.028649	0.0544
			5	3.67	10.66	41	38	68.47	5	0.0472	25	1	0.0472
2000 mg/L			10	3.82	11.10	43	40	70.10	10	0.0461	25	1	0.0461
			15	3.81	11.07	43	40	69.93	15	0.0462	25	1	0.0462
			20	3.79	11.01	42	39	71.79	20	0.0450	25	1	0.0450
			25	3.81	11.07	42	39	74.02	25	0.0436	25	1	0.0436
			30	3.81	11.07	43	40	74.13	30	0.0436	25	1	0.0436
	11	**40**	**Mean:**	**3.79**	**11.00**	**42.29**	**39.29**					**Mean Steady State:**	**0.0436**
						40.79							
M-8			0	3.88	11.27	42	39	62.91	0	0.0513	25	1	0.0513
			5	3.91	11.36	41	38	67.1	5	0.0481	25	1	0.0481
2500 mg/L			10	3.85	11.18	42	39	66.81	10	0.0483	25	1	0.0483
			15	3.88	11.27	43	10	67.78	15	0.0476	25	1	0.0476
			20	3.76	10.92	41	38	74.54	20	0.0433	25	1	0.0433
			25	3.86	11.21	42	39	70.84	25	0.0456	25	1	0.0456
			30	3.88	11.27	43	40	70.56	30	0.0458	25	1	0.0458
	11	**40**	**Mean:**	**3.86**	**11.21**	**42.00**	**34.71**					**Mean Steady State:**	**0.0449**
						38.36							
M-9			0	3.87	11.24	42	39	51.02	0	0.0633	27	0.945607	0.0599
			5	3.97	11.53	42	39	55.01	5	0.0587	26	0.972332	0.0571
3000 mg/L			10	3.81	11.07	42	39	67.56	10	0.0478	26	0.972332	0.0465
			15	3.78	10.98	41	38	69.44	15	0.0465	26	0.972332	0.0452
			20	3.79	11.01	42	39	70.66	20	0.0457	26	0.972332	0.0444
			25	3.85	11.18	43	40	68.85	25	0.0469	27	0.945607	0.0444
			30	3.82	11.10	43	40	70.63	30	0.0457	27	0.945607	0.0432
	11	**40**	**Mean:**	**3.84**	**11.16**	**42.14**	**39.14**					**Mean Steady State:**	**0.0440**
						40.64							
M-10			0	3.85	11.18	42	39	64.09	0	0.0504	25	1	0.0504
			5	3.77	10.95	42	39	70.91	5	0.0455	24	1.028649	0.0468
4000 mg/L			10	3.77	10.95	43	40	74.32	10	0.0435	23	1.058322	0.0460
			15	3.99	11.59	44	40	75.91	15	0.0425	23	1.058322	0.0450

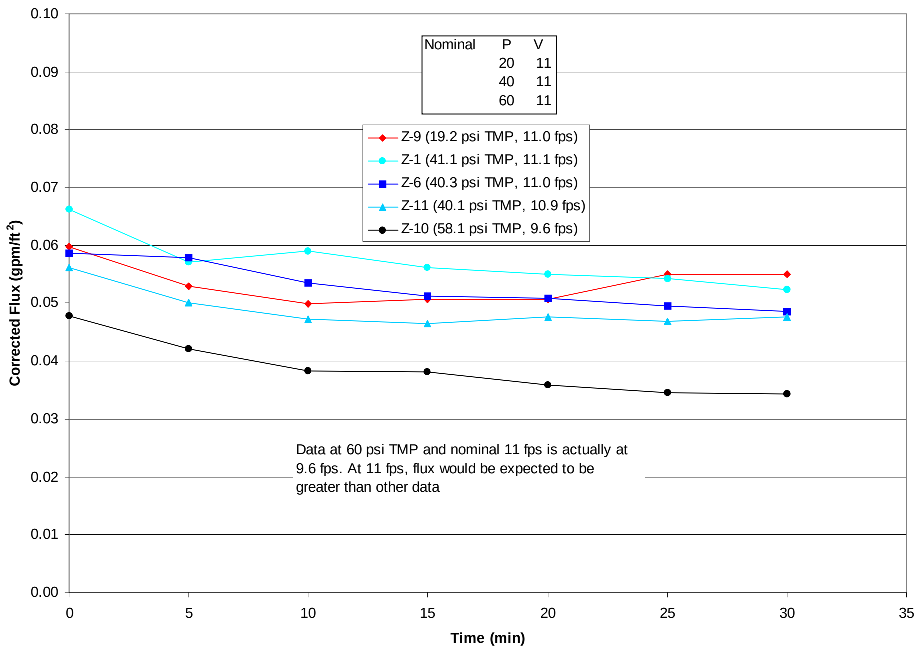
Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
			20	3.65	10.60	41	38	77.34	20	0.0418	24	1.028649	0.0430
			25	3.82	11.10	42	39	77.22	25	0.0418	24	1.028649	0.0430
			30	3.75	10.89	42	39	77.06	30	0.0419	24	1.028649	0.0431
	11	**40**	**Mean:**	**3.80**	**11.04**	**42.29**	**39.14**					**Mean Steady State:**	**0.0430**
						40.71							
M-11			0	3.86	11.21	43	40	64.97	0	0.0497	23	1.058322	0.0526
			5	3.86	11.21	43	40	68.09	5	0.0474	23	1.058322	0.0502
5000 mg/L			10	3.79	11.01	41	38	72.63	10	0.0445	23	1.058322	0.0471
			15	3.76	10.92	42	39	72.36	15	0.0446	24	1.028649	0.0459
			20	3.73	10.84	40	37	75.74	20	0.0426	25	1	0.0426
			25	3.76	10.92	42	39	76.07	25	0.0425	25	1	0.0425
			30	3.82	11.10	43	40	76.81	30	0.0420	24	1.028649	0.0432
	11	**40**	**Mean:**	**3.80**	**11.03**	**42.00**	**39.00**					**Mean Steady State:**	**0.0428**
						40.50							
H-1			0	3.85	11.18	42	39	59.76	0	0.0540	24	1.028649	0.0556
			5	3.78	10.98	41	38	66.15	5	0.0488	25	1	0.0488
			10	3.98	11.56	42	38	69.16	10	0.0467	24	1.028649	0.0480
			15	3.83	11.13	43	40	67.54	15	0.0478	23	1.058322	0.0506
			20	3.98	11.56	42	39	74.84	20	0.0432	24	1.028649	0.0444
			25	3.96	11.50	42	39	75.24	25	0.0429	24	1.028649	0.0442
			30	3.92	11.39	42	39	74.52	30	0.0433	25	1	0.0433
	11	**40**	**Mean:**	**3.90**	**11.33**	**42.00**	**38.86**					**Mean Steady State:**	**0.0437**
						40.43							
H-2			0	2.38	6.91	43	41	104.33	0	0.0310	25	1	0.0310
			5	2.55	7.41	43	40	115.35	5	0.0280	24	1.028649	0.0288
			10	2.47	7.18	41	38	121.33	10	0.0266	24	1.028649	0.0274
			15	2.47	7.18	42	39	125.12	15	0.0258	24	1.028649	0.0265
			20	2.40	6.97	44	41	121.79	20	0.0265	24	1.028649	0.0273
			25	2.34	6.80	43	40	125.42	25	0.0257	25	1	0.0257
			30	2.35	6.83	43	40	125.65	30	0.0257	25	1	0.0257
	7	**40**	**Mean:**	**2.42**	**7.04**	**42.71**	**39.86**					**Mean Steady State:**	**0.0263**
						41.29							
H-3			0	4.43	12.87	32	29	47.18	0	0.0684	25	1	0.0684

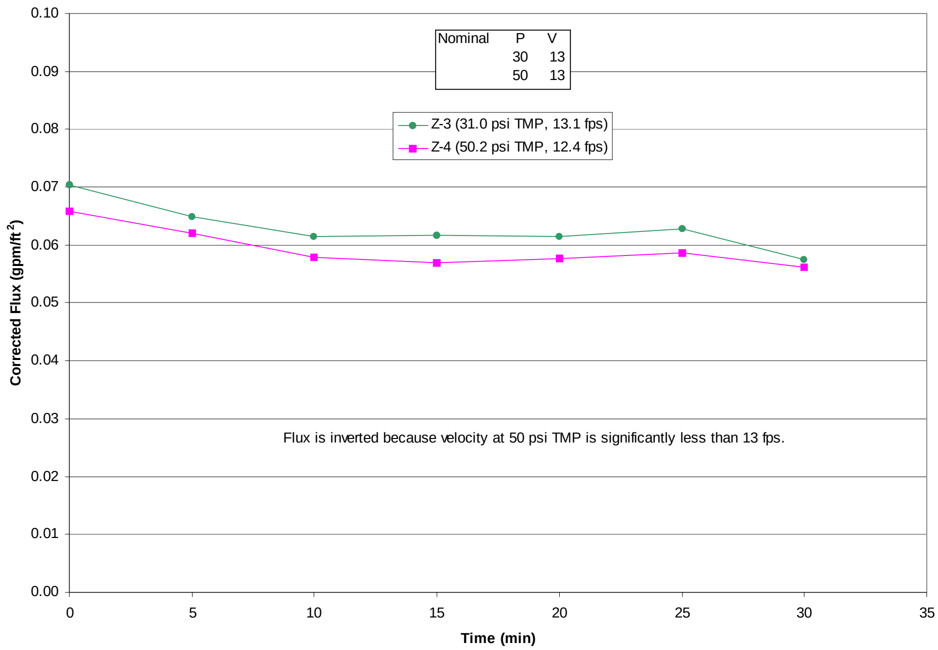
Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
			5	4.51	13.10	31	27	56.97	5	0.0567	25	1	0.0567
			10	4.53	13.16	32	28	57.1	10	0.0566	25	1	0.0566
			15	4.51	13.10	32	28	57.91	15	0.0558	25	1	0.0558
			20	4.50	13.07	32	28	58.53	20	0.0552	25	1	0.0552
			25	4.52	13.13	31	28	58.49	25	0.0552	26	0.972332	0.0537
			30	4.50	13.07	32	28	59.33	30	0.0544	25	1	0.0544
	13	**30**	**Mean:**	**4.50**	**13.07**	**31.71**	**28.00**					**Mean Steady State:**	**0.0548**
						29.86							
H-4			0	3.84	11.15	23	19	64.97	0	0.0497	23	1.058322	0.0526
			5	3.85	11.18	23	19	66.02	5	0.0489	23	1.058322	0.0518
			10	3.80	11.04	23	19	69.49	10	0.0465	23	1.058322	0.0492
			15	3.78	10.98	23	20	70.44	15	0.0458	23	1.058322	0.0485
			20	3.76	10.92	23	19	73.1	20	0.0442	23	1.058322	0.0468
			25	3.83	11.13	22	19	75.75	25	0.0426	23	1.058322	0.0451
			30	3.80	11.04	22	19	76.94	30	0.0420	23	1.058322	0.0444
	11	**20**	**Mean:**	**3.81**	**11.06**	**22.71**	**19.14**					**Mean Steady State:**	**0.0454**
						20.93							
H-5			0	3.72	10.81	41	38	64.37	0	0.0502	23	1.058322	0.0531
			5	3.82	11.10	42	39	68.3	5	0.0473	23	1.058322	0.0500
			10	3.84	11.15	41	38	72.55	10	0.0445	24	1.028649	0.0458
			15	3.88	11.27	42	39	72.2	15	0.0447	24	1.028649	0.0460
			20	3.86	11.21	42	39	72.64	20	0.0445	25	1	0.0445
			25	3.84	11.15	42	39	73.98	25	0.0437	25	1	0.0437
			30	3.81	11.07	41	38	74.8	30	0.0432	25	1	0.0432
	11	**40**	**Mean:**	**3.82**	**11.11**	**41.57**	**38.57**					**Mean Steady State:**	**0.0443**
						40.07							
H-6			0	5.19	15.08	42	39	41.75	0	0.0773	25	1	0.0773
			5	5.25	15.25	43	39	44.15	5	0.0731	25	1	0.0731
			10	5.27	15.31	44	39	45.89	10	0.0704	26	0.972332	0.0684
			15	5.29	15.37	44	39	46.73	15	0.0691	26	0.972332	0.0672
			20	5.25	15.25	44	39	48.28	20	0.0669	25	1	0.0669
			25	5.29	15.37	44	39	48.04	25	0.0672	26	0.972332	0.0654
			30	5.26	15.28	44	39	49.24	30	0.0656	26	0.972332	0.0638

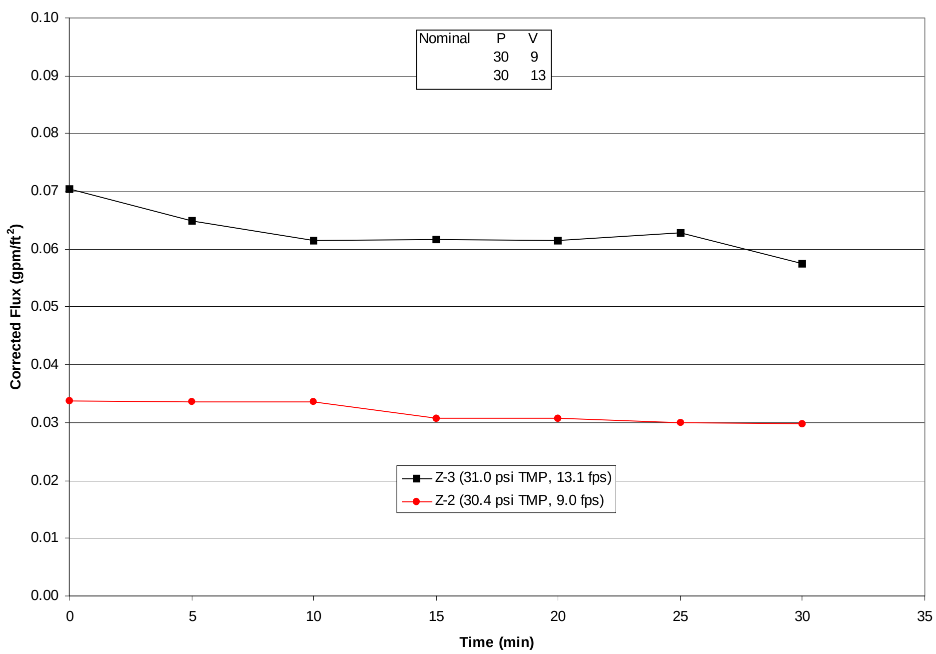
Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft²)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft²)
	15	**40**	**Mean:**	**5.26**	**15.27**	**43.57**	**39.00**					**Mean Steady State:**	**0.0658**
						41.29							
H-7			0	3.06	8.89	51	49	73.84	0	0.0437	25	1	0.0437
			5	3.09	8.98	50	48	86.8	5	0.0372	25	1	0.0372
			10	3.09	8.98	51	49	89.65	10	0.0360	25	1	0.0360
			15	3.07	8.92	52	49	90.51	15	0.0357	26	0.972332	0.0347
			20	3.08	8.95	52	50	92.66	20	0.0349	26	0.972332	0.0339
			25	3.05	8.86	52	50	94.24	25	0.0343	26	0.972332	0.0333
			30	3.12	9.06	52	50	100.17	30	0.0322	25	1	0.0322
			35	3.16	9.18	51	49	100.59	35	0.0321	25	1	0.0321
	9	**50**	**Mean:**	**3.09**	**8.98**	**51.38**	**49.25**					**Mean Steady State:**	**0.0328**
						50.31							
H-8			0	3.13	9.09	33	30	83.11	0	0.0389	23	1.058322	0.0411
			5	3.14	9.12	33	30	85.32	5	0.0378	24	1.028649	0.0389
			10	3.16	9.18	32	29	88.27	10	0.0366	24	1.028649	0.0376
			15	3.14	9.12	32	29	90.07	15	0.0359	24	1.028649	0.0369
			20	3.13	9.09	33	30	94.79	20	0.0341	24	1.028649	0.0350
			25	3.13	9.09	33	30	96.94	25	0.0333	24	1.028649	0.0343
			30	3.12	9.06	32	29	97.99	30	0.0330	24	1.028649	0.0339
	9	**30**	**Mean:**	**3.14**	**9.11**	**32.57**	**29.57**					**Mean Steady State:**	**0.0350**
						31.07							
H-9			0	4.36	12.67	50	46	56.78	0	0.0569	24	1.028649	0.0585
			5	4.37	12.69	51	47	58.96	5	0.0548	25	1	0.0548
			10	4.44	12.90	51	47	62.12	10	0.0520	24	1.028649	0.0535
			15	4.39	12.75	52	48	60.95	15	0.0530	25	1	0.0530
			20	4.38	12.72	52	48	60.74	20	0.0532	25	1	0.0532
			25	4.43	12.87	52	48	60.02	25	0.0538	25	1	0.0538
			30	4.42	12.84	51	49	58.28	30	0.0554	26	0.972332	0.0539
			35	4.41	12.81	52	48	59.67	35	0.0541	26	0.972332	0.0526
	13	**50**	**Mean:**	**4.40**	**12.78**	**51.38**	**47.63**					**Mean Steady State:**	**0.0536**
						49.50							
H-10			0	3.24	9.41	60	57	75.61	0	0.0427	25	1	0.0427
			5	3.15	9.15	58	56	83.39	5	0.0387	25	1	0.0387

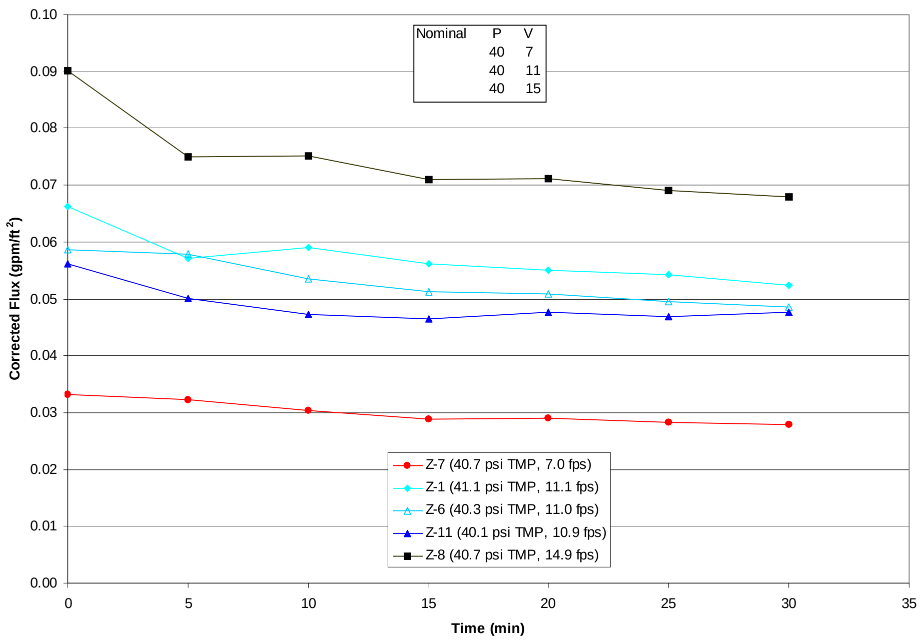
Run	Target Velocity (fps)	Target Pressure (psi)	Time (min)	Flow (gpm)	Flow (fps)	Inlet P (psig)	Outlet P (psig)	Time for 40 ml of Permeate (sec)	Run Time (min)	Flux (gpm/ft^2)	Temp (°C)	Temp. Comp.	Corr. Flux (gpm/ft^2)
			10	3.36	9.76	59	57	88.7	10	0.0364	25	1	0.0364
			15	3.51	10.20	59	56	92.17	15	0.0350	25	1	0.0350
			20	3.49	10.14	58	56	93.38	20	0.0346	26	0.972332	0.0336
			25	3.51	10.20	59	57	94.15	25	0.0343	25	1	0.0343
			30	3.47	10.08	58	56	96.53	30	0.0335	26	0.972332	0.0325
	11	**60**	**Mean:**	**3.39**	**9.85**	**58.71**	**56.43**			**Mean Steady State:**			**0.0335**
						57.57							
H-11			0	3.79	11.01	41	38	61.65	0	0.0524	26	0.972332	0.0509
			5	3.82	11.10	42	38	66.89	5	0.0483	26	0.972332	0.0469
			10	3.82	11.10	42	39	70.53	10	0.0458	25	1	0.0458
			15	3.80	11.04	42	39	71.66	15	0.0451	25	1	0.0451
			20	3.81	11.07	42	39	73.27	20	0.0441	25	1	0.0441
			25	3.77	10.95	42	39	73.47	25	0.0440	25	1	0.0440
			30	3.81	11.07	42	39	75.5	30	0.0428	25	1	0.0428
	11	**40**	**Mean:**	**3.80**	**11.05**	**41.86**	**38.71**			**Mean Steady State:**			**0.0436**
						40.29							

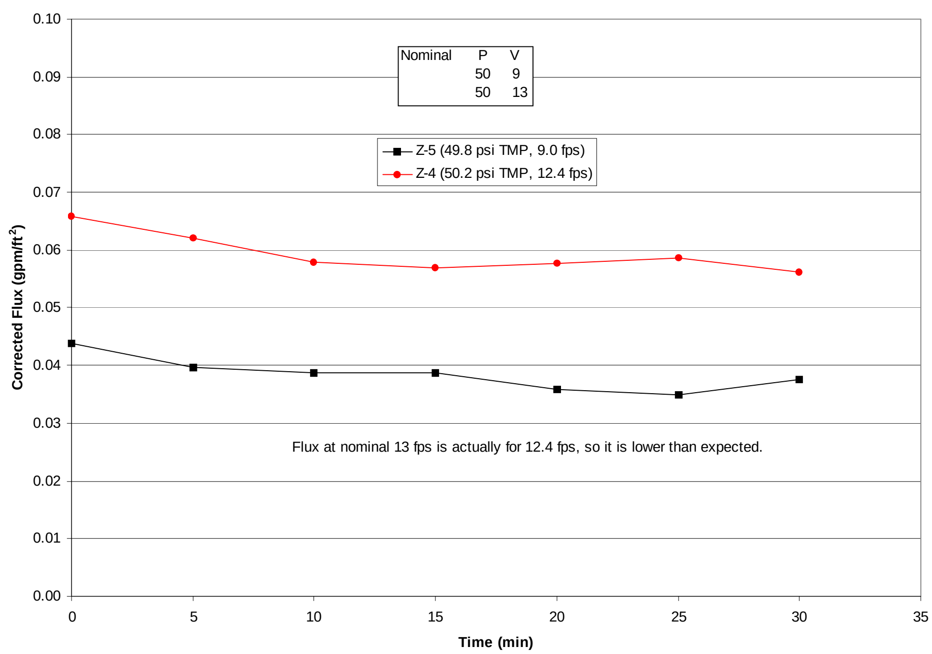

Nominal P V
30 9
50 9
Z-2 (30.4 psi TMP, 9.0 fps)
Z-5 (49.8 psi TMP, 9.0 fps)
Corrected Flux (gpm/ft²)
Time (min)

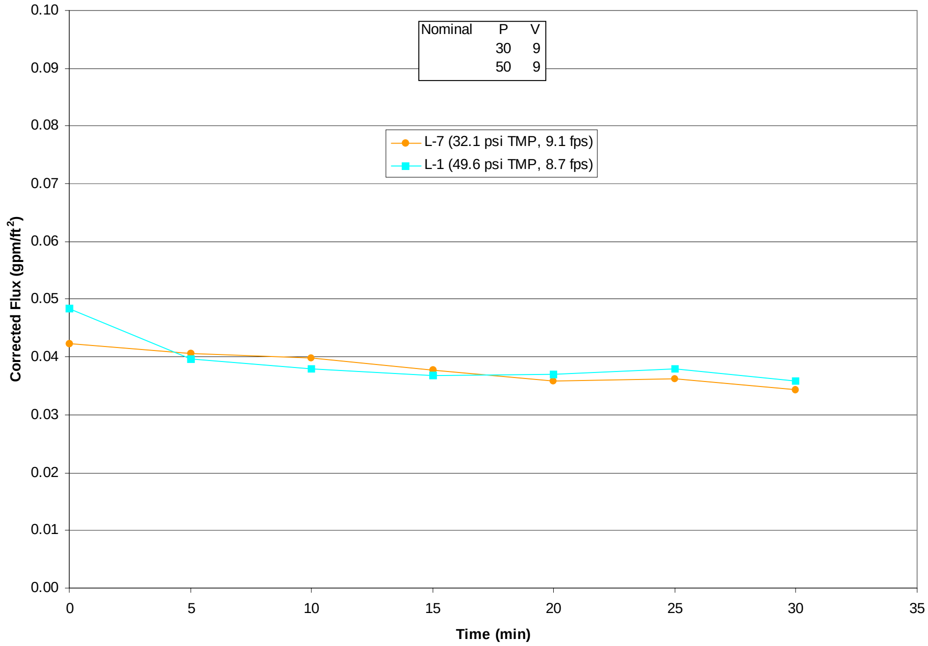

Nominal P V
20 11
40 11
60 11
Z-9 (19.2 psi TMP, 11.0 fps)
Z-1 (41.1 psi TMP, 11.1 fps)
Z-6 (40.3 psi TMP, 11.0 fps)
Z-11 (40.1 psi TMP, 10.9 fps)
Z-10 (58.1 psi TMP, 9.6 fps)
Data at 60 psi TMP and nominal 11 fps is actually at 9.6 fps. At 11 fps, flux would be expected to be greater than other data
Corrected Flux (gpm/ft²)
Time (min)

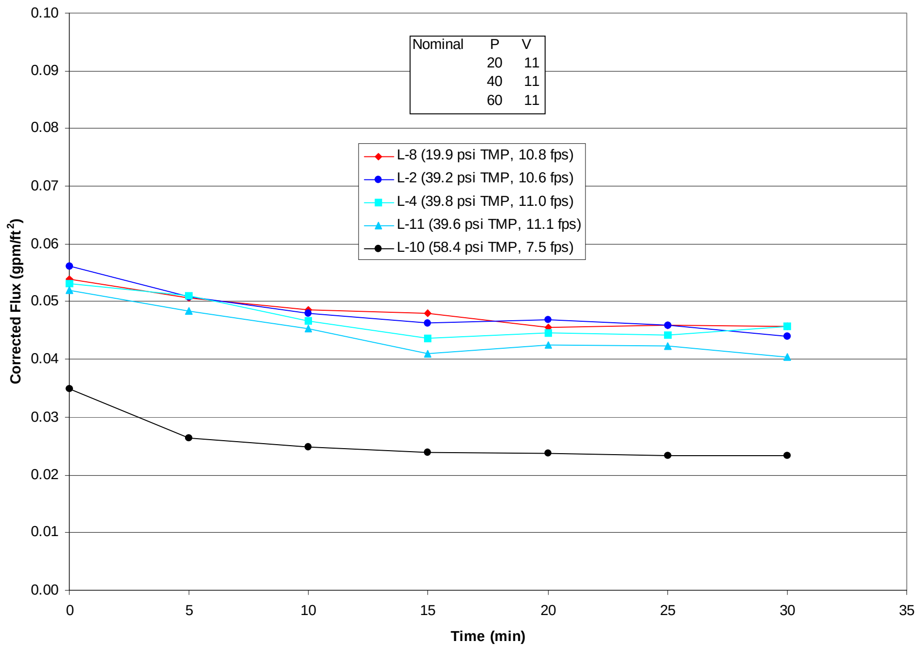

Nominal P V
30 13
50 13
Z-3 (31.0 psi TMP, 13.1 fps)
Z-4 (50.2 psi TMP, 12.4 fps)
Flux is inverted because velocity at 50 psi TMP is significantly less than 13 fps.
Corrected Flux (gpm/ft²)
Time (min)

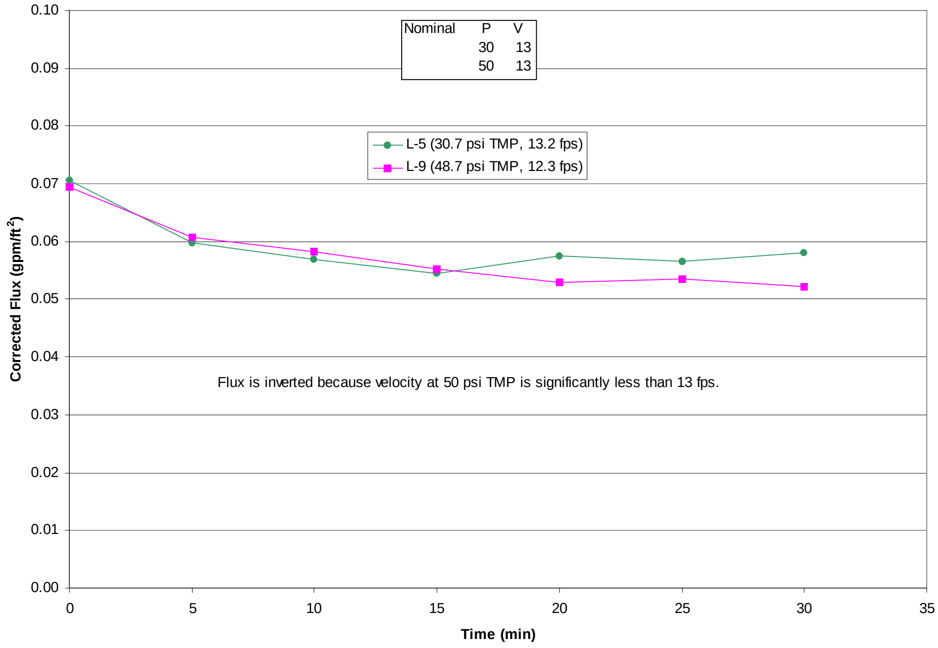

Nominal P V
30 9
30 13
Z-3 (31.0 psi TMP, 13.1 fps)
Z-2 (30.4 psi TMP, 9.0 fps)
Corrected Flux (gpm/ft²)
Time (min)

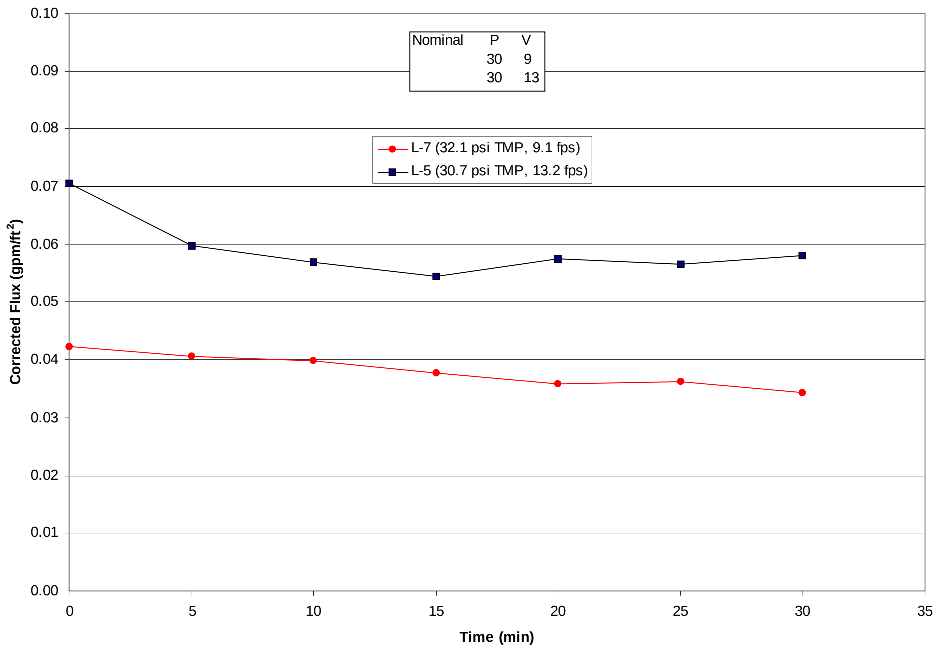

Nominal P V
40 7
40 11
40 15
Z-7 (40.7 psi TMP, 7.0 fps)
Z-1 (41.1 psi TMP, 11.1 fps)
Z-6 (40.3 psi TMP, 11.0 fps)
Z-11 (40.1 psi TMP, 10.9 fps)
Z-8 (40.7 psi TMP, 14.9 fps)
Corrected Flux (gpm/ft²)
Time (min)

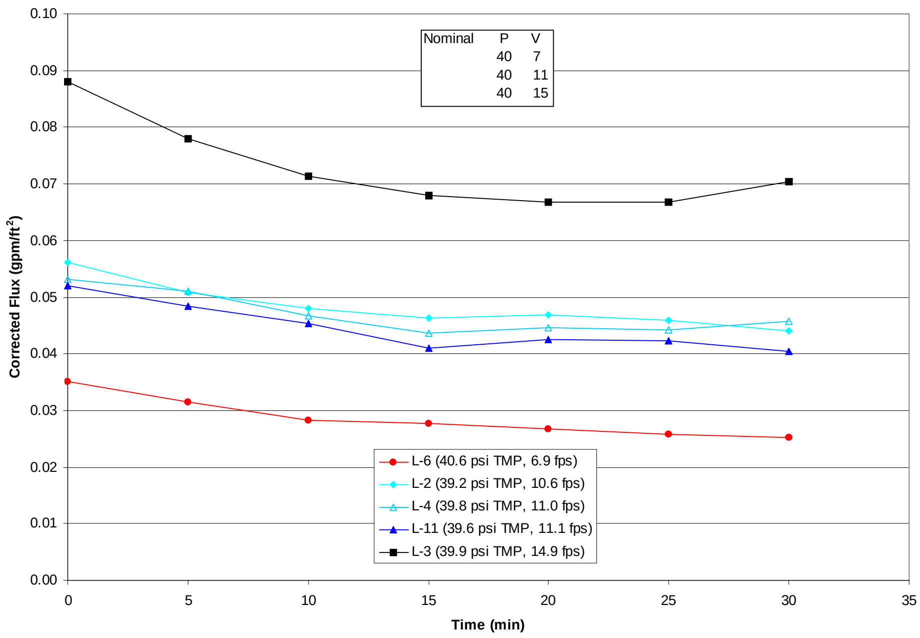

Nominal P V
50 9
50 13
Z-5 (49.8 psi TMP, 9.0 fps)
Z-4 (50.2 psi TMP, 12.4 fps)
Flux at nominal 13 fps is actually for 12.4 fps, so it is lower than expected.
Corrected Flux (gpm/ft²)
Time (min)

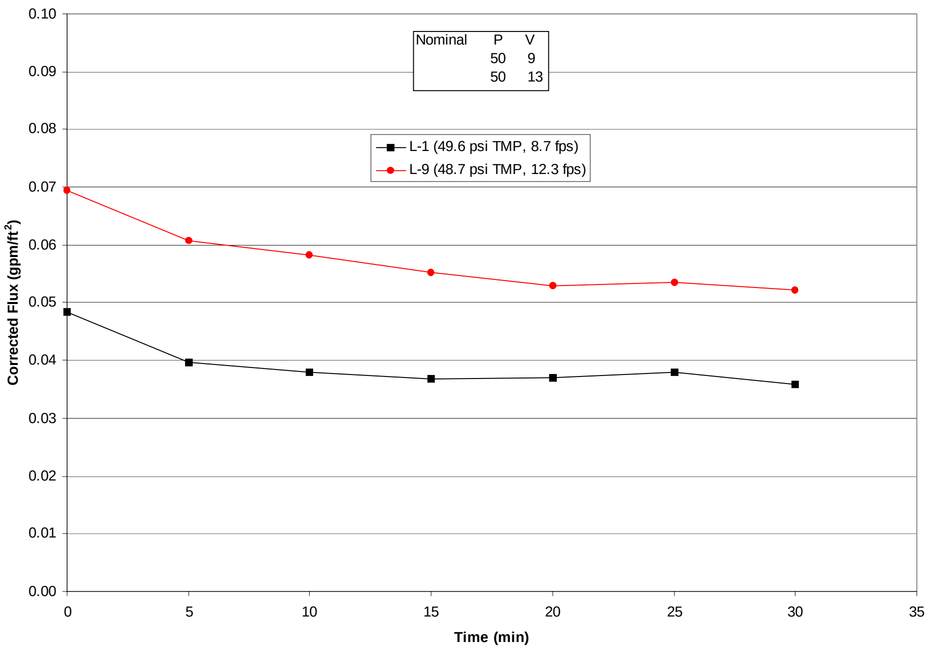

Nominal P V
30 9
50 9
L-7 (32.1 psi TMP, 9.1 fps)
L-1 (49.6 psi TMP, 8.7 fps)
Corrected Flux (gpm/ft2)
Time (min)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
25
30
35

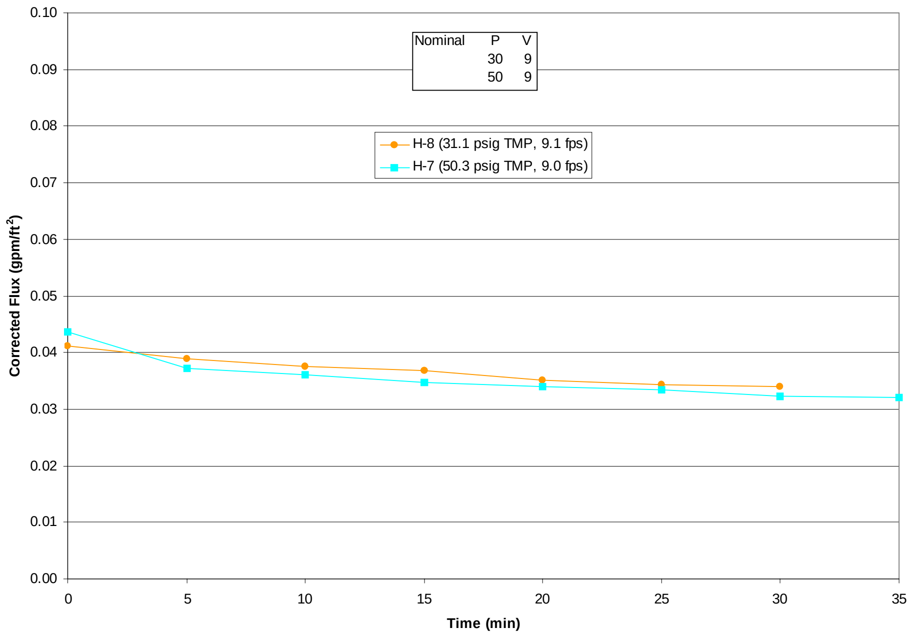

Nominal P V
20 11
40 11
60 11
L-8 (19.9 psi TMP, 10.8 fps)
L-2 (39.2 psi TMP, 10.6 fps)
L-4 (39.8 psi TMP, 11.0 fps)
L-11 (39.6 psi TMP, 11.1 fps)
L-10 (58.4 psi TMP, 7.5 fps)
Corrected Flux (gpm/ft2)
Time (min)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
25
30
35

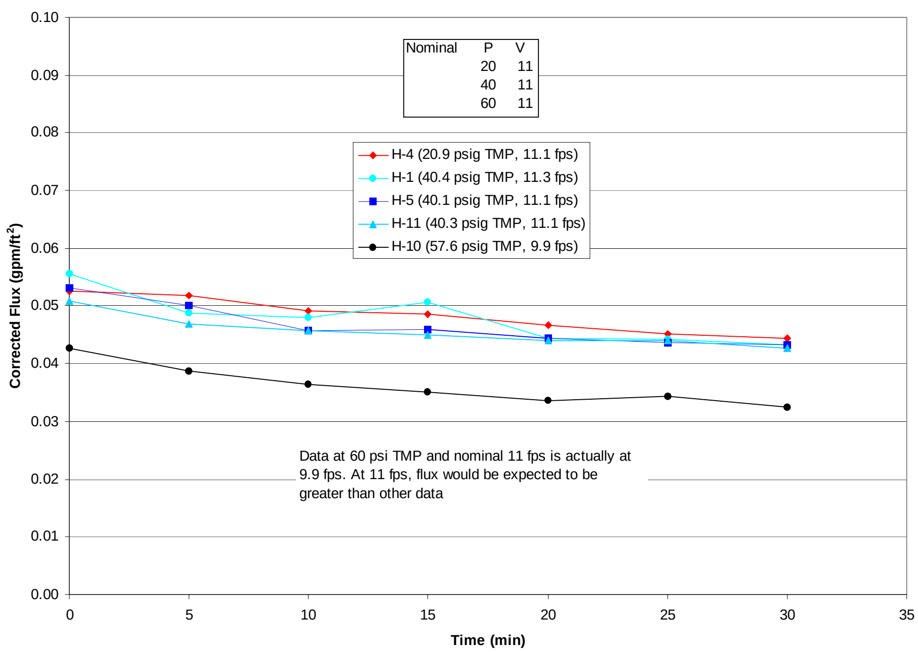

Nominal P V
30 13
50 13
L-5 (30.7 psi TMP, 13.2 fps)
L-9 (48.7 psi TMP, 12.3 fps)
Flux is inverted because velocity at 50 psi TMP is significantly less than 13 fps.
Corrected Flux (gpm/ft²)
Time (min)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
25
30
35

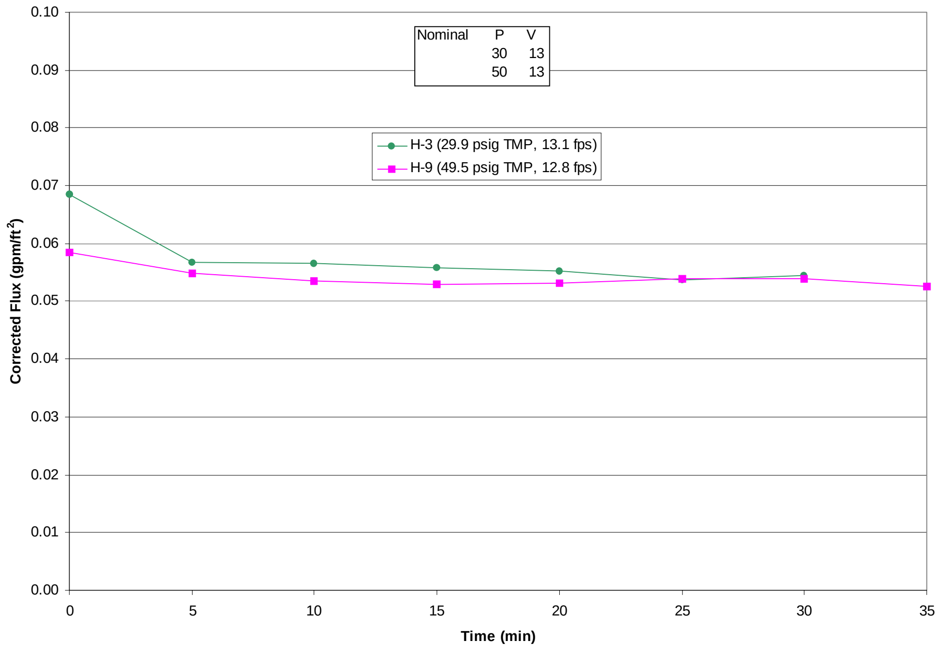

Nominal P V
30 9
30 13
L-7 (32.1 psi TMP, 9.1 fps)
L-5 (30.7 psi TMP, 13.2 fps)
Corrected Flux (gpm/ft²)
Time (min)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
25
30
35

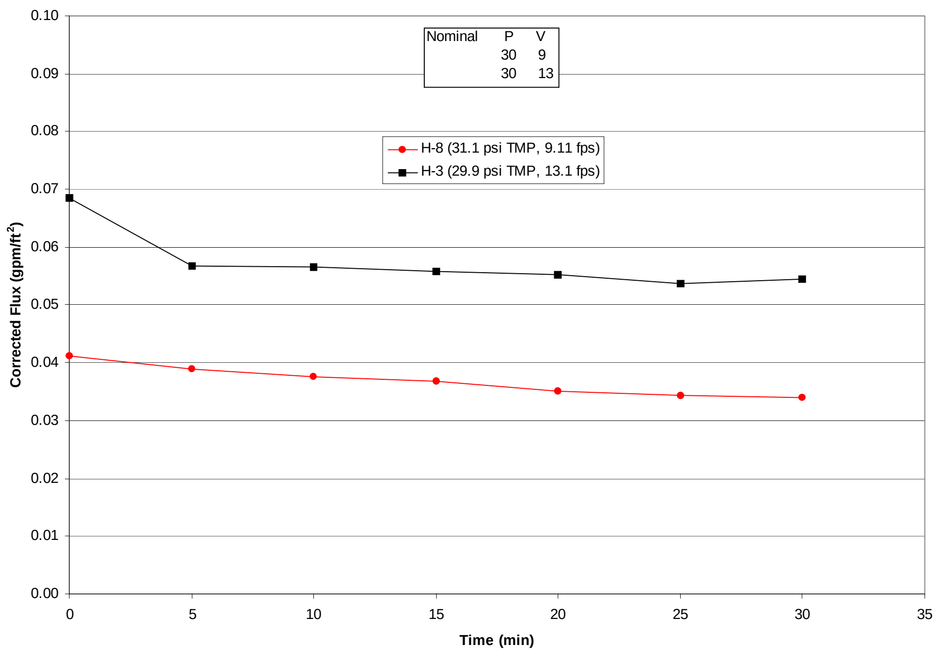

Nominal P V
40 7
40 11
40 15
L-6 (40.6 psi TMP, 6.9 fps)
L-2 (39.2 psi TMP, 10.6 fps)
L-4 (39.8 psi TMP, 11.0 fps)
L-11 (39.6 psi TMP, 11.1 fps)
L-3 (39.9 psi TMP, 14.9 fps)
Corrected Flux (gpm/ft²)
Time (min)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0
5
10
15
20
25
30
35

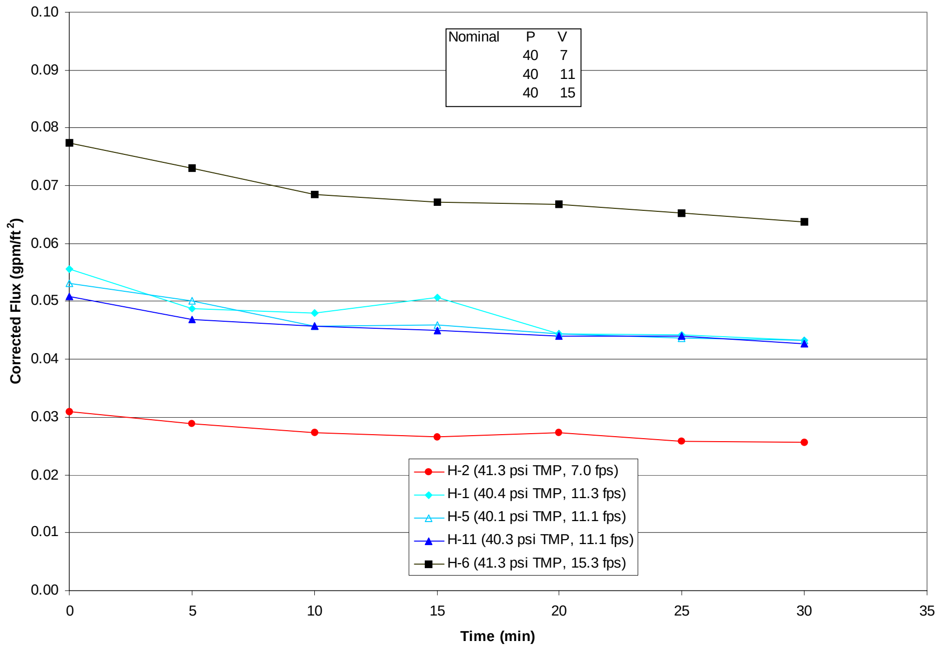

Nominal P V
50 9
50 13
L-1 (49.6 psi TMP, 8.7 fps)
L-9 (48.7 psi TMP, 12.3 fps)
Corrected Flux (gpm/ft²)
Time (min)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0
5
10
15
20
25
30
35

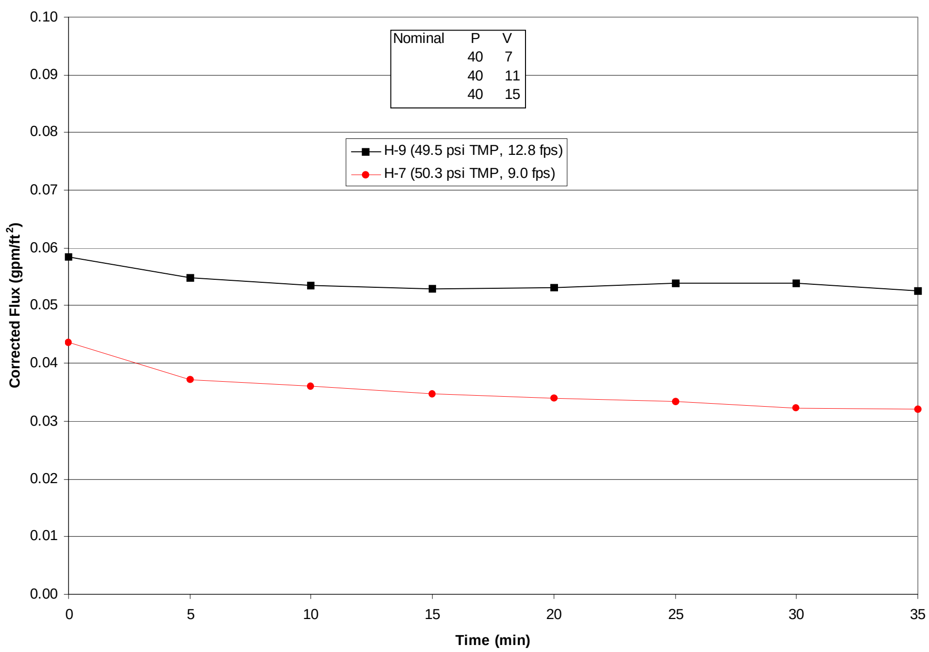

Nominal P V
30 9
50 9
H-8 (31.1 psig TMP, 9.1 fps)
H-7 (50.3 psig TMP, 9.0 fps)
Corrected Flux (gpm/ft²)
Time (min)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
25
30
35

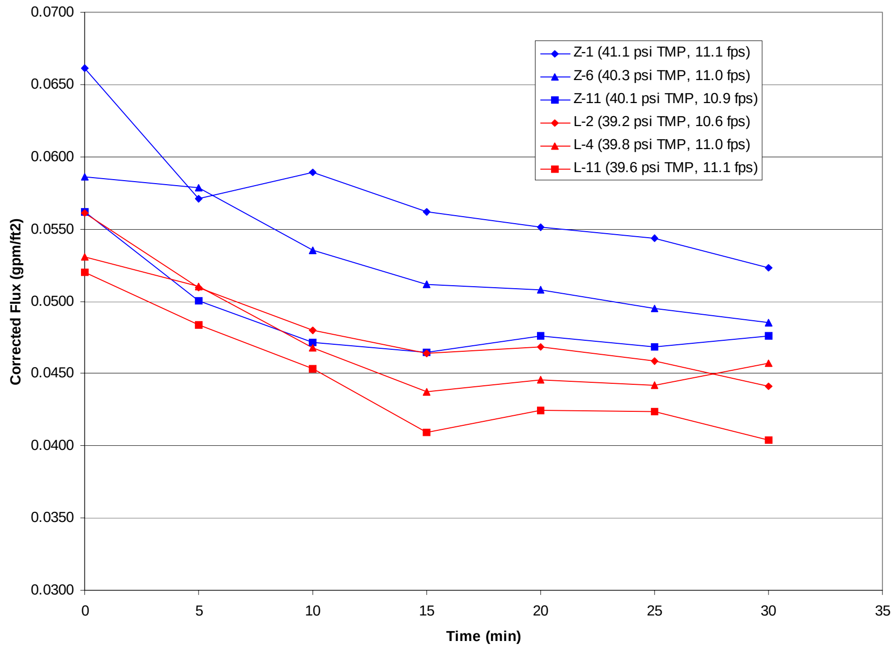

Nominal P V
20 11
40 11
60 11
H-4 (20.9 psig TMP, 11.1 fps)
H-1 (40.4 psig TMP, 11.3 fps)
H-5 (40.1 psig TMP, 11.1 fps)
H-11 (40.3 psig TMP, 11.1 fps)
H-10 (57.6 psig TMP, 9.9 fps)
Data at 60 psi TMP and nominal 11 fps is actually at 9.9 fps. At 11 fps, flux would be expected to be greater than other data
Corrected Flux (gpm/ft²)
Time (min)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
25
30
35

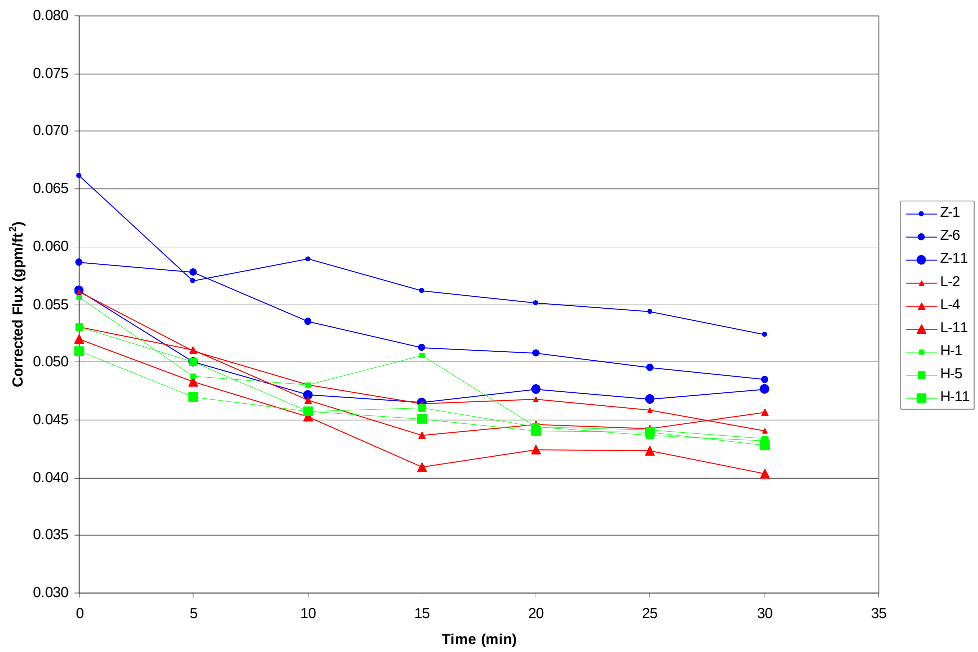

Nominal P V
30 13
50 13
H-3 (29.9 psig TMP, 13.1 fps)
H-9 (49.5 psig TMP, 12.8 fps)
Corrected Flux (gpm/ft2)
Time (min)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
25
30
35

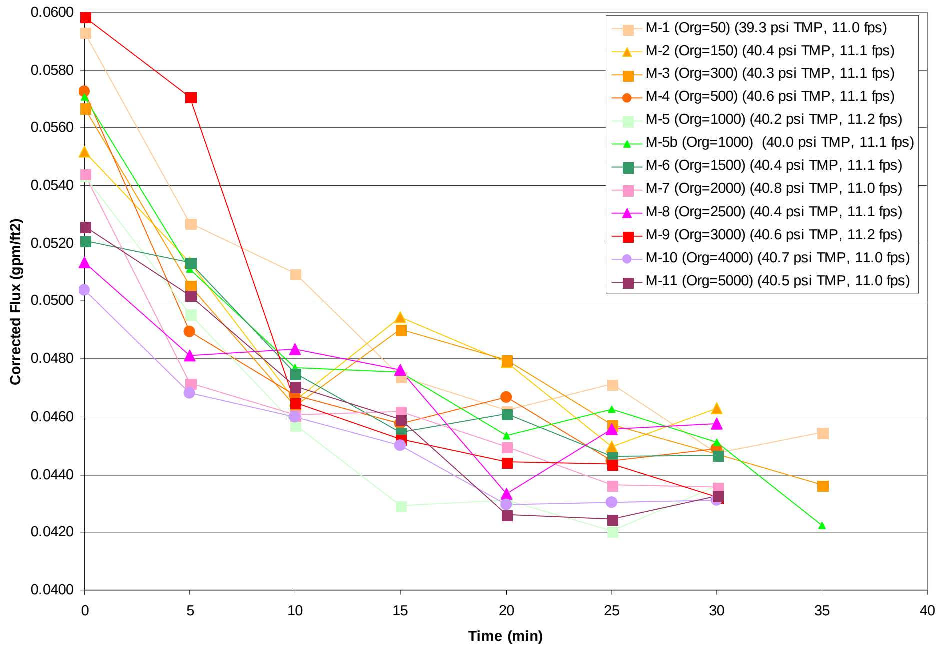

Nominal P V
30 9
30 13
H-8 (31.1 psi TMP, 9.11 fps)
H-3 (29.9 psi TMP, 13.1 fps)
Corrected Flux (gpm/ft2)
Time (min)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
25
30
35


Nominal P V
40 7
40 11
40 15
H-2 (41.3 psi TMP, 7.0 fps)
H-1 (40.4 psi TMP, 11.3 fps)
H-5 (40.1 psi TMP, 11.1 fps)
H-11 (40.3 psi TMP, 11.1 fps)
H-6 (41.3 psi TMP, 15.3 fps)
Corrected Flux (gpm/ft²)
Time (min)


Nominal P V
40 7
40 11
40 15
H-9 (49.5 psi TMP, 12.8 fps)
H-7 (50.3 psi TMP, 9.0 fps)
Corrected Flux (gpm/ft²)
Time (min)


Corrected Flux (gpm/ft2)
Time (min)
Z-1 (41.1 psi TMP, 11.1 fps)
Z-6 (40.3 psi TMP, 11.0 fps)
Z-11 (40.1 psi TMP, 10.9 fps)
L-2 (39.2 psi TMP, 10.6 fps)
L-4 (39.8 psi TMP, 11.0 fps)
L-11 (39.6 psi TMP, 11.1 fps)
0.0700
0.0650
0.0600
0.0550
0.0500
0.0450
0.0400
0.0350
0.0300
0
5
10
15
20
25
30
35


Corrected Flux (gpm/ft²)
Time (min)
Z-1
Z-6
Z-11
L-2
L-4
L-11
H-1
H-5
H-11
0.080
0.075
0.070
0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0
5
10
15
20
25
30
35


0.0600
0.0580
0.0560
0.0540
0.0520
0.0500
0.0480
0.0460
0.0440
0.0420
0.0400
Corrected Flux (gpm/ft2)
0
5
10
15
20
25
30
35
40
Time (min)
M-1 (Org=50) (39.3 psi TMP, 11.0 fps)
M-2 (Org=150) (40.4 psi TMP, 11.1 fps)
M-3 (Org=300) (40.3 psi TMP, 11.1 fps)
M-4 (Org=500) (40.6 psi TMP, 11.1 fps)
M-5 (Org=1000) (40.2 psi TMP, 11.2 fps)
M-5b (Org=1000) (40.0 psi TMP, 11.1 fps)
M-6 (Org=1500) (40.4 psi TMP, 11.1 fps)
M-7 (Org=2000) (40.8 psi TMP, 11.0 fps)
M-8 (Org=2500) (40.4 psi TMP, 11.1 fps)
M-9 (Org=3000) (40.6 psi TMP, 11.2 fps)
M-10 (Org=4000) (40.7 psi TMP, 11.0 fps)
M-11 (Org=5000) (40.5 psi TMP, 11.0 fps)

5.5 Appendix – Curve Fits from JMP

Fit of $\text{Flux} = aV^{v}P^{p}Q^{q}S^{s}(1 - bt_{adj})$

Flux = gpm/ft^2
V = velocity (fps)
P = transmembrane pressure (psi)
Q = total organics (TBP+NPH) (mg/L)
t_{adj} = cumulative run time (adjusted after t=13.5) (hr)
S = solids concentration (wt%)
a, b, p, q, s are parameters

Nonlinear Fit

Converged in the Gradient

Criterion	Current	Stop Limit
Iteration	59	60
Shortening	0	15
Obj Change	8.212934e-13	0.0000001
Prm Change	0.0000079245	0.0000001
Gradient	1.988623e-16	0.000001

Parameter	Current Value
a	0.005626668
v	1.3465218598
b	0.0033701345
q	-0.010193617
p	-0.071298492
s	-0.736696127

SSE	0.0002544523
N	45

Alpha	0.050
Convergence Criterion	0.00001
Goal SSE for CL	0.0002811028

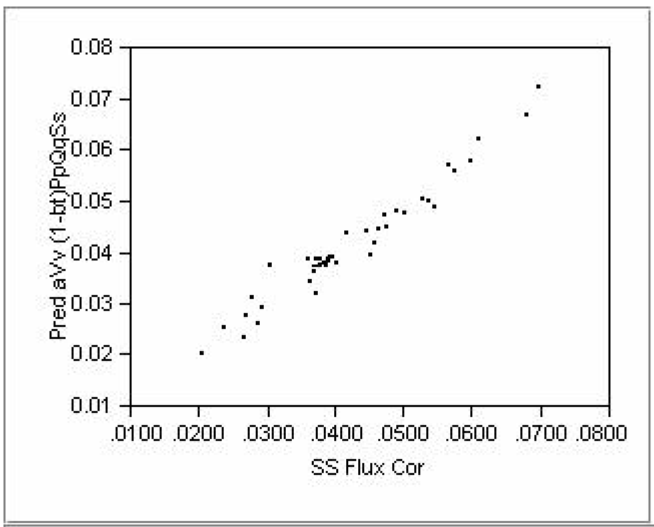
Solution

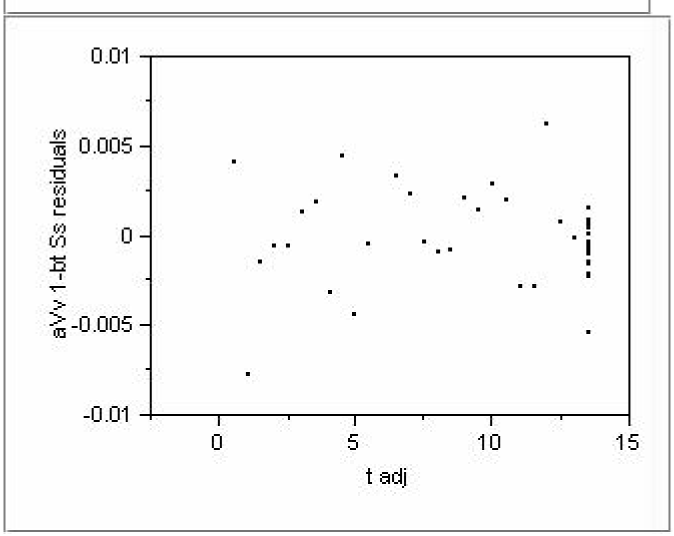
SSE	DFE	MSE	RMSE
0.0002544523	39	0.0000065	0.0025543

Parameter	Estimate	Approx. Standard Error	Lower Confidence Limit	Upper Confidence Limit
a	0.005627	0.002171	0.002543	0.002543
v	1.3465	0.05437	1.2371	1.4569
b	0.003370	0.006026	-0.009993	0.015354
q	-0.01019	0.00946	-0.02964	0.00979
p	-0.07130	0.03728	-0.14592	0.0049
s	-0.7367	0.3231	-1.3829	-0.0905

Correlation of Estimates

	a	v	b	q	p	s
a	1.0000	-0.3946	-0.1704	0.5026	-0.2821	-0.8592
v	-0.3946	1.0000	-0.1163	-0.1184	0.0458	0.0298
b	-0.1704	-0.1163	1.0000	0.6311	-0.0420	0.3103
q	0.5026	-0.1184	0.6311	1.0000	0.0219	-0.4931
p	-0.2821	0.0458	-0.0420	0.0219	1.0000	-0.0960
s	-0.8592	0.0298	0.3103	-0.4931	-0.0960	1.0000





Fit of $\mathbf{Flux = aV^{v} P^{p} Q^{q} (1 - bt_{adj})}$

Flux = gpm/ft^2
V = velocity (fps)
P = transmembrane pressure (psi)
Q = total organics (TBP+NPH) (mg/L)
t_{adj} = cumulative run time (adjusted after t=13.5) (hr)
a, b, p, q, v are parameters

Nonlinear Fit

Converged in the Gradient

Criterion	Current	Stop Limit
Iteration	4	60
Shortening	0	15
Obj Change	0.000308719	0.0000001
Prm Change	0.0646007448	0.0000001
Gradient	7.7701505e-8	0.000001

Parameter	Current Value
a	0.00264206
v	1.3503668344
b	0.0082221362
q	-0.019724438
p	-0.079136273

SSE	0.0002869069
N	45

Alpha 0.050

Convergence Criterion	0.05
Goal SSE for CL	0.000316161

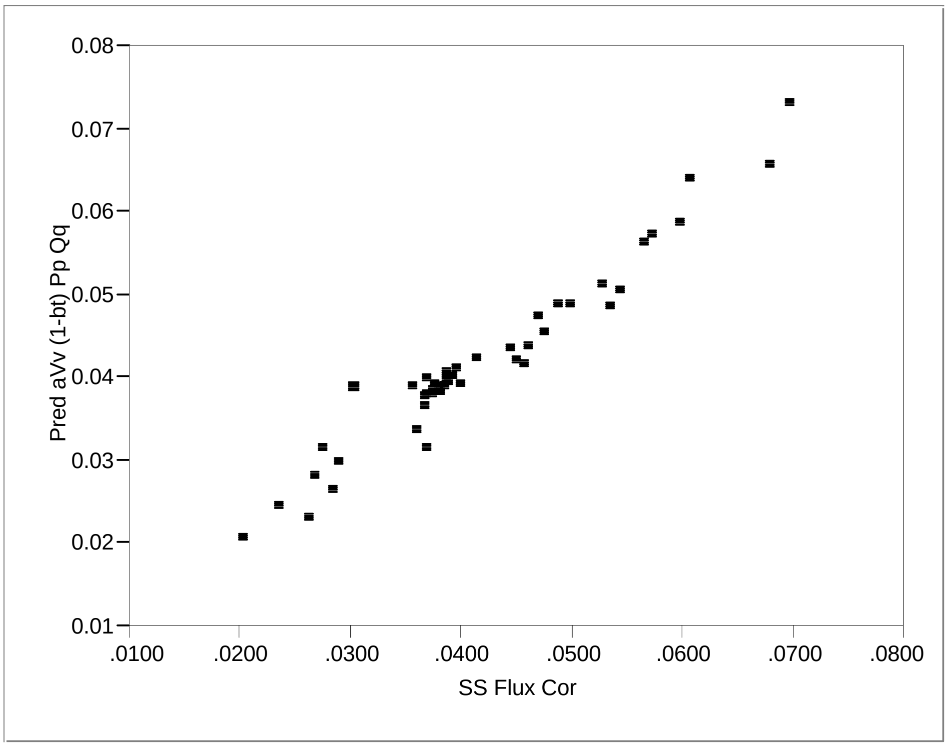
Solution

SSE	DFE	MSE	RMSE
0.0002869069	40	0.0000072	0.0026782

Parameter	Estimate	Approx. Standard Error	Lower Confidence Limit	Upper Confidence Limit
a	0.002642	0.000547	0.001728	0.004016
v	1.350	0.057	1.234	1.467
b	0.008222	0.005655	-0.004988	0.019929
q	-0.01972	0.00877	-0.03813	0.00058
p	-0.07914	0.03911	-0.15746	0.00129

Correlation of Estimates

	a	v	b	q	p
a	1.0000	-0.7219	0.1902	0.1711	-0.7145
v	-0.7219	1.0000	-0.1340	-0.1209	0.0461
b	0.1902	-0.1340	1.0000	0.9503	-0.0074
q	0.1711	-0.1209	0.9503	1.0000	-0.0244
p	-0.7145	0.0461	-0.0074	-0.0244	1.0000



Fit of $\mathbf{Flux = aV^{v}P^{p}Q^{q}(1 - bt_{adj})}$

Flux = gpm/ft^2
V = velocity (fps)
P = transmembrane pressure (psi)
Q = total organics (TBP+NPH) (mg/L)
t_{adj} = cumulative run time (adjusted after t=13.5) (hr)
a, b, p, q, v are parameters

Nonlinear Fit

Converged in the Gradient

Criterion	Current	Stop Limit
Iteration	4	60
Shortening	0	15
Obj Change	0.000308719	0.0000001
Prm Change	0.0646007448	0.0000001
Gradient	7.7701505e-8	0.000001

Parameter	Current Value
a	0.00264206
v	1.3503668344
b	0.0082221362
q	-0.019724438
p	-0.079136273

SSE 0.0002869069
N 45

Alpha 0.050

Convergence Criterion 0.05
Goal SSE for CL 0.000316161

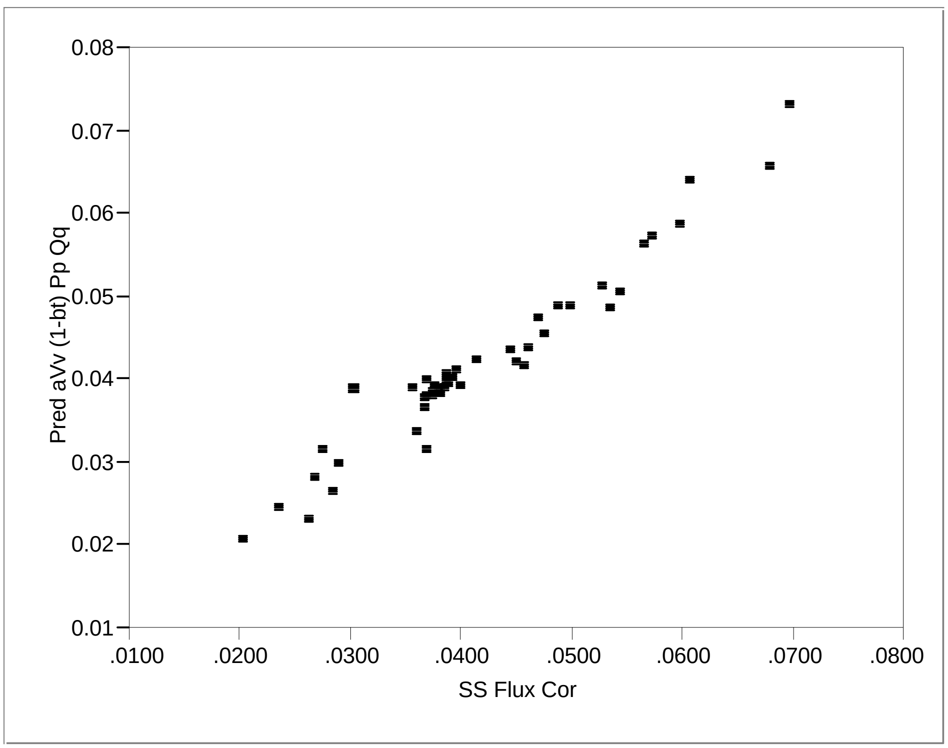
Solution

SSE	DFE	MSE	RMSE
0.0002869069	40	0.0000072	0.0026782

Parameter	Estimate	Approx. Standard Error	Lower Confidence Limit	Upper Confidence Limit
a	0.002642	0.000547	0.001728	0.004016
v	1.350	0.057	1.234	1.467
b	0.008222	0.005655	-0.004988	0.019929
q	-0.01972	0.00877	-0.03813	0.00058
p	-0.07914	0.03911	-0.15746	0.00129

Correlation of Estimates

	a	v	b	q	p
a	1.0000	-0.7219	0.1902	0.1711	-0.7145
v	-0.7219	1.0000	-0.1340	-0.1209	0.0461
b	0.1902	-0.1340	1.0000	0.9503	-0.0074
q	0.1711	-0.1209	0.9503	1.0000	-0.0244
p	-0.7145	0.0461	-0.0074	-0.0244	1.0000



Fit of $\mathbf{Flux = aV^{v}Q^{q}(1 - bt_{adj})}$

Flux = gpm/ft^2
V = velocity (fps)
Q = total organics (TBP+NPH) (mg/L)
t_{adj} = cumulative run time (adjusted after t=13.5) (hr)
a, b, q, v are parameters

Nonlinear Fit

Converged in the Gradient

Criterion	Current	Stop Limit
Iteration	3	60
Shortening	0	15
Obj Change	0.0003080764	0.0000001
Prm Change	0.0667741471	0.0000001
Gradient	8.4865869e-8	0.000001

Parameter	Current Value
a	0.0019529218
v	1.3566523696
b	0.0084367207
q	-0.019681765

SSE	0.0003152431
N	45

Alpha 0.050

Convergence Criterion	0.05
Goal SSE for CL	0.0003465571

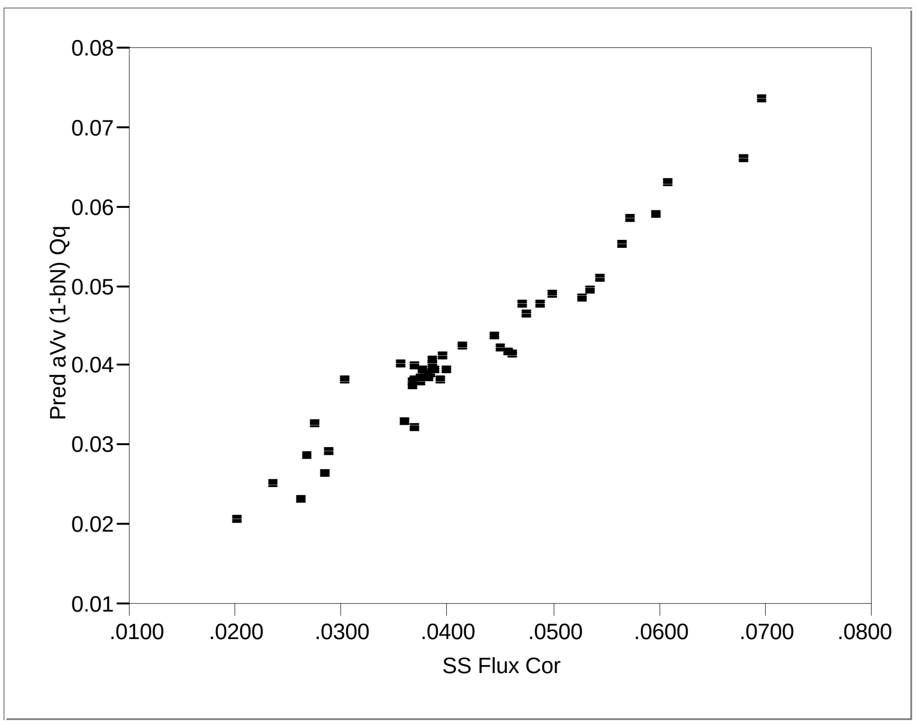
Solution

SSE	DFE	MSE	RMSE
0.0003152431	41	0.0000077	0.0027729

Parameter	Estimate	Approx. Standard Error	Lower Confidence Limit	Upper Confidence Limit
a	0.001953	0.000291	0.001438	0.00264
v	1.357	0.059	1.238	1.477
b	0.008437	0.005831	-0.005246	0.020509
q	-0.01968	0.00907	-0.03875	0.00143

Correlation of Estimates

	a	v	b	q
a	1.0000	-0.9858	0.2638	0.2191
v	-0.9858	1.0000	-0.1333	-0.1195
b	0.2638	-0.1333	1.0000	0.9504
q	0.2191	-0.1195	0.9504	1.0000



Fit of $Flux = aV^{v}S^{s}(1 - bt_{adj})$
Flux = gpm/ft^2
V = velocity (fps)
P = transmembrane pressure (psi)
Q = total organics (TBP+NPH) (mg/L)
t_{adj} = cumulative run time (adjusted after t=13.5) (hr)
a, b, s, v are parameters

Converged in the Gradient

Criterion	Current	Stop Limit
Iteration	59	60
Shortening	0	15
Obj Change	3.8329933e-7	0.0000001
Prm Change	0.0001371318	0.0000001
Gradient	1.089313e-10	0.000001

Parameter	Current Value
a	0.0054779622
v	1.3458730305
b	0.007057525
s	-0.942319127

Lock

SSE	0.0002839426
N	45
Alpha	0.050
Convergence Criterion	0.00001
Goal SSE for CL	0.0003121475

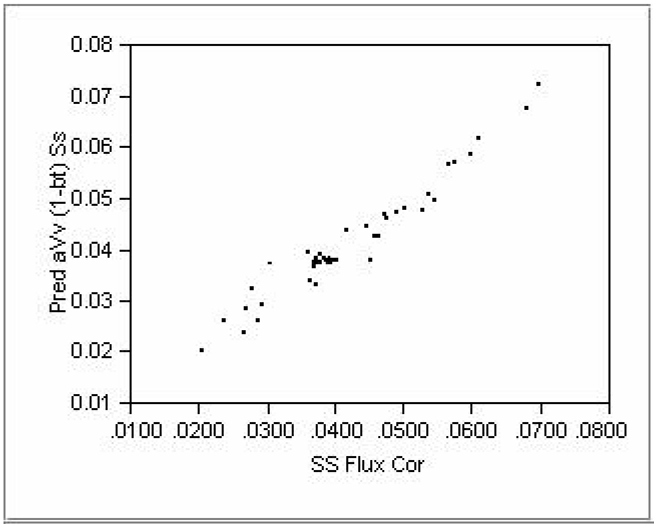
Solution

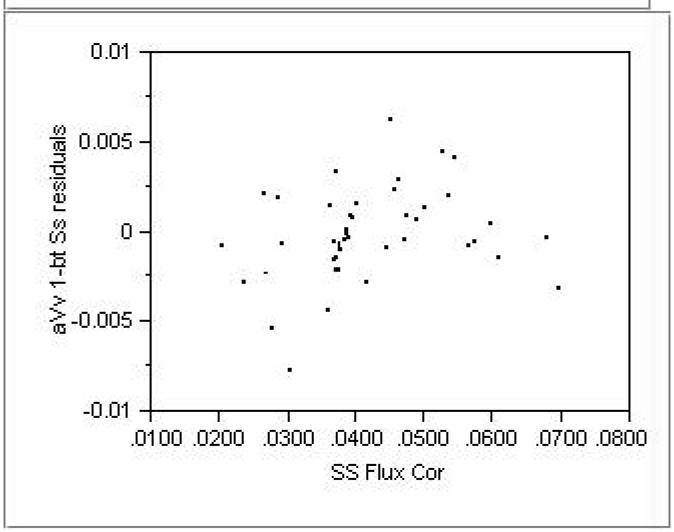
SSE	DFE	MSE	RMSE
0.0002839426	41	0.0000069	0.0026316

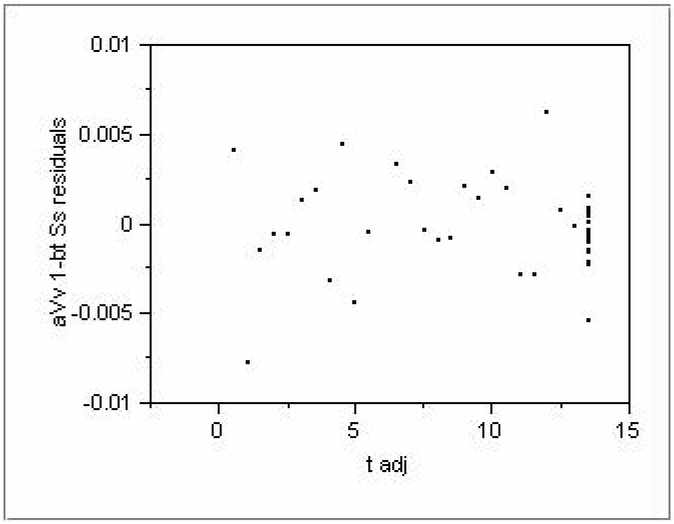
Parameter	Estimate	Approx. Standard Error	Lower Confidence Limit	Upper Confidence Limit
a	0.005478	0.001809	0.001860	0.009096
v	1.3459	0.0551	1.2354	1.4571
b	0.007058	0.004624	-0.002942	0.016239
s	-0.9423	0.2959	-1.5341	-0.3505

Correlation of Estimates

	a	v	b	s
a	1.0000	-0.3827	-0.8121	-0.9096
v	-0.3827	1.0000	-0.0522	-0.0313
b	-0.8121	-0.0522	1.0000	0.9247
s	-0.9096	-0.0313	0.9247	1.0000






0.01
0.005
0
-0.005
-0.01
aVv 1-bt Ss residuals
0
5
10
15
t adj

Fit of Flux = $aV^{v}S^{s}$
Flux = gpm/ft^2
V = velocity (fps)
S = solids concentration
a, v, s are parameters

Nonlinear Fit

Converged in the Gradient

Criterion	Current	Stop Limit
Iteration	4	60
Shortening	0	15
Obj Change	0.0013144702	0.0000001
Prm Change	0.0009129883	0.0000001
Gradient	3.9218594e-7	0.000001

Parameter	Current Value
a	0.0080168667
v	1.3501400332
s	-1.333106672

SSE	0.0002983598
N	45
Alpha	0.050
Convergence Criterion	0.00001
Goal SSE for CL	0.0003272513

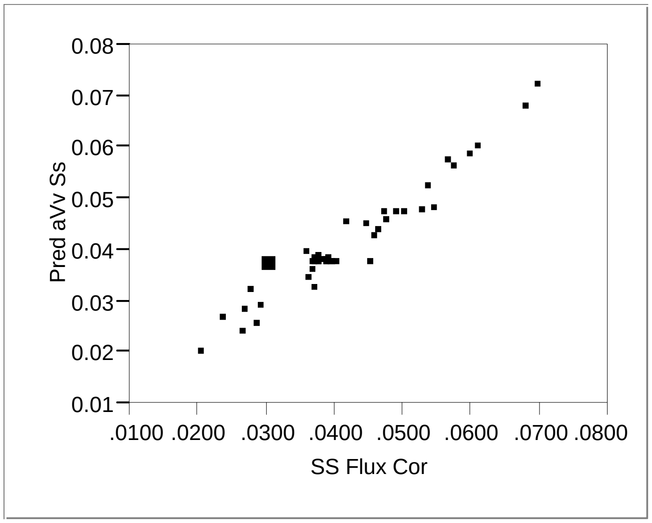
Solution

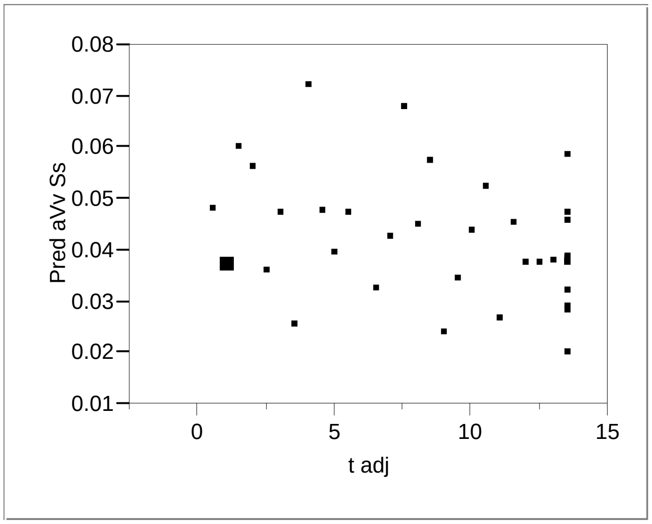
SSE	DFE	MSE	RMSE
0.0002983598	42	0.0000071	0.0026653

Parameter	Estimate	Approx. Standard Error	Lower Confidence Limit	Upper Confidence Limit
a	0.008017	0.001568	0.005391	0.010643
v	1.3501	0.0558	1.2388	1.4624
s	-1.3331	0.1148	-1.5648	-1.1023

Correlation of Estimates

	a	v	s
a	1.0000	-0.7276	-0.7156
v	-0.7276	1.0000	0.0438
s	-0.7156	0.0438	1.0000


0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Pred aVv Ss
.0100 .0200 .0300 .0400 .0500 .0600 .0700 .0800
SS Flux Cor


0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Pred aVv Ss
0
5
10
15
t adj

Fit of $\mathbf{Flux = aV^{v}(1 - bt_{adj})}$

Flux = gpm/ft^2
V = velocity (fps)
t_{adj} = cumulative run time (adjusted after t=13.5) (hr)
a, b, v are parameters

Nonlinear Fit

Converged in the Gradient

Criterion	Current	Stop Limit
Iteration	2	60
Shortening	0	15
Obj Change	0.0000272661	0.0000001
Prm Change	0.0050122417	0.0000001
Gradient	9.3709483e-9	0.000001

Parameter	Current Value
a	0.0020910329
v	1.3418623025
b	0.0194210721

SSE	0.0003425838
N	45

Alpha 0.050

Convergence Criterion	0.05
Goal SSE for CL	0.0003757578

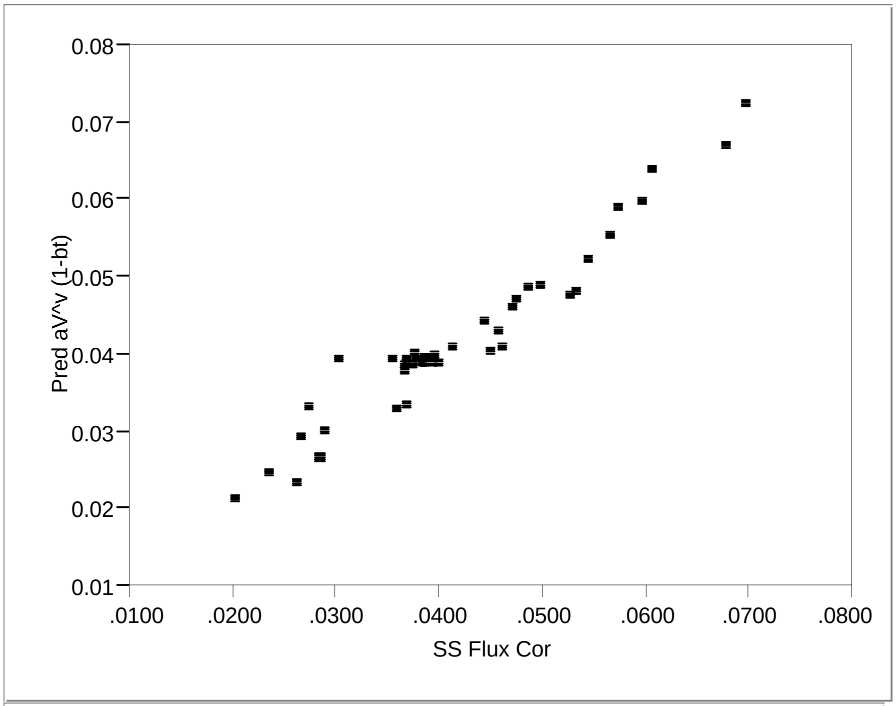
Solution

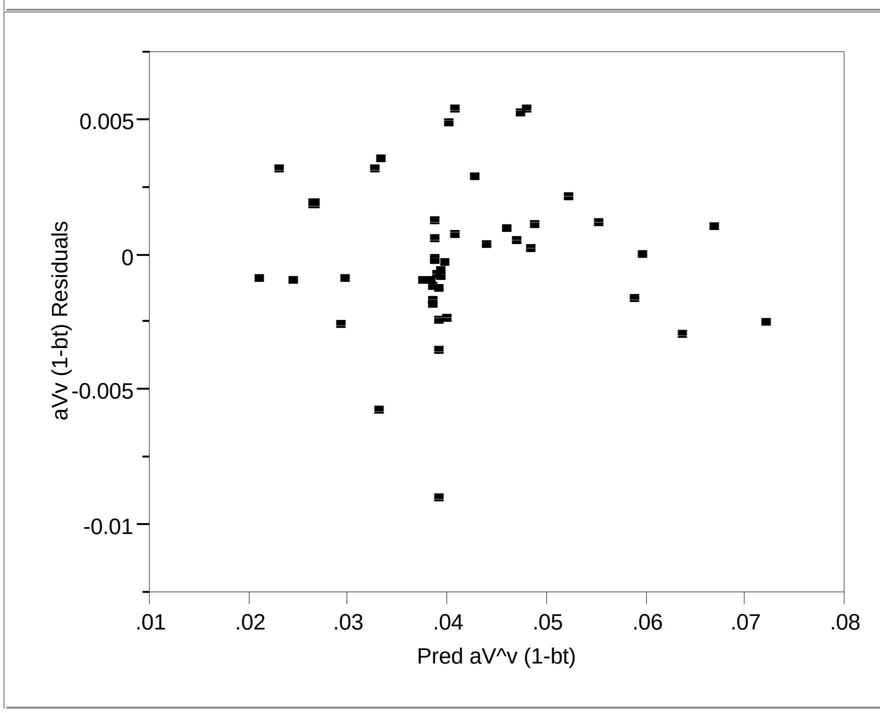
SSE	DFE	MSE	RMSE
0.0003425838	42	0.0000082	0.002856

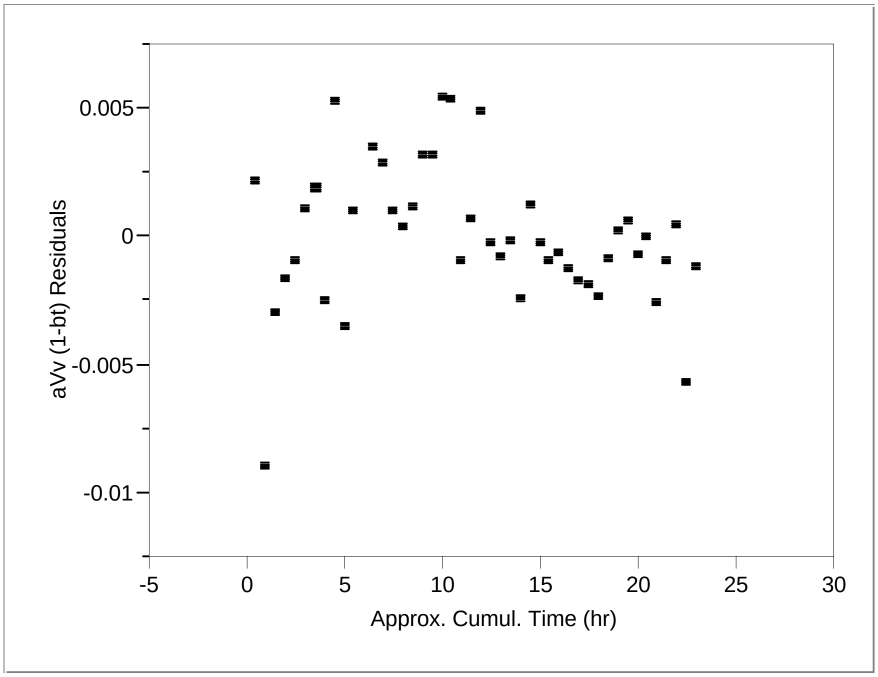
Parameter	Estimate	Approx. Standard Error	Lower Confidence Limit	Upper Confidence Limit
a	0.002091	0.000311	0.001543	0.002821
v	1.342	0.0602	1.221	1.464
b	0.01942	0.00149	0.01631	0.02233

Correlation of Estimates

	a	v	b
a	1.0000	-0.9914	0.1717
v	-0.9914	1.0000	-0.0597
b	0.1717	-0.0597	1.0000






0.005
0
-0.005
-0.01
aVv (1-bt) Residuals
-5
0
5
10
15
20
25
30
Approx. Cumul. Time (hr)

6.0 References

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