PERFORMANCE IMPROVEMENT OF CROSS-FLOW FILTRATION FOR HIGH LEVEL WASTE TREATMENT – 11189

Mark R. Duignan, Charles A. Nash, Michael R.Poirier, and Caroline E. Johnson
Savannah River Nuclear Solutions
Savannah River National Laboratory
Aiken, SC 29808

ABSTRACT

In the interest of accelerating waste treatment processing, the DOE has funded studies to better understand filtration with the goal of improving filter fluxes[†] in existing cross-flow equipment. The Savannah River National Laboratory (SRNL) was included in those studies, with a focus on start-up techniques, filter cake development, the application of filter aids (cake forming solid precoats), and body feeds (flux enhancing polymers). This paper discusses the progress of those filter studies.

Cross-flow filtration is a key process step in many operating and planned waste treatment facilities to separate undissolved solids from supernate slurries. This separation technology generally has the advantage of self-cleaning through the action of wall shear stress created by the flow of waste slurry through the filter tubes. However, the ability of filter wall self-cleaning depends on the slurry being filtered. Many of the alkaline radioactive wastes are extremely challenging to filtration, e.g., those containing compounds of aluminum and iron, which have particles whose size and morphology reduce permeability.

Unfortunately, low filter flux can be a bottleneck in waste processing facilities such as the Savannah River Modular Caustic Side Solvent Extraction Unit and the Hanford Waste Treatment Plant. Any improvement to the filtration rate would lead directly to increased throughput of the entire process. To date increased rates are generally realized by either increasing the cross-flow filter axial flowrate, limited by pump capacity, or by increasing filter surface area, limited by space and increasing the required pump load.

SRNL set up both dead-end and cross-flow filter tests to better understand filter performance based on filter media structure, flow conditions, filter cleaning, and several different types of filter aids and body feeds. Using non-radioactive simulated wastes, both chemically and physically similar to the actual radioactive wastes, the authors performed several tests to demonstrate increases in filter performance. With the proper use of filter flow conditions and filter enhancers, filter flow rates can be increased over rates currently realized today.

INTRODUCTION

Cross-flow filtration is a widely used technology to separate liquids from solids, and the world market is projected to grow to ten billion dollars by 2015 [1]. While it is a well established technology, the method of use varies widely, and the efficiency of its separation varies for each different industrial application, especially within production-end product categories, from pharmaceutical to water treatment, hazardous waste treatment, etc. For the DOE Complex the stored radioactive wastes are being prepared for long-term storage and disposal with many technologies, but treatment of much of that waste begins with the separation of suspended solids from the liquid by filtration, including cross-flow filtration. Those wastes can be very challenging to filters. Such poor performance would be a bottleneck for an entire processing cycle. A better understanding of cross-flow filtration with such wastes may help to increase filter performance and thus overall waste treatment throughput. This study finds that filter performance can be improved with the existing hardware in current treatment plants.

[†] Filter flux is the flow rate of filtered liquid per filter surface area. No standard unit exists for filter flux. Common units and equivalences: 100 L/h•m^2 = 2.78 E-05 m/s (or m^3/s•m^2) = 10 cm/hr = 0.0409 gpm/ft^2.

Filtration Specifics

The two items of focus for cross-flow filtration at the Savannah River and Hanford Sites are the filters themselves and the waste to be treated. Details of each are given later, but highlights are described here. Figure 1 is a diagram of a typical cross-flow filter arrangement in a horizontal orientation but could be vertical or at some other inclination. The arrows in the center, parallel to the tubes, represent the slurry flow or the axial velocity (AV) of the slurry. The inner tube is the porous filter medium housed by a larger outer tube to contain and direct the liquid separated from the slurry. The arrows perpendicular to the tubes represent the liquid, called the filtrate or permeate. The motive force that drives the liquid through the filter wall is the difference in pressure from the slurry to the filtrate and is referred to as the transmembrane pressure (TMP).

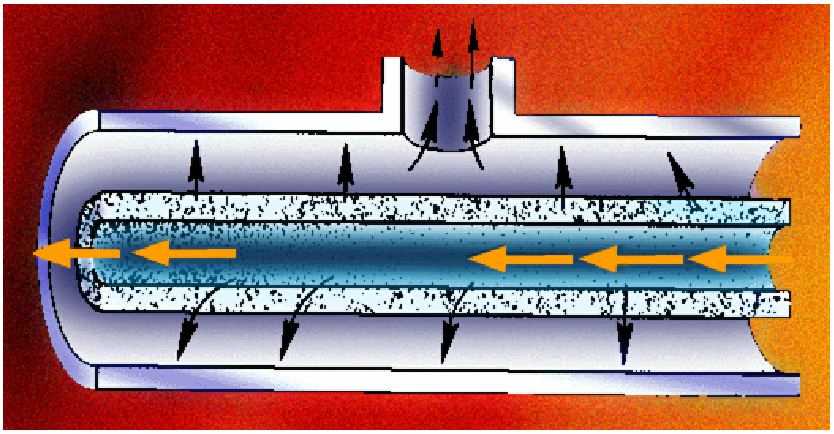

Figure 1. Typical Cross-Flow Filter Arrangement

In the past many different filter media have been used at these sites. Currently, two large treatment plants are under construction, the Waste Treatment Plant (WTP) at Hanford and the Salt Waste Processing Facility (SWPF) at Savannah River. For the former the cross-flow filters are 0.0127-m (1/2–inch) inside diameter stainless steel tubes, and for the latter, 0.0095-m (3/8-inch) inside diameter stainless steel tubes. This study determines differing performances between these filters. Both of these filters are made with a 0.1 micron nominal pore rating and of a symmetric sintered metal design. Because the only difference between these two filters is geometry, another tube design was added for comparison. This third tube has an asymmetric design, a 0.0095-m (3/8-inch) inside diameter, and a 0.1 micron absolute pore rating. While this last tube is still made primarily of sintered stainless steel, the inner tube surface is coated with a 10-micron thick layer of zirconia. To elicit a side-by-side performance of all three filter tubes they were placed in parallel in a test facility such that the same test simulant would flow through each at the same time. Because the properties of wastes to be treated can change with time, it is important to remove the issue of aging, which could confound results.

The range of wastes to be treated is large [2], but in general they usually have high soluble ionic salt contents and are radioactive. Due to the risk and costs of radioactivity, testing was done with a non-radioactive simulant; however, actual waste testing will be necessary in the future. The selected simulant was made so the chemical and physical properties were both similar to the actual waste. It was important to choose a waste that would be difficult to filter. The waste should contain components that make filtration difficult [3], e.g., iron and aluminum oxides and small particle size, and should have some past history of filtration so a comparison could be made. Two candidates were initially selected, Sludge Batch 6 and SRS Tank 8F. Due to limited resources, only one could be tested; therefore, they were both tested in a dead-end filter to make a final selection of one simulant.

Backpulsing

When dealing with micro or ultra-filtration, one operational issue often considered is how to maintain a filter surface free of cake. The rationale is that a cake-free surface will allow the solid-liquid separation to occur faster. While filtering to maintain a surface cake-free or minimize cake buildup, the predominant method is backpulsing. In many cases such as the water treatment industry, backpulsing is absolutely necessary to maintain a high permeate flux [4]. Some backpulsing frequencies can be quite high; for instance, it could be as high as 1 Hz used by some in the biochemical industry [5] where the backpulse duration lasts only fractions of a second. Some [6] state that "one method of reducing membrane fouling is rapid backpulsing" where backpulsing involves the reversal of the permeate flow through the filter membrane for very short periods, and that this "can provide in situ cleaning by removing some of the foulants from the membrane surface or pores." Up to a 30-fold increase with backpulsing over no backpulsing has been realized.

At issue is an ongoing need to keep the filter surface clean, i.e., free of cake. Is this the approach method for all slurries? When waste processing plants were designed to treat stored salt wastes at the Hanford and Savannah River sites, backpulsing was included to help maintain filter fluxes high. Unfortunately during the past decade or even longer, filter tests have shown that backpulsing has not been very effective [7-9]. While much time and effort were invested to design robust flow-reversing systems, results have not been promising.

Along with backpulsing, another method to keep the filter surface clean or to minimize cake buildup was to flow the suspension fluid very fast past the filter surface, so the shear stress would strip the cake from the wall. However, typical axial flowrates used in operation, e.g., 3-5 m/s, may not suffice for some suspensions that are viscous or have a strong affinity for the filtering surface. However, if it were possible to disassociating the wall shear from slurry flow, a shear rate may be attainable to keep the filter wall clean.

To address this need, a concept of a rotary microfilter [10] was developed that spins the filtering surface at a rate such that the filter outer surface moves at more than 18 m/s. In fact approximately 70% of the filtering surface is kept completely free of cake. Having a clean filtering surface does lead to high filtering fluxes; initially, however, when the filter is keep clean, either by backpulsing or high shear rate, the surface is always exposed to the smallest particles in a slurry. Specifically for backpulsing it has been shown that once a cake is lifted off a filter surface the smallest particles are the first to return to the surface, which accelerates depth fouling [11-12]. Because of this fact, backpulsing was recommended to be kept at a minimum [7].

Cake Development

Because of poor filter performances and the ineffectiveness of backpulsing with stored salt wastes [3, 7], SRNL test plans were developed to filter without any backpulses and to actively try to establish a cake that would be more permeable and thus lead to better filter fluxes. Of course, the filter membrane itself is a filter, but by the forming of a filter cake on the surface, a secondary filter is established [13]. When forming a cake, it is always important to take into account the nature of the slurries and sludges being filtered [14]. From past work [7] it appeared that the salt wastes adhered well to the filter surface based on the loss of the backpulse effectiveness in a very short time (hours), a time short enough that filter depth fouling was probably unlikely. Unfortunately, there is no direct evidence of surface adhesion or fast depth fouling; therefore, an assumption of good adhesion led to the method of cake development used in this study. In the past, the procedure to start and maintain filtration was to fill the filtration and slurry systems, start filtration with an immediate backpulse, and then periodically backpulse when the filtrate flux became unacceptably low [7-9]. Depending on the waste stream, the effectiveness of backpulsing dropped at different rates and eventually filtration had to be stopped to chemically clean the filter membrane to remove the depth fouling.

The intention of the present study was to not avoid cake buildup, but to actively establish a cake that would hopefully be permeable and act to filter even smaller particles than what the filter membrane was capable of handling. If successful then the developed cake would allow a high a filtrate flux. Furthermore, to maintain the flux high, a mechanism of what will be called “scouring” was tried. This is an action of stripping off some of the established cake to remove the smallest particles [15] by increasing the slurry axial velocity for a short period while no filtration is occurring.

Scouring

During the test many trials were performed to observe if filtrate flux could be improved while filtering without the need of cleaning. A method that seemed to work the best the authors termed “scouring.” The intention was that when the filter is operating with an established filter cake, the filter flux would be stopped for a few minutes while the slurry was allowed to circulate. Then axial velocity of the slurry would be increased by 50 to 80% above the operational velocity. After being held at this higher velocity, the velocity is then returned to the original value while filtrate flow is reestablished very slowly over a 15-minute period. The hope was that scouring would leave a base filter cake, free of the smallest particles, which would return the filter rate to what was initially established at start-up. If successful the further hope was this process of scouring and reestablishing of a high filter flow could be repeated indefinitely.

Cleaning

Due to depth fouling, eventually the filter performance will drop to a non-productive level or the transmembrane pressure increases beyond what is sustainable. When a filter reaches this point, generally mechanical methods, e.g., backpulsing or high shear rates, become ineffective to recover filtration. Filtration needs to stop and the filters need to be cleaned chemically. Cleaning is obviously dependent on the material causing the fouling.

For salt wastes stored at SRS and Hanford, a series of different chemicals have been used, but the most common is 2 M to 4 M nitric acid or 0.5 M oxalic acid. A benchtop study was performed [16] using actual radioactive wastes that included both of these acids and concentrations and found these acids did a similar job of cleaning. The oxalic acid was more effective at dissolving iron, titanium, and silicon, while the nitric did better with aluminum; however, both continued to dissolve all the compounds during the 8-hours of contact time. While both nitric and oxalic acids have been used for years to dissolve waste compounds, the general consensus is that oxalic does a slightly better job [9, 17-19] and was used for this test.

Filter Enhancers

In an attempt to seek other methods to improve filter performance, several filter aids and body feeds were evaluated. Filter aids are substances that coat a filter to improve overall permeability. Body feeds are compounds made to react with a slurry to flocculate solids to hopefully create a more permeable cake.

EXPERIMENTAL SETUP

Cross-Flow Filter Equipment

Figure 2 is a schematic of the test rig, made up of three basic flow loops:

1. Slurry loop – contains three 0.6-m long filters and their housings, which serve as the primary flow path for circulating slurry. This “loop” was really made of three sub-loops so the three filters could be controlled, separated to maintain the same flow conditions in each despite their geometric differences.
2. Filtrate loop – begins at the filter housing and allows the separated filtrate liquid from each filter to flow to a common header directed back to the slurry tank.
3. Cleaning loop – allows the three filters to be cleaned without removing most of the test slurry that remained in the lower portion of the test rig during cleaning.

To circulate slurries in the test rig, two 10 hp Galigher centrifugal pumps were used. The impeller and impeller housing were lined with EPDM to be compatible with both the $\mathrm{pH} > 14$ slurry that was tested and the $\mathrm{pH} < 1$ acid cleaning solutions. The two pumps were used in series for the slurry loop to attain a head of greater than 450 kPa at 225 lpm.

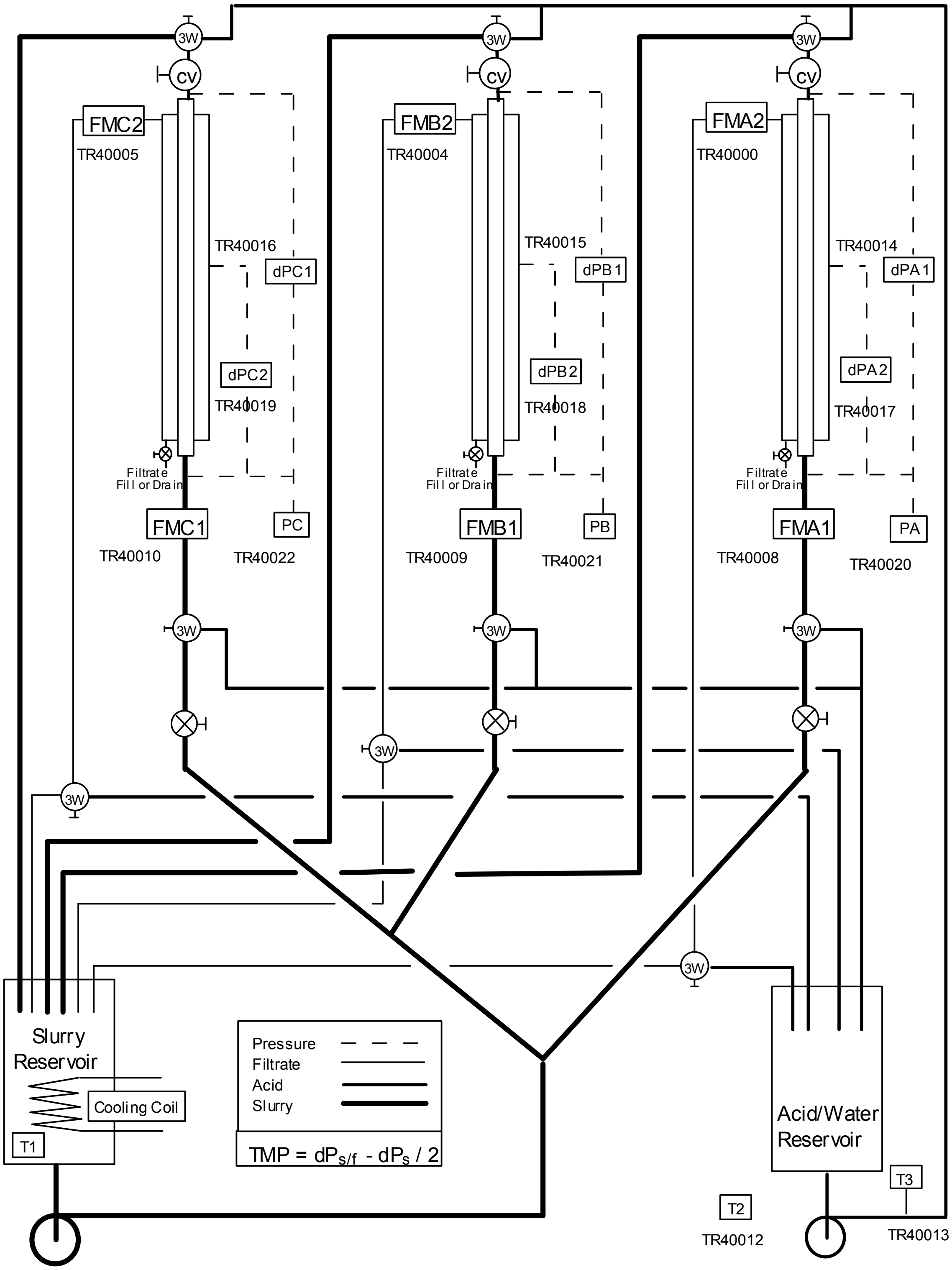

Figure 2. SRNL Pilot-Scale Cross-Flow Ultrafiltration Test Facility Schematic

Cross-Flow Filters

Details for the three cross-flow filters tested are in Table I.

Table I. Test Filter Tubes

Filter a	Actual Inside Diameter m (in.)	1 x Standard Deviation m	Actual Outside Diameter m	Medium Design b	Primary Material	Active Length m (in.)	Filter Surface Pore Rating d
1/2-inch Mott	0.01237 (0.487)	6.62E-05	0.01658	Symmetric	316L Stainless Steel	0.572 (22.5)	0.1 micron nominal
3/8-inch Mott	0.00923 (0.363)	6.91E-05	0.01301	Symmetric	316L Stainless Steel	0.572 (22.5)	0.1 micron nominal
3/8-inch Pall	0.00994 (0.391)	8.32E-05	0.01218	Asymmetric c	316L Stainless Steel	0.572 (22.5)	0.1 micron absolute

a. Mott refers to the Mott Corporation; Pall, to the Pall Corporation.
b. Symmetric = filter has same material and pore rating throughout; Asymmetric = filter has two or more materials and pore ratings.
c. Pall filter consists of 10 micron thick inner surface made of zirconia and stainless steel substrate has a much larger pore rating.
d. The word “nominal” for a filter rating is a vague term because its meaning is manufacturer dependent. Further, a “nominal” rating does not give an exact size to a filter medium but rather an approximation to the expected performance of a filter. In the case of Mott, a nominal rated 0.1-micron filter means approximately 95% of particles greater than 0.1 micron will not pass the filter. For the 0.1 micron absolute rate 100% of particles greater than 0.1 micron will not pass the filter. A rough approximation between the two ratings is a 0.1 micron; nominal has been equated to 0.7 micron nominal rating [19].

All three filter tubes were machined to the same length of 0.6 (2 ft) and after being placed in each filter housing, they had an active filter length of 0.572 m (22.5 in). Note the filter wall of the Mott tubes was of a symmetric design while the Pall filter had the asymmetric design with an inner coating of zirconia.

Instrumentation

The measurement equipment for this experiment included:

- 5 type E thermocouples with accuracies*0.6 to 1.1°C
- 6 differential pressure transducers with accuracies* 0.14 to 0.83 kPa (0.02 to 0.12 psid)
- 3 gauge pressure transducers with accuracies* 0.28 to 0.41 kPa (0.04 to 0.06 psig)
- 3 magnetic flow meters (filtrate) with accuracies* 1.89 to 6.06 E-6 m^3/m (0.0005 to 0.0016 gpm)
- 3 magnetic flow meters for slurry with accuracies* 1.14 to 2.27 E-4 m^3/m (0.03 to 0.06 gpm)
- 1 turbidity meter ±2% reading or 0.01 NTU, whichever is greater

*Accuracy is a function of the instrument and calibration. The uncertainty introduced through the use of the 16-bit data acquisition system was insignificant (<0.1% reading) and was not included in the values above.

Measurement Uncertainty

The measurement uncertainties (95% confidence level) for the important calculated quantities are as follows:

Slurry Velocity in a Filter Tube	± 9 %
Transmembrane Pressure	± 1 %
Filtrate Flux	± 12 %

Simulated Waste Slurry

Two waste simulants were obtained for this test, a HM Waste Simulant – Sludge Batch 6 (SB6) and a Purex Waste Simulant – SRS Tank 8F.

In a separate dead-end filter test, described later, the SB6 was found to filter significantly slower than the Tank 8F waste. Note, the dead-end filters used are Nalgene laboratory filter cups and not the cross-flow filter tubes. The SB6 was chosen for the cross-flow filter test, and the properties of the SB6 sludge properties are in Tables II and III. The yield stress of 54.6 Pa for SB6 simulant is equivalent of waste tanks with the highest yield stresses and therefore should be conservative in this aspect.

Table II. SB6 Sludge Makeup

Component	**Calcined Solids Wt %**	**Calcined Solids Wt %**
	Target	***Actual***
Al$_1$	16.181	15.8
Ca	1.147	1.08
Ce	0.085	0.08
Cu	0.085	0.1
Fe	17.743	18.02
K	0.021	0.24
La	0.074	0.08
Mg	0.552	0.55
Mn	5.982	6.31
Na	19.305	17.77
Ni	2.231	2.3
S	0.712	0.28
Si	1.232	1.52
Zn	0.053	0.06
Zr	0.234	0.22
Sum	66.03	64.4

Table III. Properties of SB6 Sludge

	Target	***Actual***
Slurry density g/mL	1.12 ±0.05	1.12
Total Solids, wt %	18.17 ± 2%	16.7
Insoluble Solids, wt %	14 ± 1%	10.4
<u>Anions</u>		
Nitrite, NO_2^-	8807 ±10%	11100
Nitrate, NO_3^-	6096 ±10%	6470
Phosphate, PO_4^{3-}	27 ±25%	<100
Sulfate, SO_4^{2-}	904 ±25%	1060

Notes:

Simulant properties “as-received”:

- Bingham Yield Stress 54.6 Pa
- Bingham Consistency = 17.8 cP

The SB6 was mixed with a 5.6 M supernatant to obtain the desired solids loading before testing.

The particle size for the particles for the SB6 simulant had a large variation from 0.3 to 300 microns, which captured well the ranges expected in the actual wastes [20]. In fact, particle size distribution was tri-modal with peaks at approximately 0.8, 8, and 50 microns. It was assumed this range would be very challenging to the filters.

DISCUSSION

Selection of a Simulated Waste, Solids Loading, and Filter Enhancers

Before the cross-flow filtration began, two salt waste simulants, Sludge Batch 6 (SB6) and SRS Tank 8F, were tested against each other in a dead-end filter for filterability and at two different solids loadings. To these sludges 5.6 M sodium supernatant was added to attain a solids loading of 0.1 wt% and 5 wt%. The resulting slurries were placed in four Nalgene dead-end filters with 0.45-micron nylon filters. The results indicated that SB6 simulant was the most challenging to filtration because its filtering rate was 60% slower than Tank 8F simulant at 0.1 wt% and 80% slowly at 5 wt%. Furthermore, the higher solids loading lead to significantly slower filter rates. Therefore, the SB6 slurry was selected at a 5 wt% solids loading.

Filter Enhancers

The dead-filter testing was also useful to select the best filter enhancer. The enhancers can be classified into two groups, filter aid and body feed. A filter aid is generally made of solid particle to precoat the filter surface to produce a more permeable cake; tested were silicon carbide, titanium oxide, and two types of activated carbon, DARCO® S-51HF and DARCO® S-51FF by Norit Americas, Inc. A body feed can be a chemical that acts on the slurry to flocculate solids; tested were PEO and Supefloc HX200, both by Cytec Industries, Inc. Several different combinations were tried, which determined that the body feeds did not enhance the filter flux, but some of the filter aids showed promising results. The SiC led to 15% increase in filter rate, the HF activated carbon led to 30% increase in filter rate, and the FF activated carbon resulted in a 50% increase in dead-end filtering rate. The S-51FF filter aid was the best candidate to test.

Cake Development, Long-Term Slurry Flux at 5 wt% UDS, and Scouring

The overall test results are in Figure 3. The three filters were pre-conditioned by previously subjected them with the test slurry followed by a pre-acid water rinsing, an acid cleaning, and a post-acid water rinsing. This was repeated until the water fluxed returned to those obtained before filtering with slurry. This preconditioning was to try to put the filters in a “used” condition to avoid the anomaly of new filter performance.

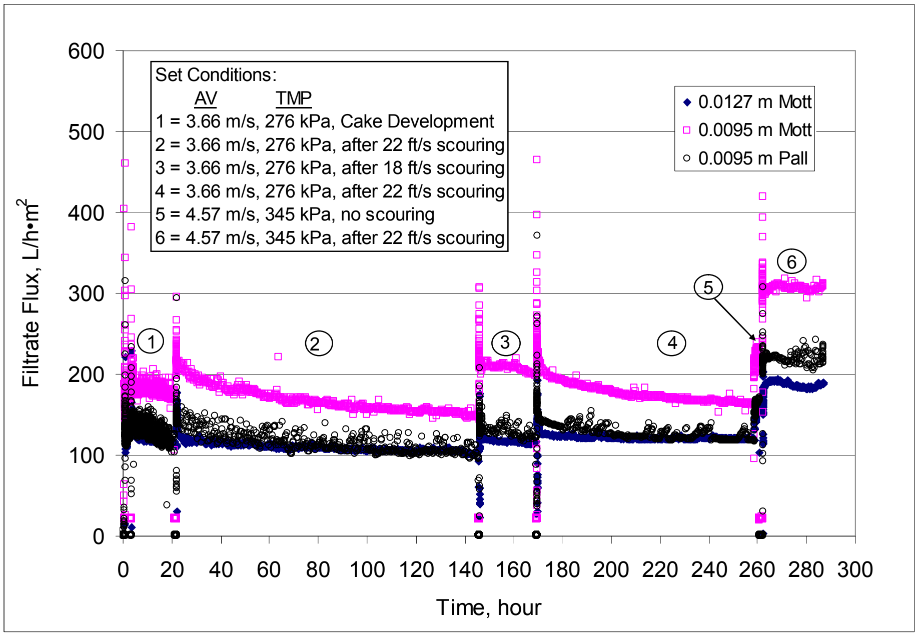

Figure 3. Long-Term 12-Day Filtration Test (Conducted at several conditions listed for the three filter tubes at 25°C ±2°C.)

Region 1: Cake Development and Scouring

For Region 1, the filter system was very slowly filled with the test slurry with the filtrate system shut so the filters would not become challenged prematurely. However, the filtrate system did slowly fill with filtrate as liquid separated from the slurry into the filter housing. This was possible because the air in the filtrate housing was drawn into the slurry, which then percolated through the slurry loop until it was released to the atmosphere from the slurry reservoir. When the slurry was circulating at a very slow rate; i.e., the axial filter velocity was less than 0.5 m/s with air stop leaving the system, the filtrate system was allowed to flow, but it was opened very slowly over a 15-minute period. Once both the filtrate and slurry loops were filled, the filtrate flow was once again stopped. Now the flow conditions for filtering were established, i.e., axial velocity (AV) = 3.66 m/s and a transmembrane pressure (TMP) = 276 kPa. (These conditions were used because they had been selected from previous work [7] as the best for filtration.) Once established and stable, then the filtrate flow was very slowly (15 minutes) engaged. With the filtrate flow established, the system was allowed to run approximately two hours to allow the filter cake to develop as noticed by a slight drop in filter rate. After that period the filters received the initial “scouring” for 15 to 20 minutes.

Scouring is the process of shutting the filtrate flow valve, increasing the slurry axial velocity to 50% to 80% above the original set velocity, allowing the high velocity slurry to flow for approximately 20 minutes, then returning the velocity back to the original setting, and finally reestablishing filtrate flow over a 15-minute period. This scouring, performed after two hours, is difficult to observe in Figure 3, but it is exactly what was done between Region 1 and Region 2. Actually, it is what was done between Regions 2 and 3, 3 and 4, and 5 and 6, noted by the jump in filtrate flux. That is, at no time were the filters cleaned or backpulsed, but only scoured. It can be seen that after each scouring the filtration flux return to approximately the same value, implying that no significant depth fouling had occurred. Over the entire 290 hours (12 days) of continuous filtering, the filters were never backpulsed or cleaned; after each scouring, the filter flux always returned to its initial value at time zero.

Region 2: Long-Term Filtering

While all the regions in Figure 3 depict the better performance of the 0.0095-m Mott filter over the 0.0127-m Mott and the 0.0095-m Pall, the 125 hours of Region 2 are highlighted for a detailed description.

An interesting feature is the higher flux of the smaller diameter filter tube. The 30 to 40% higher flux of the small Mott tube over the larger Mott tube was not a surprise as this has been studied previously, [21] but it was never observed with the same slurry at the same time; this evidence was reassuring. The other interesting aspect of the data in Region 2 is the very slow rate of decline in the filter flux. The drop in flux is approximately 30% over 5 days, a significant improvement to the 80% drops experienced from past works [7, 9]. Finally, the large difference in flux between the two tubes with the same insider diameter of 0.0095 m must be related to the different pore structure. The Mott filter is listed as a 0.1 micron nominal pore and the Pall, a 0.1 micron absolute pore. As mentioned earlier the 0.1-m Mott has been estimated [18] to be an approximately 0.7 micron absolute; therefore, the Pall had a much tighter pore structure. The smaller pores not only perform a much better job to separate the smallest solid particles but also result in a lower flux because of a much higher base membrane flow resistance. The question then becomes “is the much tighter pore needed for these type wastes?” One way to determine this would be to measure the turbidity of the filtrate. Unfortunately, the turbidity of the filtrate of each filter could not be measured because all three streams were joined in a common header, as the filtrate was returned to the slurry reservoir. However, the turbidity of the joined stream was measured, and that would tell at least the separation efficiency for the tube with the largest pore openings:

Turbidity

For deionized water used throughout testing	0.26 NTU ±0.01 NTU
From filters using only water	0.25 NTU ±0.01 NTU
From filter using the 5 wt% SB6 slurry	0.03 NTU ±0.01 NTU

These data imply that not only does the filter cake act as a secondary filter but it also prevents even the smallest particles from passing through the filter. Therefore, this means that the more open pore structure is more efficient. Of course, the pore size cannot be allowed to become too large because eventually depth fouling would confound operation.

Regions 3, 5, and 6: Higher Flow Conditions

Because of the success of a much higher and longer sustained filter flow rate than expected, it was of interest to observe if higher flow conditions would result an even higher filtrate flux. After several scourings and a return to the same axial velocity and TMP, those values were increased. This is best seen by focusing on the top set of data, i.e., 0.0095-m Mott, in all the regions in Figure 3. At the end of a successful long term run (Region 4), the flow conditions were increased to an axial velocity of 4.57 m/s and a TMP of 345 kPa, without scouring, to begin Region 5. The filter fluxes increased by about 50%, but this is only about 15% of the starting flux of Region 4. However, after a scouring was performed and then a return to the conditions of 4.57 m/s and 345 kPa to begin Region 6, the increase was 100% or about 43% above the starting point of Region 4.

Note this 43% increase occurred after 20+ hours of operation by simply scouring, which is evident at the start of both Regions 3 and 6 with the 0.0095-m Mott filter. The filtrate flux at an AV of 4.57 m/s and a TMP of 345 kPa were surprisingly high, better than 300 L/h m^2, and remained high for a full 24 hours. With continual scouring this flux may be maintained for a very long time.

Slurry Concentration from 5 to 8.5 wt% UDS

During actual waste processing, the waste solids concentration will not remain constant. Filtration will be a batch operation and liquid removal from the slurry will cause the solids concentration to increase. Because of the limited simulant for this test and the large volume needed to keep the filter facility full, the amount of material available to concentrate was limited. However, some concentration was possible and did reveal filter performance. Figure 4 is limited to only the 0.0095-m Mott filter because it demonstrated the best performance, but the two other filters performed similarly except for being lower in filtrate fluxes.

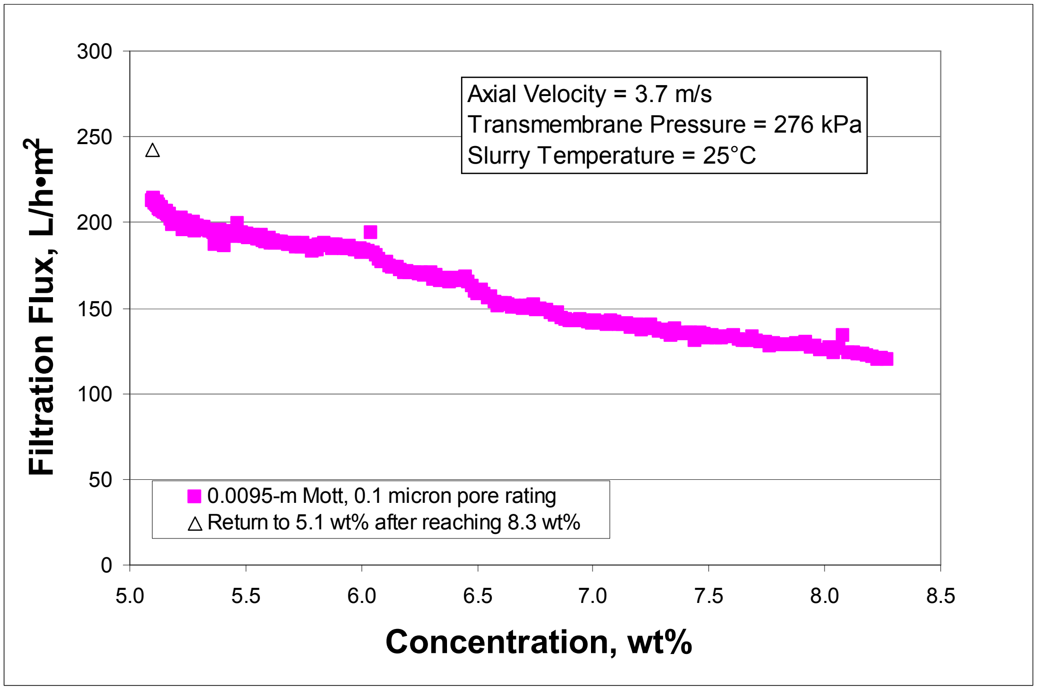

Figure 4. Filtrate Flux with the Solids Loading Increasing through 4.5 Hours of Filtration

The drop in flux in Figure 4 was expected from the increase in slurry viscosity. What was not known was the effect on the formed filter cake and if a good filter flux would return once the solids concentration was reduced to is starting point. Over a 4.5-hour period the SB6 simulant was filtered and allowed to concentrate by redirecting the filtrate to a separate container. Once the limit of the simulant volume was reached, filtration stopped; the concentration subsequently was determined to have reached 8.3 wt%. Without cleaning the filters, the removed filtrate was returned to the simulant to attain the starting concentration of 5.1 wt%, and then the filters were scoured and filtering commenced. The open diamond on Figure 4 shows that a proper flux rate was obtained again, thus indicating that the base filter cake was still intact and doing its job well.

Testing with Filter Enhancers

While the dead-end filter results imply that filter enhancers may lead to even more filter performance, enhancement failure with the test equipment and the lack of time prevented testing in the cross-flow filter facility. This test phase was left for future work.

Filter Cleaning

Several cycles of cleaning were performed during the test. Attempts to clean the filters with just water were not successful. Water rinses were useful to remove the bulk of the simulant solids that accumulated on the walls of the flow loops, but they were not sufficient to return the filtrate flux to a clean system. The use of 0.5 M oxalic acid was able to return the filters to a clean condition; however, time to soak was important. Past work used either nitric acid or oxalic acid to clean, generally for a short a period of 1 hour to over 12 hours but rarely were filters returned to a clean condition. This study found that at least 36 hours were necessary to full return the filters to a clean state. On allowing the filters to soak, the acid filter flux was checked after a few hours, 12 hours, 24 hours, 36 hours and more. With time the flux continued to improve, but between the 24-hour and 36-hour the flux tripled. When first applied, the acid turns almost immediately yellow in color indicating that iron is dissolved very rapidly, but only after three days does an accumulation of a small amount of white solids appear, assumed to be aluminum and a known filter fouler.

CONCLUSIONS

Experiments that use non-radioactive simulants for actual waste will not answer all the filtration questions to improve radioactive waste throughput; however, they will assist in focusing the scope needed to minimize radioactive testing and thus maximize safety. To that end this investigation has determined:

- SB6 was found to be more challenging to filtration than SRS Tank 8F simulant.
- Higher solids concentration presents a greater challenge to filtration.
- Filter cake is something that should be properly developed in initial filter operation.
- Backpulsing is not necessary to maintain a good filter flux with salt wastes.
- Scouring a filter without cleaning will lead to improved filter performance.
- The presence of a filter cake can improve the solids separation by an order of magnitude as determined by turbidity.
- A well developed cake with periodic scouring may allow a good filter flux to be maintained for long periods of time.
- Filtrate flux decline is reversible when the concentration of the filtering slurry drops and the filter is scoured.

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