WSRC-STI-2006-00073, REVISION 0

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TESTING AND EVALUATION OF THE MODIFIED DESIGN OF THE 25-DISK ROTARY MICROFILTER

D. T. Herman
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AUGUST 2006

Savannah River National Laboratory
Washington Savannah River Company
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Prepared for the U.S. Department of Energy Under Contract Number DE-AC09-96SR18500

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REVIEWS AND APPROVALS

8-24-2006
D.T. Herman, Co-author, Processing Chemistry Science — Date

9/8/06
M.R. Poirier, Co-author, Processing Chemistry Science — Date

9/26/2006
S.D. Fink, Co-author and Manager, Processing Chemistry Science — Date

8-24-2006
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9/29/06
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9/15/06
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CUSTOMERS

9/12/06
H.D. Harmon, SPP Technology — Date

9-12-06
P.C. Suggs, DOE Technology Development Lead — Date

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LIST OF ACRONYMS

ACTL	Aiken County Technical Laboratory
DOE	Department of Energy
EPDM	Etylenepropylenediene
FRED	Filtration Research Engineering Demonstration
gpm	Gallons per minute
NTU	Nephelometric Turbidity Units
psi	Pounds per Square Inch
RCRA	Resource Conservation and Recovery Act
RPM	Revolutions Per Minute
RMF	Rotary Microfilter
SB	Sludge Batch
SCIX	Small Column Ion Exchange
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
TMP	Transmembrane Pressure
wt %	Weight Percent

1.0 EXECUTIVE SUMMARY

This report details redesign of a commercially available rotary microfilter to meet the operational and maintenance requirements for radioactive service. Personnel developed the design and coordinated procurement of two filters followed by testing of one unit. System testing examined the ability to rinse soluble material from the system, filtration performance using several insoluble solids loadings, effectiveness in washing sludge, amount of wear to parts and maintenance of the system including the insertion and removal of the filter stack, and the ability to flush solids from the system.

The test program examined flushing the filter for soluble material by filling the system with a Rhodamine WT dye solution. Results showed that draining the system and rinsing with 50 gallons of water resulted in grater than 100X reduction of the dye concentration.

Personnel determined filter performance using various amounts of insoluble sludge solids ranging from 0.06 to 15 weight percent (wt %) insoluble solids in a 3 molar (M) sodium simulated supernate. Through approximately 120 hours of start-and-stop (i.e., day shift) operation and various insoluble solids loadings, the filter produced filtration rates between 3 and 7 gallons per minute (gpm) (0.12 – 0.29 gpm/ft^2) for a 25-disk filter.

Personnel washed approximately 80 gallons of simulated sludge using 207 gallons of inhibited water. Washing occurred at constant volume with wash water fed to a well mixed tank at the same rate as filtrate removal. Performance measurement involved collecting and analyzing samples throughout the washing for density and sodium content. Results showed an effective washing, mimicking a predicted dilution calculation for a well mixed tank and reducing the sodium concentration from 3.2 M to less than 0.3 M. Filtration rates during the washing process ranged between 3 and 4.3 gpm for one filter unit.

The filter system then concentrated the washed 15 wt % insoluble solids slurry to approximately 20 wt % insoluble solids with no operational problems with the exception of the entrainment of air due to leaking packing in the feed pump. Prior to the air entrainment, the filtration rate was approximately 4.2 gpm for one filter assembly with the process fluid temperature adjusted to 35 °C.

Personnel measured the turbidity of filtrate samples from all phases of testing. All samples measured were less than 3 NTU, with the majority of samples less than 1 NTU. Thus, all measurements fell below the process acceptance criterion of less than 5 NTU.

After slurry operations, personnel rinsed the filter with the equivalent of 250 gallons of water by re-circulating 50 gallons of water. The residual sludge solids remaining on the filter stack weighed approximately 685 grams. This amount of solids corresponds to an equivalent activity of 15.1 curies (Ci) beta and 0.38 Ci gamma radiation dose for Sludge Batch 4.

Workers completely disassembled the filter system and examined it for signs of wear and component operation. An evaluation by a John Crane Inc. representative concluded that the wear observed on the mechanical seal resulted primarily from the numerous stops and starts, the abrasive nature of the process fluid and the possibility that the seal faces did not receive enough lubrication from the process fluid. No measurable slurry bypassed the mechanical seal. While it is extremely difficult to predict the life of the seal, the vendor representative indicates a minimum of one year in present service is reasonable. Changing the seal face material from silicon-carbide to a graphite-impregnated silicon-carbide is expected to double the life of the seal. Replacement with an air seal might be expected to increase lifetime to five years.

The bottom bushing showed wear due to a misalignment during the manufacture of the filter tank. Minor adjustments to the alignment with shims and replacement of the graphite bushing with a superior material will greatly reduce this wear pattern.

2.0 INTRODUCTION

The Savannah River Site (SRS) is developing processes to treat radioactive waste. Many of these processes require the separation or concentration of solids. Crossflow filtration is the baseline filtration process. The Department of Energy (DOE) EM-21 Office of Cleanup Technologies funded the Savannah River National Laboratory (SRNL) to investigate alternative filtration methods. A study determined plausible filtration alternatives.[1] This study showed that the rotary microfilter has the potential to provide an effective alternative to traditional crossflow filtration.

The SpinTek™ rotary filter is a compact filtration system that uses membrane filters mounted on rotating disks. The flux advantage of the rotary microfilter compared to other membrane processes results from the high shear and centrifugal force acting on the boundary layer next to the membrane. This shear greatly reduces fouling of the membrane surface and increases fluid flow through the membrane. Pressure is decoupled from the feed flow rate, allowing more control over the driving force pressure and independent control of the shear applied to the filter cake. The SpinTek™ rotary filter unit uses 11-inch diameter disks and typically operates with a rotational speed of 1170 revolutions per minute (rpm).

The SpinTek™ rotary filter uses disks covered with flat sheet membranes. The disks are physically mounted and are hydraulically connected to a common hollow rotating shaft. The entire stack of membrane disks is enclosed within a vessel. The feed fluid enters the vessel and flows across the membrane surface, where permeate flows through the membrane and exits through the hollow shaft. The concentrated slurry is pumped from the chamber. Stationary surfaces, or turbulence promoters, oppose the rotating membrane disks, generating large fluid shear rates across the membrane surface.

Testing showed significant improvement in filter flux from the rotary microfilter over the baseline crossflow filter with filtration rates 2.5 – 6.5 X during the scoping tests[2], up to 10 X in the actual waste tests[3], and approximately 2 X in the pilot-scale tests[4]. An analysis on the commercially available rotary filter identified several modifications needed to make the filter more suitable for radioactive service.[5]

The authors proposed several design modifications including the development of an integrated stack containing all wear items for easy removal and replacement, and the development of an all stainless steel filter element. A patent application[6] covers the concept of removable filter stack and the welding technique used to fabricate the all stainless steel filter disk. The design is intended to provide a small footprint, high throughput filter that is easily operated and maintained.

The modified system is recommended for integration into the Small Column Ion Exchange (SCIX) program as the pre-filter for the ion exchange module pending proof of effective operation through testing.[7] In this application, two filters would be installed as a plug assembly into a Type B riser of a waste tank. Figure 1 shows the layout of the plug including the two filter units. Under this project, personnel procured two full scale (25-filter disk) units[8] for integration with a pump/filter module for deployment with the SCIX system.

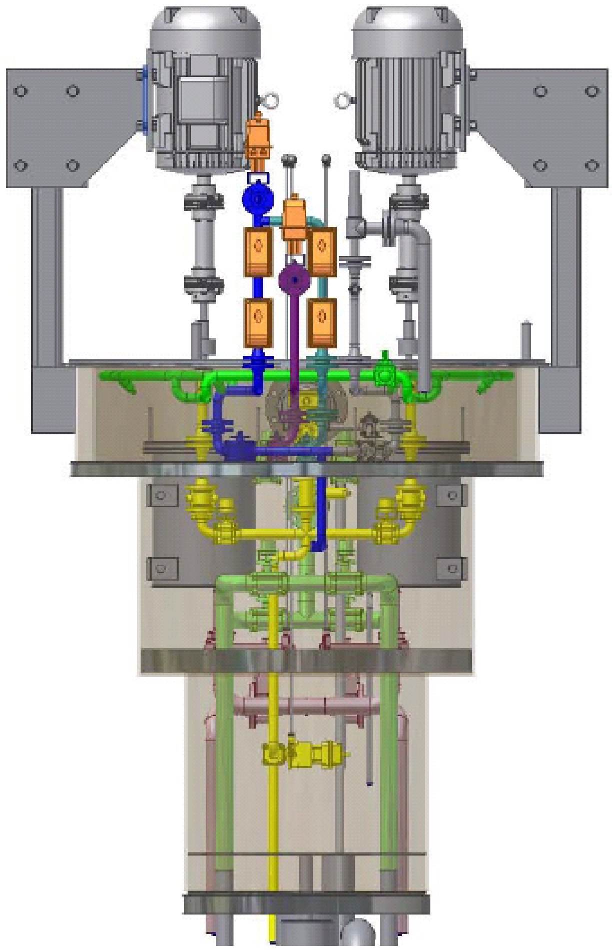

Figure 1 Conceptual Drawing of the Plug Portion of the SCIX Pump/Filter Module

The filter system is also being considered for uses including as an aid to sludge washing. The pump filter assembly would allow for the washing of slow settling sludge by filtration instead of, or in conjunction with settling and decanting.

Using the improved design, SpinTek™ fabricated two 25-disk rotary microfilter units. Following completion of the acceptance test, they shipped the units to the SRNL. Personnel installed one of the units in the High Bay at the Aiken County Technical Laboratory (ACTL) to perform checkout and testing. A task plan outlines the planned testing for the fabricated units to determine the performance of the improved design.[9] The purpose of the testing is to:

- demonstrate remote assembly and removal of the disk stack using an overhead crane;
- evaluate the ability of flush water to remove soluble (e.g., Cs-137) and insoluble (i.e., sludge) solids from the filter unit prior to removal and maintenance;
- evaluate the ability of the full-scale unit to filter a simulant of SCIX feed; and
- evaluate the ability of the rotary microfilter to perform a continuous wash of simulated SRS sludge.

This report describes testing of one filter versus these objectives.

3.0 RESULTS AND DISCUSSION

3.1 MANUFACTURE AND ACCEPTANCE TESTING

The rotary microfilter manufactured by SpinTek™ is a commercially available filter typically used in hard-to-filter and high insoluble solids streams. As originally developed, the design is less than ideal for radioactive service due to a large number of small parts and extensive use of polymers in the filter disk design. SRNL modified the design to allow removal of the entire stack of filter disks and all wear parts as a single piece. This concept allows for easy maintenance and replacement of a filter unit. SRNL personnel communicated the design to SpinTek™ and placed a purchase order for construction of two units of the reconfigured design[8]. Incorporated in the design is the manufacture of the filter disks from only stainless steel. This design alteration required development of a welding protocol for proper sealing of the membrane to the disk structure. SpinTek™ subcontracted the welding technique, as outlined in the patent application[6], to a commercial welding vendor, ProcessLogic Inc., using a non-disclosure agreement.

Following manufacture of the filter systems, SRNL personnel traveled to observe the vendor's initial testing of the filter systems. The acceptance test consisted of operation of the filter with a 5 wt % slurry of strontium carbonate ($SrCO_3$) in water, with filtrate samples analyzed for turbidity. Filtrate rates during the tests ranged from 6.5 to 8.6 gpm for one unit (0.27 – 0.36 gpm/ft^2). The maximum turbidity reading was 2.9 NTU, with most of the turbidity readings measured to be less than 1 NTU. The results of the acceptance testing are given as Attachment 1.

3.2 SYSTEM SETUP

The rotary filter contained Pall PMM050 0.5 µm (nominal) membranes for the disks. The membrane is 0.0055 inches in thickness. The manufacturer removal ratings are 90% of 0.6 µm, 99% of 2 µm and 100% of 5 µm particles. The filter disks are formed by welding the membrane to the steel support plates via the SRNL developed approach. A steel mesh resides between the membrane and support plate to allow filtrate flow through the disk. Each filter disk provides approximately 0.97 ft^2 of filtration area. The total filtration area available for the 25-disk assembly is 24.3 ft^2. Details on the design and manufacture of the filter disks are given in Reference 8.

Figure 2 shows the layout of the system that was used to test the rotary filter. The instrumentation of the system includes feed and filtrate flow meters (FM1, FM2) and pressure gauges (PG1 and PG2) on the feed and filtrate lines. The temperature of the feed tank (T) is also monitored.

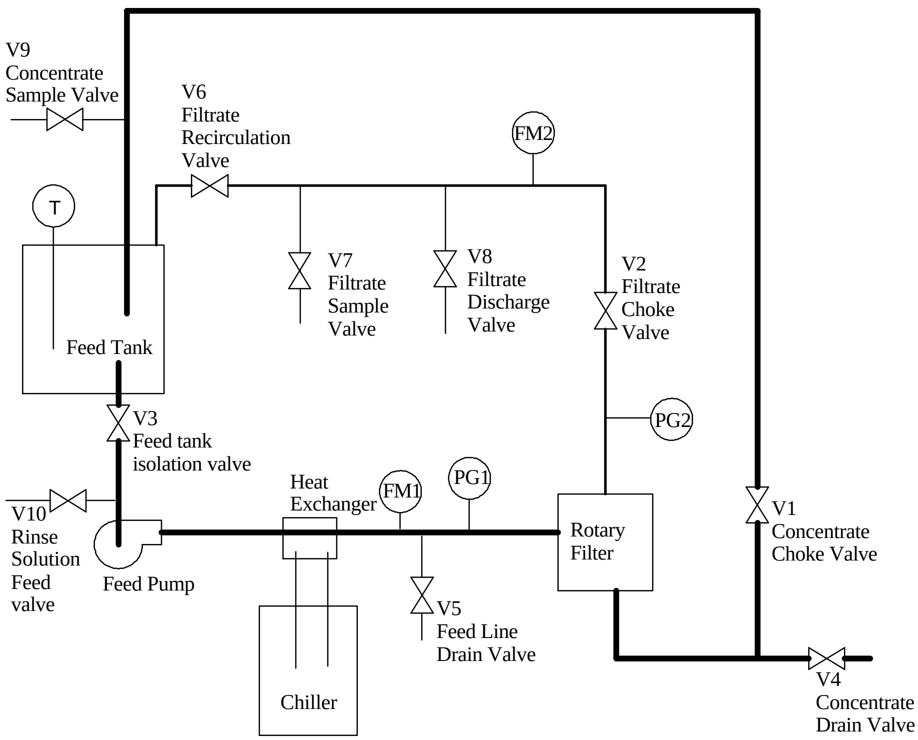

Figure 2 Schematic of Filter Test System

Figure 3 shows a photograph of the system as installed at the ACTL.

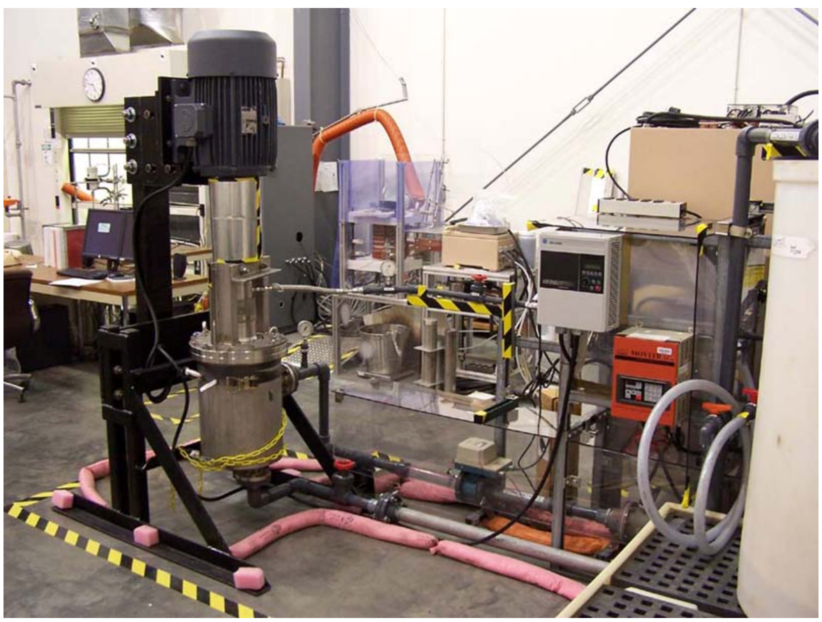

Figure 3 Rotary Filter System Installed at the ACTL

The motor support is fabricated per the drawings of the plug filter system[10] from where the arm will be welded to the plug assembly. Personnel discovered two issues during assembly of the system. The first item involves the bolt pattern for the mounting of the motor to the motor support plate. The drawing calls for 5/8th inch bolts. There is not enough room for the bolt heads for the 5/8th inch bolts. Figure 4 shows the spacing of the bolt hole in reference to the motor. SRNL recommends widening the plate to allow proper clearance for the 5/8th inch bolt and washers.

Figure 4 Bolt Hole Spacing for Motor Mount Plate

The second issue is that the motors provided by the vendor do not have lifting points. Therefore, the motor can not be moved out of the way to gain access to the filter stack. For the test program, personnel gained access by moving the entire support arm structure. This approach is not possible in the tank plug configuration. Remedying this situation will require either an enlarged motor support plate fitted with lifting points or replacing the motors with new ones manufactured with lifting points already incorporated in the motor frame.

3.3 TESTING

Testing of the rotary microfilter (RMF) occurred in four phases. The first phase demonstrated insertion and removal of the rotary filter stack using an overhead crane. The second phase of testing used a water soluble Rhodamine WT dye to determine the effectiveness of flushing the filter with water for reducing the amount of soluble contaminants (e.g., Cs-137). The third phase of testing evaluated the performance of the filter on various insoluble solids loadings typical of the feed expected in the SCIX process. Personnel used simulated sludge as the process fluid observing the filtration rate and the general operation. The testing also included evaluating the ability to flush the filter after operations. The final phase of testing determined the effectiveness and performance of the RMF for the washing of sludge. The presentation of the filtration rates in this report includes a correction for the feed temperature. The data presented are corrected to 35 °C, using the following equation.[11]

$$J(35\ °C) = J(T)\ \exp\{2500[1/(273 + T) - 1/308]\}$$

Where:

$J(T)$ = permeate flux at T °C (gpm/ft^2)
T = slurry/permeate temperature in degrees Celsius

The temperature correction factor corrects flux back to an equivalent flux at 35 °C and accounts for changes in fluid viscosity and surface tension. Additional parameters recorded during testing include feed flow rate, feed pressure, permeate pressure, and slurry temperature.

3.3.1 Filter Assembly

Figure 5 shows the insertion of the filter stack into the stationary filter housing using an overhead crane. The filter stack must be positioned over the guidance spikes to allow for proper alignment of the lid bolts. During testing, personnel positioned the stack approximately 30 times with no instances of hang-up on the lower guide spikes. Each time, workers threaded all bolts into the tapped holes with no re-positioning of the filter required.

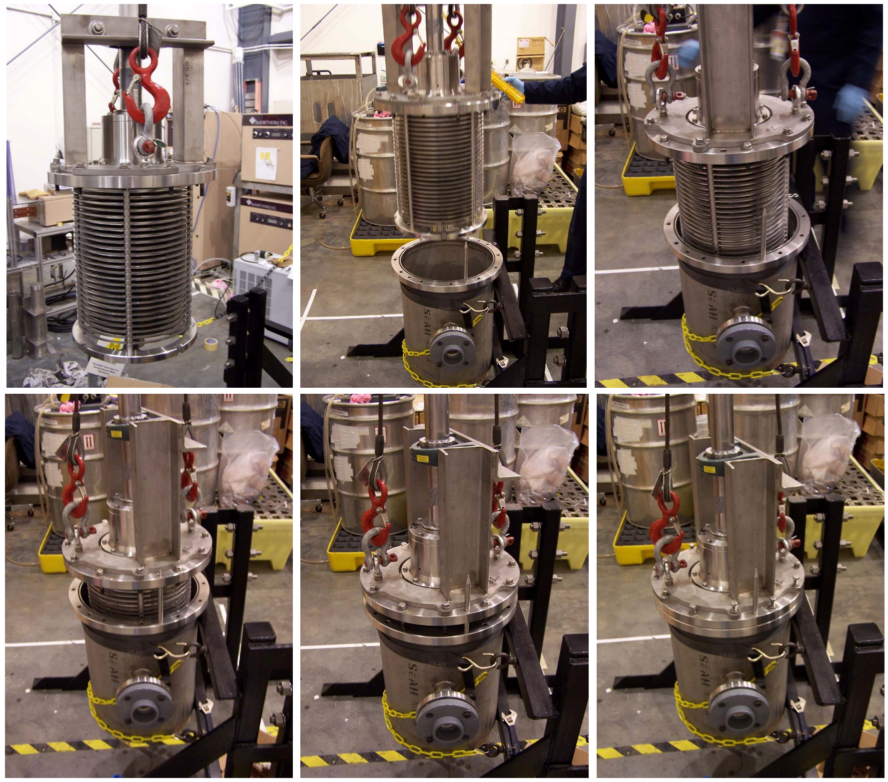

Figure 5 Insertion of the Filter Stack into Housing

During one instance, the filter stack assembly did not easily insert into the filter housing. The cause of this misalignment involved the rigging of the filter stack for the lift. One of the rigging chokers hung lower than the other choker. This gave the stack a tilt of approximately 15 degrees. At this angle, the operators had difficulty aligning the guidance spikes to insert the stack. Personnel re-rigged the stack to allow both chokers to hang approximately even and inserted the stack without incident. No further experimentation occurred to determine the maximum angle the stack may be canted and still allow proper insertion. Personnel also observed that the guide spikes may be vulnerable to extreme handling. The spikes are 6 inches long (exposed), 0.5 inches in diameter and have the potential to become bent if struck with sufficient force. Reinforcing or otherwise strengthening the guide spikes should be evaluated prior to deployment.

After the stack is inserted, 12 bolts must be fastened to secure the lid. The filtrate line is then connected. In the field, this line will incorporate a quick-connect to simplify the process. The motor is then moved into position and the flexible coupling assembled. Proper alignment of the motor to the filter shaft will minimize wear on the bearings.

3.3.2 Dye Testing

Testing examined the ability to wash soluble material from the filter. Personnel circulated water with a known concentration of Rhodamine WT dye through the system and then drained the system. They next rinsed approximately 50 gallons of clean rinse water once through the filter system. The flush lasted five minutes and personnel activated the filter rotor for 20 seconds half-way through the rinse. Technicians collected samples of the feed and filtrate outlets for analysis of the dye concentration. Figure 6 shows the visual decrease in the dye concentration during the flush.

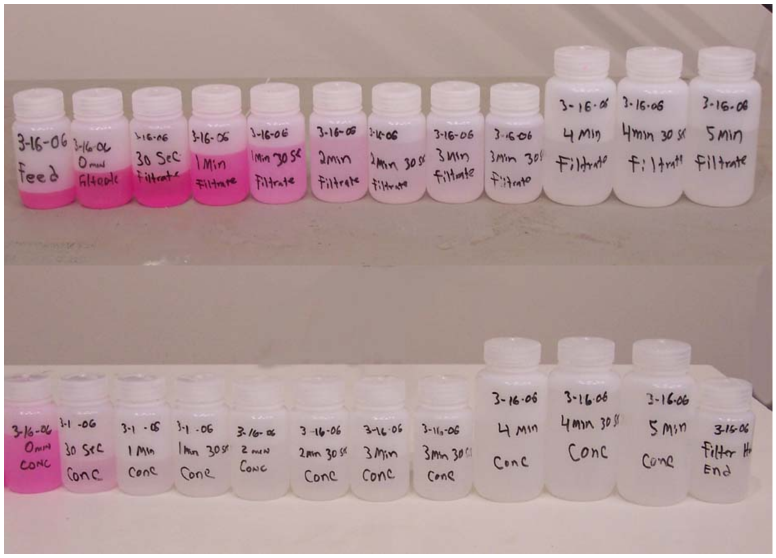

Figure 6 Filtrate and Concentrate Samples during Dye Testing

Filtrate and concentrate samples analysis used a UV-VIS Recording Spectrophotometer with the resulting concentrations from samples taken shown in Figure 7. The rapid drop off (> 100 X within five minutes) of dye concentration is due to the ability to drain the filter tank and remove the bulk of the system volume. The filtrate line and the rotary joint were purged more slowly of the dye solution and the lower flow rate required a longer duration to clear the liquid in the rotary joint and the filtrate lines. Additionally, the build up of solids on the filter disks may increase the holdup of soluble solids.

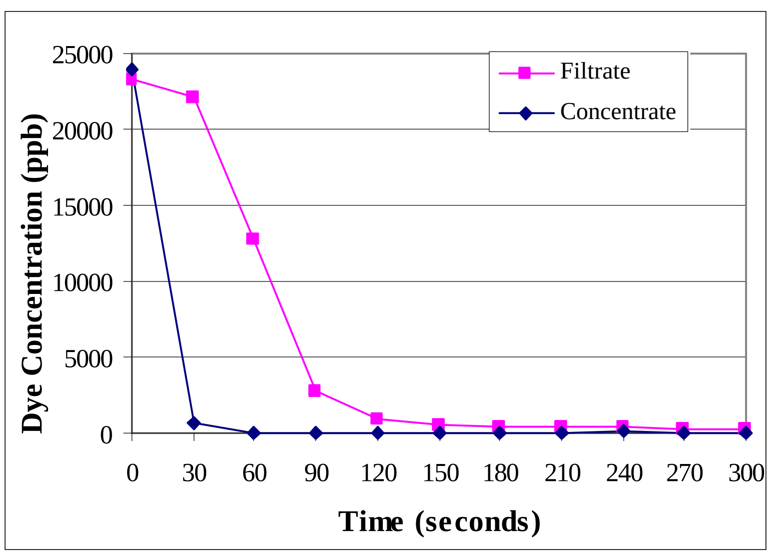

Figure 7 Concentration of Rhodamine WT Dye during Filter Flushing with 55 Gallons of Water

3.3.3 SCIX Feed Testing

The initial sludge testing occurred at several solids loadings to approximate the amount of insoluble solids from previous testing[3, 4,12,13,14,15] and the expected solids loadings in the SCIX process. The initial testing used the same Sludge Batch 2 (SB2) slurry used in testing of a commercial 3-disk unit done at the University of South Carolina facility. Personnel decanted supernate from two drums of the simulant and measured the concentration of insoluble solids in the remaining slurry. They then calculated the amount of slurry required and added to obtain the target wt % insoluble solids. The filter operated at 18 – 25 gpm feed flow rate, 40 psi transmembrane pressure (TMP), and 1170 rpm rotor speed with the concentrate and filtrate recycled to the feed tank. Technicians collected feed samples for insoluble solids measurement and filtrate samples for turbidity measurement. Table 1 shows measured wt % solids for the slurries used for the SCIX filtration testing.

Table 1 Measured wt % Solids for the Sludge Batch 2 Sludge Testing

Target wt % insoluble solids	0.06	0.29	1.29	4.5
wt % insoluble solids of slurry measured	0.12	0.23	1.12	4.72
wt % soluble solids of slurry measured	16.20	15.87	15.66	14.66

Personnel ran the filter with each solids loading for approximately 30 hours. Figure 8 shows the filtrate flow measured during the testing. At low solids loading (0.06 wt %), the filtrate rate measured 5.5 – 7.0 gpm (0.23 – 0.29 gpm/ft^2). At higher solids loading, the filtrate rate decreased to 3 – 5 gpm (0.12 – 0.21 gpm/ft^2). Figure 8 also shows pilot-scale crossflow filter data collected from testing with sludge only feed. The rotary filter flux is ~ 5X the flux from crossflow filter testing (with 40 psi TMP pressure).

Filter operation occurred on day-shift (during the normal work week) only, requiring the shutdown at the end of the day and restart the following morning. Personnel observed on several occasions a significantly lower filtration rate the following morning than where it ended on the previous day. On more than one occasion, the filtration rate improved throughout the day and sometimes returned to the previous day's filtration rate. Two issues may contribute to the overnight drop in filtration rate: the method of shutting down/re-starting the filter, which was shown to have the larger impact, and the packing of the un-agitated sludge on the filter membranes as the system sat idle overnight.

Typically, operators shutdown the system by stopping the rotor and then stopping the pump. This allowed the pump to continue to apply a pressure across the membrane and allowed solids to pack on the filters without the disks being rotated. The system then sat overnight without draining or flushing. Startup the next day included the startup of the pump with the filtrate line at least partially open to purge air. After the system reached pressure, personnel started the rotor.

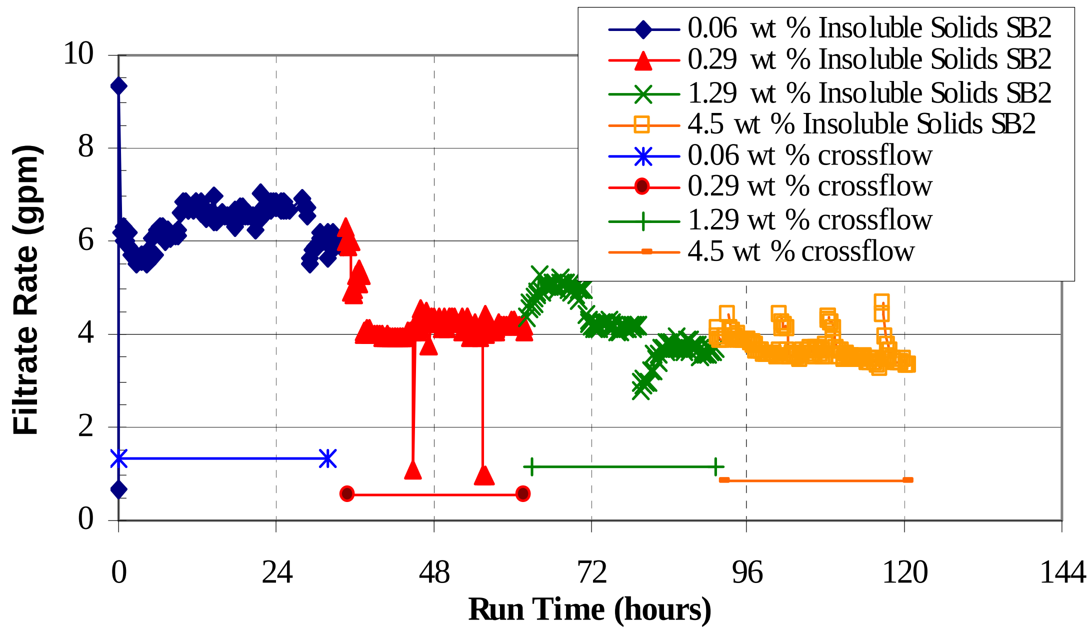

Figure 8 Filtration Rate at Various Insoluble Solids Loadings with Sludge Batch 2 Simulant Corrected to a Feed Temperature of 35 ºC

When personnel increased the feed concentration to 4.5 wt % insoluble solids they enacted a new shutdown protocol in an attempt to mitigate the overnight drop in filtration rate. They started filter operation by choking off the filtrate line (i.e., closing the filtrate valve) to allow only minimal flow prior to the rotor being shut off. The small amount of flow allowed a path for the purging of any air in the system, thereby allowing the mechanical seal to remain wetted. Personnel started the filter the following day under the same conditions, allowing a slight flow out the filtrate line while starting the rotor to spin the disks. When the rotor reached normal operating speed, personnel opened the filtrate line and adjusted the TMP to 40 psi. After enacting this protocol, no significant drops in the filtration rate occurred after the filter sat overnight.

During testing, personnel targeted a TMP of 40 psi. Feed pressure varied throughout the testing. Personnel used higher feed pressures to simulate the additional pressure required for the pump filter module in the SCIX project. These higher pressures are required to transport filtrate from the SCIX prefilters to another tank and pass through the ion exchange column. Feed pressure and TMP throughout the testing are shown with the corresponding filtration rate in Figure 9.

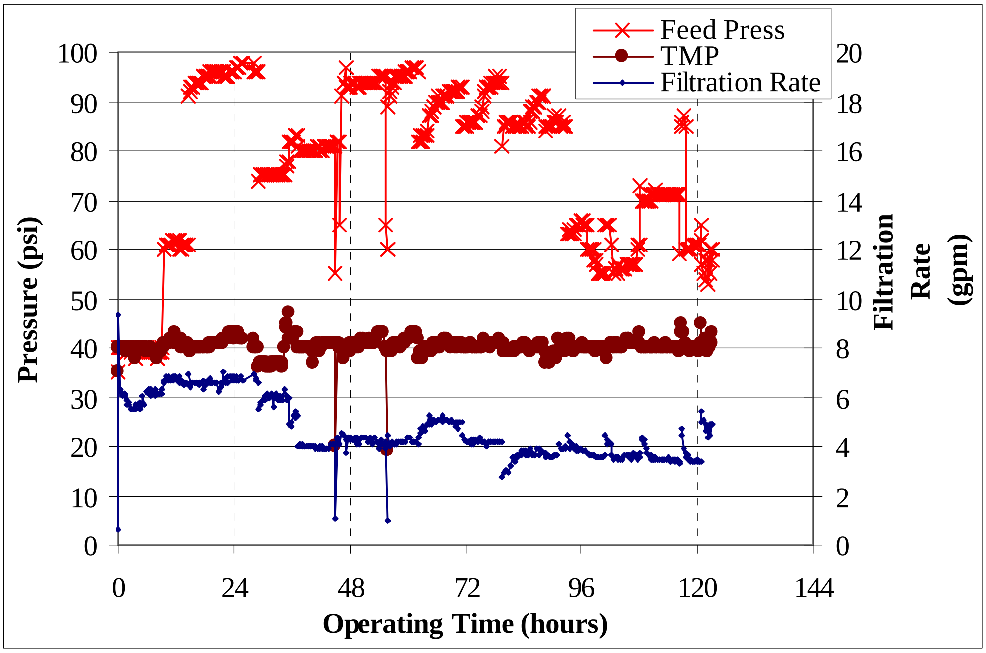

Figure 9 Feed and TMP Pressure Relative to Filtrate Flow Rate at all Insoluble Solids Loadings with Sludge Batch 2 Simulant and Corrected to a Feed Temperature of 35 °C

Personnel allowed feed pressure to rise through a days testing, with the TMP adjusted to maintain 40 psi. No noticeable trend occurred for a change in filtration rate relative to the feed pressure. Operators made two attempts during testing to remove filtercake in situ by dropping the TMP to a minimum value and maintaining the rotor speed. Though not dramatic (less than 5%), noticeable improvements in the filtrate flow rates occurred.

Figure 10 shows the feed rate to the filter. The vendor recommends 1 to 2 gpm of feed flow rate per disk. Therefore, this unit should operate with a feed rate between 25 and 50 gpm. Feed rates remained lower during the testing due to limitations of the pump available for testing. The pump is slightly undersized to minimize the pump dead head pressure to protect the system. The vendor tested the filter for a maximum operational pressure of 120 psi.

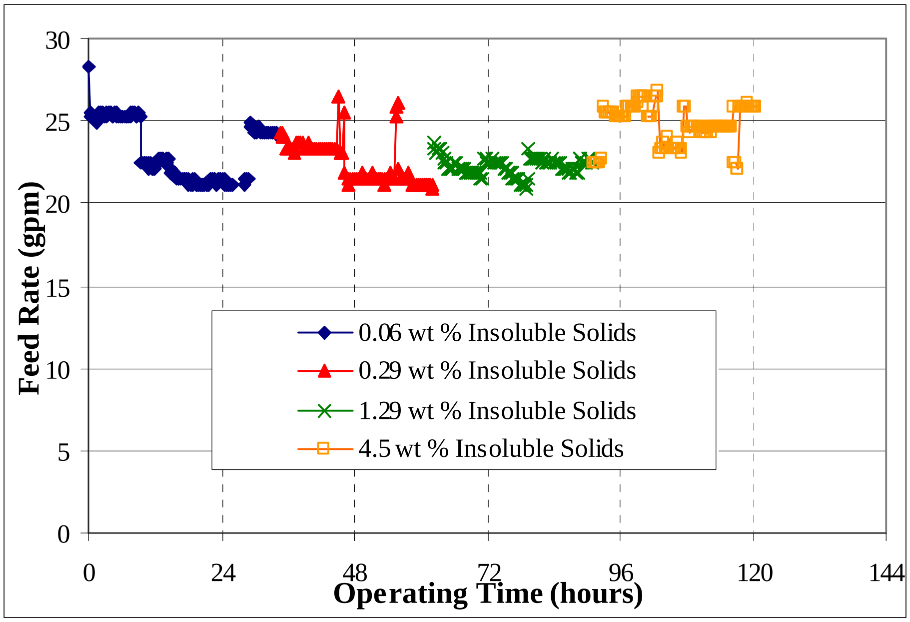

Figure 10 Filter Feed Flow Rate

Feed rates fell even lower for the higher solids testing described later in this report. These lower rates resulted from changing of the feed pump to a progressive cavity pump required to move the higher solids loading of the feed.

At the completion of the filtration testing, personnel drained the system and rinsed using de-ionized water. A drum (50 gallons) of de-ionized water was recirculated until five system volumes, approximately 60 gallons, of rinse water passed through the system. The rotor operated at maximum speed for approximately 2 minutes during the rinse. Personnel then disassembled the filter and inspected. The condition of the stack and the interior of the filter tank are shown in Figure 11 and Figure 12.

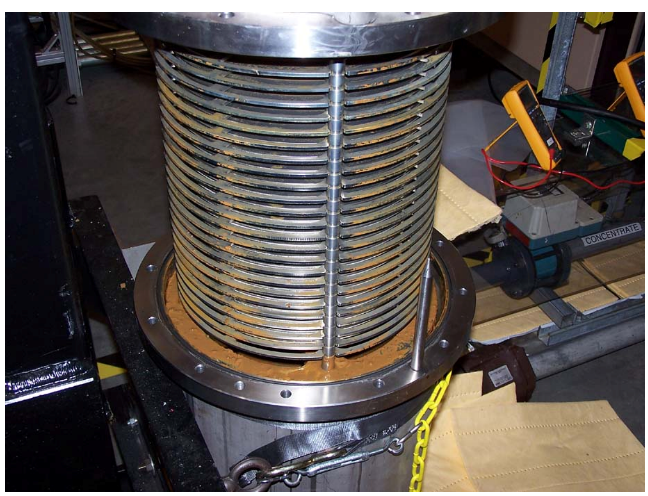

Figure 11 Filter Stack Run with 4.5 wt % Sludge Batch 2 Simulant after Rinsing

Figure 12 Filter Tank Run with 4.5 wt % Sludge Batch 2 Simulant after Rinsing

They next disassembled the filter stack and inspected individual disks. Figure 13 and Figure 14 show the observed difference in the filter cake accumulation typical for their respective locations in the filter stack. Figure 13 shows the two sides of the second disk from the bottom, while Figure 14 shows the top disk in the stack. Also note that both disks show more filter cake on the top side of the disks. This behavior is believed due to the sludge gravity settling and agglomerating overnight while the filter sat idle. The top sides of the filter disks consistently contained more filter cake.

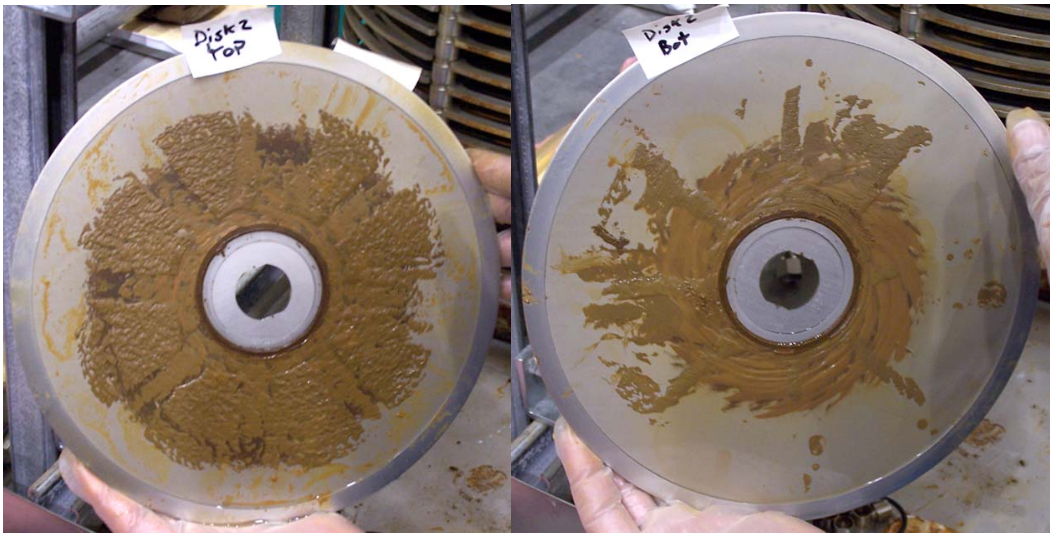

Figure 13 Second Disk from the Bottom of the Stack, Top and Bottom Sides Showing Filter Cake after Running 4.5 wt % Sludge Batch 2 Simulant

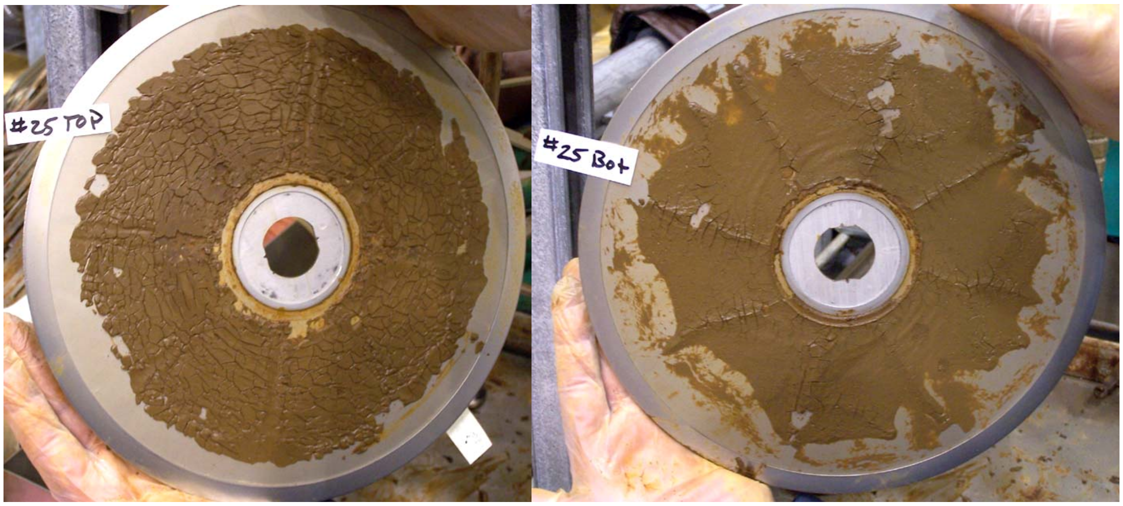

Figure 14 Filter Disk at the Top of the Stack Top and Bottom Views Showing Filter Cake after Running 4.5 wt % Sludge Batch 2 Simulant

3.3.4 Sludge Washing

For the purpose of testing the application of the rotary filter for sludge washing, SRNL procured 200 gallons of simulated sludge without hazardous (i.e., RCRA) metals.[16] This sludge is referred to as Type 2 sludge throughout this report. Personnel performed a comparison measurement by filtering the Type 2 sludge at the same insoluble solids loading as the SB2 simulant. Personnel removed supernate from the SB2 slurry and added it to a known quantity of the Type 2 sludge to obtain 4.5 wt % insoluble solids. By filtering the same supernate at the same insoluble solids loading, a direct comparison is made to determine if the sludge solids have any effect on the filtration flow rate. Since the supernate became diluted slightly by adding the new simulant solids as a slurry, we expect the filtration rate to be slightly higher than the SB2 simulant. Figure 15 compares the filtration flow rates for both simulants after correcting the data for the difference in temperature. The reference temperature is 35 °C.

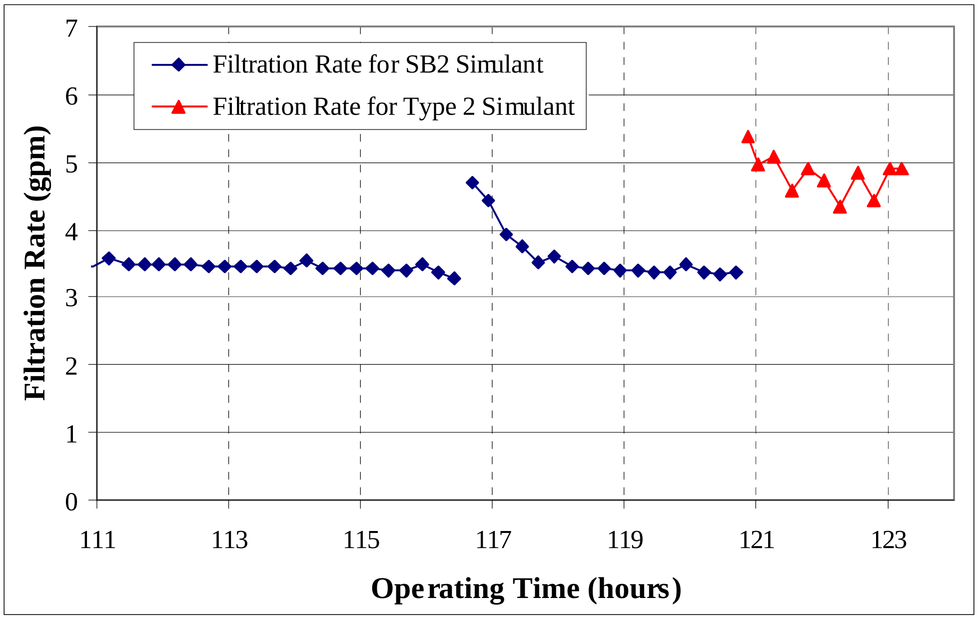

Figure 15 Filtrate Flow Rate of Sludge Batch 2 and the Type 2 Simulant Using the Same Supernate and Corrected to a Feed Temperature of 35 ºC

The data shows that the new sludge compares favorably with the SB2 simulant under the same conditions. The slightly higher filtration rate is anticipated due to the dilution of the supernate, a thinner particle size distribution and possibly fewer fines in the sludge solids due to less shear applied to the new simulant.

Sludge washing occurred using 80 gallons of sludge. The Type 2 sludge originally contained ~ 1 M sodium. Since the expected concentration in the actual sludge washing operation is ~ 3 M sodium, personnel increased the sodium concentration in this sludge by removing 22 gallons of supernate from 80 gallons of the as-received sludge and replacing with 22 gallons of a 9 M sodium solution. The recipe of the concentrated salt solution is given in Table 2. The added salt solution raised the soluble sodium concentration to 3.2 M.

Table 2 Recipe of the Concentrated Salt Solution Added to the As-Received Type 2 Sludge

Species	Concentration (M)
NaOH	3.82
$NaNO_2$	1.04
$NaNO_3$	4.28

Technicians prepared 207 gallons of inhibited water (0.01M NaOH, 0.011M $NaNO_2$) in four drums for the washing of the soluble ions from the sludge. During the wash, workers fed the inhibited water to the feed tank at approximately the same volumetric rate as removing the filtrate. They accomplished this "constant volume" wash by matching the readout of the filtrate flow meter with the addition rate of the wash water as well as watching the level in the feed tank. As the inhibited water drum emptied and the filtrate drum filled, personnel recirculated the filtrate while changing the feed and product drums.

Figure 16 shows the filtrate flow rates during the washing as well as the 4.5 wt % filtration flow rate data for the SB2 and Type 2 sludge simulants for comparison. The filtration flow rate for the washing of the 15 wt % insoluble solids showed only a slight, approximately 10%, drop in the filtration rate when compared to the 4.5 wt % insoluble solids slurry. As the filter continued to operate, the filtration rate increased slightly. An increase in filtrate flow is expected as the soluble solids concentration decreased thus reducing the viscosity of the bulk fluid.

Figure 16 also compares the rotary filter filtration rate with crossflow filter filtration rate from testing with SRS SB2 simulant and monosodium titanate at 12 wt % solids and Hanford Tank AN-102 simulant at 15 wt % solids. The filtration rate with the rotary microfilter is ~ 6X higher.

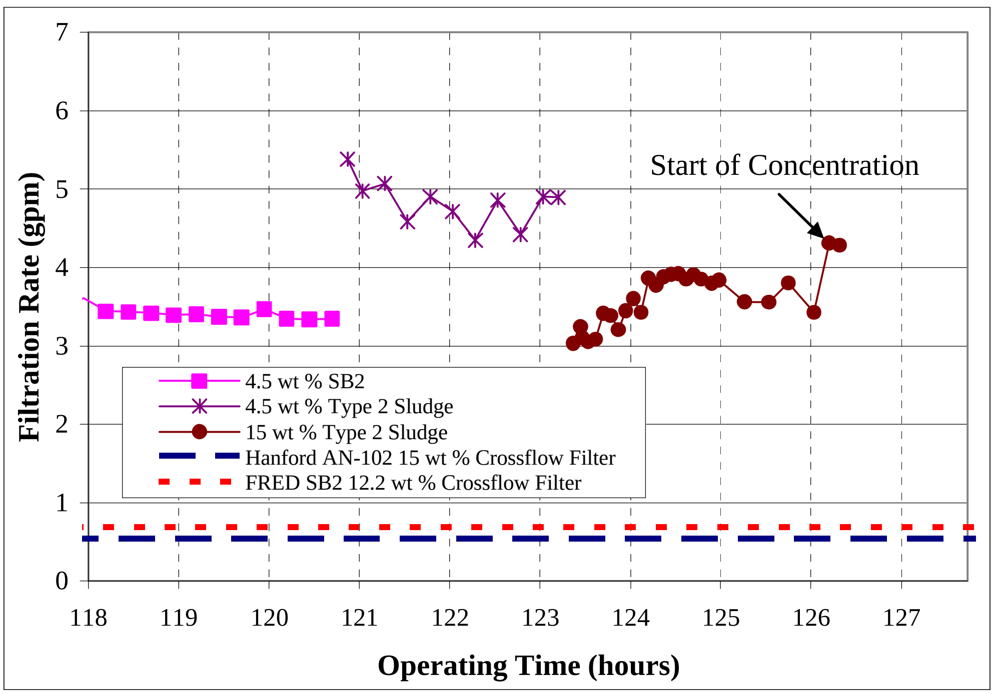

Figure 16 Filtration Rates for 4.5 wt % and 15 wt % Simulated Sludge and Corrected to a Feed Temperature of 35 °C with Comparisons to Crossflow Filtration of Hanford Simulant[17] and FRED SB2 Data[18]

Technicians collected filtrate samples during the washing process to analyze for density with selected samples also analyzed for sodium concentration. Figure 17 shows a plot of the sodium concentration as the washing proceeded. Also included are the predicted sodium concentration and the density of all of the filtrate samples collected.

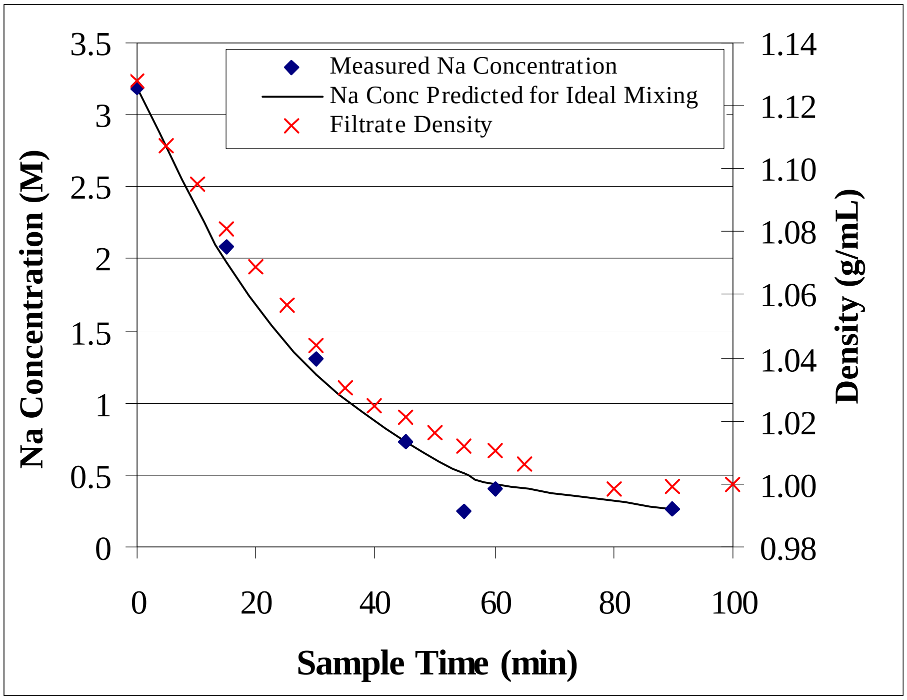

Figure 17 Filtrate Sodium Concentration and Density during the Washing of 15 wt % Type 2 Simulated Sludge

The analyzed filtrate samples follow the predicted sodium concentration indicating effective washing and a well mixed system.

When the washing was completed, personnel set the system to recycle the filtrate to the feed tank. The system operated at this condition for almost 2 hours to obtain additional filtration flow rate data. They then concentrated the feed by removing ~20 gallons of filtrate to raise the insoluble solids concentration to approximately 20 wt %.

During concentration, the filtrate line started purging large air bubbles and personnel observed a significant amount of air bubbles in the filtrate line. Personnel later determined that air was entrained into the system during this evolution. The source of the air is the pump's packing. As the air entered the filter, it vented through the filtrate lines since the filters are the highest point in the system. Personnel verified this conclusion later in the post test rinsing. Technicians placed the second rinse drum into position after the filter system drained. As the rinse water pumped into the system, personnel expected the drum level to drop as the system refilled. They observed that the drum level only lowered as the filtrate line opened. As the filtrate line closed, the drum liquid level rose. The pump suction line is below and away from the return line and could not re-entrain air; therefore, another air entry path did not exist. Personnel observed no leaks at any flow and pressure in the plumbing system other than at the feed pump packing. This leak ceased after reaching a minimum speed on the pump motor.

Due to the amount of air entrainment, the filtrate flow meter readings proved both inaccurate and erratic during the concentration phase. The flow meter indicated flows of 4 to 5 gpm which did not appear realistic. Personnel performed several flow rate checks by measuring the volume of filtrate produced in a fixed time to obtain more accurate filtrate flow data. The resulting flow rates are shown in Figure 18. We believe these filtration rates are lower than expected due to the filtration efficiency lost due to the purging of the air. The initial data point at the end of concentration indicated a filtration rate of over 4 gpm (corrected for temperature).

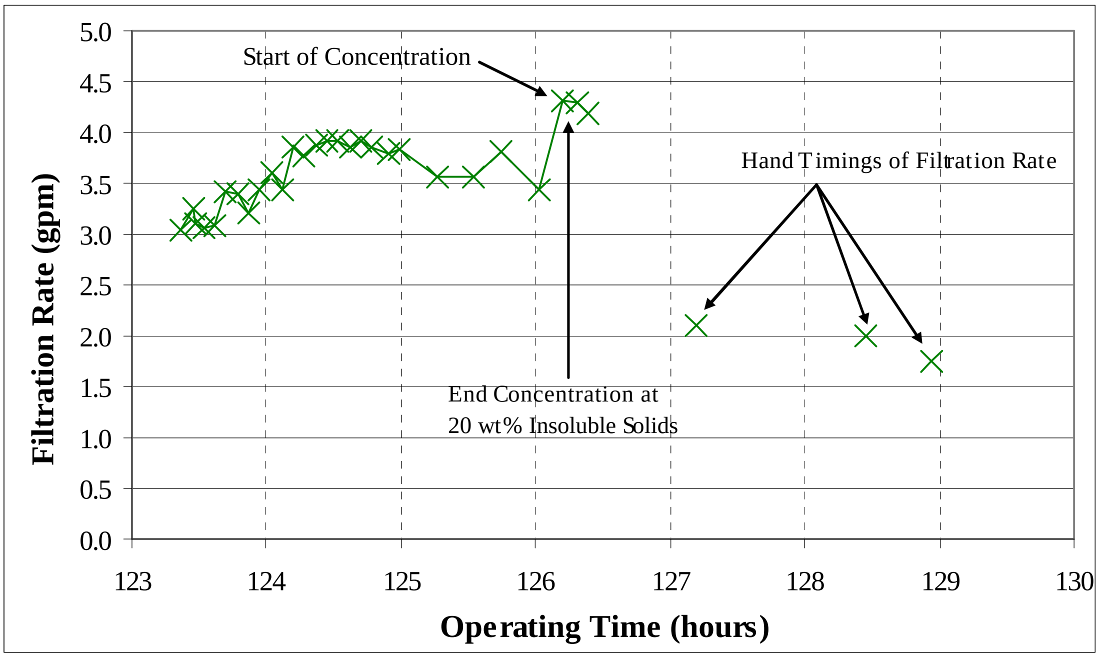

Figure 18 Filtrate Flow Rate for 15 wt % and Concentration to 20 wt % Insoluble Solids Slurry and Corrected to a Feed Temperature of 35 ºC

After completion of sludge washing and concentration, personnel rinsed the filter system using two separate 55 gallon drums of rinse water. They recirculated the first drum at approximately 8 to 10 gpm for approximately six minutes. The rotor operated at 1175 rpm for approximately two minutes during the rinse. They then drained the filter system and circulated a second drum of water through the system at 10-12 gpm for approximately 10 minutes. The rotor operated at full speed for approximately one minute during this rinse. During both rinses, a significant amount of air entrained into the system. We believe the filter tank never became full (i.e., "water solid") during either rinse cycle. This is based on the amount of air continuously purged through the filtrate line as well as audible noises coming from the tank. Figure 19 and Figure 20 show the post rinse condition of the filter stack and the inside of the filter tank respectively. The majority of the system components proved relatively free of sludge solids. The largest deposits occurred on the filter disks and the bottom support plate. A layer of slurry approximately 1/8 inch thick remained in the bottom of the filter tank. The side walls of the tank proved essentially clean.

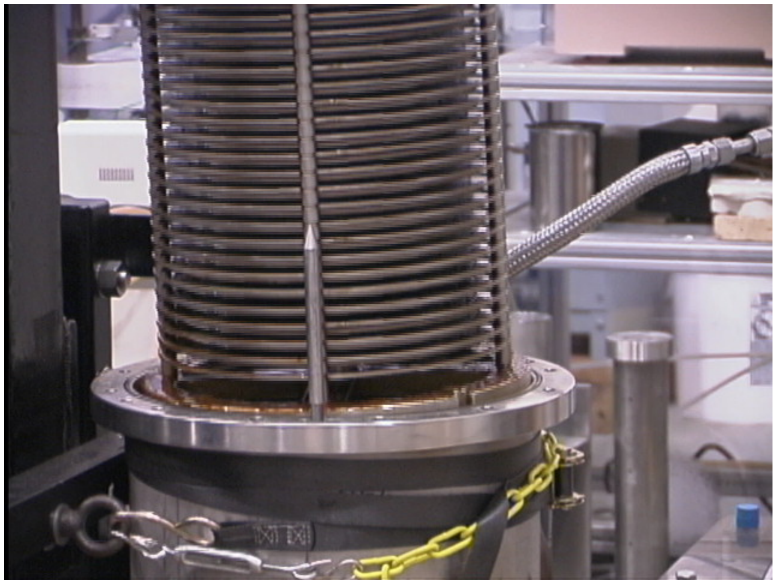

Figure 19 Rinsed Filter Stack after 20 wt % Sludge Testing

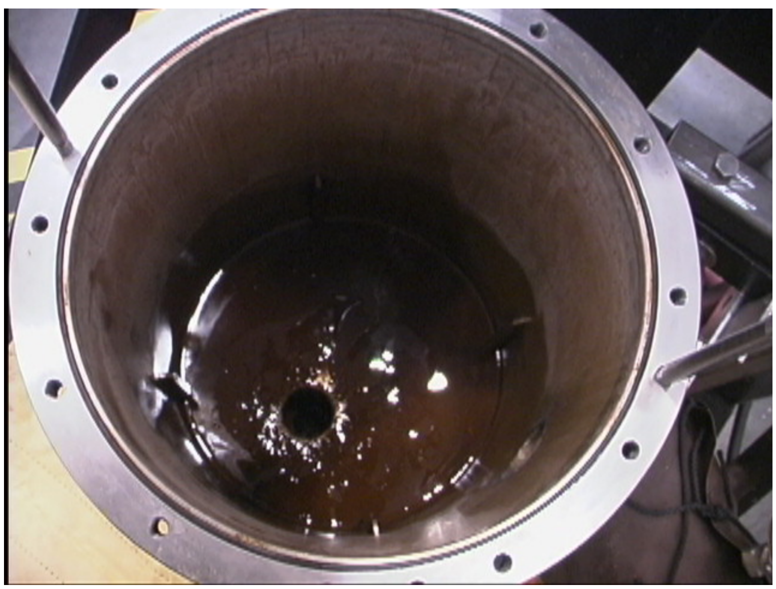

Figure 20 Rinsed Filter Tank after Filter Operation with 20 wt % Insoluble Solids

Personnel disassembled the filter stack and inspected the individual disks. Figure 21 and Figure 22 show two of the disks as removed from the stack following the rinse method described previously.

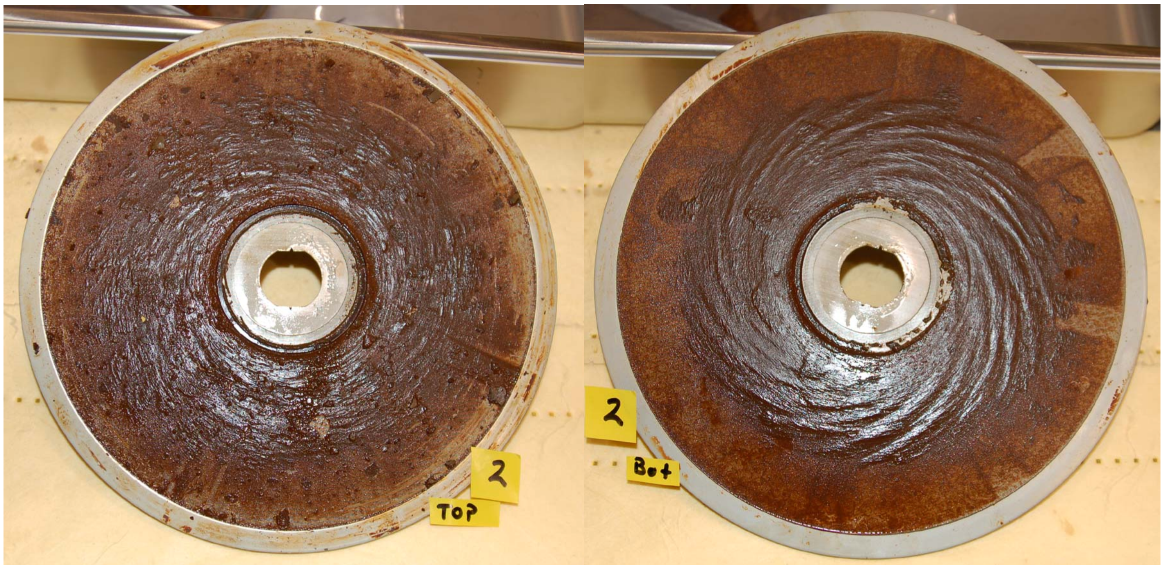

Figure 21 Second Filter Disk from the Bottom of the Filter Stack after Running 15-20 wt % of the Type 2 Simulated Sludge

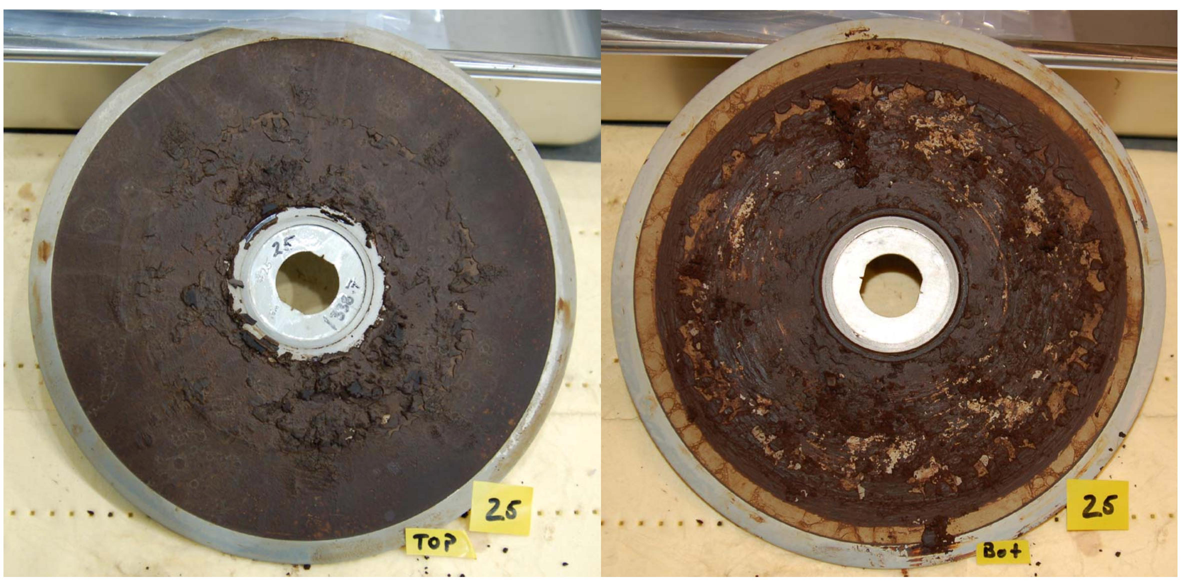

Figure 22 Filter Disk at the Top of the Stack, Top and Bottom Views Showing Filter Cake after Running 15-20 wt % of the Type 2 Simulated Sludge

As expected, the filter cake accumulation increased after processing the higher insoluble solids slurry. Note that, as can be seen in Figure 22, the filter cake began dissipating (i.e., sloughing from the surface). Several other disks had similar results.

3.3.4.1 Comparison of Continuous Washing with the Rotary Microfilter versus Batch Washing

One potential application for the pump/filter module incorporating two rotary filters is for the continuous washing of sludge to support sludge processing. The typical batch method of washing involves the addition of large volumes of inhibited water to a waste tank, mixing the tank contents, then settling and decanting the supernate. This process is repeated until the desired sodium molarity is reached. The rate at which the wash occurs and the final concentration of the insoluble solids depends upon properties of the material (e.g., settling time) in the tank. The use of the pump filter module for a continuous wash process reduces the amount of wash water required by washing more concentrated slurry in a continuous process.

The following is a comparison of the washing process[a] for a tank containing

Liquid volume (gal)	421,357
Sludge volume (gal)	27,221
Solids (kg)	258,435
wt % solids	12.48
Na Molarity	3.01

For the Settle and Decant method, the washing scenario begins with the addition of 304,952 gallons of wash water to the tank. After mixing and settling, 159,003 gallons are decanted leaving a Na molarity of 2.07. An additional 141,325 gallons of wash water and 20,135 gallons of sodium nitrite solution are added and the tank contents are mixed. After a series of decants, an additional 136,540 gallons of wash water are added. After a series of decants, the final volume of the tank is 465 075 gallons with a Na molarity of 1.23. The predicted wt % solids are 13.05. This process requires use of 582,817 gallons of wash water.

For the rotary filter method, the scenario begins with the use of the pump filter module with two 25-disk rotary filters concentrating the tank contents from 12.48 to 15 wt %. The continuous wash for a well mixed tank requires a wash volume based on:

$$V_w = V_s * ln\ (C_i/C_f)$$

where:

V_w = volume of wash water,
V_s = supernate volume,
C_i = initial sodium concentration, and
C_f = final sodium concentration.

[a] J. Gillam, Case 15c_081606 Washing Spreadsheet

In this case, the initial concentration is 3.01 M sodium and the final concentration is 1.2 M sodium. With the initial concentration of the tank contents, the volume of the supernate in the tank is reduced from 421,357 gallons to 367,090 gallons. The calculated volume of wash water required to reduce the sodium concentration from 3.01 to 1.2 is 337,583 gallons. Thus the required wash water is reduced by 245,234 gallons, or 42% of that required in the batch approach. Washing at the original 12.48 wt % solids, it is predicted that 387,488 gallons of wash water would be required. This would reduce the required wash water by 195,329 gallons, or 66% of the amount of wash water required in the batch approach.

At a filtration rate of 3.5 gpm with a well mixed feed tank, a pump/filter module with two 25-disk rotary filters would require approximately 40 days with 75% attainment to wash after concentrating the slurry to 15 wt %.

The results of the wash water calculations are summarized in Table 3.

Table 3 Water Volume Required to Wash from 3.01 M Na to 1.2 M Na

Method	Calculated Wash Water Volume (Gallons)
Settle and Decant	582,817
Rotary Filter, washing at15 wt %*	337,583
Rotary Filter, washing at 12.48 wt %*	387,448

* Assumes a continuous well mixed tank

Similar results were obtained by H. Elder in studying the possibility of using the rotary filter for sludge washing.[19] In that study, however, only a 26 % reduction in wash water is cited since the calculation did not take credit for concentrating the slurry prior to washing.

The rotary filter wash water calculations assume that the tank is continually mixed. It is unlikely that constant mixing will be accomplished for the duration of the washing process with the rotary filter due to the durability of the waste tank slurry pumps. Intermittent mixing would require additional wash water due to the reduction of washing efficiency.

3.4 ANALYTICAL RESULTS

3.4.1 Turbidity

Technicians collected samples of the filtrate throughout the testing program and measured for turbidity using a Hach Model 2100P Turbidimeter. They checked the meter using standards before and after analyzing the samples. Figure 23 provides the results. As can be seen in the graph, the turbidity of all samples remained less than 3 NTU, with the majority of the samples less than 1 NTU. All filtrate samples appeared clear with no visible solids or discoloration. The acceptance criterion for turbidity is less than 5 NTU.[20] All samples fell well under this criterion.

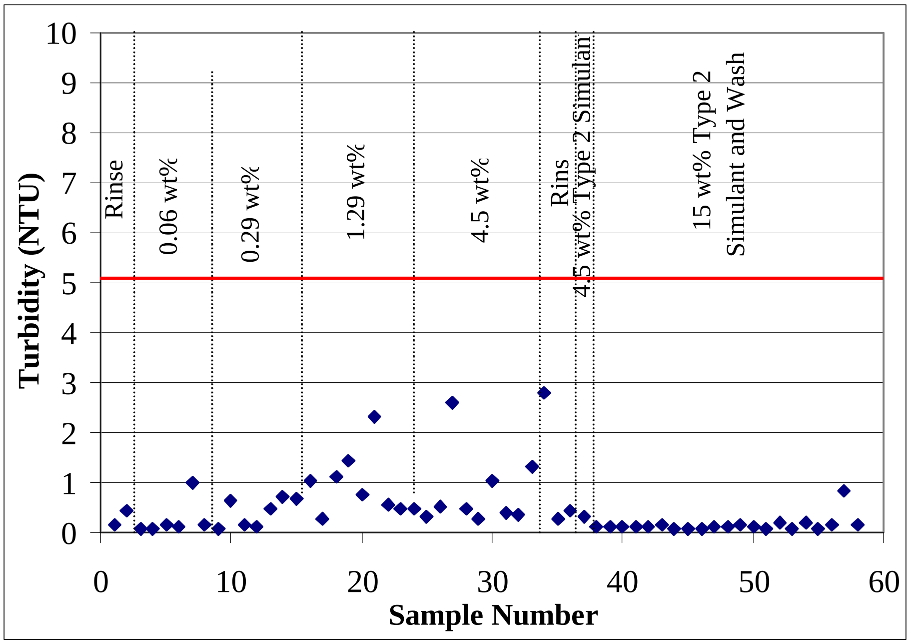

Figure 23 Turbidity Measurements of Filtrate Samples

3.4.2 Sludge Rheology

Personnel submitted five samples of the sludge for rheology measurements: the 4.5 wt % material for each slurry, the 15 wt % insoluble solids prior to being washed, the 15 wt % insoluble solids after completion of the washing, and the slurry after concentration to ~20 wt %. The unwashed 15 wt % slurry had a yield stress of 7.9 Pa. After washing, the yield stress increased to 12.4 Pa, which is consistent with previous testing. The 20 wt % slurry had a yield stress of 31 Pa, which would make it very difficult to pump or mix.

Table 4 Solids Concentration and Yield Stress of Feed Slurries

Slurry Target	Unwashed 4.5 wt % Insoluble Solids (Sludge Batch 2)	Unwashed 4.5 wt % Insoluble Solids (Type 2)	Unwashed 15 wt % Insoluble Solids (Type 2)	Washed 15 wt % Insoluble Solids (Type 2)	Washed 20 wt % Insoluble Solids (Type 2)
wt % Soluble Solids	14.64	11.16	15.70	1.43	1.23
wt % Insoluble Solids	4.85	4.50	13.15	15.65	19.31
Yield/Shear Stress (Pa)	5.4	0.2	7.9	12.4	31.2
Plastic Viscosity (cP)	8.5	2.5	10.1	8.7	13.9

3.4.3 Material Accumulation on Disks

Figure 24 shows the mass of the material accumulated on or inside of the disk after rinsing the system following operation with 4.5 wt % SB2 simulant and with the 15-20 wt % slurry of the Type 2 sludge simulant. The mass shown for the 4.5 wt % SB2 is obtained by subtracting the average amount of liquid retained by all 25 disks from the weight of the disk after rinsing. The mass shown for the disks from the rinse of the 15-20 wt % slurry are obtained by the difference between the weight of the disk as removed from the filter and the weight of the disk after mechanically removing solids from the surface of the disk. It should be noted that, for some disks, the filter cake bridged to the turbulence promoter and that material is not included in the weight of the disk.

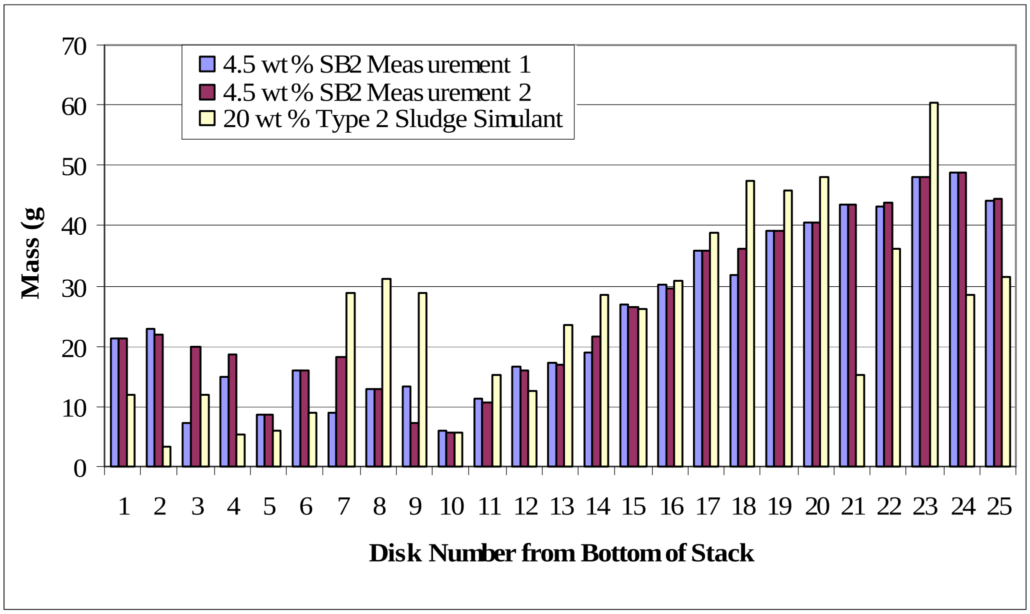

Figure 24 Mass of Material Accumulated on Filters Disks after Rinsing of 4.5 wt % Sludge Batch 2 Simulant and the 20 wt % Type 2 Sludge

Evaluation of the data indicates that the mass accumulated on the disks generally rises after the 14th disk from the bottom of the stack. This change in accumulated material is believed due to the location of the feed inlet on the tank. Flow enters the filter housing impinging on the edges of disks 10 through 13 as counting from the bottom of the stack. The filter tank outlet is on the bottom of the tank so the primary flow washes over the lower disks. The primary source of the flow to the upper disks is the mixing in the tank caused by the rotor. Personnel confirmed this difference in filter cake accumulation by inspection of the individual disks during disassembly of the filter stack.

The height of the feed inlet is defined by the ability to fit the piping in the plug design. An increase in the inlet pipe height location could potentially provide a more even distribution of flow thereby potentially reducing the filter cake accumulation on the upper disks. This would potentially maintain a higher filtration rate for a longer period of operation. At worst, the pattern in filter cake accumulation would shift to the upper disks. The same or possibly a slight increase in benefit may occur if the feed inlet is split at two heights due to better flow distribution.

Comparisons are possible for the condition of the stack after previous rinsing of the 4.5 wt % SB2 slurry testing. Figure 11 and Figure 12 show the condition of the filter stack and the inside of the tank after rinsing with 55 gallons of rinse water recirculated for the equivalent of two complete volumes. The tank sidewalls appeared cleaner after rinsing the 20 wt % insoluble solids feed than after rinsing the 4.5 wt % insoluble solids SB2 slurry. This observation is likely attributed to the additional volume or rinse water after the 20 wt % testing. No significant deposits existed on the filter tank walls after either rinse. This finding indicates that there is good mixing throughout the tank even with the limited volume of the rinses. There was no indication of dead areas where insoluble solids collected.

After disassembly of the filter stack, personnel collected and dried sludge from all components to determine the amount of sludge solids left in the system. Using this mass, the activity of the filter after being rinsed in radioactive service is estimated. The activity of the sludge solids is calculated for the analysis of the SB4 sludge material[21]. The total beta/gamma activity for SB4 is 22 mCi/g of beta and 0.56 mCi/g of gamma in dried sludge. The mass of the dried sludge recovered from the disk stack is 685 g. This amount of solids equates to an activity of 15.1 Ci beta and 0.38 Ci gamma for SB4 material. Additional activity may be present due to soluble species interstitial to the sludge solids not removed during rinsing.

3.4.4 Particle Size of Slurry Solids

Figure 25 shows the particle size of the SB2 and Type 2 sludge samples. The SRNL Analytical Development Section measured the particle size with a Microtrac S3000 using a carrier fluid containing 1.91 M NaOH, 2.14 M $NaNO_3$, and 0.52 M $NaNO_2$. The median particles of the SB2 and Type 2 sludge samples are 3.32 and 2.34 micron, respectively. The median particle size of the Type 2 sludge is ~ 30% smaller than the SB2. The standard deviations of the sludge (50th percentile particle size divided by 16th percentile particle size) of the SB2 and Type 2 sludge samples are 4.37 and 1.65, respectively. In the SB2 slurry, 21.8% of the particles were less than 1 micron, while 3.8% of the Type 2 sludge contained particles less than 1 micron. Even though the Type 2 sludge had a smaller median particle size, its smaller standard deviation (i.e., narrower dispersion of particle sizes) and lower fraction of fines is expected to produce a higher filtration rate than the SB2.

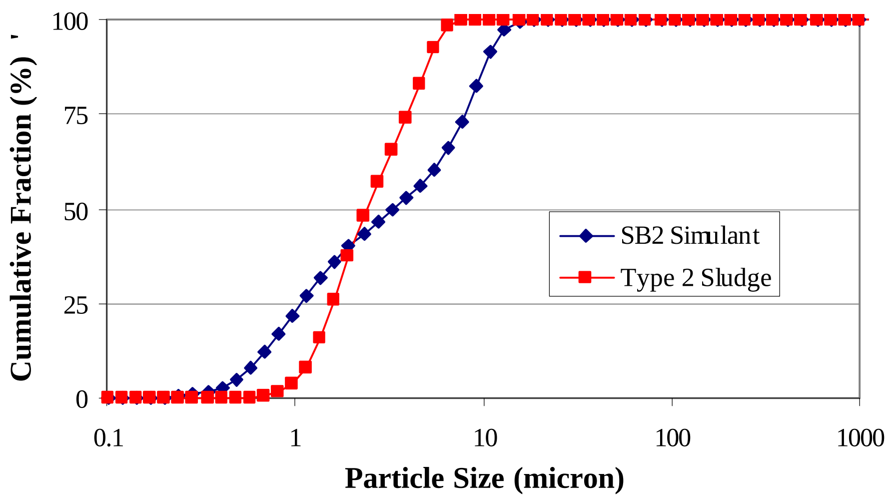

Figure 25 Particle Size Distribution of the Simulated Sludge Solids

3.5 SYSTEM/COMPONENT PERFORMANCE

During operation, the primary concern for the design of the filter is to have adequate cooling to the mechanical seal. Since the seal is located in a pocket at the top of the filter, purging of the air through the filtrate line is needed. The filtrate lines are the highest point and allow air to escape the filter housing. The design includes a small impeller added during fabrication of the filter at the vendor shop for the purpose of directing process fluid towards the mechanical seal and thus allowing continuous cooling. To determine if the housing had purged all air, personnel observed the filtrate flow meter readout. With air in the line, the filtrate flow rate reads very erratically. When the flow stabilized, we presumed that the air successfully purged from the filter housing. We substantiated this conclusion during testing by observing the filtrate stream for a steady liquid stream (i.e., absence of visual evidence of air purge in the filtrate stream).

3.5.1 Main Shaft Seal

Leakage from the main shaft mechanical seal is expected to be the first indication of wear on the rotary filter but will not be the ultimate failure mechanism of the filter. In the SCIX plug configuration, when the seal begins to pass process fluid, process fluid will flow out of the weep hole to the bottom of the plug and drain to the tank. Spray rings included in the design allow for decontamination of the equipment in the event of such a leak.

As seal wear worsens, the seal will pass enough material to exceed the capacity of the weep hole to drain and process fluid will eventually penetrate the bearing. Although the bearing itself is sealed, process fluid will eventually enter the bearing and cause it to fail prematurely. Prior to failure, indications such as increases in the amount of power required to operate the filter and indications of fluid in the plug drain will manifest. Monitoring of the motor power will provide a means to identify the onset of this condition. Failure of the bearing will require the replacement of the filter stack assembly.

We selected the main shaft seal, a John Crane Inc. Type 1, for the filter after consulting with John Crane Inc. representatives and providing the working conditions. The greatest concern with the seal is the ability to maintain proper coolant and lubrication. We avoided a water seal for service due to prior troubles with that style of seal in similar applications. The filter vendor's (i.e., SpinTek™'s) experience is that operation of the rotor provides sufficient turbulence to maintain a constant flow of process fluid to the seal faces to maintain cooling and lubrication. The standard seal on the original design of the SpinTek™ filter is a water-cooled seal. Lowering of the inlet piping in the filter added concern that insufficient fluid would reach the seal location to purge trapped air and keep the seal faces cooled. We added an impeller to the design to direct process fluid flow at the seal to aid in maintaining proper flow.

Personnel completely disassembled the seal and inspected the components. Inspection involved both the seal manufacturer's representative and SRNL personnel. Personnel inspected three primary components of the seal for indications of wear. Inspection of the elastomer bellows (made from ethylenepropylenediene, EPDM) gives an indication of the cooling provided to the seal, inspection of the seal drive mechanism indicates the consistency of the coolant/lubrication, and inspection of the seal faces indicate the amount of lubrication provided between the seal faces.

Excessive heating would compromise the integrity of the elastomer bellows. Personnel monitored the seal temperature by the use of an optical pyrometer directed at the seal through the bearing housing weep hole. The temperature readings obtained showed no rise in the seal temperature with most readings only slightly above ambient temperature. Careful inspection of the elastomer bellows, shown in Figure 26, indicated no obvious damage due to overheating. Therefore, we conclude that the filter design maintained sufficient cooling to prevent overheating of the seal.

Figure 26 The Shaft Seal Elastomer Bellows after 120 Hours of Testing

Personnel then inspected the drive of the mechanical seal (shown in Figure 27). The “fan” blades design increases circulation of the process fluid to the seal area providing cooling. Excessive wear or notching in the drive tabs would indicate intermittent lubrication of the seal. During intermittent lubrication, the seal faces would dry and cause additional drag across the seal faces. As additional lubricant is eventually made available, the drag is again reduced. Such cycling results in wear or damage to the drive pins in the seal. In this testing, SRNL and vendor inspection found no evidence of wear on the drive pins and therefore we conclude that consistent lubrication to the seal persists during operation. The fan blade design appears successful for this application.

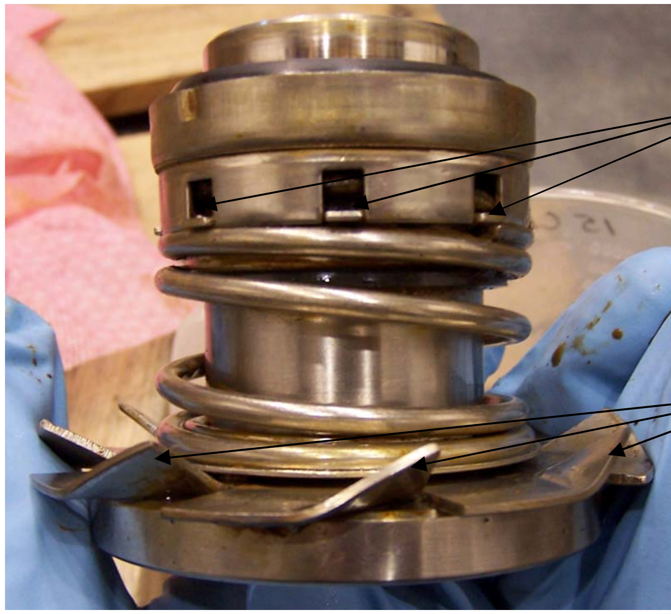

Figure 27 Shaft Seal Drive Mechanism after 120 Hours of Testing

Figure 28 and Figure 29 show the two faces of the mechanical seal after 120 hours of testing.

Figure 28 Photo Showing the Wear on the Rotor of the Mechanical Seal after 120 Hours of Testing

A visible wear groove can be seen on the stationary portion of the seal shown in Figure 29. The initially identified design risk involves wear due to excessive heat between the seal faces due to lack of cooling and lubrication. The wear observed on the seal face is attributed to a significant number of starts and stops, an abrasive process fluid, and some amount of dry running of the seal during early stages of testing. The seal vendor considers the amount of wear observed to be at the high end of normal wear. Therefore, the observed wear is greater than desired. The John Crane Inc. representative indicated that the operation of a mechanical seal in constant stop/start service pushes any mechanical seal into the higher end of expected wear. The extent of the wear indicated that the amount of lubrication between the seal faces is less than optimal and may have accelerated the wear of the seal faces. Although it is extremely difficult to predict the lifetime of a mechanical seal, the vendor representative concludes that a minimum of one year is a reasonable expectation for the service conditions under which the seal was operated. The lifetime of the seal can be improved by changing the seal face material from silicon-carbide to graphite-impregnated silicon-carbide. The addition of the graphite to the silicon-carbide increases the lubricity of the seal faces. According to the John Crane Inc. representative, by switching to this material the service life of the seal would be expected to double. The change of the seal material described will have no effect on the construction or filtration performance of the system.

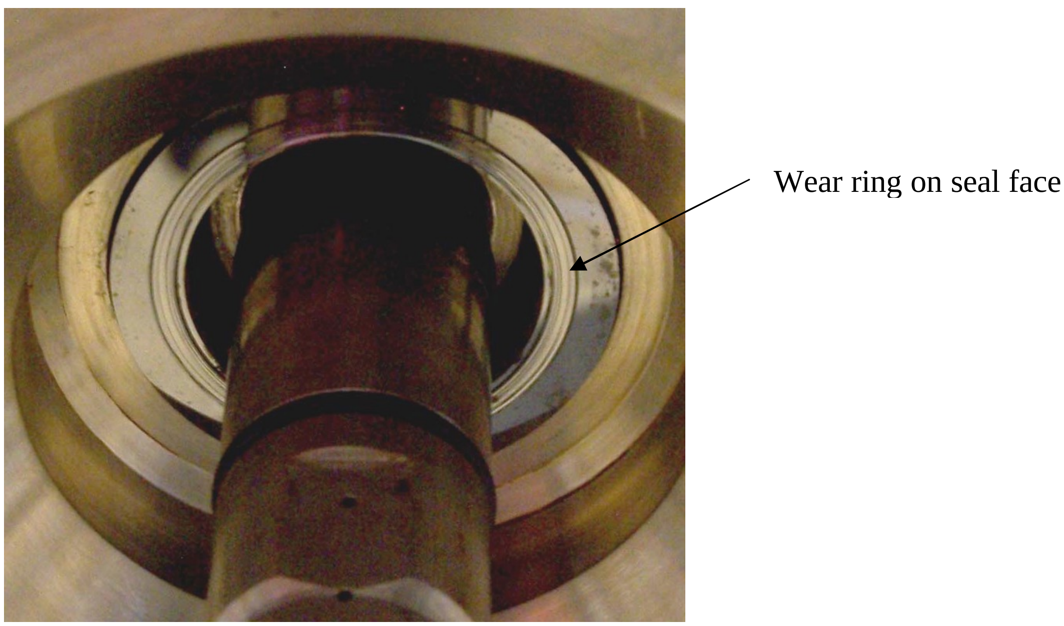

Figure 29 Photograph of the Wear on the Shaft Mechanical Seal Stationary Face after 120 Hours of Testing

3.5.2 Rotary Joint

Testing used the rotary joint from each of the two filter units. (The parts from the two filters are interchangeable.) The first rotary joint started with visible passing of fluid over the mechanical seal faces. This manifested itself as a weeping of filtrate from one of the two weep holes. Figure 30 shows traces of the filtrate drips from the upper weep hole of the rotary joint.

Figure 30 Traces of Filtrate Drips from Rotary Joint Upper Weep Hole

Personnel first noted the weeping during the 0.06 wt % insoluble solids testing with the SB2 simulant. We identified the material leaked as the filtrate crossing the faces of the mechanical seal. After consulting with the seal manufacturer, we believe that operating the system without a pressure drop across the seal faces may have contributed to the weeping. During initial testing and acceptance testing at the vendor, the filtrate line discharged directly to atmosphere. No back pressure was applied to the filtrate line. With no back pressure applied, there was no pressure drop across the seal faces and therefore the seal spring provided the only force applied to keep the seal faces together. The manufacturer recommends at least one atmosphere of pressure across the seal face during operation to keep the seal faces properly set. The frequency of the drops reached a maximum of 11 drips per minute. As the filter system operated with a pressure across the seal faces, the drips slowed significantly. The drip rate slowed to an average less than 1 drip every 10 minutes. This decrease occurred over approximately 50 hours of operation. All drips emerged from the upper weep hole on the rotary joint. No fluid passage occurred from the lower weep hole at any time during operation of the filter.

Personnel swapped the second rotary joint for the first after completing the SB2 simulant testing. This rotary joint operated for approximately 12 hours with one drip observed.

3.5.3 Bushing

The bushing for the filter is made of graphite. Appreciable wear occurred on the bushing during testing, primarily due to the misalignment of the bottom plate.

During the manufacture of the filter tanks, the vendor welded the guidance spikes in place as much as 0.060” off of center. We placed shims on the bottom plate of the filter stack to decrease the loose design tolerance. The even placement of the shims on the bottom plate and the subsequent alignment to the uneven placement of the tank bottom guidance spikes caused the bottom plate to sit off center. This, in turn, induced a localized stress on the graphite bushing causing accelerated and uneven wear. This resulted in the directional wear of the bushing during testing as shown in Figure 31.

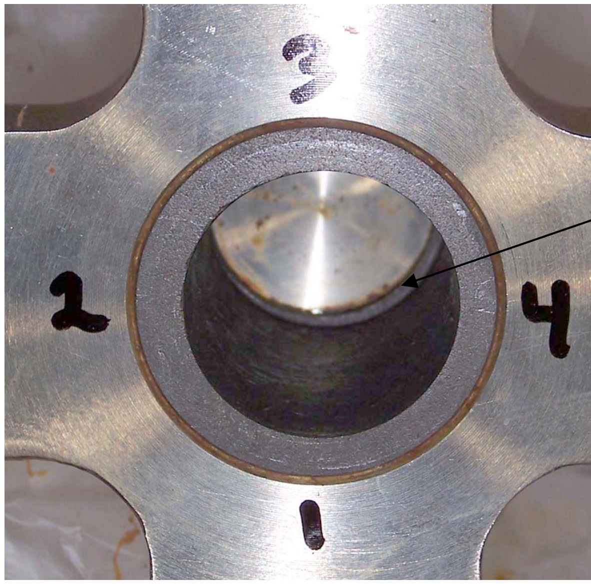

Figure 31 Wear on Graphite Bushing Due to Misalignment

One filter disk had indications of contact between the outer edge of the disk and the turbulence promoters. Personnel noted minor gouges on over half of the 3 inch hubs that fit between the turbulence promoters. The gouges did not appear to affect the performance or lifetime of the filter. The markings on the hubs range between 0 and 200° of the circumference, indicating that the hubs did not constantly contact the turbulence promoters during the 360° travel path. The wear marks show that the hubs were not concentric to the shaft during operation in spite of attempts to center during assembly of the filter stack. The designed gap between the hubs and turbulence promoters is 0.031 inches and the vendor has stated that contact between the hubs and turbulence promoters in not uncommon. Some open tolerance exists in the fit between the shaft and hubs per the original vendor design. Smaller tolerances could reduce the likeliness of contact between the hubs and turbulence promoters. This could increase the concentricity of hubs to the shaft, and therefore, improve overall shaft balance.

Due to the amount of wear observed, we recommend replacing the graphite with a more wear resistant material such at silicon carbide. The silicon carbide bushings are less than $300 each and have a lead time of approximately 4 weeks. The use of this, or a similar material, would require an additional part made of similar material attached to the end cap of the shaft to prevent excessive wear on the shaft itself, or a hardened coating on the steel shaft. The use of the second piece to protect the shaft would require the receiving cup in the bottom plate to be enlarged to accept the bushing. This would be accomplished by removing the current receiving cup and replacing with a larger cup and machining to the correct dimensions.

4.0 CONCLUSIONS

The re-designed rotary filter performed well in all aspects of testing. The insertion and removal of the filter stack proved repeatable with the alignment of the lid bolts always accurate, though a strengthening of the exterior guide spikes may be required. The design of the support arm for the SCIX plug/filter module requires a modification to allow additional spacing for the motor plate mounting bolts. The addition of a lifting point is required to efficiently move the motor for access to the filter stack since lifting points are not provided on the procured motors.

Personnel tested the ability to flush the filter for soluble material by filling the system with a Rhodamine WT dye solution. Results show that by draining the system and rinsing with 50 gallons of water, the dye concentration is reduced by more than 100X.

Filter performance testing used various amounts of insoluble sludge solids ranging from 0.06 to 15 wt % insoluble solids in a 3.2 M sodium simulated supernate. The filter produced filtration rates between 3 and 7 gpm for a 25 disk filter. At these filtration rates, the pump filter module would provide 6 to 14 gpm of clear filtrate for the ion exchange process. High feed pressure required to carry the filtrate through a downstream ion exchange column showed no adverse effect on filtration.

Personnel washed approximately 80 gallons of simulated sludge in 3.2 M sodium supernate using 207 gallons of inhibited water to 0.3 M. The washing occurred as a continuous process with the wash water added at the same rate as filtrate removal. Technicians obtained samples throughout the washing and analyzed for density and sodium content. Results show an effective washing mimicking a predicted dilution calculation for a well mixed tank.

The filter system then concentrated the washed 15 wt % insoluble solids slurry to approximately 20 wt % insoluble solids with no operational problems with the exception of the entrainment of air at the feed pump. This air entrainment reduced the filtration rate, but resulted from leaking packing in the feed pump rather than filter operating problems. The initial measured feed rate at 20 wt % insoluble solids was approximately 4.2 gpm at an equivalent process fluid temperature of 35 ºC.

The turbidity of filtrate samples from all phases of testing measured less than 3 NTU, with the majority of samples less than 1 NTU. Thus, all measurements fell below the criterion of less than 5 NTU.

After slurry operations, workers effectively rinsed the filter with the equivalent of 250 gallons of water. The filter stack contained 685 grams of residual sludge solids. This amount of solids equates to an equivalent activity of 15.1 Ci beta and 0.38 Ci gamma for Sludge Batch 4.

Personnel disassembled the filter system and examined for signs of wear and component operation. Wear occurred on the primary seal and is attributed to the numerous stops and starts, the abrasive nature of the process fluid and the possibility that the seal faces did not receive enough lubrication from the process fluid. Examination of the seal components showed no indication of heat damage, thus indicating that the seal received adequate cooling during operation. Also, there is no indication of damage to the drive mechanism, thus indicating that lubrication is consistent. While it is extremely difficult to predict the life of the seal, the vendor representative indicates a minimum of one year in present service conditions is reasonable. Changing the seal face material from silicon-carbide to a graphite-impregnated silicon-carbide is expected to double the life of the seal. Replacement of the current seal with an air seal could increase the lifetime to 5 years.

The bottom bushing showed wear due to a misalignment during the manufacture of the filter tank. Replacing the graphite bushing with a more wear resistant material such as a carbide material will increase the lifetime of the bushing. This replacement requires a more wear resistant part or coating to prevent excessive wear of the shaft.

5.0 FUTURE WORK

Follow-on development work for the modified design should focus on extending the lifetime of the filter unit and increasing filtration rate. Areas of focus should include extending the life of the primary seal and the bottom bushing. Failures of these two items are considered the primary and secondary means, respectively, of failure and subsequent replacement of the unit. Additional work could include methods to remove filter caking on the disks.

The location of the seal requires a complete purge of air from the filter tank to allow process fluid to lubricate and cool the seal. The highest air purge point is the filter disks, which requires the system to purge air prior to starting the rotation of the disks. This allows filter cake to accumulate on the disks before the shear can prevent the initial caking. We recommend investigating the use of an independently cooled seal either by liquid or gas. Decoupling of the seal cooling could prevent the possibility of accelerated wear due to excessive heat. An air-cooled seal such as the John Crane Inc. Type 2800 could potentially add significantly to the life of the primary seal. John Crane Inc. claims that this seal technology has a design life of 5 years. The seal is in service with kaolin slurries and low level radioactive service on a granulator. This seal may require minor machining or, at worst, the replacement of the shaft and seal housing to test with the current filters. The cost of the seal is less than $4000.

The bottom bushing life can be significantly extended if the graphite bushing is replaced with a more wear resistant material such as silicon carbide. In this configuration, an additional carbide sleeve or coating on the shaft is required to prevent the transfer of the wear to the filter shaft. This may require modification of the bottom plate to allow for the additional sleeve. Carbide bushings would cost approximately $300 each with a lead time of approximately 4 weeks.

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SpinTek Systems Speedy Data Sheet

CUSTOMER		MEMBRANE			SURFACE AREA		Test setup				OPERATOR	DATE
WSRC		0.5 Pall			28 ft2		Rotor #1 with Spintek union #1				Jason Gilmour	10/10/2006
FEED SAMPLE		INITIAL FEED VOLUME		FINAL FEED VOLUME		FINAL CONCENTRATE					FINAL FLUX	
5% SrCO3		~40 Gal		~40Gal		n/a					384 gfd	
TIME OF DAY HH:MM	ELAPSED TIME HH:MM	FEED FLOW GAL/MIN	FEED PRESS. PSI	Perm. PRESS. PSI	FEED TEMP °F	PERMEATE FLOW gal/min	PERMEATE CIARITY ntu	ROTARY UNION TEMP. °F	HOUSING TEMP. °F	COMMENTS	FLUX GPD/SQFT	
Initial clean water flux												
10:13	0:15	17.00	105	65	84	8.57	n/a	78.00	76.50		465.6	
2 hour 5% Solids test (SrCO3)												
10:55	0:05	17.00	105	65	82	6.98	1.0/1.28	n/a	n/a		402.0	
11:10	0:20	17.00	105	65	92	6.82	.62 / .5	81.00	77.50		392.8	
11:26	0:36	17.00	105	65	93	6.67	.84/.24	81.50	78.50		384.0	
11:45	0:55	17.00	105	65	92	6.67	.35/.27	81.50	80.50		384.2	
11:57	1:07	17.00	105	65	91	6.50	.25/.27	81.50	79.50		374.4	
12:10	1:20	17.00	105	65	92	6.67	.31/.39	81.00	80.00		384.2	
12:25	1:35	17.00	105	65	92	6.67	.45/.32	81.50	79.50		384.2	
12:40	1:50	17.00	105	65	92	6.67	.36/.42	81.00	81.00		384.2	
12:56	2:06	17.00	105	65	92	6.67	.33/.48	81.00	81.50		384.2	
Test to check permeate flow with no permeate back-pressure.												
12:45	1:55	n/a	48	7	92	6.38	n/a	n/a	n/a		367.5	
Clean water flux after 15 minute acid wash.												
2:40	0:15	17.00	105	65	85	7.70	n/a	n/a	n/a		443.5	

CUSTOMER	MEMBRANE	SURFACE AREA	Test setup	OPERATOR	DATE
WSRC	0.5 Pall	25 ft^2	Rotor #2 with Spintek union #2	Jason Gilmour	10/11/2005

FEED SAMPLE	INITIAL FEED VOLUME	FINAL FEED VOLUME	FINAL CONCENTRATE	FINAL FLUX
5% SrCO3	-40 Gal	-40Gal	n/a	493 gfd

TIME OF DAY HH:MM	ELAPSED TIME HH:MM	FEED FLOW GAL/MIN	FEED PRESS. PSI	Perm. PRESS. PSI	FEED TEMP °F	PERMEATE FLOW gal/min	PERMEATE CLARITY ntu	ROTARY UNION TEMP. °F	HOUSING TEMP. °F	COMMENTS	FLUX GPD/SQFT
Initial clean water flux											
9:00	0:15	17.00	105	65	80.5	8.33	n/a	75.00	75.00		479.8
2 hour 5% Solids test (SrCO3)											
9:30	0:05	17.00	'05	65	79	8.33	.57/.43	7.60	73.50		479.8
9:45	0:20	17.00	'05	65	91.5	8.57	.57/.45	75.00	74.50		493.6
10:00	0:35	17.00	'05	65	95	8.57	.37/.36	77.50	76.00		493.6
10:15	0:50	17.00	'05	65	97	8.57	.30/.38	78.50	77.50		493.6
10:30	1:05	17.00	'05	65	95.5	8.57	.36/30	78.50	78.50		493.6
10:45	1:20	17.00	'05	65	95	8.57	.28/.37	80.50	81.50		493.6
11:00	1:35	17.00	'05	65	95	8.57	.31/.37	79.50	78.00		493.6
11:15	1:50	17.00	'05	65	96	8.57	.33/.33	82.00	78.50		493.6
11:25	2:00	17.00	'05	65	95.5	8.57	.38/.36	79.50	78.50		493.6
Test to check permeate flow with no permeate back-pressure.											
11:30	2:05	n/a	50	10	95	8.57	n/a	n/a	n/a		493.6
Clean water flux after 15 minute acid wash.											
2:10	0:15	17.00	'05	65	81	8.57	n/a	n/a	n/a		493.6