

**Contract No:**

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

**Disclaimer:**

This work was prepared under an agreement with and funded by the U.S. Government. Neither the U. S. Government or its employees, nor any of its contractors, subcontractors or their employees, makes any express or implied:

- 1 ) warranty or assumes any legal liability for the accuracy, completeness, or for the use or results of such use of any information, product, or process disclosed; or
- 2 ) representation that such use or results of such use would not infringe privately owned rights; or
- 3) endorsement or recommendation of any specifically identified commercial product, process, or service.

Any views and opinions of authors expressed in this work do not necessarily state or reflect those of the United States Government, or its contractors, or subcontractors.



# Laboratory-Scale Integrated ARP Filter Test

M. R. Poirier  
P. R. Burket

March 2016

SRNL-STI-2015-00485, Revision 0



## **DISCLAIMER**

This work was prepared under an agreement with and funded by the U.S. Government. Neither the U.S. Government or its employees, nor any of its contractors, subcontractors or their employees, makes any express or implied:

1. warranty or assumes any legal liability for the accuracy, completeness, or for the use or results of such use of any information, product, or process disclosed; or
2. representation that such use or results of such use would not infringe privately owned rights; or
3. endorsement or recommendation of any specifically identified commercial product, process, or service.

Any views and opinions of authors expressed in this work do not necessarily state or reflect those of the United States Government, or its contractors, or subcontractors.

**Printed in the United States of America**

**Prepared for  
U.S. Department of Energy**

**Keywords:** ARP, Crossflow, 512-S,  
Sintered-Metal Filter

**Retention:** *Permanent*

# Laboratory-Scale Integrated ARP Filter Test

**M. R. Poirier**  
**P. R. Burket**

March 2016

---

Prepared for the U.S. Department of Energy under  
contract number DE-AC09-08SR22470.



## REVIEWS AND APPROVALS

### AUTHORS:

---

M. R. Poirier, Hanford Research Programs	Date
------------------------------------------	------

---

P. R. Burket, Engineering Process Development	Date
-----------------------------------------------	------

### TECHNICAL REVIEW:

---

C. A Nash, Advanced Characterization and Process Technology Reviewed per E7 2.60	Date
-------------------------------------------------------------------------------------	------

### APPROVAL:

---

B. J. Wiedenman, Manager Advanced Characterization and Process Technology	Date
------------------------------------------------------------------------------	------

---

D. E. Dooley, Director Environmental & Chemical Process Technology Research Programs	Date
-----------------------------------------------------------------------------------------	------

---

E. J. Freed, Manager DWPF/Saltstone Facility Engineering	Date
-------------------------------------------------------------	------

## Summary

The Savannah River Site (SRS) is currently treating radioactive liquid waste with the Actinide Removal Process (ARP) and the Modular Caustic Side Solvent Extraction Unit (MCU). Recently, the low filter flux through the ARP of approximately 5 gallons per minute has limited the rate at which radioactive liquid waste can be treated. Salt Batch 6 had a lower processing rate and required frequent filter cleaning. There is a desire to understand the causes of the low filter flux and to increase ARP/MCU throughput.

This task attempted to simulate the entire ARP process, including multiple batches (5), washing, chemical cleaning, and blending the feed with heels and recycle streams. The objective of the tests was to determine whether one of these processes is causing excessive fouling of the crossflow or secondary filter. The authors conducted the tests with feed solutions containing 6.6 M sodium Salt Batch 6 simulant supernate with no MST.

The conclusions from this work follow.

- No catastrophic fouling of the crossflow or secondary filters was observed during the testing.
- The filter flux of the 0.1 micron crossflow filter was larger than the flux of the 0.5 micron crossflow filter suggesting that there may have been fine particles in the feed that fouled the 0.5 micron crossflow filter more than the 0.1 micron crossflow filter.
- The crossflow filter flux was larger during the first cycle than during the second cycle for both the 0.1 and 0.5 micron crossflow filters indicating that the washing, chemical cleaning, and blending may have formed fine particles that fouled the crossflow filters.
- The pressure drop across the 0.5 micron crossflow filter increased more from cycle 1 to cycle 2 than the pressure drop across the 0.1 micron crossflow filter indicating that the washing, chemical cleaning, and blending may have formed fine particles that fouled the 0.5 micron crossflow filter more than the 0.1 micron crossflow filter.
- No significant fouling of the secondary filters was observed during batches. This result contrasts with ARP experience with MST-containing feeds, but agrees with the limited ARP data with no MST strike.

## TABLE OF CONTENTS

Summary .....	5
Introduction.....	7
Experimental .....	7
<i>Equipment</i> .....	7
Filter Apparatus.....	7
<i>Test Protocol</i> .....	9
Quality Assurance .....	11
Results.....	11
<i>Crossflow Filter</i> .....	11
Conclusions .....	14
References.....	14

## Introduction

The Savannah River Site (SRS) is currently treating radioactive liquid waste with the Actinide Removal Process (ARP) and the Modular Caustic Side Solvent Extraction Unit (MCU). Recently, the low filter flux through the ARP of approximately 5 gallons per minute has limited the rate at which radioactive liquid waste can be treated. Salt Batch 6 had a lower processing rate and required frequent filter cleaning. There is a desire to understand the causes of the low filter flux and to increase ARP/MCU throughput.

One plausible cause of the low filter flux is plugging of the primary (i.e., crossflow) or secondary filters. Much of the testing that was conducted to design and develop the filtration process in ARP focused on one aspect of the process (e.g., filtration, washing, chemical cleaning) rather than the entire process.

This task attempted to simulate the entire ARP process, including multiple batches (5), washing, chemical cleaning, and blending the feed with heels and recycle streams. The objective of the tests was to determine whether one of these processes is causing excessive fouling of the crossflow or secondary filter. Potential causes of filter fouling include precipitation of salts from a supersaturated salt solution, precipitation of aluminate from a decrease in pH due to washing, precipitation of aluminate from blending salt solution with heels, precipitation of sodium oxalate from blending salt solution with a heel containing oxalic acid, and precipitation of sodium oxalate from blending oxalic acid with a heel containing salt solution. The authors conducted the tests with feed solutions containing 6.6 M sodium Salt Batch 6 simulant supernate with no MST. The TTQAP stated that the feed would contain MST. Because the ARP was considering changing to no MST addition, they requested the authors to conduct the test without MST.

## Experimental

### *Equipment*

#### Filter Apparatus

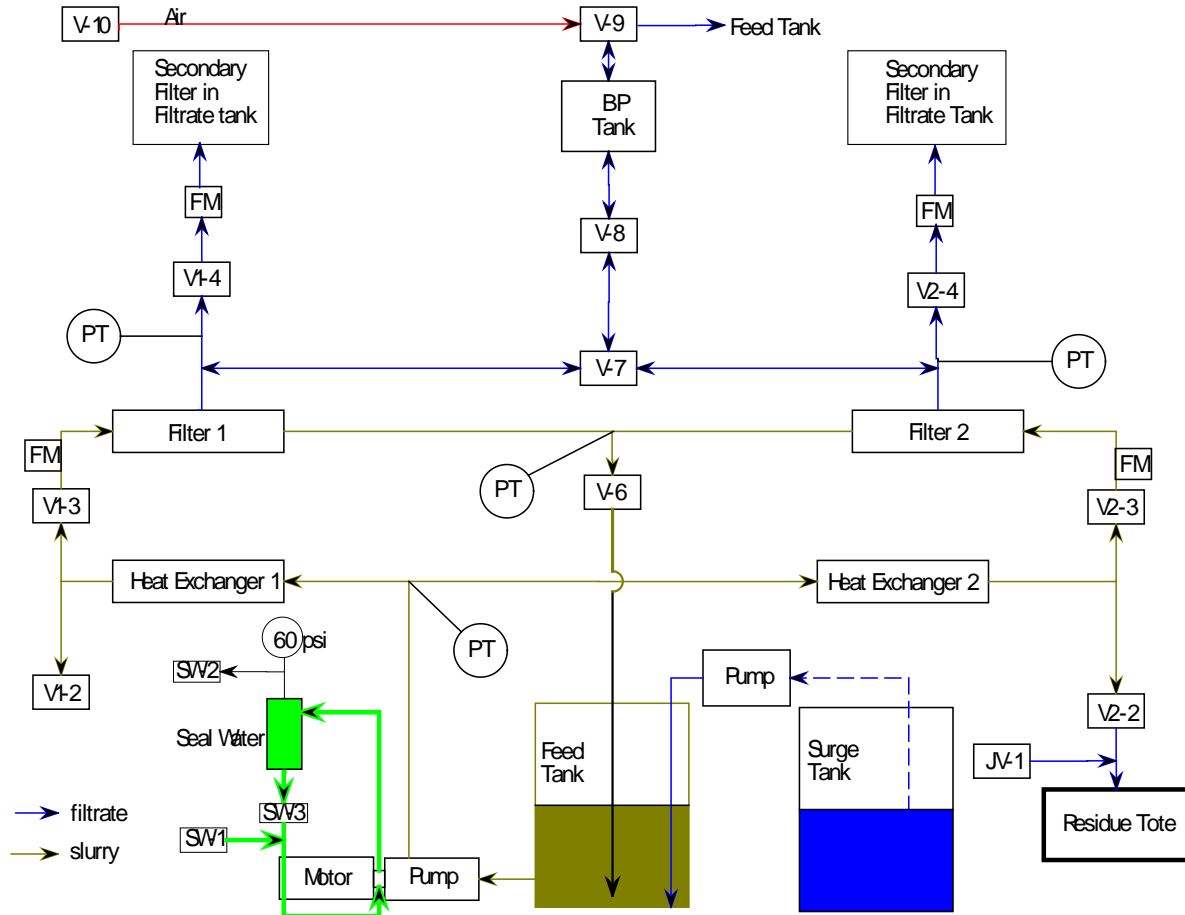
SRNL personnel constructed a bench-scale filtration apparatus. Figure 1 shows the layout of the bench-scale filtration apparatus. The apparatus has an ~ 10 gallon feed tank with an impeller to mix the tank contents. The mixing system was not designed to be prototypic of the ARP; it was designed to suspend any solid particles in the feed slurry. A centrifugal pump draws the slurry from the feed tank and pumps it into two parallel lines at ~ 3.0 gpm for each filter (6.0 gpm total). Each line has a heat exchanger to control the temperature of the feed slurry to  $25 \pm 2$  °C. The slurry flows past a tee where the two lines meet and the inlet pressure transducer is located. Beyond the tee there is one valve on each line which can be used to adjust the flow rate to each filter. Following each valve is a  $0 - 5 \text{ gpm} \pm 0.1 \text{ gpm}$  magnetic flowmeter which is used to measure the flow of slurry into each filter. The filters are located downstream of the flowmeters. After exiting the filters, the concentrated slurry streams are combined and returned to the feed tank. The concentrate line has a manual backpressure valve and an automated backpressure valve connected in parallel. The outlet from each of these valves returns the slurry to the bottom of the feed tank. All lines are 1/2" stainless steel (SS) tubing except for the instrument lines to the pressure transducers which are 1/4" SS tubing, and the filtrate lines, which are 3/8" and 1/4" tubing.

The filtrate leaves each filter through 3/8" and 1/4" tubing. Pressure transducers measure the filtrate pressure immediately after each filter. The filtrate is transported through a flow meter and to the filtrate tank.

One of the crossflow filters is a 0.1  $\mu\text{m}$  pore size, 3/8 inch ID Mott® porous metal crossflow filter and the other is a 0.5  $\mu\text{m}$  pore size, 3/8 inch ID Mott® porous metal crossflow filter. Both filters are 24 inches in length and constructed of sintered stainless steel. A computer was used to record the pressures, feed flow rates, filtrate flow rates, and feed tank temperature as well as to control the automatic backpressure valve located after the filters. A secondary filter was installed in the filter system downstream of the pressure



transducer on the filtrate side of each of the crossflow filters, to look for potential fouling of the secondary filter as has been observed at ARP. The filter is a Pall 2220 filter apparatus fitted with a flat sheet  $0.5\ \mu\text{m}$  Mott sintered stainless steel filter. The secondary filter area in the test rig was selected to approximate the ratio of secondary filter area to crossflow filter area in the ARP. To keep the ratio the same between the ARP and the test rig, the secondary filter area would be  $0.0141\ \text{ft}^2$  or  $13.1\ \text{cm}^2$  ( $0.197\ \text{ft}^2 * 16.5\ \text{ft}^2/230\ \text{ft}^2$ ). This area is based on an ARP crossflow filter area of  $230\ \text{ft}^2$ , an ARP secondary filter area of  $16.5\ \text{ft}^2$ , and a bench-scale crossflow filter area of  $0.197\ \text{ft}^2$ . The test rig filter surface area was selected to be  $9.6\ \text{cm}^2$  ( $0.0103\ \text{ft}^2$ ). A smaller secondary filter was selected to use an off the shelf filter and to increase the accumulation of solid particles at the filter surface (i.e., make any fouling of the secondary filter more noticeable).



symbol	meaning
V1-x	Valves for filter 1 train
V2-x	Valves for filter 2 train
V-x	Valves common to both trains
SW-x	Seal Water Valve
JV-x	Jabsco pump valve
FM	flow meter
PT	Pressure transducer

**Figure 1. Schematic of Laboratory-Scale Crossflow Filter Unit**

### ***Test Protocol***

The integrated filter tests were conducted as follows. Prior to testing, the apparatus was chemically cleaned with 0.5 M oxalic acid and 1 M nitric acid. Rather than using a prototypic ARP cleaning method, the filters were cleaned by draining the feed slurry from the filter system into the feed tank and removing the feed slurry from the feed tank. After the feed slurry was removed from the system, approximately 3 gallons of 0.5 M oxalic acid was added to the feed tank. The oxalic acid was recirculated through the filter system (on both the feed side and the filtrate side) for at least 1 hour, drained into the feed tank, and removed. After the oxalic acid was removed, approximately 3 gallons of 1 M nitric acid was added to the feed tank. The nitric acid was recirculated through the filter system for at least 1 hour, drained into the feed tank, and removed. The filter system was flushed with deionized water until the pH was greater than 6.<sup>a</sup> [All filter cleaning was conducted at ambient temperature] The cleaning protocol was selected to have a clean filter and a comparable starting point for each test rather than to be prototypic. Following chemical cleaning, the filter system was run with deionized water to establish a clean water flux for each of the filters. The clean water flux prior to testing was 2.8 gpm/ft<sup>2</sup> for the 0.5 micron filter and 0.96 gpm/ft<sup>2</sup> for the 0.1 micron filter.

The simulated salt solution was based on the Salt Batch 6 analysis.<sup>1</sup> Table 1 shows the composition of the salt solution. The salt solution was prepared by dissolving sodium hydroxide in deionized water, adding aluminum nitrate to react with the sodium hydroxide forming sodium aluminate, and adding the remaining components in order of increasing solubility. The salt solution contained no oxalate or silicon. The simulated salt solution was not filtered prior to addition to the feed tank. Any precipitated solids remained in the feed solution. The reason for not filtering the salt solution before adding it to the feed tank is that the feed to the ARP has a high ionic strength and likely contains precipitated solids.

**Table 1. Composition of Simulated Salt Solution**

<u>Ion</u>	<u>Concentration (M)</u>
Na <sup>+</sup>	6.6
K <sup>+</sup>	0.01
OH <sup>-</sup>	2.22
NO <sub>3</sub> <sup>-</sup>	3.03
NO <sub>2</sub> <sup>-</sup>	0.51
AlO <sub>2</sub> <sup>-</sup>	0.23
CO <sub>3</sub> <sup>-2</sup>	0.22
SO <sub>4</sub> <sup>-2</sup>	0.071
Cl <sup>-</sup>	0.0085
PO <sub>4</sub> <sup>-3</sup>	0.0045

The feed was run through the crossflow filters at an axial velocity of 8.7 ± 0.1 ft/s and a feed pressure of 40 ± 2 psid. The axial velocities were kept the same by measuring the volumetric flow rate through each filter and adjusting a valve upstream of each filter to keep them equal. The feed pressures were equal by design. The filter feed and concentrate lines of the two filters were connected to eliminate any differences in pressure between the two filters. Because of the pressure drop across the secondary filter, the transmembrane pressure may differ slightly between the two crossflow filters.

Filtration cycle 1 was performed by adding 9.5 gallons of simulated salt solution (containing no MST) to an empty filter feed tank. The salt solution was processed through the crossflow filters at a feed flow rate of 3 gpm and a feed pressure (average of feed and concentrate pressures) of 40 psi. Filtrate was removed until the fluid volume in the feed tank was 2.7 gallons. Pressures, flow rates, and temperatures were

<sup>a</sup> Measured pH was 9 prior to measuring clean water flux and adding simulated salt solution.

measured every minute by the data acquisition system. The volumes used in the test were based on the volumes used in the ARP and scaling them down based on filter area.

For batches 2 – 4, 6.8 gallons of fresh supernate was added to the feed tank and processed in the same manner as batch 1.

This section describes the washing process.

- The washing process began by adding 0.71 gallons of simulated salt batch 6 to the surge tank and transferring 0.59 gallons of simulated salt batch 6 from the surge tank to the feed tank.
- Approximately 0.72 gallons of 0.02 M NaOH was added to the surge tank, and then 0.72 gallons was transferred from the surge tank to the feed tank.
- An additional 0.72 gallons of 0.02 M NaOH was added to the surge tank, and then 0.72 gallons was transferred from the surge tank to the feed tank.
- An additional 0.72 gallons of 0.02 M NaOH was added to the surge tank, and then 0.72 gallons was transferred from the surge tank to the feed tank.
- Next, wash water (0.02 M NaOH) was added to the feed tank until the volume was 5.6 gallons.
- An additional 2.72 gallons of wash water was added to the feed tank while operating the filter in a feed and bleed mode (i.e., additional wash water was added at the same rate filtrate was being removed).
- After the feed and bleed was complete, the contents of the feed tank were concentrated to 2.8 gallons.
- Following volume reduction to 2.8 gallons in the feed tank, the contents of the filtrate tank were transferred to a residue tank leaving a heel of 2.2 gallons and the contents of the feed tank were transferred to a residue tank leaving a heel of 2.2 gallons.
- Next, 0.15 gallons of 50 wt % NaOH was added to the filtrate tank and 0.69 gallons of 2.7 M NaOH was added to the feed tank.

This section describes the filter cleaning process.

- The filter cleaning began by adding 450 mL of 0.02 M NaOH to the backpulse tank.
- Additional 0.02 M NaOH was added to the surge tank to bring the volume to 0.51 gallons.
- The contents of the surge tank were recirculated through the crossflow filter for 60 minutes at an axial velocity of 3 – 5 ft/s.
- An additional 0.11 gallons of 0.02 M NaOH was added to the backpulse tank. The contents of the backpulse tank were gravity drained through the 0.1 micron crossflow filter and into the surge tank.
- An additional 0.11 gallons of 0.02 M NaOH was added to the backpulse tank. The contents of the backpulse tank were gravity drained through the 0.5 micron crossflow filter and into the surge tank.
- The contents of the surge tank were recirculated through the crossflow filter for 60 minutes at an axial velocity of 3 – 5 ft/s.
- An additional 0.11 gallons of 0.02 M NaOH was added to the backpulse tank. The contents of the backpulse tank were gravity drained through the 0.1 micron crossflow filter and into the surge tank.
- An additional 0.11 gallons of 0.02 M NaOH was added to the backpulse tank. The contents of the backpulse tank were gravity drained through the 0.5 micron crossflow filter and into the surge tank.
- The contents of the surge tank were transferred to the feed tank leaving a heel of 0.13 gallons.
- The backpulse tank was filled with 0.36 gallons of 0.02 M NaOH, and the backpulse tank contents were gravity drained through the 0.1 micron crossflow filter and into the surge tank.
- The backpulse tank was filled with 0.36 gallons of 0.02 M NaOH, and the backpulse tank contents were gravity drained through the 0.5 micron crossflow filter and into the surge tank.
- The contents of the surge tank were transferred to the feed tank, leaving a heel of 0.13 gallons.
- Following the transfer, 0.38 gallons of 0.5 M oxalic acid was added to the surge tank.
- The oxalic acid was recirculated from the surge tank through the crossflow filters for 60 minutes at an axial velocity of 3 – 5 ft/s.

- The backpulse tank was filled with 0.11 gallons of 0.02 M NaOH, and the backpulse tank contents were gravity drained through the 0.1 micron crossflow filter and into the surge tank.
- The backpulse tank was filled with 0.11 gallons of 0.02 M NaOH, and the backpulse tank contents were gravity drained through the 0.5 micron crossflow filter and into the surge tank.
- The contents of the surge tank were recirculated through the filters for 60 minutes at an axial velocity of 3 – 5 ft/s.
- Following the recirculation, the contents of the surge tank were transferred to the feed tank, leaving a heel of 0.13 gallons.

Following cleaning of the filters, the system was flushed in the following manner.

- The surge tank was filled with 0.02 M NaOH to a volume of 0.51 gallons.
- The contents of the surge tank were recirculated through the filters for 60 minutes at an axial velocity of 3 – 5 ft/s.
- The backpulse tank was filled with 0.11 gallons of 0.02 M NaOH and the contents gravity drained through the 0.1 micron filter.
- The backpulse tank was filled with 0.11 gallons of 0.02 M NaOH and the contents gravity drained through the 0.5 micron filter.
- The contents of the surge tank were transferred to the feed tank leaving a heel of 0.13 gallons.
- The backpulse tank was filled with 0.19 gallons of 0.02 M NaOH and the contents gravity drained through the 0.1 micron filter.
- The backpulse tank was filled with 0.19 gallons of 0.02 M NaOH and the contents gravity drained through the 0.5 micron filter.
- The contents of the surge tank were transferred to the feed tank leaving a heel of 0.13 gallons.
- The feed and filtrate tank were prepared for the next filtration cycle by adding 0.11 gallons of 50 wt % NaOH to the feed tank and 1.1 gallons of 2.7 M NaOH to the feed tank.

The next filtration cycle was performed in the following manner. For batches 1 – 5, 6.8 gallons of fresh supernate was added to the feed tank and processed in the same manner as cycle 1, batch 1.

### Quality Assurance

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.

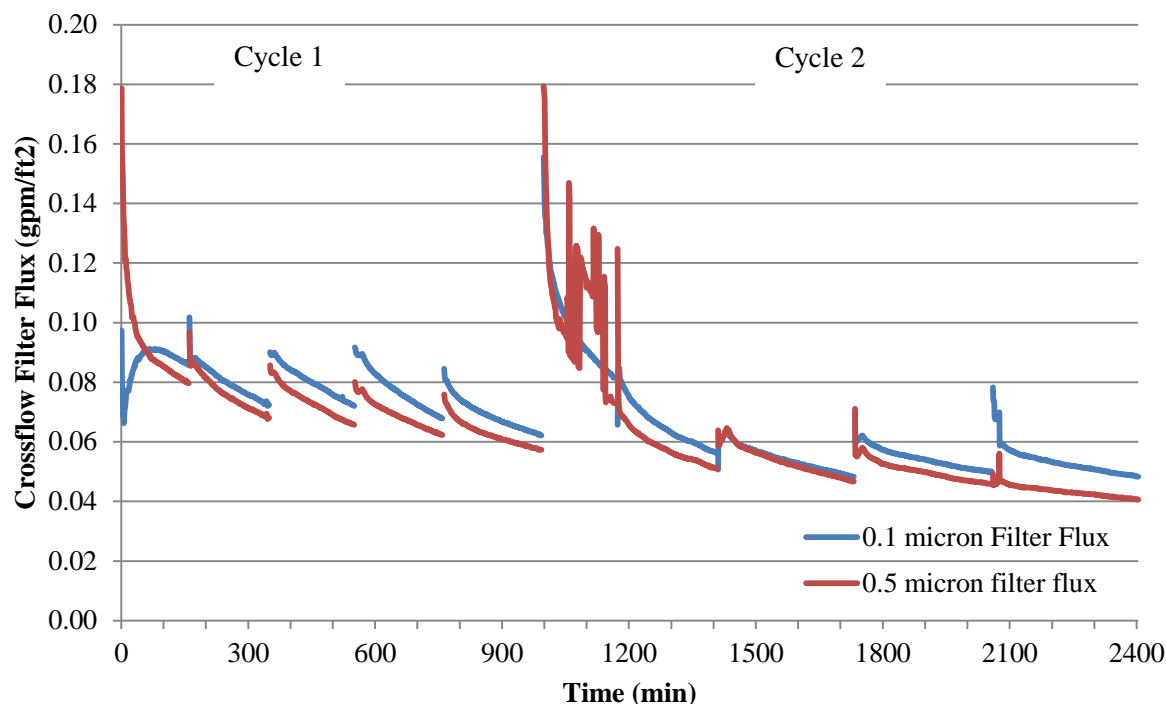
The plan for this testing is described in TTQAP SRNL-RP-2014-00874, Rev. 1. The M&TE were calibrated prior to the start of testing. Data collected are recorded in Laboratory Notebook SRNS-NB-2015-00002.

## Results

### *Crossflow Filter*

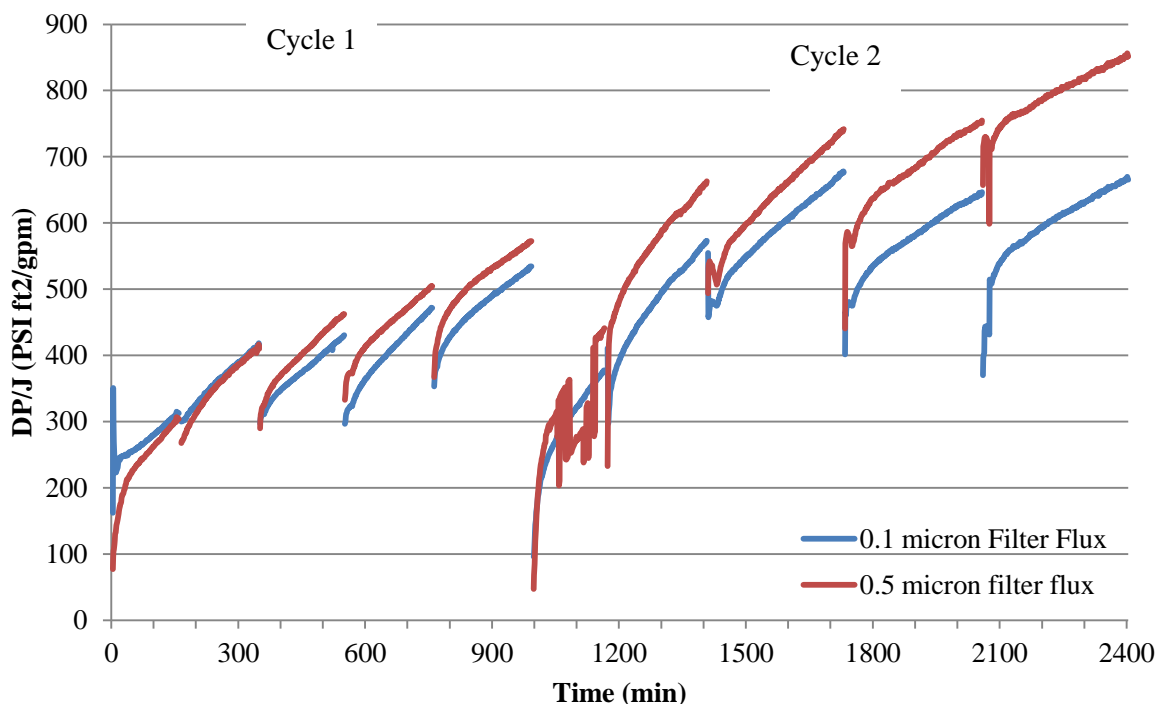
Figure 2 shows the crossflow filter flux as a function of time for the 0.1 and 0.5 micron crossflow filters. The data show some fouling during each batch. The 0.1 micron filter shows a higher flux than the 0.5 micron filter. This could be an indication that some of the particles fouling the filters are small enough to fit in the pores of the 0.5 micron filter but not small enough to fit in the pores of the 0.1 micron filter. There is some recovery of flux at the start of each batch. This is not surprising given that additional fresh feed is added to the feed tank and the bulk insoluble solids concentration is decreased compared to the end of the previous batch. The chemical cleaning provided an initial recovery of filter flux, but after the first batch, the filter flux is lower in the second cycle compared to the first cycle. This result could be an indication of solid particles forming as a result of washing, chemical cleaning, or blending of heels. A

steady-state may have been reached by the end of the second cycle, but more data is needed to draw a conclusion.



**Figure 2. Crossflow Filter Flux during Integrated Test**

Figure 3 shows the pressure drop across the crossflow filter normalized by the filter flux. The data show an increase in pressure drop of approximately 50 – 100% during each batch. This increase is larger than the increase observed in the tests with sodium oxalate and MST containing slurry (~10-25%), but smaller than the increase observed in the tests with MST and sodium aluminosilicate containing slurry (~4X) and MST and gibbsite/boehmite containing slurry (~3 – 4X). With the exception of the first batch of the first cycle, the pressure drop across the 0.5 micron filter is larger than the pressure drop across the 0.1 micron filter. The pressure drop across the 0.5 micron filter shows larger increase from cycle 1 to cycle 2 than the pressure drop across the 0.1 micron filter. This result suggests that the washing, chemical cleaning, or blending with heels may have formed fine particles that fouled the 0.5 micron crossflow filter more than the 0.1 micron crossflow filter.

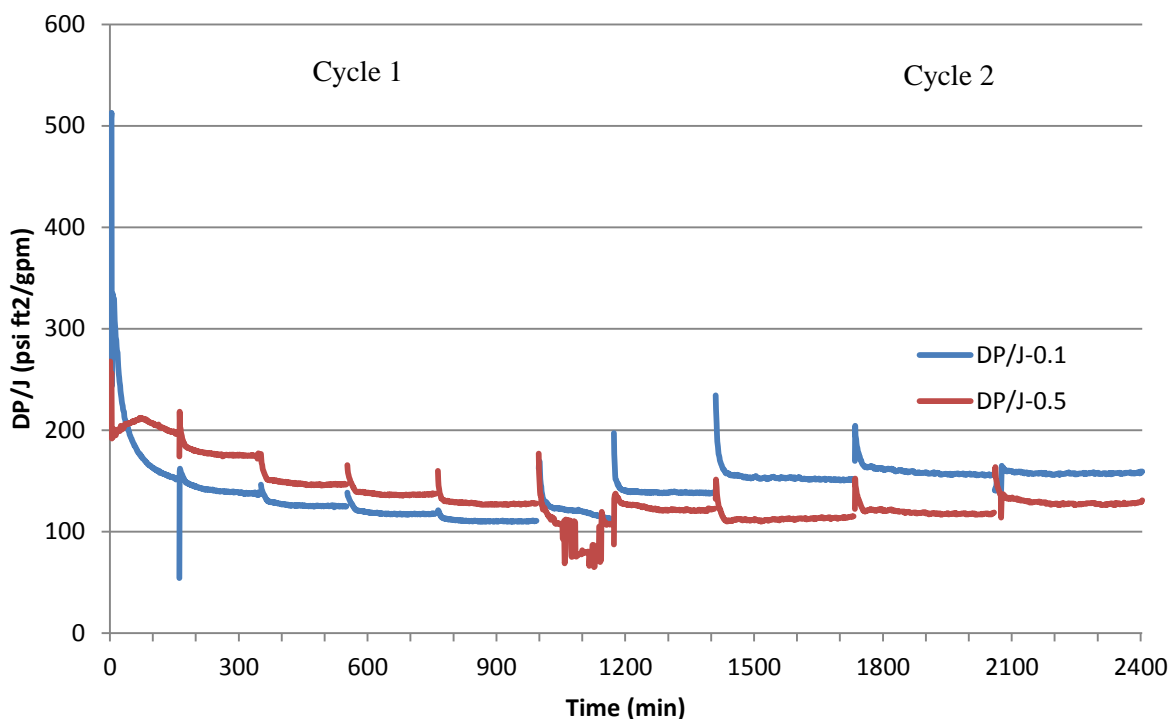


**Figure 3. Pressure Drop across Crossflow Filter during Integrated Filter Test**

Figure 4 shows the pressure drop across the secondary filter normalized by the crossflow filter flux measured during the integrated test. The data do not show any significant change in pressure drop during the batches. This result is similar to the test results with feeds containing MST and sodium oxalate, but in contrast with the test results with feeds containing MST and sodium aluminosilicate or MST and gibbsite/boehmite.<sup>4</sup> The pressure drop across the secondary filter down stream of the 0.1 micron crossflow filter was larger in the second cycle than in the first cycle. However, there does not appear to be a significant difference in the pressure drop across the secondary filter down stream of the 0.5 micron crossflow filter between the first and second cycles. During the first cycle, there appears to be a decrease in pressure drop across the secondary filter with increasing batch number.

The observations from Figure 4 differ from ARP experience with MST-containing feed slurries. The ARP observed increases in the normalized pressure drop (pressure drop divided by filtrate flow rate) across the secondary filter with increasing batch number. This difference could be from only running five batches in this test compared to approximately 50 – 70 batches in an ARP cycle or from the presence of MST in the ARP feed.

Recent ARP experience without using MST has not shown an increase in pressure drop across the secondary filter with increasing batch number, but ARP has only run a few batches.



**Figure 4. Pressure Drop across the Secondary Filter during Integrated Filter Test**

## Conclusions

The conclusions from this work follow.

- No catastrophic fouling of the crossflow or secondary filters was observed during the testing.
- The filter flux of the 0.1 micron crossflow filter was larger than the flux of the 0.5 micron crossflow filter suggesting that there may have been fine particles in the feed that fouled the 0.5 micron crossflow filter more than the 0.1 micron crossflow filter.
- The crossflow filter flux was larger during the first cycle than during the second cycle for both the 0.1 and 0.5 micron crossflow filters indicating that the washing, chemical cleaning, and blending may have formed fine particles that fouled the crossflow filters.
- The pressure drop across the 0.5 micron crossflow filter increased more from cycle 1 to cycle 2 than the pressure drop across the 0.1 micron crossflow filter indicating that the washing, chemical cleaning, and blending may have formed fine particles that fouled the 0.5 micron crossflow filter more than the 0.1 micron crossflow filter.
- No significant fouling of the secondary filters was observed during batches. This result contrasts with ARP experience with MST-containing feeds, but agrees with the limited ARP data with no MST strike.

## References

1. Martino, C.J., Herman, D.T., Pike, J.A., and Peters, T.B., "Actinide Removal Process Sample Analysis, Chemical Modeling, and Filtration Evaluation," Doc No. SRNL-STI-2013-00700, Rev 0, June 2014.
2. I. Bodey, "Filterability Tests using SRR's reconditioned monosodium titanate and vendor supplied monosodium titanate", Z-TTR-S-00003, January 21, 2014.

3. M. R. Poirier and P. R. Burket, "Task Technical and Quality Assurance Plan for MST Filterability Tests", SRNL-RP-2014-00162, February 19, 2014.
4. M. R. Poirier and P. R. Burket, "Impact of Sodium Oxalate, Sodium Aluminosilicate, and Gibbsite/Boehmite on ARP Filter Performance", SRNL-STI-2015-00465, December 2015.



**Distribution:**

T. B. Brown, 773-A  
D. E. Dooley, 999-W  
A. Fellingner, 773-42A  
S. D. Fink, 773-A  
C. C. Herman, 773-A  
E. N. Hoffman, 999-W  
F. M. Pennebaker, 773-42A  
W. J. Wiedrnman, 773-42A  
W. R. Wilmarth, 773-A  
Records Administration (EDWS)

E. A. Brass, 249-8H  
C. K. Chiu, 704-27S  
E. J. Freed, 704-S  
A. G. Garrison, 248-9H  
B. A. Gifford, 704-56H  
K. L. Lang, 707-7E  
D. J. Martin, 241-152H  
A. R. Shafer, 704-27S  
V. Jain, 766-H

P. R. Jackson, DOE-SR, 703-46A  
J. A. Crenshaw, 703-46A