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Development of a Crossflow Filter to Remove Solids from Radioactive Liquid Waste: Comparison of Test Data with Operating Experience -- 9119

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ABSTRACT

In 2008, the Savannah River Site (SRS) began treatment of liquid radioactive waste from its Tank Farms. To treat waste streams containing ^{137}Cs, ^{90}Sr, and actinides, SRS developed the Actinide Removal Process (ARP) and the Modular Caustic Side Solvent Extraction Unit (MCU). The Actinide Removal Process contacts the waste with monosodium titanate (MST) to sorb strontium and select actinides. After MST contact, the process filters the resulting slurry to remove the MST (with sorbed strontium and actinides) and any entrained sludge. The filtrate is transported to the MCU to remove cesium. The solid particle removed by the filter are concentrated to ~ 5 wt %, washed to reduce the concentration of dissolved sodium, and transported to the Defense Waste Processing Facility (DWPF) for vitrification.

The authors conducted tests with 0.5 μ and 0.1 μ Mott sintered stainless steel crossflow filter at bench-scale (0.19 ft^2 surface area) and pilot-scale (11.2 ft^2). The collected data supported design of the filter for the process and identified preferred operating conditions for the full-scale process (230 ft^2). The testing investigated the influence of operating parameters, such as filter pore size, axial velocity, transmembrane pressure, and solids loading, on filter flux, and validated the simulant used for pilot-scale testing.

The conclusions from this work follow.

- The 0.1 μ Mott sintered stainless steel filter produced higher flux than the 0.5 μ filter.
- The filtrate samples collected showed no visible solids.
- The filter flux with actual waste is comparable to the filter flux with simulated waste, with the simulated waste being conservative. This result shows the simulated sludge is representative of the actual sludge.
- When the data is adjusted for differences in transmembrane pressure, the filter flux in the Actinide Removal Process is comparable to the filter flux in the bench-scale and pilot-scale testing.
- Filter flux increased with transmembrane pressure, increased with axial velocity, and decreased with concentration in agreement with classical crossflow filtration theories.

INTRODUCTION

The Savannah River Site has developed a treatment process, called the Actinide Removal Process (ARP), to remove strontium and select actinides from radioactive liquid waste. In this process, liquid waste containing nominally 600 mg/L of sludge particles is transported to a tank. MST (0.4 g/L) is added to the tank, which is mixed for 24 hours. After 24 hours, the slurry is filtered to remove the insoluble sludge and MST particles. The filtration continues until the feed slurry is concentrated to 5 wt % insoluble solids. The filtrate is transported to a solvent extraction process to remove cesium or to the feed tank for a grout process to stabilize the waste. The solids are washed to reduce the sodium concentration. The concentrated, washed solids are transported to the Defense Waste Processing Facility (DWPF) for vitrification.

The filtration process is one of the rate limiting steps for this process. To size the filtration equipment and maximize throughput, the authors conducted pilot-scale filtration testing with simulated waste streams and bench-scale filtration testing with actual waste. This work defined the final design for the operating facility. The ARP started processing waste in May 2008.

This paper describes the testing conducted and compares the observed behavior with the performance of the filter after startup of the ARP.

TEST DESIGN

Equipment

This report discusses four sets of scale-up tests to support the design of the ARP. The four tests are bench-scale actual waste tests with a 0.5 μ filter, bench-scale actual waste tests with a 0.1 μ filter, pilot-scale simulant tests with a 0.5 μ filter, and pilot-scale simulant tests with a 0.1 μ filter. All testing used filter tubes fabricated by Mott Corporation.

The bench-scale testing occurred in the Savannah River National Laboratory (SRNL) Shielded Cells. The equipment contained a sintered stainless steel 0.5 μ pore-size cross-flow filter of 0.5 inches outer diameter (OD), 0.375 inches inner diameter (ID), and 2-ft length. The equipment included a feed vessel, a feed pump, a heat exchanger to control solution temperature, a magnetic flow meter to measure the filter feed rate, and pressure gauges to measure feed, concentrate, and filtrate pressure. A graduated glass cylinder located down stream of the filter measured the filtrate flow rate, or flux. Personnel determined the flux, by measuring the time to collect a known volume of filtrate. The working volume of the equipment measures approximately 800 mL.

The pilot-scale filtration testing occurred at the Filtration Research Engineering Demonstration (FRED) located at the University of South Carolina. The FRED facility contains a filter element with seven filter tubes. Each tube is constructed of sintered stainless steel, 0.75 inches OD, 0.625 inches ID, and 10 feet long. The filter elements tested had pore sizes of 0.1 and 0.5 μ. The FRED facility uses identical filter tubes to the ARP, but the number is less. The equipment contains flow meters to measure feed and filtrate flow rates, pressure gauges to measure feed, concentrate, and filtrate flow rates, and thermocouples to measure temperature.

The filter in the ARP contains 144 filter tubes. Each tube is 10 foot long, 0.75 inches OD, and 0.625 inches ID. The tubes are constructed of sintered stainless steel with a pore size of 0.1 μ.

Slurries Tested and Operating Conditions

In the 0.5 μ pore-size bench-scale test with actual waste test[1], the feed slurry contained 5.6 M sodium salt solution from two tanks, sludge composite from three tanks, and MST. The ratio of sludge to MST was 0.6:0.55. The axial velocity varied from 6 – 12 ft/s and the TMP varied from 15 – 41 psi. The insoluble solids concentration varied from 0.06 – 4.5 wt %. We collected filtration data at varying axial velocity, TMP, and solids loading in a statistically designed test. Following each change in test conditions, the filter was backpulsed to remove the filter cake. Each test condition was held for at least 30 minutes to obtain steady-state.

Subsequent bench-scale testing examined both 0.1 μ and 0.5 μ pore-size filters using actual waste test, the feed slurry contained 5.6 M sodium salt solution from collected from four tanks, a sludge sample from a feed tank to DWPF, and MST.[2] The ratio of sludge to MST was 0.6:0.55. The axial velocity varied from 6 – 14 ft/s and the TMP varied from 15 – 41 psi. The insoluble solids concentration varied from 0.06 – 4.5wt %. The filter pore size was 0.5 and 0.1 μ. We collected filtration data at varying axial velocity, TMP, and solids loading in a statistically designed test. Following each change in test conditions, the filter was backpulsed to remove the filter cake. Each test condition was held for at least 30 minutes to obtain steady-state.

In the 0.5 μ pore-size pilot-scale simulant filtration tests[3], the feed slurry contained 5.6 M sodium salt solution, simulated SRS sludge, and MST. The sludge MST ratio was 6:5.5 based on 600 mg/L entreated sludge and 550 mg/L MST. The axial velocity varied from 12 – 26 ft/s and the transmembrane pressure (TMP) varied from 12 – 68 psi. The insoluble solids concentration varied from 0.03 – 3.3 wt %. We collected filtration data at varying axial velocity, TMP, and solids loading in a statistically designed test. Following each change in test conditions, the filter was backpulsed to remove the filter cake. Each test condition was held for at least one hour to obtain steady-state.

In the 0.1 μ pore-size pilot-scale simulant filtration tests[4], the feed slurry contained 5.6 M sodium salt solution, simulated SRS sludge, and MST. The sludge MST ratio was 6:5.5 based on 600 mg/L entreated sludge and 550 mg/L MST. The axial velocity varied from 6 – 14 ft/s and the transmembrane pressure (TMP) varied from 15 – 45 psi. The insoluble solids concentration varied from 0.06 – 12 wt %. We collected filtration data at varying axial velocity, TMP, and solids loading in a statistically designed test. Following each change in test conditions, the filter was backpulsed to remove the filter cake. Each test condition was held for at least one hour to obtain steady-state.

RESULTS

Bench-Scale Actual Waste Test with 0.5 μ Filter

Figure 1 shows the filter flux from bench-scale actual waste tests using feed slurries containing 0.29 wt % solids.[1] The figure shows a correlation between filter flux and TMP. The data also show good agreement between filter flux with actual waste and filter flux with simulated waste. Similar results occurred at other concentrations of solids. The filtrate showed no visible solids. In general, the filter flux proved higher with actual waste than with simulant, suggesting the simulated sludge is a conservative source of solids for filter testing. Possible reasons for this occurrence are the smaller tube diameter and shorter tube length.

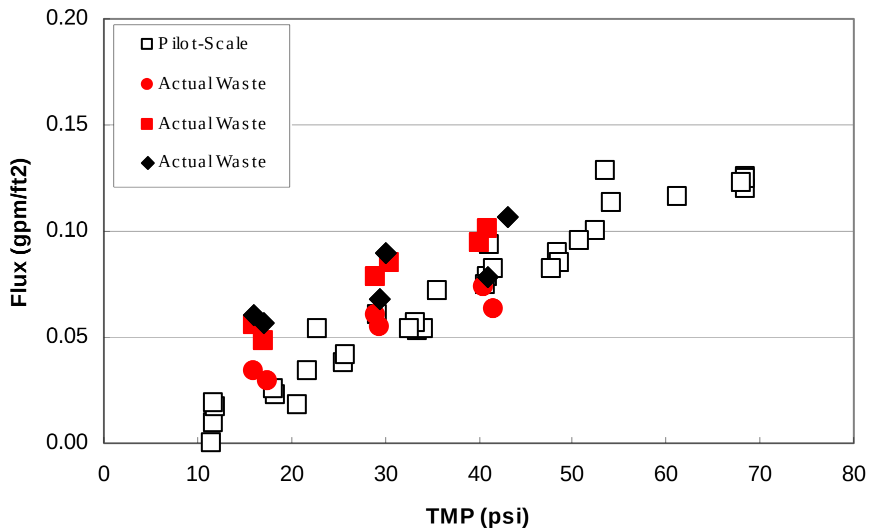

Figure 1. Bench-Scale Actual Waste Filter Flux with 0.29 wt % solids.

The bench-scale filter tube is 0.375 inches in ID, while the pilot-scale filter tubes are 0.625 inches in ID. Given the same axial velocity, the smaller diameter tube will have a higher wall shear stress. This higher wall shear stress will reduce the filter cake thickness and increase filter flux.

The shorter tube length has the following effect on the filtration rate. When the feed slurry enters the filter tube, it develops and builds up a boundary layer in the entrance region. In the entrance region, the mass transfer rate is higher. The higher mass transfer rates help remove solid particles from the filter cake. The filter flux is higher in the entrance region than in the remainder of the filter tube. With a shorter tube, the entrance region occupies a larger fraction of the filter and the average mass transfer rate (and filter flux) will be higher.

Bench-Scale Actual Waste Test with 0.1 μ Filter

In subsequent testing with both 0.1 μ and 0.5 μpore-size filters, the data shows higher filter flux with a 0.1 μ filter than with a 0.5 μ filter. The filter flux averaged 0.135 gpm/ft^2 with the 0.1 μ filter versus 0.082 gpm/ft^2 with the 0.5 μ filter for slurry containing 1.4 wt % solids. The filtrate showed no visible solids. Similar data was obtained for more concentrated slurries. The result is not intuitively obvious, since a 0.5 μ filter has less resistance to flow than a 0.1 μ filter, everything else being the same. However, the smaller particles in the feed slurry (< 1 μ) are more likely to become trapped in the pores of the 0.5 μ filter than the 0.1 μ filter. When the particles are trapped in the 0.5 μ filter pores, the filtrate resistance increases dramatically greatly reducing the effective porosity of the filter. When the particles remain in the slurry cake on the surface of the 0.1 μ filter, they form a filter cake with higher porosity than the fouled 0.5 μ filter which does not increase the resistance as much and this filter cake readily removed by backpulsing.

Pilot-Scale Simulant Test with 0.5 μ Filter

Figure 2 shows the filter flux as a function of TMP and solids loading for the pilot-scale testing using 0.5 μ pore-size filters and simulated waste. The data shows strong correlation with TMP and solids loading. One reason for the high correlation between the flux and TMP is the high axial velocity in this test. The corresponding plot of filter flux as a function of axial velocity (not shown) does not indicate a correlation for these variables. The testing also showed backpulsing the filter is an effective means for recovering filter flux. The filtrate contained no visible solids, indicating that the filter removed the solid particles from the feed slurry. Given the ARP filter area of 230 ft^2, the data suggests the ARP filtration rate will be 4.6 – 27 gpm at 40 psi TMP.

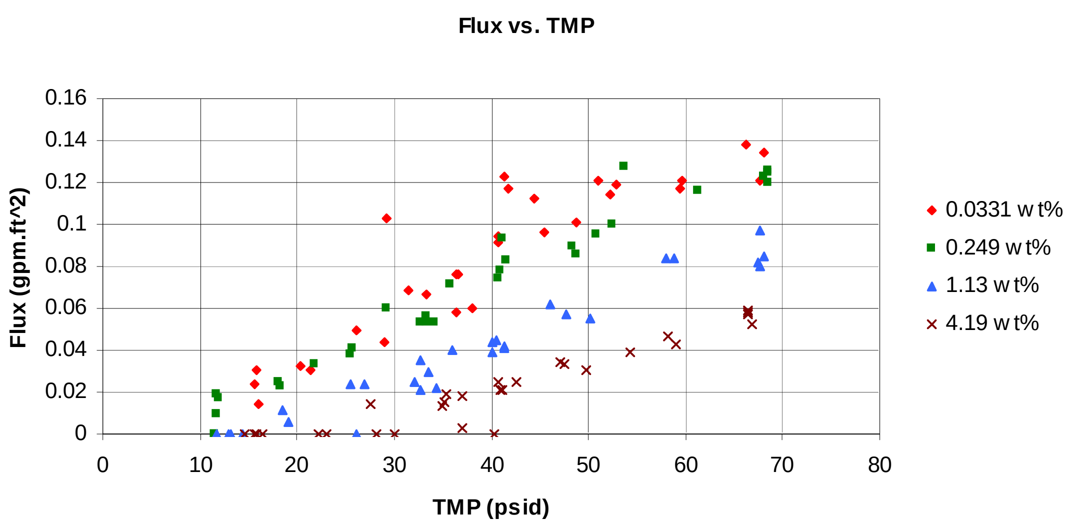

Figure 2. Filter Flux for Pilot-Scale Simulant Test with a 0.5 μ Filter

A statistical analysis of the data resulted in the following model:

$$J\ (\text{gpm/ft}^2) = 0.015 + 0.0019\ P\ (\text{psi}) - 0.019\ \ln[C\ (\text{g/L})] + 0.000035\ v(\text{ft/s})^2/C(\text{g/L})^2$$

where J is filter flux, P is transmembrane pressure, C is solids concentration, and v is axial velocity. The model predicts filter flux will increase with higher transmembrane pressure, increase with greater axial velocity, and decrease with elevated solids concentration in agreement with classical crossflow filtration theories.

Pilot-Scale Simulant Test with 0.1 μ Filter

Figure 3 shows the filter flux from the pilot-scale filter test using simulated waste and 0.1 μ pore-size filters. The data shows higher filter flux with a 0.1 μ filter than with a 0.5 μ filter. At nominal 0.05 wt % solids, the filter flux averaged 0.133 gpm/ft^2 with the 0.1 μ filter versus 0.086 gpm/ft^2 with the 0.5 μ filter. At nominal 4.5 wt % solids, the filter flux averaged 0.069 gpm/ft^2 for the 0.1 μ filter versus 0.022 gpm/ft^2 with the 0.5 μ filter.

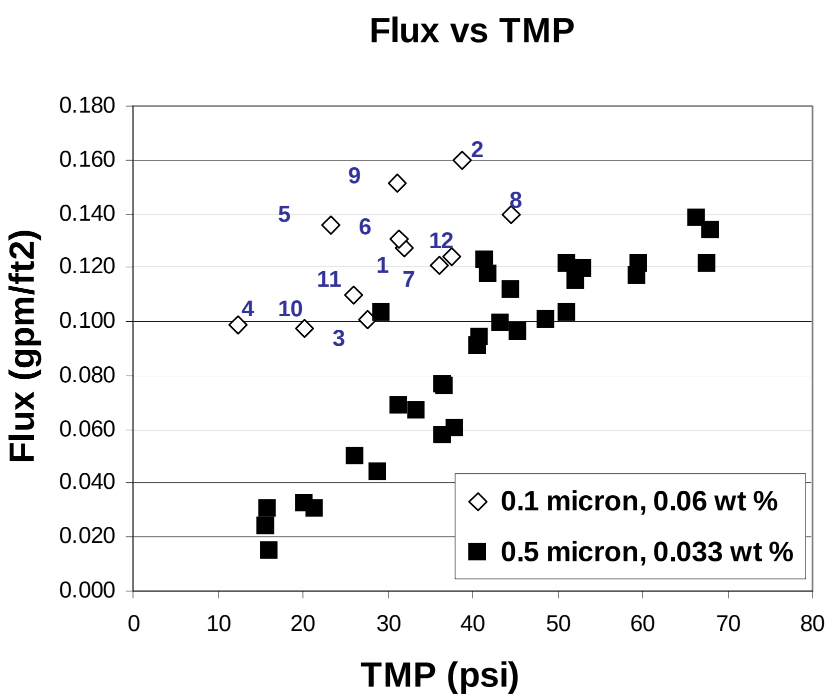

Figure 3. 2003 Pilot-Scale Simulant Filter Test with a 0.1 μ Filter

Actinide Removal Process Operations

Figure 4 shows the data from the Actinide Removal Process. The data was collected at lower TMP than the test data. The lower transmembrane pressure occurred because a secondary, or guard, filter down-stream had a much higher pressure drop than expected. This high resistance through the guard filter decreased the overall filtration rate. If one assumes the filter flux is a linear function of transmembrane pressure and extrapolates the filter flux to a TMP of 40 psi, one see a similar filter flux between the test data and the ARP.

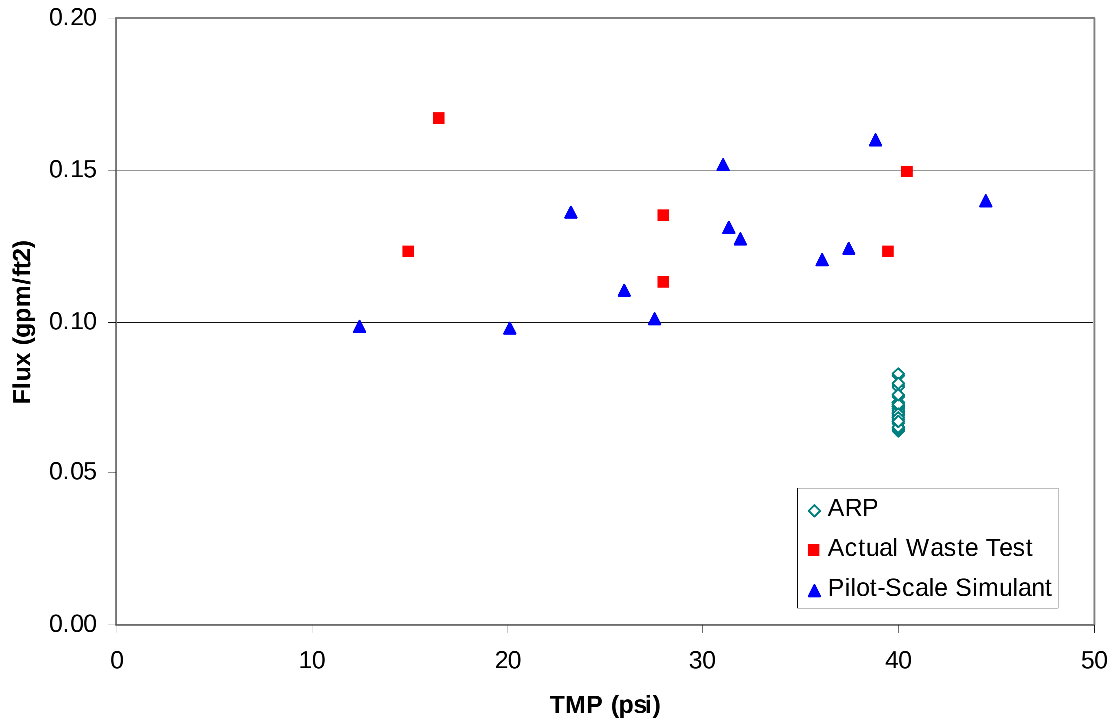

Figure 4. ARP Filtration Data

CONCLUSIONS

The conclusions from this work follow.

- The 0.1 μ Mott sintered stainless steel filter produced higher flux than the 0.5 μ filter.
- The filtrate samples collected showed no visible solids.
- The filter flux with actual waste was comparable to the filter flux with simulated waste, with the simulated waste being conservative. This result shows the simulated sludge is representative of the actual sludge.
- When the data is adjusted for differences in transmembrane pressure, the filter flux in the Actinide Removal Process proved comparable to the filter flux in the testing.
- Filter flux increased with transmembrane pressure, increased with axial velocity, and decreased with concentration in agreement with classical crossflow filtration theories.

REFERENCES

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