DEVELOPMENT OF A ROTARY MICROFILTER FOR SAVANNAH RIVER SITE HIGH-LEVEL WASTE APPLICATIONS

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ABSTRACT

The processing rate of Savannah River Site (SRS) high-level waste decontamination processes are limited by the flow rate of the solid-liquid separation. The baseline process, using a 0.1 micron cross-flow filter, produces ~0.02 gpm/sq. ft. of filtrate under expected operating conditions. Savannah River National Laboratory (SRNL) personnel identified the rotary microfilter as a technology that could significantly increase filter flux, with throughput improvements of as much as 10X for that specific operation. With funding from the U. S. Department of Energy Office of Cleanup Technology, SRNL personnel are evaluating and developing the rotary microfilter for radioactive service at SRS.

This work includes pilot-scale and actual waste testing to evaluate system reliability, the impact of radiation on system components, the filter flux for a variety of waste streams, and relative performance for alternative filter media. Personnel revised the design for the disks and filter unit to make them suitable for high-level radioactive service. Work to date provides the following conclusions and program status.

- The actual waste testing conducted with Tank 37H supernate and Tank 51H sludge showed a 10X increase in flux over similar tests conducted with cross-flow filters.
- Pilot-scale simulant testing showed a 1.5 – 3X increase in flux over similar tests conducted with cross-flow filters.
- The pilot-scale rotary filter operated for over 3000 hours without significant mechanical problems.
- Pilot-scale testing with irradiated filter disks (at ~5 year equivalent dose) showed no adverse impact on filter flux, but some weakening of the epoxy-Ryton® bond. A reduction in flux was observed, but the reduction is believed to be due to differences in feed particle size.
- The authors modified the design of the filter disks to remove epoxy and Ryton®. The new design includes welding both stainless steel and ceramic filter media to a stainless steel support plate. The welded disks were tested in the pilot-scale unit. They showed good reliability and met filtrate quality requirements.
- The authors modified the design of the unit, making removal and maintenance easier. Fabrication of the unit for remote, nuclear service is in progress.
- The project team plans to use the rotary microfilter as a filter in advance of a small column ion exchange process under development for potential deployment in SRS waste tank risers.

INTRODUCTION

The Department of Energy is developing processes to treat SRS radioactive waste. In the first step, personnel contact the incoming salt solution that contains entrained sludge with monosodium titanate (MST) to adsorb strontium and select actinides. The process filters the resulting slurry to remove the sludge and MST. The filtrate receives further treatment to remove cesium.

Cross-flow filter testing performed by SRNL and the University of South Carolina (USC) with simulated waste showed relatively low filtration rates of 0.03 – 0.08 gpm/sq. ft. Additional testing conducted with actual waste showed similar filtration rates. Personnel conducted a review of solid-liquid separation technologies and identified the rotary microfilter as a plausible improvement over the tubular cross-flow filter in the current baseline.

The rotary microfilter combines centrifugation with membrane filtration. Solids are removed from the liquid at the membrane surface, and the centrifugal force acts to keep the surface clean, minimizing the formation of a filter cake. The centrifugal force is used to slough off any solids accumulation, allowing more flow through the filter membrane. The effect is comparable to increasing the axial velocity of a cross-flow filter without increasing system pressure requirements.

The rotary microfilter disks can be constructed with most commercially available filter media (i.e., filter disks could be fabricated using 0.1 or 0.5 micron porous metal filter sheets similar to the Mott cross-flow filters in the current design bases, or could use filter media produced by other manufacturers). Rotary filter systems are commercially available (from SpinTek, ASPECT USA, Pall, and Canzler LLC). The SpinTek unit has been used in radioactive service at Los Alamos National Laboratory (i.e., for low-level waste), while the ASPECT USA equipment has found use in Russia (for high-level waste).

SRNL researchers tested the rotary microfilter as an alternative to the cross-flow filters in the current baseline of the Salt Waste Processing Facility and the Actinide Removal Project. The data showed significant improvement in filter flux with the rotary microfilter over the baseline cross-flow filter (i.e., 2.5 – 6.5X during viability tests, up to 10X in the actual waste tests, and approximately 1.5 - 3X in the pilot-scale tests).

The authors received funding from the U. S. Department of Energy, Office of Cleanup Technology to continue the development of this technology for SRS radioactive service.

APPROACH

The work focused on several areas: evaluating alternative rotary microfilter vendors; redesigning the equipment for radioactive service; engineering studies to evaluate the risks; determining downstream impacts, costs and benefits of deploying this technology; and performing actual waste and pilot-scale testing of the technology.

Alternative Manufacturers

The authors identified and evaluated the following rotary microfilter manufacturers: SpinTek, Pall Corporation, Canzler LLC, and ASPECT USA. They held meetings and conference calls with each of the manufacturers to investigate their rotary microfilter designs, their operating experience with the units, and how they would modify their units for high-level radioactive waste service. They also consulted with current users of the equipment to develop an understanding of performance history.

The SpinTek unit has been commercialized for many years. Interviews with users indicate good performance of the equipment. The users indicate rather infrequent need for chemical cleaning. The vendor produces 25 disk units (with 25 sq. ft. filter area). The equipment needs modification in design and manufacturing prior to use in long-term radioactive service but can be deployed using the standard design with some minor modifications. The equipment is manufactured in the United States.

The ASPECT design is very similar to the SpinTek design. The equipment has been used in high-level radioactive waste service for at least 5 years on a wide variety of waste streams. The equipment experienced minor operational and design problems with personnel rapidly fixing them as they occurred. One unit, at Murmansk Shipping Company, treats a waste stream containing ~ 450 mg/L ferric hydroxide and requires chemical cleaning every 100 hours. Their largest existing unit contains 5 disks. The solids loading in feeds for their units are 0 – 1 wt %, which is the lower range of solids loadings expected for SRS applications. The Murmansk operations typically prefilter the feed to the rotary microfilters through a sand filter to remove large particles. The units are manufactured in Russia.

The Pall design employs a spinning shell rather than a spinning disk. The technology has been developed and tested at pilot-scale, but not commercialized or tested at full-scale. Pall is a United States company and is the largest filter manufacturer in the world. The vendor quotes a fabrication time of one year.

The Canzler unit uses multiple shafts with disks spinning in the gaps. Canzler, a German company, has built demonstration and pilot-scale units, but no units have been sold in the United States

After conducting the meetings and conference calls, and reviewing design information provided by the manufacturers, SRNL researchers recommended that SRS use the SpinTek rotary microfilter in future high-level waste applications.

Equipment Redesign for Radioactive Service

A filter disk design has been proposed using the enhancements developed in previous testing at SRNL. These enhancements are intended to increase the reliability of the filter disks in a radioactive environment. Additional upgrades in materials and fabrication are included in the proposed design, increasing the consistency during fabrication. Currently, the disks are made by hand and can have dimensional and mass variances. The proposed disk design uses a stainless steel support plate instead of the Ryton® plate in the current design. A stainless steel mesh replaces the polyethylene mesh in the current design. By incorporating these proposed changes all elastomers are removed from the design of the disk extending the expected life of the disk in radioactive service.

The new design decreases the space required for each disk without sacrificing filtration area. This change allows deploying additional disks, and therefore filter area, per volume of the filtration system. Disks with the new design have been fabricated and successfully tested. The authors fabricated the welded disks with stainless steel and ceramic filter media. The disks showed good solids removal efficiency and operability. Current testing is evaluating the relative performance of the different media.

The redesign effort for the filter unit includes reducing the number of polymer seals in the equipment, reducing the number of small parts, strengthening the equipment for radioactive service, and improving on the current mechanical seals. The results of this effort will provide a filter system specifically designed for radioactive service. The new design will allow for reliable operation and maintenance in a radioactive environment.

The unit design effort is complete, and two 25-disk units are being fabricated.

Engineering Support

Personnel also performed an engineering evaluation of the technology, which included developing a process flow sheet, determining the impact of the technology on the SRS High-Level Waste system, performing a risk assessment, determining locations for the technology in existing facilities, and performing a cost/benefit analysis.

The flow sheet showed that employing the rotary microfilter technology in either of two available facilities (Building 512-S or 241-96H) will increase the number of batches processed annually by the Actinide Removal Project by 25 – 50%. The cost benefit analysis identified additional costs of approximately $3 million for installation and 5-year operation of the rotary filter in either 512-S or 241-96H. The calculated 5-year benefit is $4.5 million for installation in Building 512-S.

The rotary microfilter technology will not add any chemicals beyond those currently used in the SRS High-Level Waste system. The equipment could allow SRS to concentrate the slurry to a higher solids loading, reducing the amount of water sent to the Defense Waste Processing Facility. The equipment will likely require less frequent chemical cleaning, reducing the amount of oxalic acid added to the SRS High-Level Waste system. The risk assessment identified risks, such as procurement delays and equipment failure, as well as risk mitigation strategies.

Personnel developed designs to install rotary microfilters in Building 512-S, Building 241-96H, at a tank top, and in a tank riser. The current plans will employ the rotary filter as a prefilter to the small column ion exchange process being developed by SRNL and Oak Ridge National Laboratory personnel. In this process, two 25-disk rotary filters are placed in a tank riser (Tank 41H), the concentrated solids are returned to the tank, and the filtrate is transferred to an ion exchange column in another tank (Tank 51H). A review of filtration technologies showed that the rotary filter would produce higher throughput than a cross-flow filter for this application. The team has completed Process and Instrument Drawings and Layout Drawings for this process.

Actual Waste Testing

Personnel performed actual waste tests with a standard commercial version of the rotary filter. The tests provide additional operating data, help evaluate the impact of radiation on the rotary microfilter, and help assess feasibility of using SpinTek's existing filter disk design in radioactive waste applications.

The tests used a SpinTek model II-1 rotary microfilter located in the SRNL shielded cells. The actual-waste feed for the tests consisted of SRS high-level waste Tank 37H supernate (5.6 M sodium), SRS high-level waste Tank 51H sludge, and MST. Testing examined 0.1 micron and 0.5 micron filter Mott disks.

After the completion of the actual waste testing, the filter remained in the shielded cells for approximately one year. The researchers restarted the filter to determine if the extended inactivity in the radiation area adversely impacted the filter system. The estimated dose to the filter unit was 10,000 - 160,000 rem. The feed for this test contained 7 liters of simulated (5.6 M sodium) supernate, 3 liters of Tank 37H supernate, Tank 51H sludge, and MST.

Figure 1 shows sample test results comparing the rotary filter flux with cross-flow filter flux (using 0.5 micron filter media). The filter flux with the rotary filter is significantly higher (~ 10X) than with the cross-flow filter.

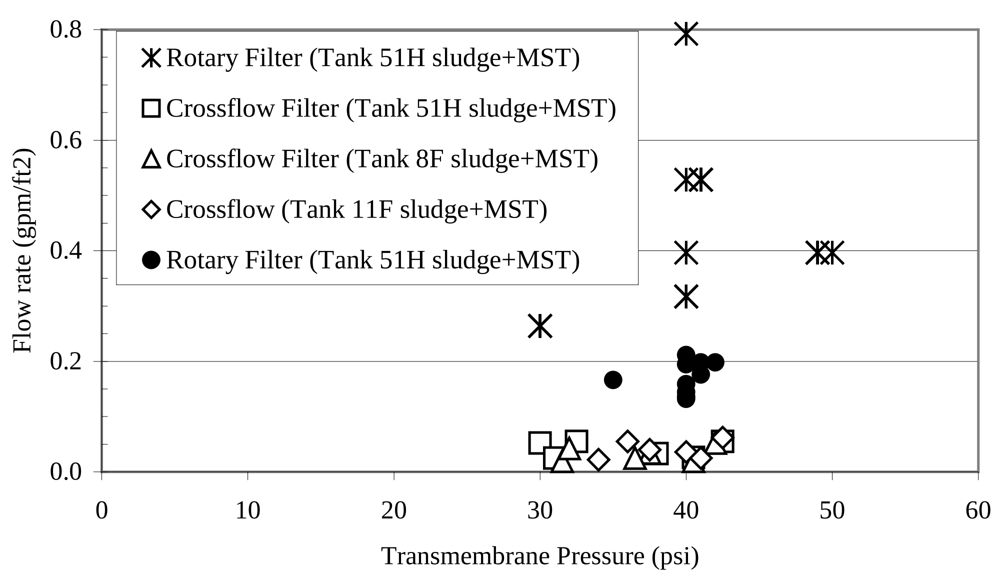

Fig. 1. Comparison of rotary and cross-flow filter performance with SRS actual waste at 4.5 wt % solids.

Next, personnel removed the filtrate stream from the recirculation loop and concentrated the feed slurry. They measured flux rates until the feed pump was starved for feed and would no longer pump effectively. Figure 2 shows the test data.

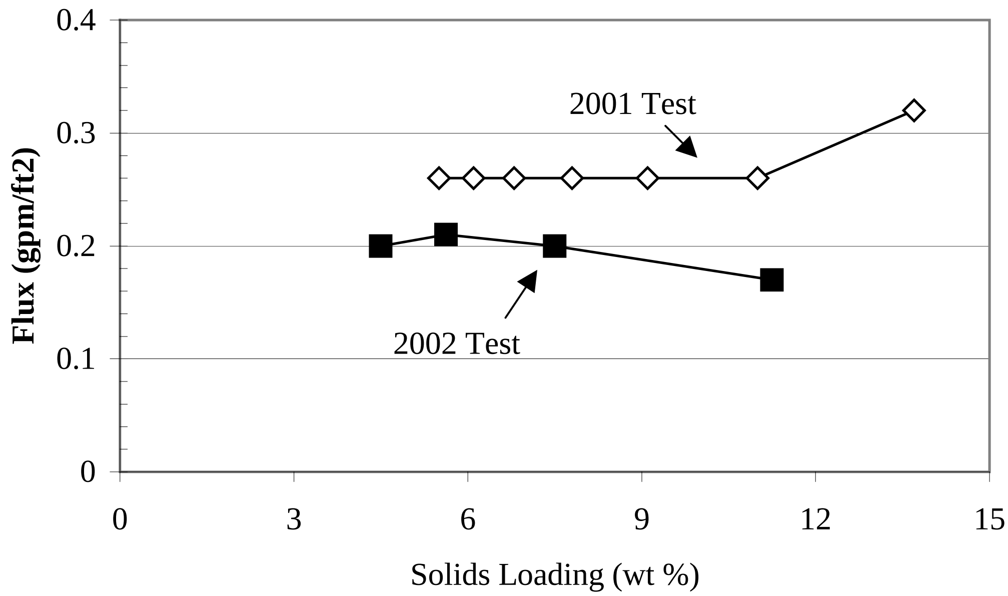

Fig. 2. Rotary filter flux as a function of feed solids concentration.

The data shows the rotary microfilter maintains fluxes ~10X that required for the design target (0.02 gpm/sq. ft.) for MST/sludge slurries containing as high as 12 wt % solids. The potential to operate at higher concentrations offers the ability to reduce the water sent to the Defense Waste Processing Facility.

Restarting the rotary filter after a one-year idle period in a high radiation field showed no significant effect on the system. Personnel resumed testing the equipment without incident and operated with no problems. Visual inspection of the filtrate indicated no solids present. We concentrated the feed to an estimated 12 wt % solids – based on volume of filtrate removed – with no decline in flux from the increased solids loading.

Pilot-Scale Simulant Testing

The pilot-scale simulant rotary microfilter tests were conducted as follows. Three types of filter disks were selected for these tests (i.e., 0.5 micron stainless steel, 0.1 micron stainless steel, and 0.1 micron ceramic/stainless steel). All filters incorporated the use of the stainless steel permeate carrier mesh. The ceramic membrane is SpinTek's standard filter media. The filter structural material, Ryton® (Polyphenylene sulfide + fiberglass + minerals), was analyzed for hardness, and the entire disk was irradiated in a Co-60 source. The hardness of the Ryton® was measured after the irradiation of the disk to determine if a change in material properties could be discerned.

The stainless steel filters received an estimated 5-year radiation dose (165 MRad), and the ceramic filters received a 2.5-year radiation dose (83 MRad). Following the irradiation, the filters were placed in the pilot-scale rotary microfilter unit and tested with feed slurries containing 0.29 and 4.5 wt % solids. Each set of filter disks was tested for at least one week. These loadings allow comparison with previous cross-flow filter test data. The testing showed a decrease in filter flux, but otherwise, no operational problems or adverse effects from the radiation exposure. Figures 3 and 4 show the test results.

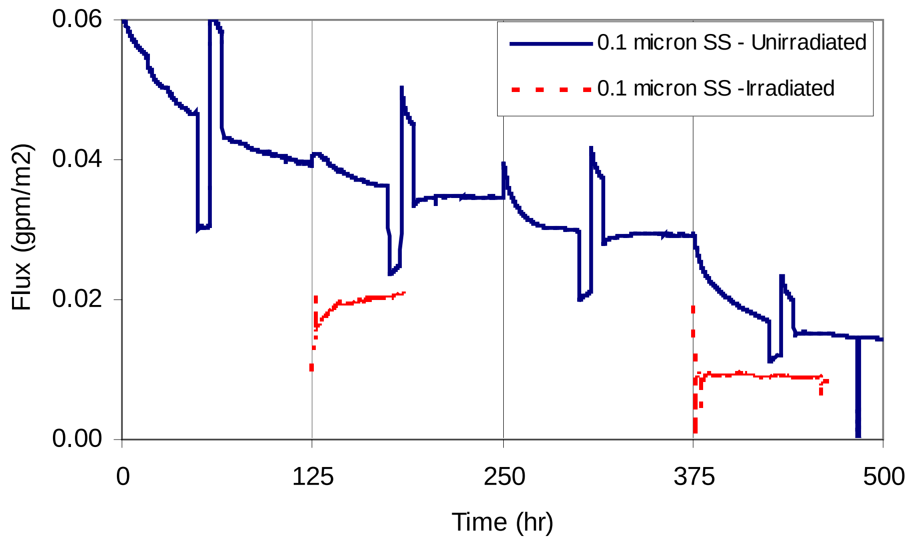

Fig. 3. Impact of 5-year equivalent irradiation dose on rotary microfilter flux for pilot-unit.

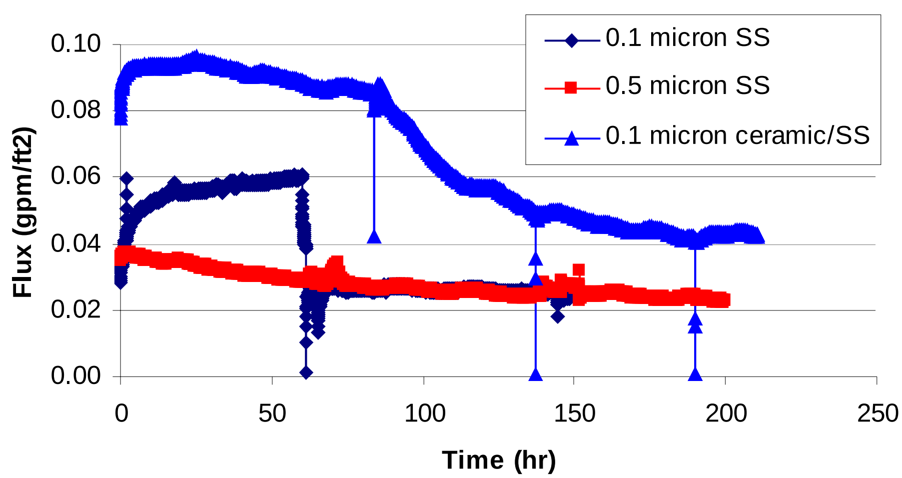

Fig. 4. Comparison of rotary microfilter media at pilot-scale.

The filter disks showed a decrease in filter flux over results from the previous pilot-scale test. The researchers attributed the decrease to changes in feed particle size between the tests. During the testing, personnel collected filtrate samples periodically and analyzed them for turbidity (with a target clarity of < 5 Nephelometric Turbidity Units [NTU]). During testing with the 0.1 micron stainless steel (SS) disk, one sample showed high turbidity (> 200 NTU). Subsequent samples showed turbidity less than 5 NTU. We are uncertain of the cause of the high turbidity, but it did not persist through the test. All filtrate samples from tests with the 0.5 micron SS filters and the 0.1 micron ceramic filters showed turbidity less than 5 NTU.

None of the nine disks tested experienced a catastrophic failure, but some evidence of delamination was observed. Separation started to occur between the epoxy and the base Ryton® material. The disks were sectioned and it was observed that the joint had not failed. The pilot-scale rotary filter has run for over 3000 hours with no significant operating problems.

The authors performed a filter reliability test with average salt solution simulant (3 M NaOH plus other sodium salts) containing 6 wt % insoluble solids (sludge and MST) using disks exposed to gamma radiation. To perform the test, they exposed Ryton® samples to radiation (0 – 450 Mrad) and/or caustic (3 M). After exposure, the samples were analyzed by Attenuated Total Reflectance-Fourier Transform Infrared Spectroscopy (ATR-FTIR).

Analysis of the Ryton® exposed to the five year equivalent dose (165 MRad) showed the Ryton® was degrading, weakening the bond between the Ryton® and the epoxy. The analysis showed radiation caused the formation of biphenyl, sulfone, sulfino and other sulfate species. The coupons exposed to caustic showed a surface enriched with fiberglass and aluminosilicate fibers. A five year life is anticipated for the off the shelf vendor filter disks, and the two year life assumed in the risk assessment and cost/benefit analysis is probably conservative.

The authors are currently testing welded disks in the pilot-scale rotary filter. The testing has shown good solids removal efficiency. The purposes of the testing are to select the filter media for the demonstration unit that is currently being fabricated and to determine the optimum filter parameters.

The authors are currently integrating the rotary filter with the small column ion exchange project. That task places two 25-disk rotary filters in a waste tank riser. In this deployment, the filtrate will transfer to an ion exchange column in Tank 51H, with the concentrated solids returned to the waste tank.

CONCLUSIONS

Work to date provides the following conclusions and program status.

- The actual waste testing conducted with Tank 37H supernate and Tank 51H sludge showed a 10X increase in flux over similar tests conducted with cross-flow filters.
- Pilot-scale simulant testing showed a 1.5 – 3X increase in flux over similar tests conducted with cross-flow filters.

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