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DEVELOPMENT OF A ROTARY MICROFILTER FOR RADIOACTIVE 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) demonstrated significantly higher filter flux for actual waste samples using a small-scale rotary filter. 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.

The authors improved the design for the disks and filter unit to make them suitable for high-level radioactive service. They procured two units using the new design, tested them with simulated SRS wastes, and evaluated the operation of the units. Work to date provides the following conclusions and program status.

- The authors modified the design of the filter disks to remove epoxy and Ryton®. The new design includes welding both stainless steel and ceramic coated stainless steel filter media to a stainless steel support plate. The welded disks were tested in the full-scale unit. They showed good reliability and met filtrate quality requirements.
- The authors modified the design of the unit, making installation and removal easier. The new design uses a modular, one-piece filter stack that is removed simply by disassembly of a flange on the upper (inlet) side of the filter housing. All seals and rotary unions are contained within the removable stack.
- 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 and is undergoing testing in the current work.
- 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. The authors are currently conducting testing with the more wear resistant bushing.
- The project team plans to use the rotary microfilter as a filter in advance of an ion exchange process under development for potential deployment in SRS waste tank risers.

INTRODUCTION

The Savannah River Site (SRS) is developing processes that include filtration to treat radioactive waste. The first step of many of these processes is monosodium titanate (MST) addition to sorb strontium and select actinides followed by filtration to remove the MST and entrained sludge solids. The filtrate may receive additional treatment, by a technology such as ion exchange, to remove cesium.

The baseline solids removal technology uses crossflow filtration. Cross-flow filter testing performed by Savannah River National Laboratory (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. The authors 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).

SRNL researchers tested the rotary microfilter as a technology to increase solid-liquid separation throughput. The testing showed significant improvement in filter flux with the rotary microfilter over the baseline crossflow filter (i.e., 2.5 – 6.5X during scoping tests, as much as 10X in actual waste tests, and approximately 3X in pilot-scale tests).

SRNL received funding from DOE EM-21, Office of Cleanup Technologies, to develop the rotary microfilter for high level radioactive service. The work focused on evaluating alternative rotary microfilter vendors, redesigning the equipment for radioactive service, engineering studies to evaluate the risks, determining downstream impacts, assessing costs and benefits of deploying this technology, performing actual waste and pilot-scale testing of the technology, and evaluating alternative filter media. The work led to the decision to design, fabricate and perform testing on a full-scale rotary microfilter for potential SRS Tank Farm applications.

SRS is evaluating the use of the rotary microfilter for Enhanced Processes for Radionuclide Removal (EPRR) and sludge washing. The Hanford site is examining the technology for Supplemental Pretreatment and Bulk Vitrification.

The EPRR is intended to provide a parallel processing path to the Modular Caustic Side Solvent Extraction Unit (MCU). It consists of two in-riser rotary microfilter units that feed ion exchange columns. Salt solutions will feed the process and may contain up to 2 wt % solids. The process will add MST to the salt solution to sorb strontium and select actinides. The rotary filter will remove the MST and entrained sludge from the feed slurry.

This paper will describe the effort to redesign the filter unit and filter membranes for use in high level radioactive waste treatment, and discuss the operating performance of the filter units fabricated using the new design.

EQUIPMENT REDESIGN FOR RADIOACTIVE SERVICE

We identified 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[i] covers the concept of the removable filter stack and the welding technique used to fabricate the all stainless steel filter disk. The design provides a small footprint, high throughput filter that is easily operated and maintained.

Filter Disk

We identified the most prominent design weaknesses of the commercial off-the-shelf unit. These weaknesses were the Ryton® support plate, the polyethylene mesh, the epoxy bead to seal the membrane to the support plate, and polymeric elastomers. We modified the filter disk design to mitigate or eliminate these weaknesses.

The modified design for the filter disks eliminates polymer components, replacing them with stainless steel. The polyethylene mesh between the filter membrane and the filter support plate was replaced with stainless steel. The new disk design uses a stainless steel support plate instead of a Ryton® plate. To keep the disk weight the same, the stainless steel plate is thinner than the Ryton® plate, decreasing the volume of each filter disk. This change allows placing additional disks within the same volume housing or reducing the volume of the unit without decreasing the filter area. The overall increase in filter area per system volume is 15 – 20%.

Each filter disk provides approximately 0.96 ft^2 of filtration area (nominal 1 ft^2/disk). The total filtration area available for the 25 disk is 24.1 ft^2 (nominally 25 ft^2).

Additional upgrades in fabrication are included into the modified design, increasing the consistency during fabrication. Currently, the disks are made by hand and can have dimensional and mass variances. The membranes are attached to the support plate with a bead of epoxy. The modified disk is assembled using laser welding in place of the epoxy.

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.

Filter Unit

The commercial off-the-shelf design is less than ideal for radioactive service due to a large number of small parts and extensive use of polymers in the filter design. Elements in the current design were modified to make the configuration more reliable in radioactive service. Areas of modification include the fabrication tolerances, selection of a mechanical seal, and consolidation of internal parts.

SRNL reconfigured 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. By incorporating the disks and turbulence promoters into a single filter cartridge, the replacement of the filters is greatly simplified. In this design the filters, seal and turbulence promoters would all be replaced in the event of disk or seal failure. A sketch of the modified design is shown as Figure 1.

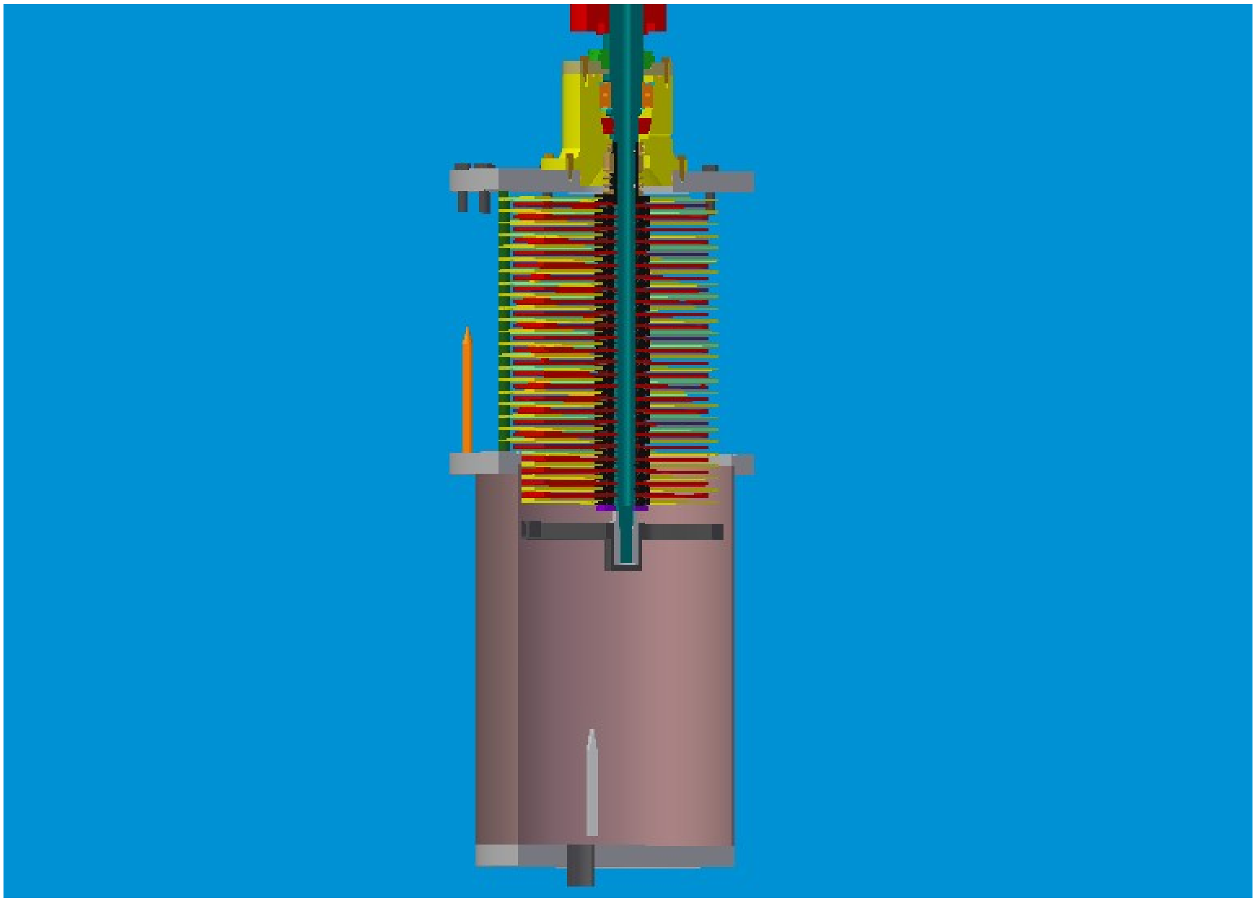


Figure 1 Cutaway of Modified Rotary Filter Design

The modified design reduced the number of slurry seals from two to one. The original design of the SpinTek filter uses a water-cooled seal. The type of seal was changed from a water seal to a bellows seal. 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 the operation of the rotor provides sufficient turbulence to maintain constant flow of process fluid to the seal faces to maintain cooling and lubrication. 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.

The commercial off-the-shelf unit uses a ceramic coated membrane. While this membrane produces higher flux than the stainless steel membranes tested, the stainless steel membranes have shown better durability. Both Pall and Mott membranes were evaluated for ease of fabrication, durability, throughput, and solids removal efficiency. Following the evaluation, we chose Pall PMM050 0.5µ (nominal) membranes for the disks. The membrane is 0.0055" in thickness. The manufacturer removal ratings are 90% of 0.6µ, 99% of 2µ and 100% of 5µ particles. The Pall membrane was easier to weld, produced more consistent filter disks, and produced higher flux than the Mott disks. Both Pall and Mott membranes effectively removed solids from the feed slurries.

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.

ROTARY FILTER FABRICATION AND TESTING

After making these design changes, we procured two filter units from SpinTek. SpinTek fabricated the filters, tested them, and shipped them to SRNL. After receiving them, we assembled one of the units, and tested it with feeds that would by typical of the EPRR and sludge washing processes. After the testing, we disassembled the unit, and inspected the mechanical seal, rotary joint, and bushing for wear. Figure 2 shows a photograph of the system as installed.

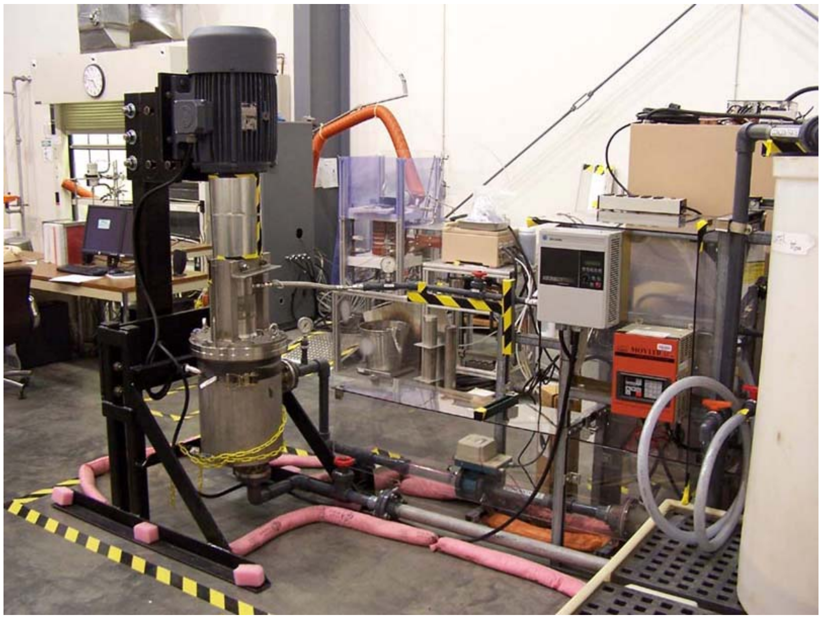


Figure 2 Rotary Filter System Installed View

Figure 3 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.

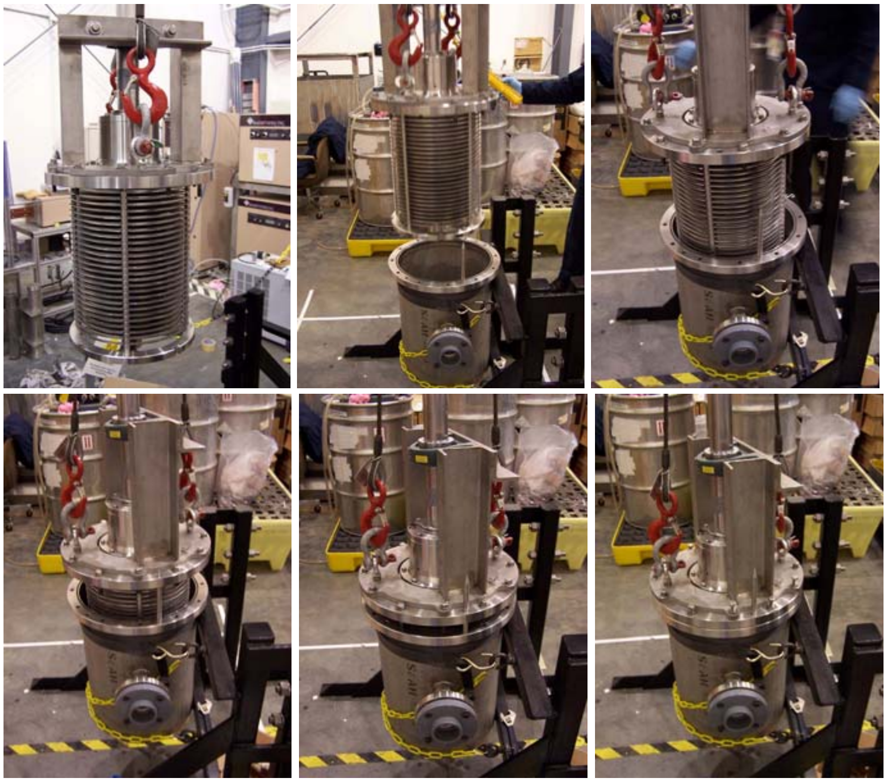


Figure 3 Insertion of the Filter Stack into Housing

Main Shaft Seal

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.

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 of the filter. In the in-riser 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 is itself 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 onset of this condition. Failure of the bearing will require the replacement of the filter stack assembly.

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 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 indicates 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 4, indicated no obvious damage due to overheating. Therefore we conclude that the filter design maintained sufficient cooling to prevent overheating of the seal.

Figure 4 The Shaft Seal Elastomer Bellows after 120 Hours of Testing

Personnel then inspected the drive of the mechanical seal (shown in Figure 5). 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.

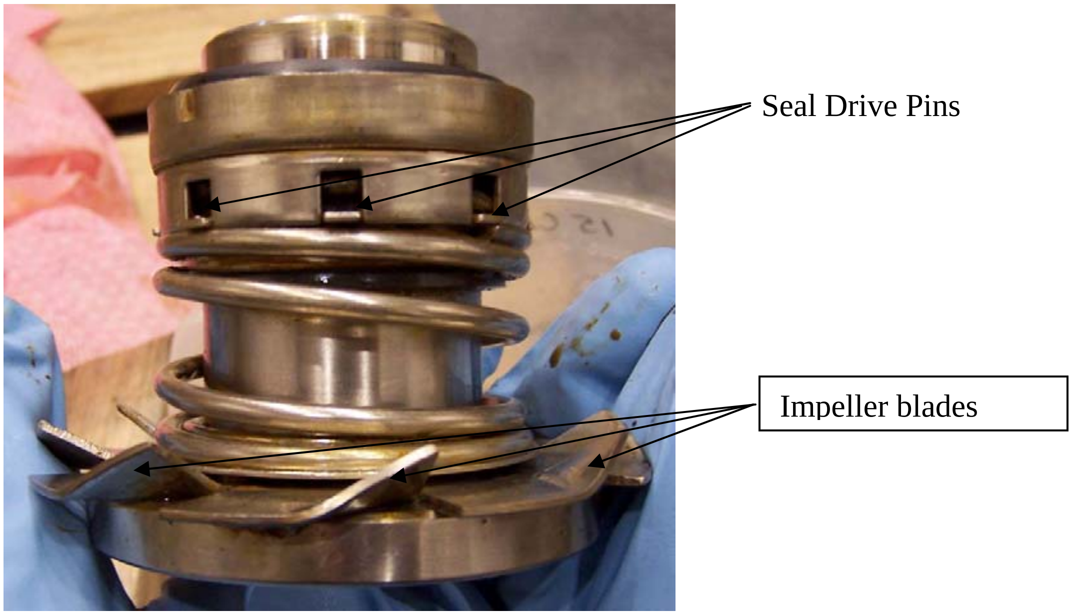


Figure 5 Shaft Seal Drive Mechanism after 120 Hours of Testing

Figure 6 and Figure 7 show the two faces of the mechanical seal after the 120 hours of testing.

Figure 6 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 7. 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 the testing. The seal vendor considers the amount of observed 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 John Crane representative also stated that the expected service could increase up to 5X if the mechanical seal was replaced with an air seal.

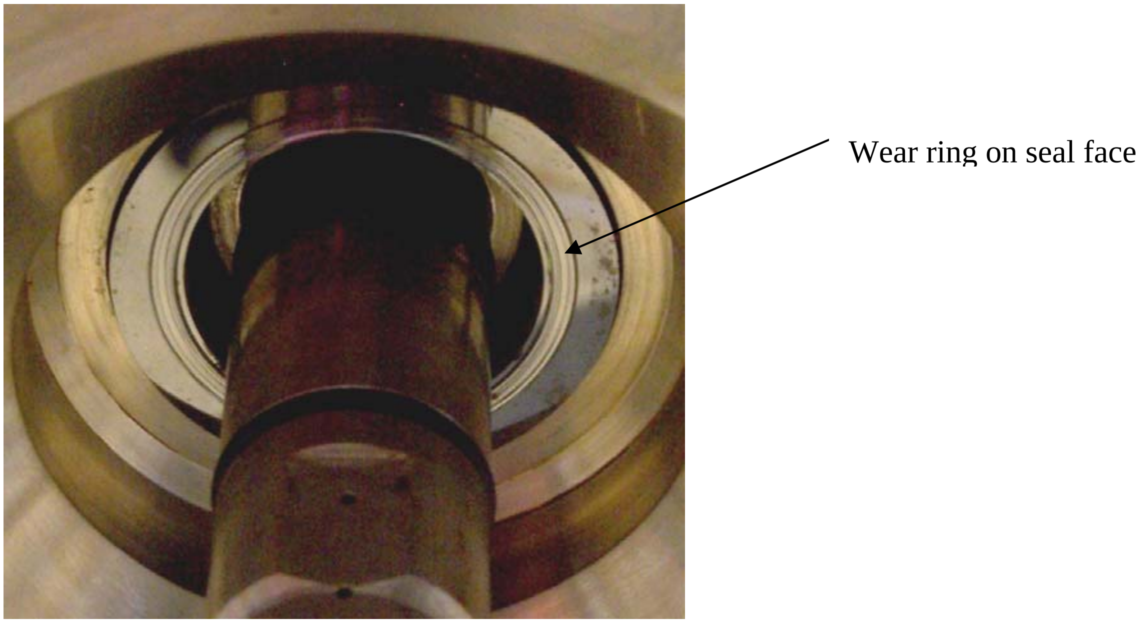


Figure 7. Photograph of the Wear on the Shaft Mechanical Seal Stationary after 120 Hours of Testing

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 8 shows the traces of the filtrate drips from the upper weep hole of the rotary joint.

Figure 8 Traces of Filtrate Drips from Rotary Joint Upper Weep Hole

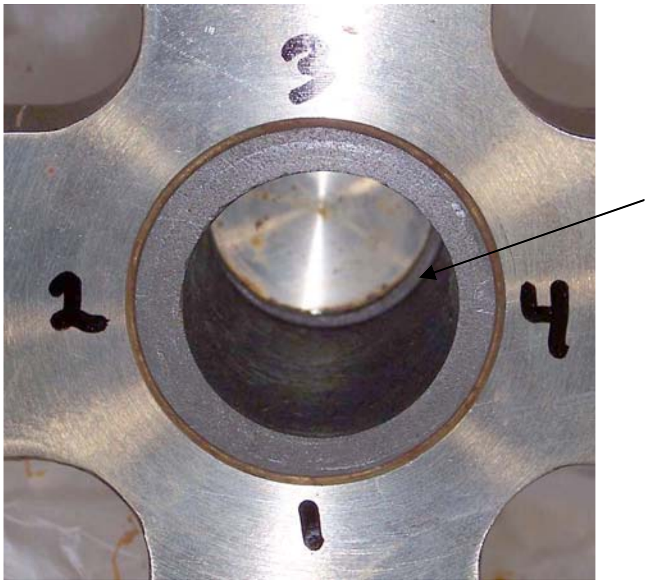
Personnel first noted the weeping first noticed during the 0.06 wt % insoluble solids testing. We identified the material leaked as the filtrate crossing the faces of the mechanical seal. After consulting with the seal manufacturer, we believe that operating the system without a pressure drop across 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.

During testing, personnel swapped the second rotary joint for the first. This rotary joint operated for approximately 12 hours with one drip observed.

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 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 9.



0.060” Offset caused by wear

Figure 9. 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 as well as increase concentricity of hubs to the shaft therefore improving overall shaft balance.

Due to the amount of wear observed, we recommended replacing the graphite with a more wear resistant material such at silicon carbide. 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.

PLANS

Working with Oak Ridge National Laboratory and TTI Engineering, the authors developed a design to place two rotary microfilters in an SRS waste tank riser. SRS is currently integrating the rotary filter with the EPRR project. In this application two filters will be installed into a Type B riser and the plug assembly of a waste tank. Figure 10 shows the layout of the plug including the two filter units. The filtrate will transfer to an ion exchange column, with the concentrated solids returned to the waste tank.

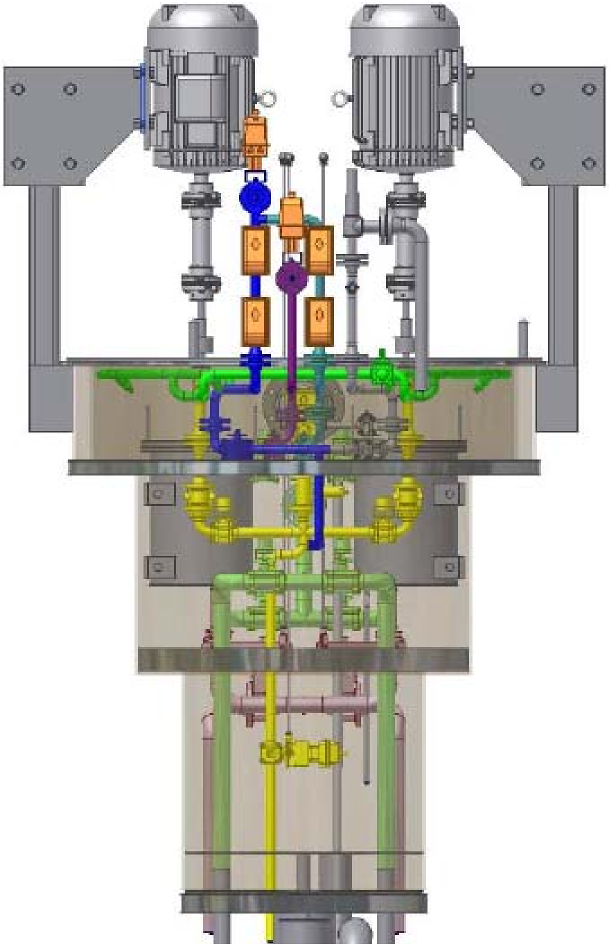


Figure 10. Conceptual Drawing of the Plug Portion of the EPRR Pump/Filter Module

CONCLUSIONS

Work to date provides the following conclusions and program status.

- The authors modified the design of the filter disks to remove epoxy and Ryton®. The new design includes welding both stainless steel and ceramic coated stainless steel filter media to a stainless steel support plate. The welded disks were tested in the full-scale unit. They showed good reliability and met filtrate quality requirements.
- The authors modified the design of the unit, making installation and removal easier. The new design uses a modular, one-piece filter stack that is removed simply by disassembly of a flange on the upper (inlet) side of the filter housing. All seals and rotary unions are contained within the removable stack.
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- 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. The authors are currently conducting testing with the more wear resistant bushing.
- The project team plans to use the rotary microfilter as a filter in advance of an ion exchange process under development for potential deployment in SRS waste tank risers.

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[i] Patent Application D. T. Herman and D. N. Maxwell, S/N 11/245,843 “Rotary Filtration System,” October 7, 2005.