Deployment of a Modular Cross-Flow Filter for Radioactive Waste

September 18, 2000

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ABSTRACT

A full-scale cross flow filter system was successfully deployed at the Oak Ridge National Laboratory for pretreatment of radioactive waste from the Melton Valley Storage Tank system. The system, designed as a stand-alone compact processing unit, consists of two filter modules (4.65 m^2 total surface area) with associated pump and piping, a filtrate collection and transfer system, a chemical cleaning system, modular shielding, and spill containment systems. The system was used to process tank supernatant to remove suspended solids and prevent fouling of downstream process systems. The system met expectations for performance of equipment and processing capability. Small-scale experimental data predicted filtrate flux values in the range of 0.063 to 0.32 L/s (1 to 5 gal/min) and actual production for the entire operation was between 0.038 to 0.5 L/s (0.6 and 8.0 gal/min). Transmembrane pressure was the controlling operating parameter when the suspended solids content of the feed was less than 0.1 wt %. When the suspended solids content increased to levels above 2.0 wt %, the effect of axial velocity and transmembrane were roughly equivalent.

INTRODUCTION

Across the nation-wide Department of Energy (DOE) complex, plans are being developed for retrieval and treatment of radioactive waste stored in aging underground storage tanks. The waste consists of concentrated liquid salts mixed with insoluble sludges. Effective treatment of the liquid fraction of this waste may require a preliminary solid/liquid separation step to remove solids that would otherwise interfere with downstream processes such as ion-exchange, solvent extraction, and evaporation. In addition, disposal costs can sometimes be reduced substantially by separating the low activity liquids from higher activity sludges.

At Oak Ridge National Laboratory (ORNL), radioactive waste from past national defense programs, nuclear power research, and isotope production programs is stored in many underground storage tanks across the site. An important effort is now underway to empty these tanks and consolidate all radioactive tank waste in a single tank farm. Once consolidated, the waste will be processed for final disposal through privatization contracts. Consolidation generally involves the use of specially designed waste retrieval systems to mobilize, mix, and transfer liquid/sludge slurries through existing piping networks to the targeted tank farm, the Melton Valley Storage Tanks. Since the sludge contains most of the radioactive components of the waste, disposal costs can be reduced by separating the sludge from the liquid. The overall plan is to process the sludge for disposal as mixed, transuranic waste at the Waste Isolation Pilot Plant in Carlsbad, NM. The liquid fraction will be concentrated by evaporation and treated by ion-exchange to separate radioactive cesium. The resultant liquid will be solidified and disposed of as low-level waste at the Nevada Test Site. For this plan, solid/liquid separation systems are needed to consolidate the sludge in a group of eight, 190-m^3 (50,000-gal) tanks and to prevent sludge components from interfering with evaporation and ion-exchange processes.

Because the liquid is highly radioactive, the filtration system must be very reliable with low maintenance attributes, and must be capable of remote, automated operations. The DOE has identified cross-flow filtration as a primary technology for this application. Cross-flow filtration (CFF) employs the use of tubular porous metal filters with small pore size (0.5 micron in this case) for applications where automation, reduced secondary waste generation, and low maintenance requirements are important. A full-scale modular CFF system was designed, fabricated, installed, and successfully deployed for treatment of liquid low-level radioactive waste from the Melton Valley Storage Tanks (MVST) at Oak Ridge National Laboratory (ORNL). The skid-mounted, automated CFF system, with a 4.65 m^2 (50 ft^2) filter surface area, was operated in series with ion-exchange and evaporator systems to remove suspended solids and prevent fouling of ion-exchange materials and heat exchange surfaces. The deployment of this system at ORNL represents the first time that this technology has been applied as a modular, self-contained system for highly radioactive waste.

WORK DESCRIPTION

Cross-flow filtration is a commercial technology involving the use of tubular porous metal filter elements arranged in a configuration similar to a shell and tube heat exchanger. Liquid with suspended solids is pumped through the tubes at relatively high velocity and moderate pressure. The liquid permeates through the tube walls to the shell side of the unit where it can be collected and transported to downstream processes. The more concentrated liquid/solid mixture is recirculated through the tubes until the targeted solids concentration is reached. The final concentrated slurry is then discharged to holding tanks for subsequent processing prior to disposal. The high tube-side velocity employed helps minimize the buildup of solids on the tube surface that would otherwise lead to low filtrate production. An automated, moderate-pressure backflushing process referred to as "backpulsing" is also used to minimize solids buildup. The system can also be chemically cleaned should small particles of solids penetrate and plug the pores of the filter.

A full-scale CFF system was designed based on data obtained from bench-scale development testing performed by the Savannah River Technology Center (SRTC)[1] and Oak Ridge National Laboratory (ORNL)[2] in 1996. This testing was performed with simulants and samples of real waste using small-scale, single-element filter units. Engineering specifications were developed by ORNL, and a commercial company was selected in a competitive bidding process to design and fabricate the system. The system was designed, fabricated, and installed at ORNL over a 21- month time frame from August 1997 to May 1999. After preoperational testing, the system was used to process about 170,000 L (45,000 gal) of radioactive storage tank waste in June, July, and August 1999.

During operations, performance data for the SLS system was collected, analyzed, and compared to data from previous bench-scale development testing to evaluate the ability to predict full-scale performance based on small-scale single-element filter testing. Additional operational information was collected to evaluate the overall feasibility of deploying this technology as a modular compact processing unit.

RESULTS

The full-scale CFF system was fabricated in Peterborough, Ontario by NUMET Engineering LTD. The system, measuring approximately 6 m in length, 3 m wide, and 3.7 m in height consists of two filter modules with associated pump and piping, a filtrate collection and transfer system, a chemical cleaning system, and modular shielding. Containment for the system includes a steel outer enclosure and liquid containment pans. Steel walls, 5.1-cm thick, are strategically placed and layered around the process components for shielding of gamma radiation. The two cross-flow filter modules are 1.52 m long with a bundle of 31 filter tubes, each providing 2.32 m^2 of filtering surface area. With shielding, the system weighed approximately 37,000 Kg (40 tons) and was transported to Oak Ridge on a single flatbed trailer. The system was designed for fully automated, remote operation from a control room located about 30 m from the system. A photo of the system is shown in Figure 1. The system was installed above-grade, adjacent to the underground MVST vault containing eight 190,000-L (50,000-gal) waste storage tanks. The feed system for the CFF module, consisting of two double-diaphragm pumps, was installed separately within the MVST pump/valve vault and connected to MVST waste transfer piping.

The MVST waste is primarily a highly concentrated (about 5*M*), alkaline sodium nitrate-based solution with lower concentrations of potassium nitrate, sodium carbonate, and other salts. The tanks also contain a large amount of insoluble sludge, consisting primarily of calcium carbonate, uranium oxides, and various metal hydroxides. The waste was generated from past national defense programs, nuclear power research, and isotope production programs. The principal radionuclides in the liquid waste include ^{137}Cs, ^{90}Sr, ^{60}Co, and trace quantities of other fission and activation products. The primary radionuclides in the sludge include ^{137}Cs, ^{90}Sr, uranium isotopes, and transuranic isotopes.

Fig. 1. CFF system installed adjacent to Melton Valley Storage Tanks.

The Melton Valley Storage Tank system is classified as a DOE Class II Nuclear Facility. As such, the CFF installation required thorough review and revision of the facility safety analysis documentation to take into account the potential hazards of the CFF operation. A formal DOE readiness assessment was required to evaluate system design, administrative controls, and personnel readiness prior to operations.

The initial test of the CFF system involved the filtration of supernatant from Tank W-31. Filter performance information was collected while operating the system under conditions defined in several test sequences. The most important operating variables for cross-flow filtration are transmembrane pressure (pressure difference between the waste flowing through the porous tubes and the filtrate on the shell side of the tube bundle), axial velocity (velocity of liquid flowing through the tubes), and the percent by weight (wt%) of suspended solids in the feed. A basic factorial experimental design was used in which target values for transmembrane pressure (69, 138, and 207 Kpa) and axial velocity (1.2, 2.1, and 3.0 m/s) were controlled while monitoring filtrate production. A set of at least nine different operating conditions using three pressures and three velocities were defined and run in random order. The third important variable, solids content of the feed, could not be controlled during the tests. To minimize the influence of feed composition, the tests were run during times when solids content was reasonably constant. Solids content was measured continuously using an in-line Coreolis mass flowmeter.

Figure 2 shows the flowsheet for the CFF feed system and filtration loop. The transfer pump suction legs for the tank system are all located less than 30 cm from the bottom of the tanks. To avoid transferring concentrated sludge to the SLS system at initial startup, the existing progressive-cavity (Moyno) transfer pumps are operated to circulate the tank at high flow (12 L/s) to clear a depression in the sludge surrounding the suction leg. After clearing the sludge from the suction leg, the progressive cavity pumps are deenergized and operation of the CFF feed pumps can begin. The feed rate from the waste tank to the CFF filtration loop was specified for a flow of 1.9 to 3.0 L/s. With the maximum filtrate production rate expected to be about 0.32 L/s, the concentrate return flow to the tank (feed rate minus filtrate rate) is only slightly less than the feed flow. Since concentrate stream is returned to the tank from which the feed is taken, a gradual increase in the solids content of feed is expected. The rate at which the solids content rises will depend upon the extent to which the suction leg remains clear of sludge, the amount of liquid in the tank, and the extent to which solids settle in the tank before the liquid is pumped through the filter again.

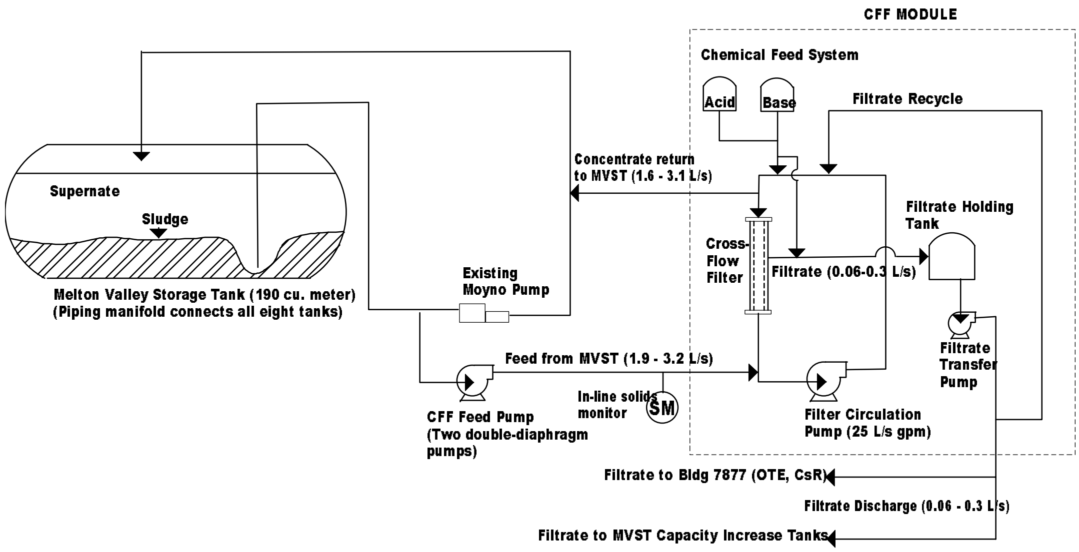

Fig. 2. Flowsheet of the cross-flow filter system deployed at ORNL.

Tables I and II summarize operating data collected for two test campaigns conducted for two different waste tanks and ranges of feed suspended solids content. The quality and overall production rate of filtrate consistently met the requirements for feed to the downstream processes. Based on analysis of feed and filtrate samples, 99.8% of insoluble solids and 99.9 % of insoluble calcium was removed from the feed. The system was designed to provide 0.063 to 0.32 L/s (1 to 5 gal/min) of filtrate and actual production for the entire operation was between 0.038 to 0.5 L/s (0.6 and 8.0 gal/min).

Table I. CFF test data for Tank W-31.

Transmembrane pressure (Kpa)	Axial flow (L/s)	Axial velocity (m/s)	Avg. filtrate flow (L/s)	Avg. filtrate flux (L/s/m^2)	Max. flux (L/s/m^2)	Min. flux (L/s/m^2)
112	10.7	1.2	0.32	0.068	0.084	0.038
102	18.9	2.1	0.30	0.065	0.078	0.051
143	26.8	3.0	0.38	0.082	0.087	0.061
138	10.7	1.2	0.36	0.076	0.085	0.073
138	18.9	2.1	0.37	0.080	0.086	0.065
138	18.9	2.1	0.36	0.077	0.079	0.073
138	18.9	2.1	0.36	0.077	0.079	0.070
138	26.8	3.0	0.38	0.081	0.086	0.076
138	26.8	3.0	0.38	0.082	0.085	0.074
207	10.7	1.2	0.43	0.092	0.098	0.068
207	18.9	2.1	0.43	0.093	0.098	0.090
207	26.8	3.0	0.45	0.097	0.102	0.087

Other test conditions:
1) Test was conducted over a 15 hr period beginning June 21, 1999.
2) Average flow of feed was 3.4 L/s.
3) Time between backpulse was 60 min.
4) TSS content of feed ranged from zero to 0.1 wt %.

Table II. CFF test data for Tank W-26

Transmembrane pressure (Kpa)	Axial flow (L/s)	Axial velocity (m/s)	Avg. filtrate flow (L/s)	Avg. filtrate flux ($L/s/m^2$)	Max. flux ($L/s/m^2$)	Min. flux ($L/s/m^2$)
138	11	1.2	0.053	0.011	0.018	0.009
138	18.9	2.1	0.062	0.013	0.020	0.011
138	26.8	3	0.066	0.014	0.034	0.012
172	11.2	1.2	0.061	0.013	0.038	0.009
172	18.9	2.1	0.072	0.015	0.051	0.011
172	18.9	2.1	0.067	0.014	0.025	0.011
172	18.9	2.1	0.067	0.014	0.054	0.011
172	26.8	3	0.078	0.017	0.028	0.013
172	26.8	3	0.071	0.015	0.025	0.012
172	29	3.3	0.083	0.018	0.035	0.014
172	29	3.3	0.076	0.016	0.057	0.012
207	11	1.2	0.066	0.014	0.024	0.010
207	18.9	2.1	0.071	0.015	0.026	0.012
207	26.8	3	0.081	0.018	0.035	0.013

Other test conditions:
1) Tests were conducted over a 25 hr time period beginning August 13, 1999.
2) Average flow of feed was 2.5 L/s.
3) Time between backpulse was 60 min
4) Suspended solids content of feed was 2.1 to 4.0 wt %

Figure 3 shows the raw operating data collected for the test information given in Table 1 for Tank W-31. The data for transmembrane pressure and axial flow show step changes as operating conditions are adjusted for the performance tests. Data for transmembrane pressure shows significant fluctuation due to the pulsation of feed flow from the double-diaphragm feed pumps. Axial flow is very steady due to the smooth operation of the filter loop pump manufactured by DISFLO Corporation, El Cajon, CA. Filtrate is produced and collected in 450 L batches, therefore, filtrate flow is indicated only when the filtrate holding tank is being filled. Once full, the filtrate holding tank is transferred to the receiving tank for the ion-exchange processing system. Figures 4 and 5 show the influence of axial flow and transmembrane pressure on the rate of filtrate production. This data clearly indicates that transmembrane pressure has a much greater influence on filtrate production when the solids content of the feed is low, less than 0.1 wt % in this case. When Tank W-26 supernatant was processed, the solids content of the feed was much higher due to the physical properties of the solid phase. Figures 6 and 7 show the influence of transmembrane pressure and axial flow on filtrate flux. The solids content of the feed was in the range of 2.1 to 4.0 wt %. Under these conditions, transmembrane pressure had a lesser impact on filtrate flux and the influence of axial velocity increased significantly.

Comparing the data from this operation with the data previously collected from single-element real-waste tests indicated reasonable agreement with the range of filtrate rates achieved, but there were limitations in the ability to predict filter performance and the influence of operating parameters. Sludge samples were collected from many different waste tanks for these tests. The difference in sludge compositions led to a wide range of filter flux performance data. When small samples of sludge are circulated within a small-scale test system, the particle size range of the sample can be reduced significantly by pump shear. This can reduce filtrate rate and mask the positive influence of increasing axial velocity. If a conservative approach is taken in using single-element test data in scale-up calculations, the amount of filter area required for the full-scale system can be over-estimated. In this case, the full-scale performance data was within the envelope of the single-element data.[2]

The modular system (pumps, valves, sensors, monitors, and controls) functioned very well during both processing campaigns. Shielding and containment systems operated per design. Infrequent feeds of heavy sludge caused some difficulties, but the system design allowed for recovery from these problems with minimal down time.

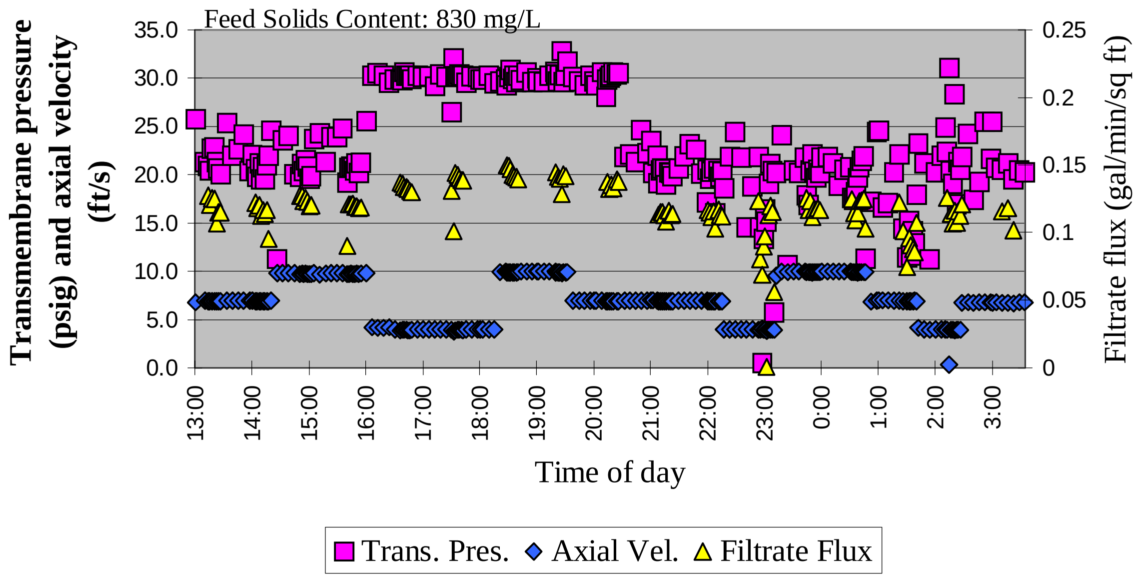

Fig. 3. Cross-flow filter operating data for Tank W-31.

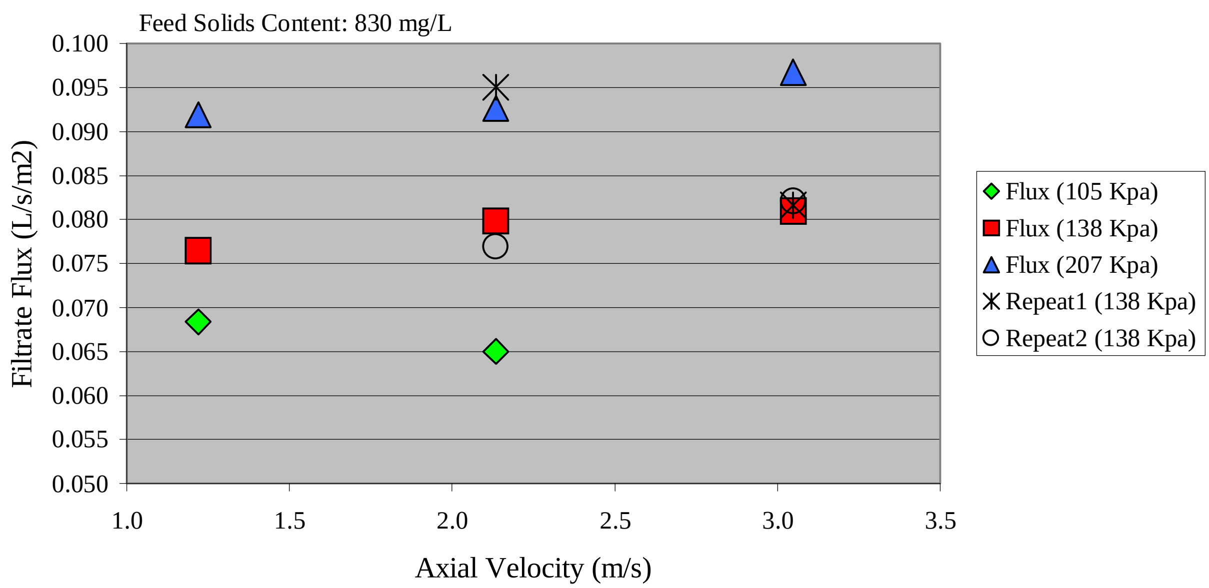

Fig. 4. Filtrate flux as a function of axial velocity for Tank W-31.

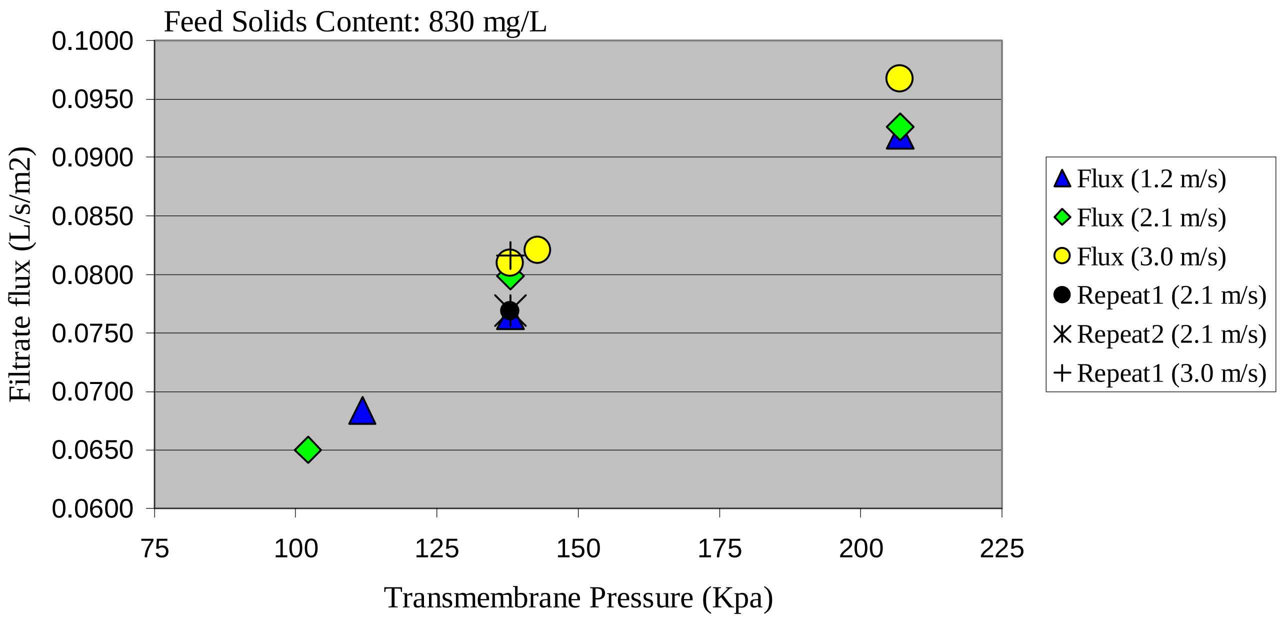

Fig. 5. Filtrate flux as a function of transmembrane pressure for Tank W-31.

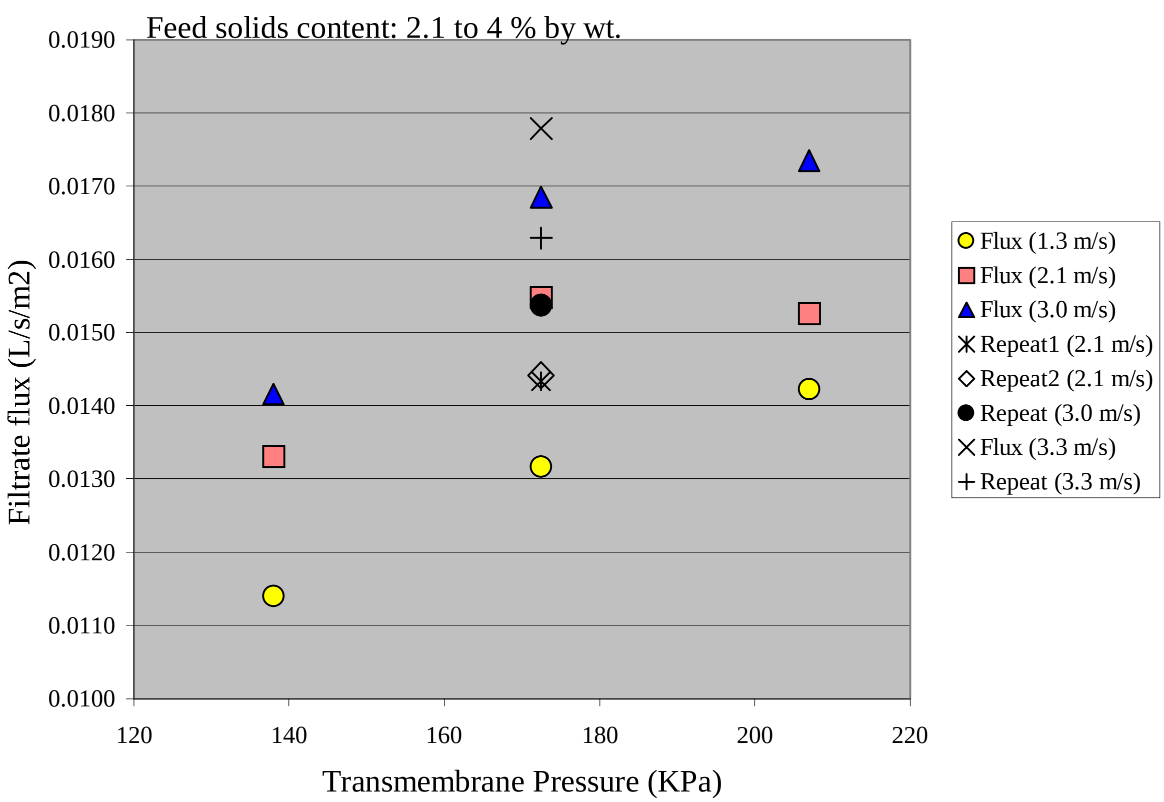

Fig. 6. Filtrate flux as a function of transmembrane pressure for Tank W-26.

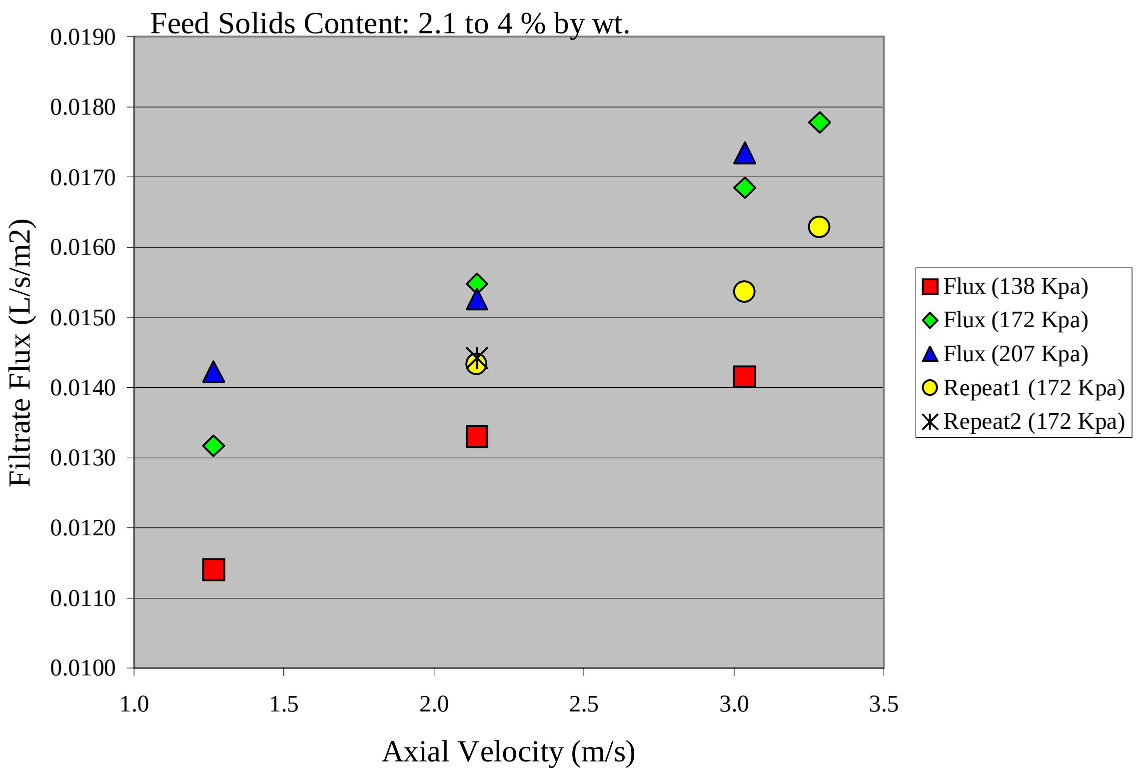

Fig. 7. Filtrate flux as a function of axial velocity for Tank W-26.

CONCLUSIONS

The results indicate that cross-flow filtration technology can be deployed successfully as a modular compact processing system for treatment of radioactive tank waste. The system operated well with very little unscheduled down-time. Performance data indicated that transmembrane pressure had a dominant influence on filtrate flux when the insoluble solids content of the feed was less than 0.1 wt %. When solids content reached 2.1 wt % and higher, the influence of axial velocity and transmembrane pressure on filtrate flux were comparable. Comparing bench-scale real-waste test data and full-scale performance data indicates that full-scale performance can be predicted to a reasonable degree, though the limited volume of feed in bench scale testing limits the ability to predict the influence of the important operating parameters. The filtration data and equipment performance information collected in this study is being used to further the continuing effort in testing, designing, and deploying treatment systems for the nationwide cleanup of DOE radioactive tank waste.

REFERENCES

1. D. J. MCCABE, B. W. WALKER, and R. A. PETERSON, “Oak Ridge Gunite Simulant Filtration Test Results”, Savannah River Technology Center, Westinghouse Savannah River Company, Aiken, SC, WSRC-TR-96-0234, September 30, 1996.
2. T. E. KENT, J. R. FARMER, and J. H. WILSON, “Development and Deployment of a Full-Scale Cross-Flow Filtration System for Treatment of Liquid Low-Level Waste at Oak Ridge National Laboratory,” Chemical Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-2000/27, in press.