LOW-LEVEL LIQUID WASTE PROCESSING PILOT STUDIES USING A VIBRATORY SHEAR ENHANCED PROCESS (VSEP) FOR FILTRATION

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ABSTRACT

A previous EPRI study evaluated potential treatment methods for the removal of iron from BWR waste streams. Of the methods investigated, high shear filtration using the vibratory shear-enhanced process (VSEP) showed the most promise to effectively and economically remove high iron concentrations from backwash receiving tank waste.
A VSEP filter uses oscillatory vibration to create high shear at the surface of the filter membrane. This high shear force significantly improves the filter's resistance to fouling thereby enabling high throughputs with very little secondary waste generation. With a VSEP filter, the waste feed stream is split into two effluents- a permeate stream with little or no suspended solids and a concentrate stream with a suspended solids concentration much higher than that of the feed stream.

To evaluate the feasibility of using a VSEP concept for processing typical high iron containing BWR radwaste, a surrogate feedstream containing up to 1,700 ppm iron oxide (as Fe_2O_3) was used. This surrogate waste simulates radioactive waste found at Exelon's Limerick and Peach Bottom (powdered resin condensate) plants, and in Hope Creek's (deep bed condensate) radwaste systems. Testing was done using a series L (laboratory scale) VSEP unit at the manufacturer's and contractor's laboratories. These tests successfully demonstrated the VSEP capability for producing highly concentrated waste streams with totally "recyclable" permeate (e.g., greater than 95% recovery).

Additionally, the VSEP concept was evaluated in the laboratory for application in processing long time stagnant sump waste and boric acid concentrate streams at the decommissioned Rancho Seco Plant. Again, the VSEP was able to directly produce concentrate streams for sludge processing while recovering greater than 90% of the feed (as a permeate stream that can easily be overboarded to the environs or recycled). Furthermore, some boric acid concentration was also achieved.

Following successful surrogate testing at the manufacturer's laboratory, further pilot testing was performed at the Contractor's facility in both the "L" and "P" (pilot) modes. Again, very high iron concentrations were achieved demonstrating the capability of the concept on a larger scale. [Note that the "P" mode involves a multi-membrane stack

totaling about 16 ft^2 of filtration area as opposed to the ½ ft^2 in the "L" mode.] Following these confirmatory tests, the VSEP was tested on site at the Peach Bottom Atomic Power Station with actual phase separator tank wastes. Again, both "L" and "P" modes were used to re-confirm membranes selection on actual plant wastes and determine optimum process rates (flux – gpm/ft^2), recommended concentration factors (% solids), membrane life expectations, and scale-up information for full size systems.

Similarly, a pilot scale ("P" mode) unit was tested on actual plant decommissioning wastes at the Rancho Seco plant. Here again, optimum systems design parameters were determined for full size systems while maintaining high concentration factors and excellent quality permeate.

INTRODUCTION

The application of advanced membranes in condensate system filter/demineralizers (f/d) has allowed the elements to operate with a minimum precoat (<0.1 lb./ft^2) or with no precoat (non-precoat). Either mode can assist plants in achieving goals that target improved corrosion product removal significant reductions in solid waste generation and associated disposal costs. However, utilities have found that the operation of these advanced membranes can present distinct problems related to liquid radwaste (LRW) processing.

When using minimum or non-precoat elements, the waste slurry from the f/d's does not possess adequate spent media to promote efficient settling. Additionally, these elements have a higher iron removal efficiency, and the f/d backwash contains a significantly higher percentage of small (<1 micron) iron particles. The population of very small and highly charged particles remains in suspension and takes on the characteristics of colloidal materials. Both of these factors contribute to poor settling characteristics and inefficient settling in the phase separator.

EPRI evaluated the feasibility and economics of three technologies for the removal of iron from phase separators at 2 host BWR plants; crossflow filtration, high shear filtration, and hydrocyclone separation (1). This study demonstrated that high shear filtration was the most viable technology for iron removal.

A VSEP filter uses oscillatory vibration to create high shear at the surface of the filter membrane. This high shear force significantly improves the filter's resistance to fouling thereby enabling high throughputs with very little secondary waste generation. With a VSEP filter, the waste feed stream is split into two effluents- a permeate stream with little or no suspended solids and a concentrate stream with a suspended solids concentration higher than that of the feed stream.

A pilot test program was developed to demonstrate the use of high shear filtration on Nuclear Power plant surrogate and actual waste streams for the removal of high iron concentrations. Additionally, as several plants are in various phases of their decommissioning plans, many still must process wastewater accumulated since plant shutdown. Many of the water storage tanks are filled with not only sub system drain-down water, but contain large amounts of sludge, and sometimes chemical wastes. Often, these water storage tanks also contain process system chemicals such as boric acid. The pilot test program was extended in scope to provide additional test results on this variety of liquid waste streams present at our host decommissioned plant.

METHODS

1) **Preliminary Economic and Performance Analyses**: Baseline economic and performance data was collected from a member BWR plant processing high iron liquid radwaste with no chemical pretreatment. Using the EPRI WasteLogic™ Liquid Processing Manager code (2), the baseline was compared to the following processing options: Polymer enhanced filtration, crossflow filtration, high shear filtration, and hydrocylcone processing. Various concentrate processing strategies were reviewed, including sending the concentrate to the phase separator, to a high integrity container (HIC), or processing with concentrate drying technology.
2) **Surrogate Test Conditions with simulated high iron wastes**: Initial laboratory testing was performed using simulated iron oxide wastes at ~1,200 ppm Fe_2O_3 for Limerick Generating Station simulated wastes and a slight admixture (<5%) spent powdered resin for the Peach Bottom simulated wastes. Follow up laboratory surrogate screening was also performed using simulated waste from the Hope Creek Station (1,700 ppm Fe_2O_3) Four to five membranes were evaluated in each of the laboratory scale preliminary evaluations. Finally, surrogate testing was performed on simulated Floor Drain Sludge (17,000 ppm total solids + 1,600 ppm boric acid to reach pH 4.3 and caustic added to reach near neutral pH - 105uS/cm and 1,000uS/cm , respectively), and simulated concentrated waste (13,000 ppm total solids + 6,000 ppm boric acid to reach pH 5.8, 1,580 uS/cm, simulating Rancho Seco wastes.
3) **Surrogate Testing Protocols**: This test program consisted of two major phases; membrane selection, and a concentration study. Membrane selection was performed in the manufacturer's facility by installing various membranes one at a time a laboratory scale VSEP unit. The test system was then operated for several hours for each membrane during which operational and performance data were collected. For this phase of testing, the permeate and concentrate effluents were routed back to the feed tank to maintain a constant feed stream iron concentration. After all membranes were tested, an assessment was made of their relative performance and the best performing membrane was selected for further testing. The system configuration for this phase of the work is shown in Figure 1 below. The concentration study is an assessment of the change in the membrane's flux vs. concentration using the best membrane from the previous testing. For this phase, permeate was routed to a separate collection tank and only the concentrate was returned back to the feed tank as shown in Figure 2. With this configuration, the feed stream's solids concentration increases with operating time.

4) **Pilot Testing Protocols:** For the "P" mode laboratory testing representing the Limerick and Peach Bottom wastes, the candidate membrane of choice was configured in a 19 element stack of approximately 16.7 ft^2. The VSEP is run in similar configurations as with the "L" mode (Figures 1 and 2), but with higher flow rates and allowed to proceed to much higher sludge concentrations (concentrate stream to 'paste' consistency). Membrane cleaning concepts that would be applicable to actual plant criteria were also evaluated.

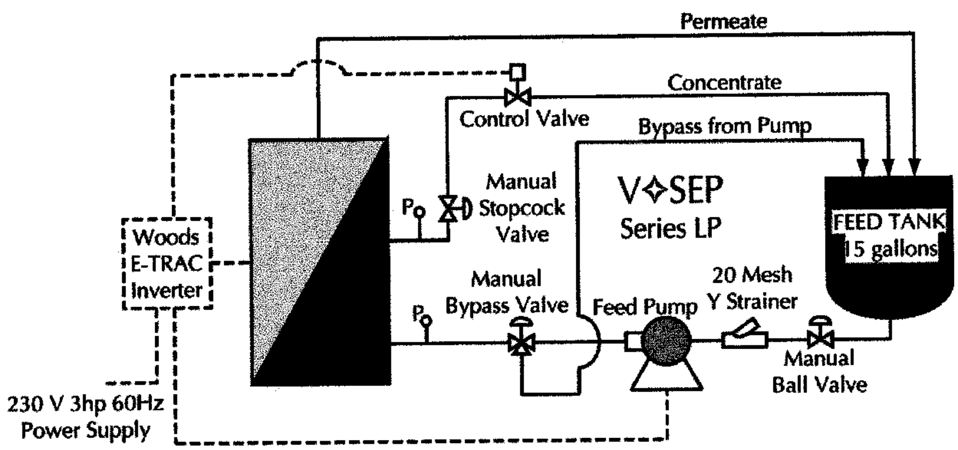

Fig. 1 "Line Out Study" System Configuration

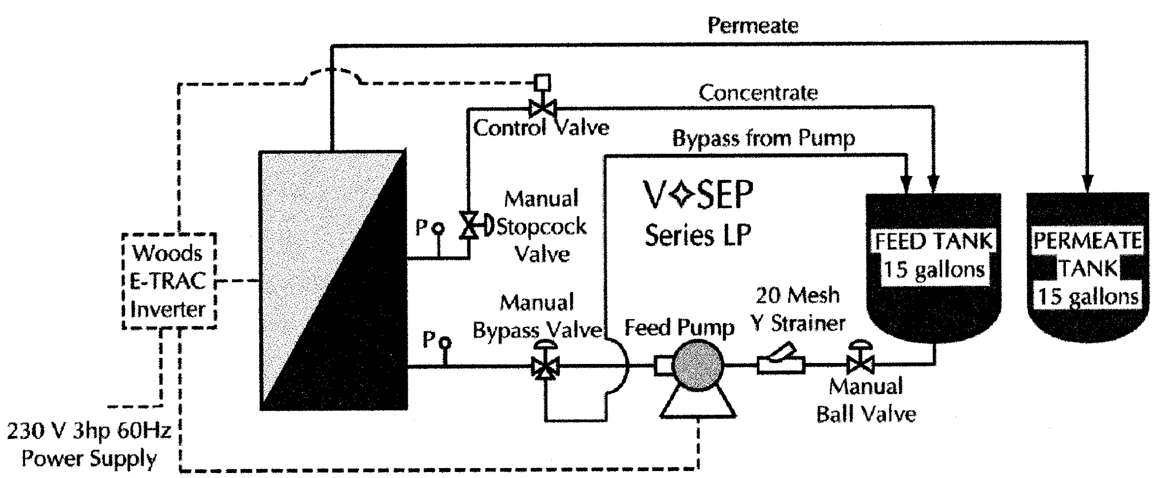

Fig. 2 Concentration Mode System Configuration

RESULTS

Economic Evaluation: Various processing technologies were evaluated to determine the most cost effective means for iron removal from backwash receiving tank waste streams. High Shear Filtration processing, followed by sending the concentrates to the phase separator, was shown to result in the greatest cost savings over the baseline annual program costs of processing the high iron waste with no chemical treatment at a member BWR. These costs are ranked in Table I.

Table I : WasteLogic™ Cost Ranking for the Technologies Evaluated

Process Option	Cost in Dollars		
	per Gallon Processed	per Cubic Foot Generated	Rank by Total Cost (1 = most cost effective)
Standard Operation	*.04*	*684*	9
Polymer Enhanced Operation	.04	734	8
Crossflow with Concentrate to Phase Separator	.02	849	3
Crossflow with Concentrate Processed in HIC	.02	849	3
Crossflow with Concentrate Drying Technology	.04	1,264	7
High Shear with Concentrate to Phase Separator	.02	812	1
High Shear with Concentrate Processed in HIC	.02	812	4
High Shear with Concentrate Drying Technology	.03	1,214	6
Hydrocyclone with Concentrate to Phase Separator	.02	817	2

Surrogate Testing

Laboratory testing in both the "L" and "P" modes showed that for commonly available membranes, iron oxides could be routinely concentrated from ~1,200 ppm to as high as 84,000 ppm, with full recovery of membrane performance after system flushing (emulating shutdown and startup conditions).

A concentrate study was performed using simulated waste from the Hope Creek Station using the best-performing membrane found during the membrane selection process. 15 gallons of simulated waste was run through the system on a single pass. The % solids of the feed stream was 0.15%, and the % solids of the final concentrate waste stream was 1.96%, resulting in a concentration factor of 13. The test run resulted in a generation of 93.4lbs. of permeate and 7.8 lbs of concentrate, for a % recovery of 92.3% of the feed process liquid in the permeate stream.

Surrogate testing was also performed on simulated wastes from the Rancho Seco plant. Solids concentration factors of 2.6 were observed in both Floor Drain Sump and Boric Acid Concentrate surrogate waste streams. A 90% minimum feed recovery was achieved with the Floor Drain Sump wastes, and a minimum feed recovery of 90-95% was achieved with the Boric Acid Concentrate surrogate wastes. Two membranes (nano filtration and reverse osmosis) were tested for boron removal efficiencies using simulated floor drain waste. The reverse osmosis membrane performed the best, with removal efficiencies of 74-78% at neutral and raw feed pH conditions (Table II).

Table II: Boron Removal from Simulated Floor Drain Waste

Feed pH	Feed Boron	NanoFiltration Permeate Boron	Removal Efficiency NanoFiltration	Reverse Osmosis Permeate Boron	Removal Efficiency Reverse Osmosis
4.3	42.5 ppm	29 ppm	32 %	9.51 ppm	78 %
7.1	65.3 ppm	34 ppm	52 %	16.96 ppm	74 %

Pilot Testing: As part of the initial L-mode pilot test process at Peach Bottom station, several hour single-pass runs were performed using five different singly-stacked membranes. The permeate showed decreased turbidity, and >99% iron removal factor in all cases tested (Table III). In some instances, feed and permeate samples were analyzed for isotopic removal efficiency. As shown in Figure 3, near quantitative removal of the measured nuclides was achievable.

The pilot scale testing at Rancho Seco also showed that the VSEP filter with the appropriate membrane can be very effective in removing suspended and dissolved solids. For example, in the first series of "P" mode testing, feed recoveries of ~95% were readily achieved. Boric acid was concentrated by greater than a factor of ten and no membrane fouling due to silica (at near neutral pH, traditional RO systems at Rancho Seco only achieved 3X concentration of boron before the membranes became fouled). Soluble activity (primarily cesium nuclides) were concentrated by about ten-fold, while insoluble activity was concentrated by more than a hundred-fold.

Table III : L-Mode Iron Removal Test Results from Peach Bottom

Membrane	Sample Time/Date	Feed ppm Fe	Conc. ppm Fe	Permeate ppm Fe	Permeate Turbidity (NTU)	Fe Removal Factor (%)
1	8/12/00 14:30	16.9	14.1	0.022	0.058	99.87
	8/12/00 19:35	15.8	17.8	0.019	0.051	99.88
	8/12/00 19:45	15.4	17.9	0.022	0.050	99.86
2	8/13/00 15:50	14.2	17.6	0.015	0.055	99.89
	8/13/00 17:45	17.3	17.8	0.012	0.053	99.93
	8/13/00 18:05	14.7	21.1	0.012	0.053	99.92
3	8/14/00 13:28	16.8	19.8	0.025	0.051	99.85
	8/14/00 16:35	16.3	23.2	0.011	0.062	99.93
	8/14/00 16:50	15.2	72.3	0.005	0.048	99.97
4	8/15/00 11:30	14.2	14.3	0.014	0.048	99.90
	8/15/00 15:43	13.2	16.8	0.021	0.049	99.84
	8/15/00 16:00	12.2	438	0.018	0.048	99.85
5	8/16/00 14:10	11.8	13.8	0.018	0.048	99.85
	8/16/00 16:50	12.1	15.9	0.046	0.048	99.62
	8/16/00 17:10	11.6	140	0.061	0.049	99.47

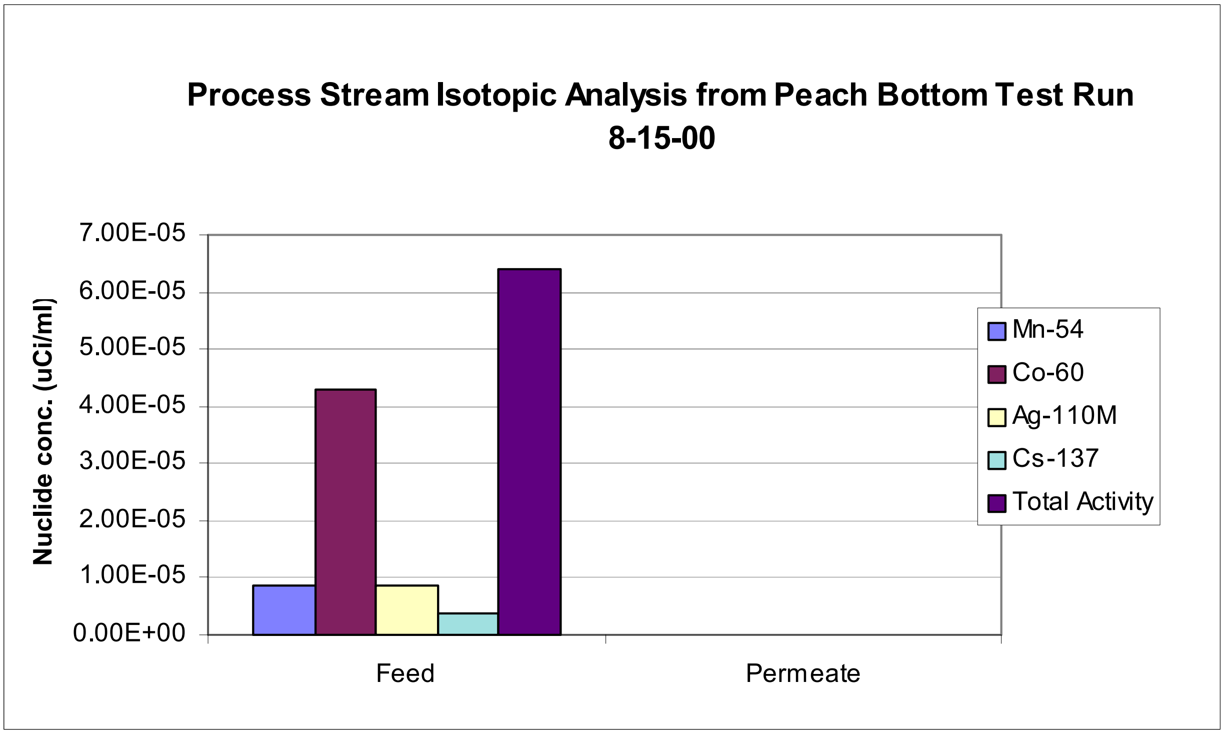

Fig. 3: Activity removal from L-mode test run at Peach Bottom

DISCUSSION

Economic and performance review has showed that high shear filtration (1), with concentrates returning to the phase separator, to be the most sound strategy of those investigated for removal of high iron wastes from BWR liquid streams. As this technology has been successfully implemented in other industries, but not in the commercial nuclear industry, our laboratory and pilot groundwork testing was necessary in order to better judge its actual processing potential for nuclear power plants.

The laboratory test data demonstrates that simulated iron oxide wastes from three different plants can be highly concentrated in single passes through a VSEP unit. The laboratory testing also showed that, in concept, wastes could be concentrated with the VSEP process for Backwash Receiving Tank, Floor Drain Sludge, and Boric Acid Concentrate Waste Streams. Surrogate testing also suggests that high shear filtration using a reverse osmosis membrane may be a potentially useful application for boric acid removal from liquid waste streams. However, further test work would be necessary to increase the recovery rates from those achieved in this study, including studies with increased pH control.

The test data from Peach Bottom shows that high iron removal rates can be achieved on various membranes using actual plant wastes as well. It should be noted though, that although iron concentration factors of >99% were achieved, these were short runs, and longer, sustained run data is needed to make more sound judgments on potential concentration factors for scale-up applications. Nuclide removal performance rates should likewise be more fully evaluated using longer test runs, and with a better understanding of the process chemistry. High shear filtration has not been tested in this study as a technology for direct nuclide removal from liquid waste streams, as removal rates would be expected to be highly dependant on the soluble vs. insoluble nuclide fractions of the waste streams. However, certainly some removal of insoluble nuclides would be expected in the concentration process, and high shear filtration, perhaps followed by an ion exchange process targeting the soluble remaining fraction, should warrant future investigations for effective liquid radwaste processing applications.

Excellent performance results are being obtained at both the in-plant "P" mode test programs on actual plant waste streams. Thus, it is apparent that once these pilot scale studies are completed, full-scale systems can be specifically designed that will greatly improve the plant's processing capabilities with significantly reduced operating and disposal costs.

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