A WASTE TREATMENT SYSTEM FOR REMOVING SILICA

FROM PRESSURIZED WATER REACTOR BORATED WATER SYSTEMS

Deborah P. Swindlehurst
Associated Technologies, Inc.
Charlotte, North Carolina 28281

ABSTRACT

Nuclear fuel fabricators and Nuclear Steam Supply System (NSSS) manufacturers set recommended limits on impurities in the borated water systems of pressurized water reactors. One of these compounds is silica. Silica deposited on fuel cladding could inhibit heat transfer causing local hot spots which could eventually lead to fuel cladding failure. The use of a Boron Recycle System to recover boron also retains and recycles silica; therefore, silica must be removed preferentially from the borated water. Reverse osmosis achieves this separation with cellulose acetate membranes. A silica removal project is presently underway at Zion Generating Station, Zion, Illinois and the results of the operation are presented in this paper.

BACKGROUND

Westinghouse has placed stringent restrictions on the silica concentrations in water systems that come in contact with nuclear reactor fuel. Specifically, the silica concentration cannot exceed 0.2 ppm in the Spent Fuel Pool (SFP) or the Refueling Water Storage Tanks (RWST). Early in 1983, Commonwealth Edison Company (CECO) solicited bids for a silica removal system and/or service for reducing the silica content in the SFP and RWSTs. Reverse osmosis (RO) was one of the alternatives considered because of a test performed at Zion Generating Station in 1980. (The results of which are published in "Waste Boric Acid Reclamation by Membrane Technology," Waste Management '81.) In that test, waste from the Auxiliary Building Equipment Drain Tank was used as the feed in evaluating spiral wound and hollow fiber cellulose acetate membranes. The hollow fiber membranes were found to give more consistent rejections than the spiral wound membranes. The silica rejection averaged 75% while boron rejection averaged 8.5%. The performance of the Dow hollow fiber membrane indicated that reverse osmosis can accomplish silica removal with minimum loss of boron from borated water systems.

In March 1983, Associated Technologies, Inc. (ATI) was contracted to remove the silica from the Spent Fuel Pool and the Refueling Water Storage Tanks. ATI provided a skid mounted system and operators necessary to reduce the concentration of silica in the tanks and pool down to the specified 0.2 ppm limit. CECO indicated that the silica level in the SFP was 6 ppm and that there was approximately 2 ppm silica in each RWST. Since boron is added to the water for moderation, removing the silica would also result in a loss of boron. Silica rejection is higher than boron rejection; therefore, a significant amount of boron could be saved with a reverse osmosis system as opposed to bleeding off the volume of water from the SFP or RWSTs while maintaining the specified minimum boron concentration required for operations (feed and bleed).

In June 1983, ATI shipped and assembled the system beside the Spent Fuel Pool at Zion. Piping modifications had been made to take the feed from the discharge of the Refueling Water Purification Pump, pipe the product back downstream of the Spent Fuel Pool Filter, and send the concentrate to the Holdup Tank (HUT). Within a week the system was ready for operation.

THE SYSTEM

The skid mounted system consists of a low pressure feed pump, a 0.5 micron sintered stainless steel microfilter, a high pressure booster pump and the reverse osmosis permeators consisting of Dow cellulose acetate hollow fiber membranes (see Fig. 1). The purpose of the microfilter is to remove suspended silica and also protect the RO from fouling. The microfilter was designed to be backflushed periodically to remove the filtered solids. CECO provided a 0.45 micron cartridge prefilter upstream of the ATI system to provide additional protection.

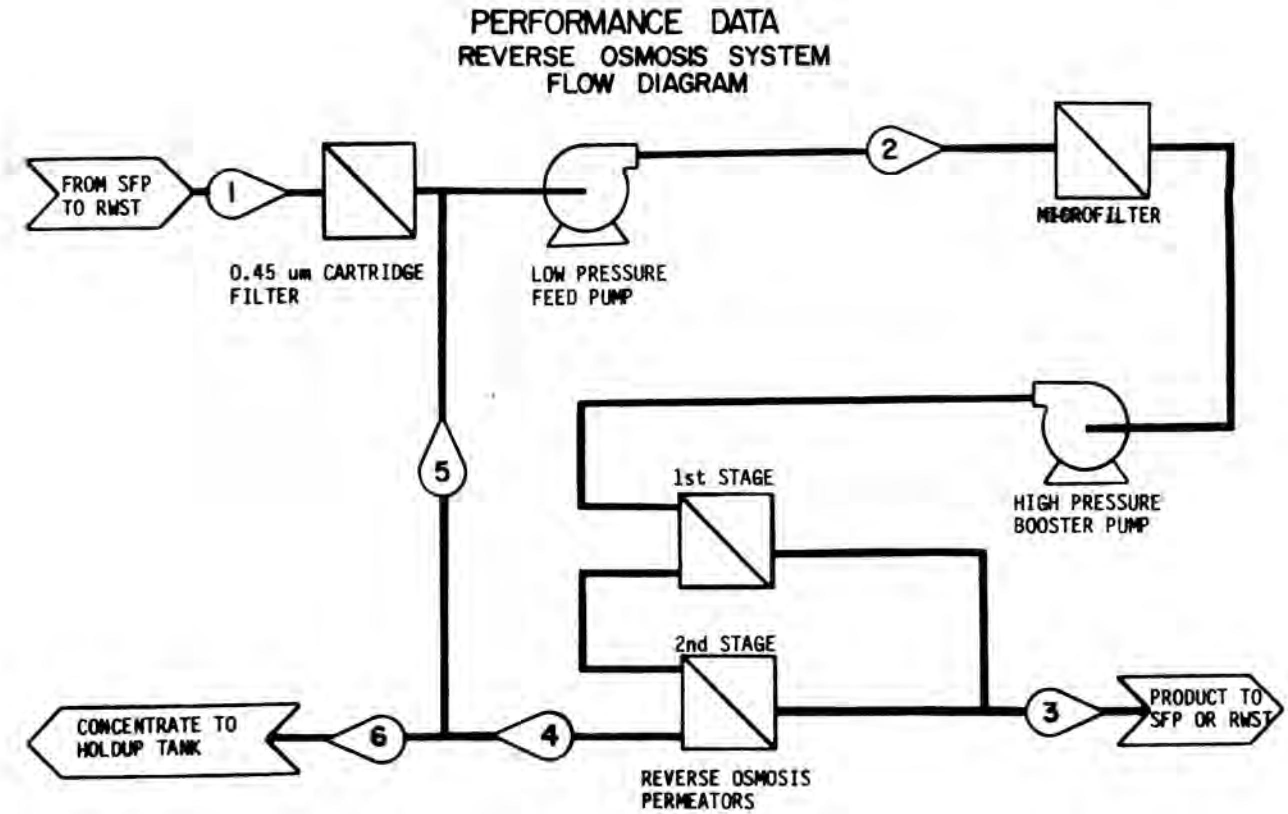
RWST or SFP water is supplied by the feed pump to the microfilter. The booster pump then increases the feed pressure to the level required to force the permeate through the membranes. The feed is supplied by a distributor core to the center of each RO housing. The cleaned product water permeates into the hollow fiber membranes leaving the concentrated "reject" water on the shell side. Valves on the discharge of the booster pump and on the concentrate header are throttled to achieve the desired product and concentrate flows of 51 gpm and 18 gpm, respectively. Twelve gallons per minute of concentrates are recycled to the feed header upstream of the feed pump. Recycling increases the system recovery thereby minimizing the flow rate of concentrates and the loss of boron.

The reverse osmosis unit achieves separation in two stages. In the first stage, three membrane housings receive fresh feed. Their concentrate streams combine and feed into the single-housing second stage. The concentrates of this stage are the only concentrates effluent for the system. All four product lines for both of the stages are combined as the final RO product.

The product water is recycled back to the RWST or SFP, and the concentrates are directed to the waste holdup tank for further treatment by Zion's Waste Processing System.

OPERATION

Processing of RWST 1 began on December 15. After 75 hours of processing, the microfilter was removed from the system for cleaning. The recommended cleaning procedure is recirculating a 2% citric acid



Sample of Performance Data (after 15 hours of operation)						
Line Number	1	2	3	4	5	6
Flowrate (gpm)	56	68	50	18	12	6
Silica Concentration (ppm)	1.2	3.0	12.2	0.23	0.23	0.23
Boron Concentration (ppm)	2391	2726	4093	2247	2247	2247
pH	5.24	5.12	4.96	5.04	5.04	5.04
Conductivity (umho/cm)	9.65	11.4	6.80	31.5	31.5	31.5

Fig. 1. System Flow Diagram.

solution through the unit. It was determined that the solution should be heated to 100°F, so a tank heater was ordered and acid cleaning is tentatively scheduled for mid-March.

Meanwhile, processing continued on RWST 1 until the silica level had been reduced to less than 0.2 ppm. Total processing time required to reach this level was 247 hours. The Spent Fuel Pool is currently being processed.

MEASUREMENTS

In order to monitor the system, samples of the product and concentrates streams were taken every two hours during startup (once per shift during normal operation). The sample points for the product and concentrates streams are nodes 3 and 4, respectively, on Fig. 1. These samples were analyzed for boron and silica concentrations, pH and conductivity by the Radiation Chemistry Department at Zion.

RWST 1 was also regularly sampled during processing to monitor the boron concentration in the tank. CECO maintains boron level at or above 2000 ppm, and regular sampling was necessary to indicate when makeup was required. A 2100 ppm boron concentration was to be maintained in the tanks in order to provide a margin of safety over the 2000 ppm minimum limit.

Pressure, temperature, flowrate, pH and conductivity were also recorded hourly at various points in the system to ensure that the system maintained a steady operating state.

RESULTS

In order to evaluate the performance of the system, the rejections for both silica and boron are required. To calculate rejection, the concentrations in the RWST (feed) and product streams are inserted into the following equation:

$$\gamma_i = \ln \frac{\frac{C_p}{C_f}\frac{Rr}{1+r} - \frac{1+r-R}{1-r}}{\frac{C_p}{C_f} R-1} \cdot \frac{1}{\ln \frac{1+r-R}{1+r}} \qquad (1)$$

where, feed refers to stream before recycle

γ_i = membrane rejection for solute i (silica or boron)

C_f = concentration of i in feed

C_p = concentration of i in product

r = recirculation ratio, recycle flowrate/feed flowrate

R = recovery, product flowrate/feed flowrate

Using this equation, the rejections for silica and boron were determined for each sample taken.

During operation, membrane rejections for silica averaged 94.4% on feed concentrations gradually decreasing from 1.3 to 0.43 ppm (Fig. 2). Based on this high silica rejection rate, it is estimated that the boron makeup required during processing RWST 1 will be less than one-fourth the amount of boron that would be lost in a feed-and-bleed operation. A sample of the operating parameters of the system is given in Fig. 1.

In comparing the results reported in "Waste Boric Acid Reclamation" with the rejections obtained by the ATI Silica Removal System, it is clear that the rejections reported here are higher than those reported for the Dow hollow fiber membranes in the test. The discrepancy is due to different methods for calculating rejection and not due to inconsistent performance by the Dow membranes.

Processing will continue until the silica levels in all three tanks have been reduced to 0.2 ppm. Based on the average rejections obtained to date, this should require another 1200 hours of operation.

REFERENCES

1. C. BASNER, T. HILLMER, and J. MARKIND, "Waste Boric Acid Reclamation by Membrane Technology - A Volume Reduction Process," Waste Management '81 Symposium, Tucson, Arizona, February 23-26, 1981, Vol. 2, p. 789, University of Arizona (1981).

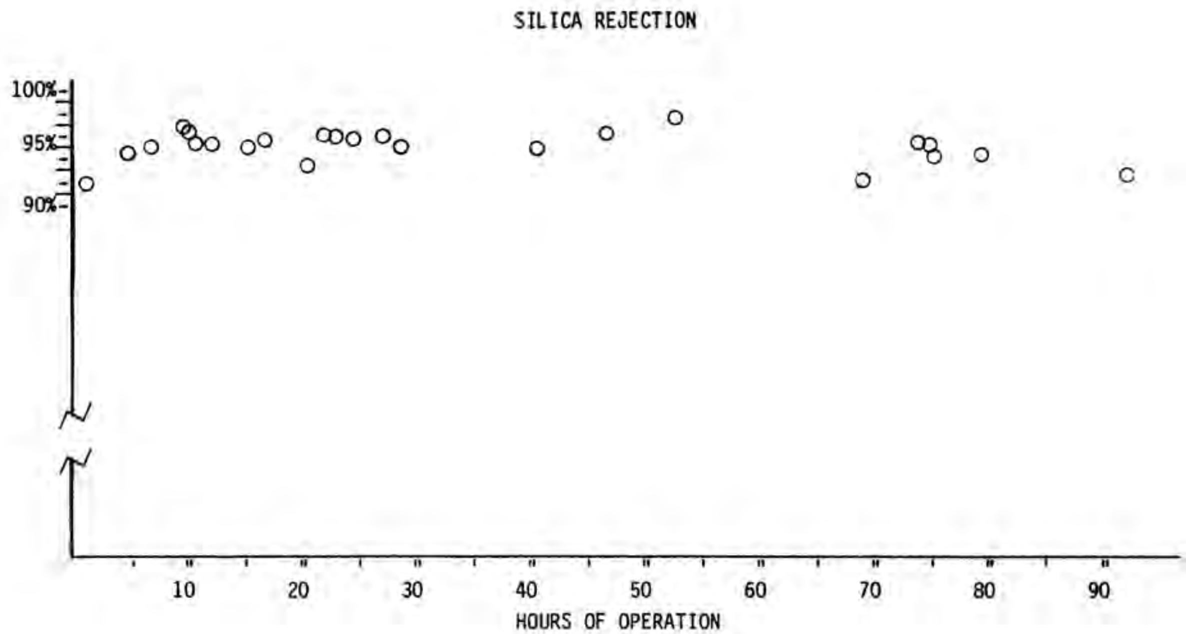


Fig. 2. Membrane Performance on RWST 1 Water.