Continuous Flow Seawater RO System for Recovery of Silica-Saturated RO Concentrate

(WRF-09-12)
(TWDB No. 0704830769-Amendment No. 3)

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Quarterly Report No. 3
(April thru June 2010)

Status Summary

A. Summary of Tasks Completed

Task 1 (*Design, Build, and Install System*) was completed and Task 2 (*Collect Data and analyze samples*) and Task 3 (*Analyze Data and Evaluate System Performance*) are still underway and are being conducted concurrently.

B. Assessment of Actual vs. Planned Progress

As pointed out in the previous quarterly reports, the three-month delay in executing the contract between all of the parties resulted in the project starting out in December instead of October. Therefore, the project end-date was shifted by several months (to November 2010 for pilot testing), as were the start and end dates for each task. Thus, Task 2 was scheduled to start in April and end in August. Task 3 was scheduled to start in May and end in September. At this time, both tasks are slightly ahead of schedule.

C. Tasks for Upcoming Period

The upcoming period (i.e. quarter no. 3) will continue to be devoted to Tasks 2 and 3.

D. Problems Encountered

Problems were encountered with equipment failure and membrane fouling, and in some cases the two were inter-related, as discussed below.

With respect to equipment failure, we had problems with the water level switch (again) in the feed tank, the high-pressure positive displacement pump (as noted in previous quarterly report), one of the pH sensors, the high pressure relief valve, and the low pressure feed pump (again). The water level switch that had already been replaced once failed again, even though it was specifically intended for use in salt water. This time, the contractor replaced the switch with a float-type switch, which has worked well to date.

The high-pressure positive displacement pump had previously had one of the piston sleeves replaced, but apparently the other two were also defective. The supplier replaced the other two sleeves, but they acknowledged that the pump still does not sound right. The supplier ordered another pump (which is standing by) to be installed if/when the current one fails.

The pH sensor that failed is located at the inlet of the pump and it measures the pH of the feed water into the membrane. It is connected to the acid feed pump and is used to control the pH of the feed water. Therefore, it is an important part of the control system and must be functional. A representative of the manufacturer (George Fisher) looked at the probe and concluded that the cracked glass sensor was probably defective from the outset. After the electrode was replaced, the system functioned normally.

The high pressure relief valve is on the discharge side of the positive displacement pump and it protects the unit from over-pressurization. The problem was detected by comparing the data-logged inlet flow rate to the sum of the permeate and bleed flow rates. The data showed that the volume of water entering the system was greater than the volume leaving. Inspection of the drain lines revealed that there was flow in the high-pressure relief line. The valve was replaced when attempts to adjust it failed.

The low pressure feed pump that provides water to the feed tank was a residential water pressure booster pump. Although it was not made to handle salty water, the contractor thought it would last for at least the duration of the project. It didn't, and neither did its replacement. The third attempt involved using a centrifugal pump that we had used in a previous project at the site. The contractor installed an hydraulic pressure switch to control the on-off functioning of the pump. This is considered a temporary fix (because the cycle frequency is too short) until a pressure tank is installed.

E. Technical Summary

Response to Comments from WRF or PAC

Comment 1: I think it is important to mention the types of sensors that were originally used that did not work as well as the type that they were replaced with since the interference with certain types of instruments may be common in implementing this on a full scale basis. This notation may help prevent similar startup issues with full scale plants.

Response 1: The original sensors were made by George Fisher (some are still in use in the system), but the one in the feed tank that was being affected by the stray current has been replaced with one made by Cole Parmer because it measures conductivity in a different way (i.e. toroidally).

Comment 2: I would like to see a % Rejection column in the table and maybe note that the Bleed water concentrations are also the RO Feed water concentrations. The description of Table 1 in the paragraph that precedes it call out feed water which, I believe, corresponds to the KBH Concentrate which is not descriptive of the RO Feed as it is blended with concentrate.

Response 2: We will add the % rejection in future tables where appropriate. Also, we will point out that the RO feed and bleed water are a mixture of KBH concentrate and SWRO concentrate.

Comment 3: Please explain why the low pH caused a high conductivity in the permeate

Response 3: Anions and cations do not carry current to the same degree. The hydrogen ion is the most mobile of all of the ions, having an equivalent conductance more than five times greater than the common ions of sodium, calcium, chloride, etc. The low pH of the permeate has a preponderance of hydrogen ions compared to other ions, so the conductivity is disproportionately high for the relatively low TDS of the water.

Comment 4: What is the design flow rate into the SWRO pilot?

Response 4: The system is designed to provide a feed flow of up to 10 gpm. We have been operating the system to maintain a permeate flow rate of 0.5 gpm.

Comment 5: What is the array and what are the membrane elements (size, brand) used in the SWRO pilot?

Response 5: The SWRO pilot plant has a single 4” pressure vessel with only one GE-Osmonics seawater membrane.

<u>Data Collection, Data Analysis, and Findings</u>

Data are collected at one-minute intervals anytime the system is running in the automatic mode (i.e. during all test runs). The data collected include various flows, conductivities, pressures, and the pH of the feed water. Part of the data sheet from 6/24 is shown in Table 1.
During this quarter, test runs were made with the feed conductivity set at 30,000, 35,000, 40,000, 45,000, and 55,000 µS/cm.
The test runs made at feed conductivity settings of 30,000 and 35,000 µS/cm were uneventful. A graph of the run at 30,000 is shown in Figure 1. The results from the run at 35,000 µS/cm are shown in Table 2. There was very good rejection for all of the parameters measured.

Table 1 – Sample of Data Sheet (20 min on 6/24/2010)

Date/Time Stamp	Feed Flow	Drain Flow	Permeate Flow	Concentrate Flow	Tank Cond.	Feed Cond.	Permeate Cond.	Concentrate Cond.	Feed Temp.	Feed pH	Membrane Pressure	Concentrate Pressure
6/24/2010 12:00	0.7	0	0.49	6.84	33339	32429	1333	34530	29.7	3.7	377	375
6/24/2010 12:01	0.7	0	0.51	6.79	33211	32820	1321	34188	30.3	3.7	387	364
6/24/2010 12:02	0.7	0	0.51	6.79	33571	32478	1368	34676	29.5	3.8	383	365
6/24/2010 12:03	0.7	0	0.5	6.87	33468	32845	1358	34334	30.2	3.8	371	371
6/24/2010 12:04	0.7	0	0.49	6.86	33417	32429	1331	34383	30.5	3.8	381	372
6/24/2010 12:05	0.7	0	0.49	6.84	33339	32747	1333	34554	30.1	3.8	384	369
6/24/2010 12:06	0.7	0	0.5	6.86	33622	32503	1338	33968	31.4	3.8	392	369
6/24/2010 12:07	0.7	0	0.51	6.86	33185	32600	1363	34407	30.5	3.7	386	366
6/24/2010 12:08	0.6	0	0.5	6.83	33725	32723	1363	34383	31.3	3.8	378	370
6/24/2010 12:09	0.7	0	0.49	6.87	34033	32869	1365	34432	30.6	3.7	392	369
6/24/2010 12:10	0.7	0	0.49	6.83	33417	32723	1358	34554	30.6	3.8	391	371
6/24/2010 12:11	0.7	0	0.49	6.87	33211	33235	1355	34994	29.8	3.8	387	371
6/24/2010 12:12	0.6	0	0.49	6.89	33931	33284	1350	34652	30.7	3.8	391	378
6/24/2010 12:13	0.7	0	0.5	6.83	33828	33113	1387	35189	30.1	3.8	395	375
6/24/2010 12:14	0.7	0	0.49	6.84	34085	33577	1375	35042	30.2	3.8	389	377
6/24/2010 12:15	0.7	0	0.48	6.89	33648	34017	1350	35531	29.8	3.8	382	377
6/24/2010 12:16	0.6	0	0.49	6.88	33699	33284	1350	35628	29.9	3.8	388	374
6/24/2010 12:17	0.7	0	0.49	6.9	33828	33675	1358	34627	31.5	3.8	395	379
6/24/2010 12:18	0.7	0	0.49	6.94	34085	33333	1331	35067	30.7	3.8	393	382
6/24/2010 12:19	0.7	0	0.5	6.88	34291	33650	1355	36166	29	3.7	392	381
6/24/2010 12:20	0.6	0	0.49	6.93	34008	33186	1370	35311	30.6	3.8	405	382

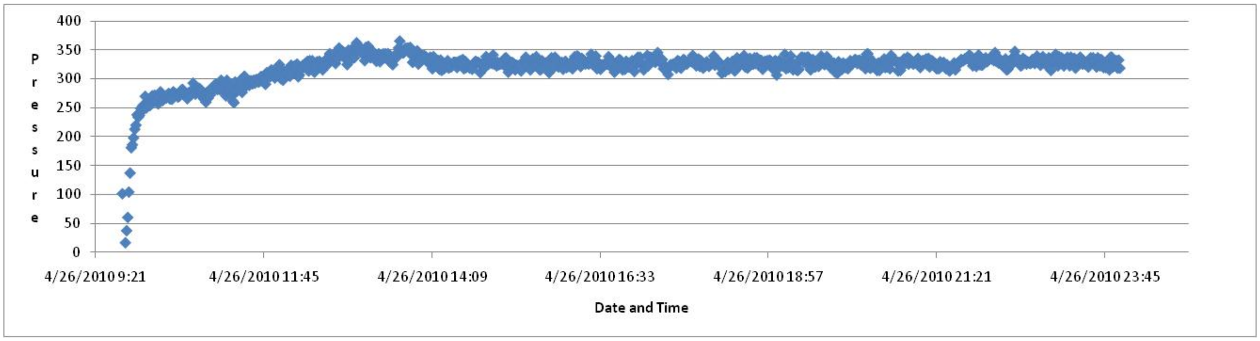

Figure 1 – Pressure vs. Time for Feed Conductivity Set at 30,000 µS/cm

Table 2 – Results at 47% Recovery

Parameter	KBH Conc	SWRO Perm	% Rejection
Hardness	2610	5	99.8%
Ca	570	1	99.8%
Mg	186	1	99.5%
Sodium	2950	66	97.8%
Potassium	86	2.7	96.9%
Chlorides	6050	167	97.2%
Sulfates	1800	23	98.7%
Silica	155	2	98.7%
Cond	19,400	1030	94.7%
TDS	12970	268	97.9%

The next test run was conducted at a conductivity setting of 40,000 µS/cm. The system ran well for one day, but on the second day, the high-pressure relief valve began releasing some of the feed water. This caused a higher flow rate of KBH concentrate into the feed tank, diluting the feed water, so the conductivity in the feed tank decreased back to below 40,000 µS/cm, getting as low as 34,000 µS/cm. The problem was discovered on the second day and remedied by temporarily putting the discharge from the high-pressure by-pass line back into the feed tank. Within two and one-half hours, the conductivity in the feed tank reached 40,000 µS/cm. Three hours later, samples were collected and the conductivity was raised to 45,000 µS/cm. The conductivity reached 45,000 µS/cm within two hours, with the pressure relatively constant at about 525 psi for one hour. Thereafter, however, the pressure steadily increased. The system was shut down remotely when the pressure reached 653 psi within about an eight hour time period. The approximate time associated with the aforementioned events is shown in Figure 2. Inspection of the feed tank the next morning revealed that there was a large amount of white precipitate everywhere in the tank.

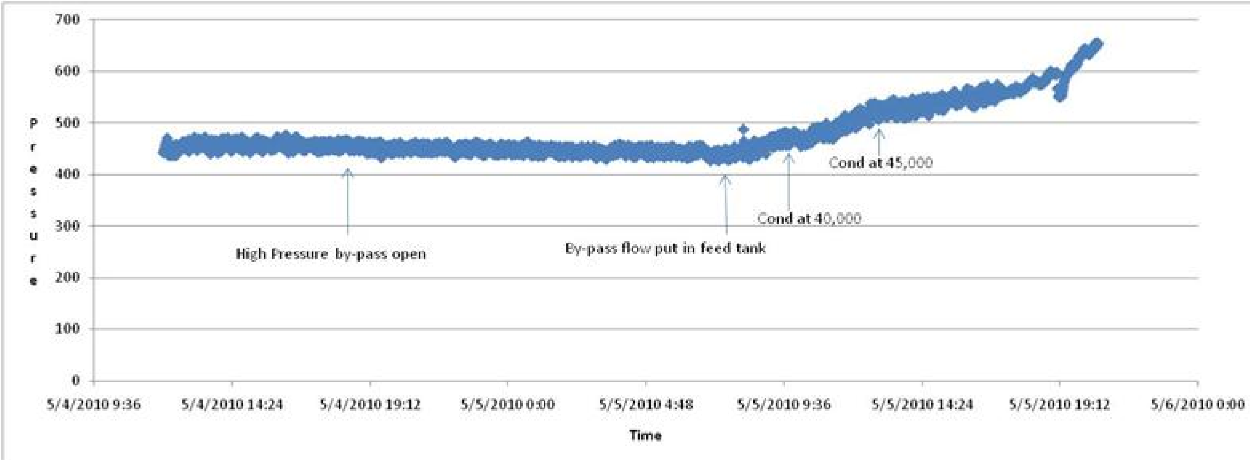

Figure 2 – Events with Running SWRO System Between 40,000 and 45,000 µS/cm

Inspection of the feed tank the next morning revealed that there was a large amount of white precipitate everywhere in the tank (A subsequent wet chemical analysis of the precipitate indicated that it was calcium sulfate). We immediately executed a flush of the system with KBH permeate and then tested the system by running the SWRO unit at a feed setting of 23,000 µS/cm. Figure 3 is a plot of membrane pressure vs. feed conductivity for different dates. The April 26th date precedes any fouling events. The May 10th date is after the first fouling event, with only a flush using KBH permeate. The pressure is clearly elevated for a given conductivity compared to the April 26th date. After the membrane was chemically cleaned with a calcium sulfate cleaner from King Lee, however, the pressures returned to normal as shown by the curve for the May 17th date. The other two dates are subsequent to other fouling and cleaning events as discussed below. The similarity of the pressures for given conductivities indicate that the chemical cleaning was effective in all cases.

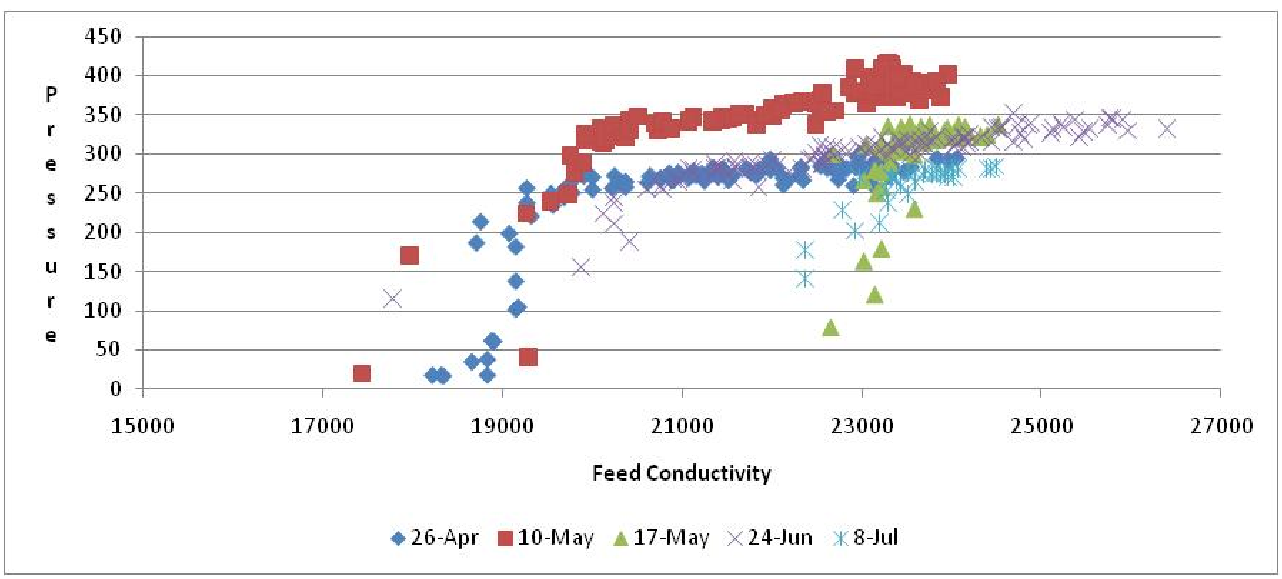

Figure 3 – Membrane Pressure vs. Feed Conductivity

After the first membrane cleaning was determined to be a success, testing was resumed where it left off, with a conductivity feed setting of 45,000 µS/cm. The system appeared to work flawlessly for day one, as shown in Figure 4 by the nearly perfectly horizontal trend line for the first day, so the conductivity was raised to 55,000 µS/cm and the system was started over again at approximately Noon on 6/9/10.

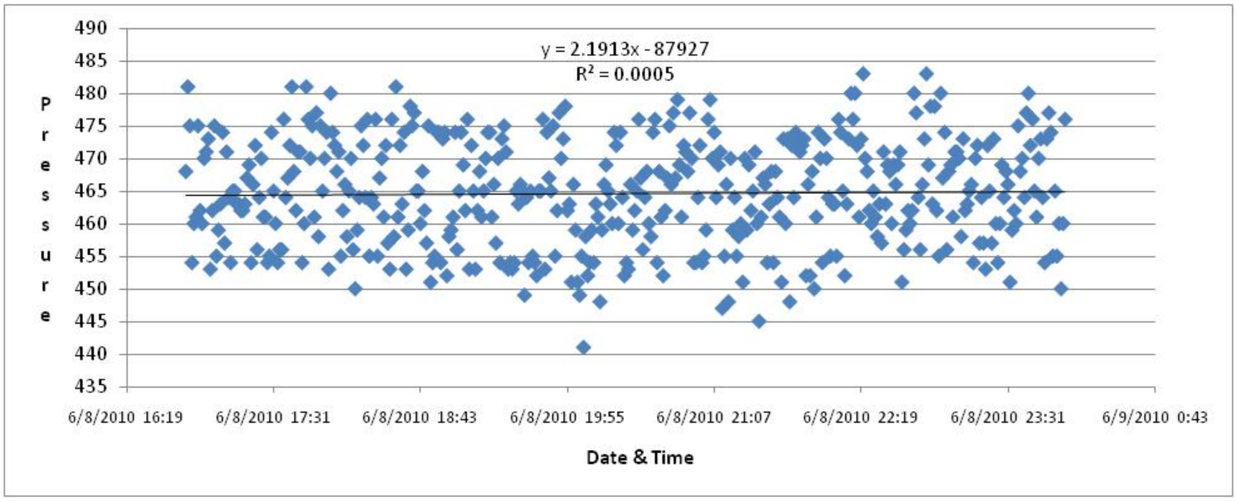

Figure 4 – Pressure vs. Time at 45,000 µS/cm

However, as shown in Figure 5, the trend line was slowly increasing during the last eight hours of day one at a conductivity of 45,000 µS/cm, indicating that fouling *might* have been occurring imperceptibly. Figure 6 is a plot of the pressure vs. conductivity from the beginning of each of the two runs, and the two curves are virtually right on top of each other, indicating that if fouling was occurring, it was certainly minimal before the start of the run at 55,000 µS/cm. Approximately five hours after the start of the test run at 55,000 µS/cm, the low pressure feed pump that supplies the feed tank with KBH concentrate failed. The high pressure pump kept working, drawing down the feed tank and making it more concentrated at a faster rate, because no "dilution water" was coming in. Figure 7 is a plot of feed conductivity vs. pressure for the run.

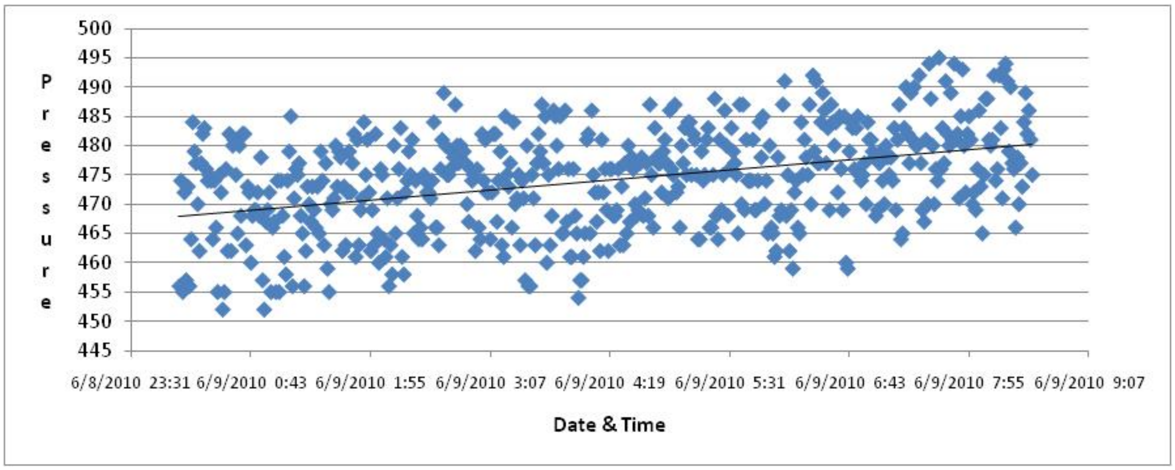

Figure 5 - Pressure vs. Time at 45,000 µS/cm During Last Eight Hours of Run

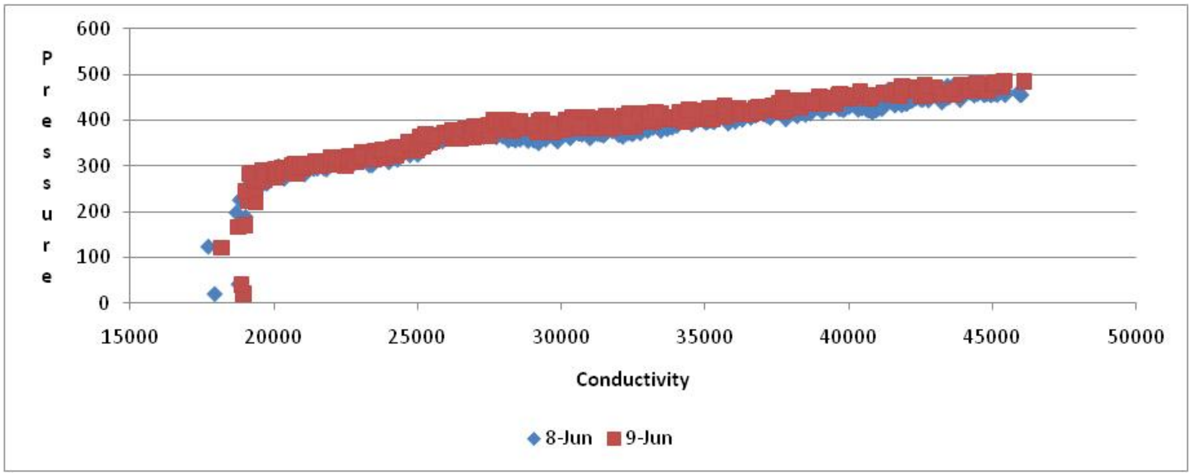

Figure 6 - Feed Conductivity vs. Pressure from Start of Each Run

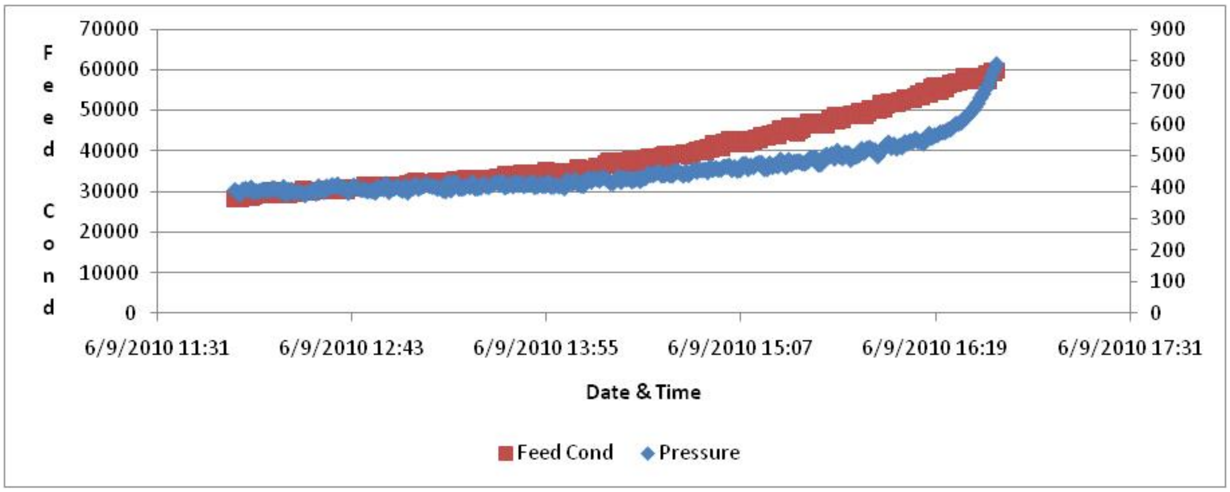

Figure 7 – Feed Conductivity and Feed Pressure vs. Time

The figure shows that the rapid pressure change started when the feed conductivity was about 55,000 µS/cm at a pressure around 550 psi. The pressure got to 789 psi in less than 30 minutes after that, and the system was automatically shut down by the low-water float switch.

The membrane was cleaned for the third time and the system was re-started with the feed conductivity set at 55,000 µS/cm. Figure 8 shows the feed conductivity and membrane pressure for the last 12 hours of operation at a conductivity of 55,000 µS/cm.

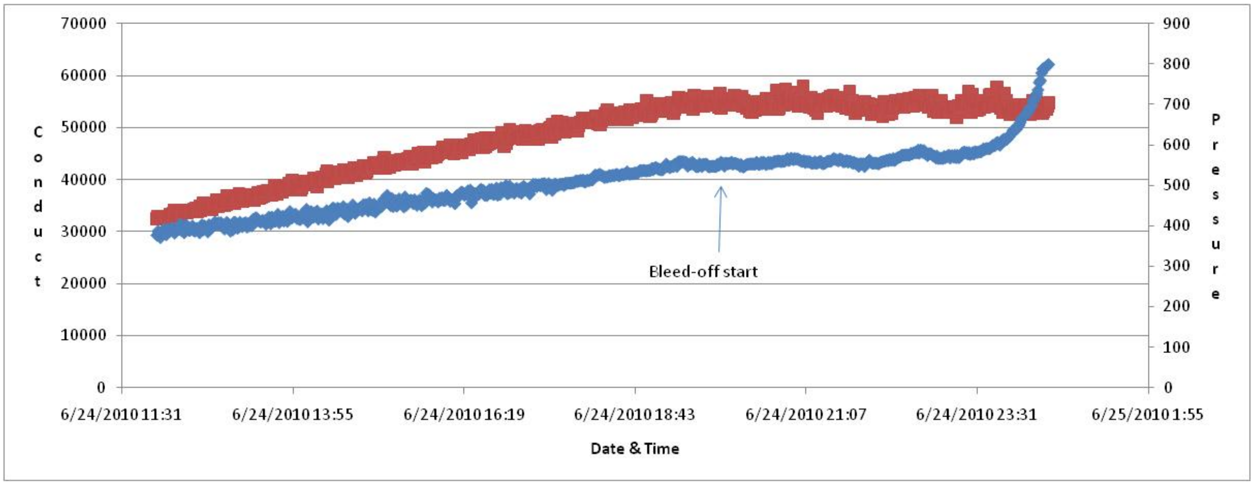

Figure 8 - Feed Conductivity and Membrane Pressure at 55,000 µS/cm

The set point of 55,000 µS/cm was reached at about 7:15 PM (when the bleed valve first opened) and remained constant thereafter as shown in the upper curve. The pressure remained constant at around 550 psi for about 90 minutes, after which it began to increase slowly for the next three hours to 580 psi. At that point, the pressure rapidly increased (in about one hour) to 800 psi, at which time the system automatically shut down because of high pressure.
These results indicate that with the current set-up and operating conditions, the limit of repeatable recovery appears to occur somewhere between 45,000 and 55,000 µS/cm, which represent recoveries in the range of 60% – 66%, which is less than the recoveries of 85 to 90% achieved using batch feed methods.

Work Plan

In the upcoming quarter, we plan to try other operating schemes to see if the recovery can be increased without fouling the membrane. One option is to increase the dosage of the antiscalant that inhibits calcium sulfate precipitation. A second option is to try to install some type of temperature control in the feed tank. Some forms of calcium sulfate become less soluble as the temperature increases. In our system, the temperature has gotten as high as 38 ^{0}C in the feed tank. We will attempt to modify the small heat exchange unit we have so that it will fit into the continuous flow SWRO unit. A third option we will consider is decreasing the flux. In any case, we expect to do enough testing in this quarter to be able to know, with a high degree of certainty, what maximum recovery of KBH concentrate can be achieved with the continuous flow SWRO system.

Budget Summary

Attached

Publications

No papers were submitted during this reporting period.