Pilot Testing of a New Ultrafiltration Membrane for Treatment of Manatee County's Surface Water Supply

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The University of Central Florida and Harn R/O Systems Inc. are currently in the process of pilot testing the Toyobo Durasep UPF0860 hollow fiber ultrafiltration (UF) membrane on a difficult-to-treat Florida surface water supply. Pilot testing of the UF membrane commenced on March 12, 2010, at the Lake Manatee Water Treatment Plant (WTP) in Manatee County. The pilot test is being conducted to: (1) demonstrate the usefulness of UF membrane technology for producing drinking water downstream of conventional surface water treatment, and (2) evaluate the performance of the Toyobo UF membrane on highly organic Florida surface water.

Ultrafiltration is a membrane process that separates suspended solids from water, similar to conventional media filters. However, UF membrane filtration is capable of removing colloidal, microbiological, and particulate matter much smaller than conventional filters are capable of removing. UF membranes can consistently produce filtered water with turbidity values below 0.05 NTU (Duranceau, 2001). Importantly, the quality of the water source treated by UF technology affects membrane performance, which increases the value of pilot studies to optimize UF system operating parameters (Mallevialle, Odendall, and Wiesner, 1996).

In order to pilot test the Toyobo UF membrane, it was necessary to find a suitable site with a reliable and representative Florida surface water supply. Surface water in Florida is known for being low in total hardness, microbially-active, warm, and highly organic in nature. These water quality characteristics represent significant daily challenges to conventional treatment plant operations. The WTP was

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identified as an ideal location for the pilot test because it purifies a surface water source with the aforementioned water quality characteristics. The WTP, which treated an average of 23.35 million gallons per day of surface water in 2009, uses the Lake Manatee Reservoir as its surface water source (Manatee County Utilities Department, 2009).

The WTP practices surface water purification through a conventional treatment process that includes alum coagulation, flocculation, sedimentation, filtration, and disinfection. At the head of the treatment works, the utility doses powdered activated carbon (PAC), as needed, for the removal of taste and odor compounds. Surface water then flows into rapid mix basins where alum and lime are added to facilitate coagulation. Next, a polymer is added during flocculation to promote the formation of a settleable floc. Following sedimentation, water is dosed with additional lime for pH adjustment and a small dose of chlorine before flowing into filter beds to facilitate removal of unsettled particles. Since the WTP also treats a groundwater supply, filter effluent is blended with treated groundwater before final disinfection with chloramines, corrosion prevention, hydrofluosilicic acid addition, and distribution.

Description of Ultrafiltration Pilot

The UF pilot incorporates one Toyobo Durasep UPF0860 ultrafiltration hollow fiber membrane operated in an inside-out dead-end configuration. Toyobo's membrane fibers are composed of hydrophilic polyethersulfone (PES) modified using blended polyvinylpyrrolidone chemistry. The UF hollow fiber membrane has an outside fiber diameter on the order of 1.3 mm (0.051 inches) and an inside fiber diameter of 0.8 mm (0.031 inches), with an average pore size diameter of 0.01 µm offering 150,000 dalton cutoff.

The pilot is controlled electronically by a programmable logic controller (PLC) and is equipped with onboard pressure gauges and transmitters, feed and backwash pumps with variable frequency drives (VFDs), feed and filtrate turbidity meters, flow meters, a particle counter, two chemical feed systems, water sample taps, and an air compressor for pneumatic valve operation. Data is logged by the pilot on two-minute intervals to facilitate data analysis and pilot performance evaluation. A touch screen user interface allows for the configuration of pilot operating parameters and the monitoring of pilot status.

The feed water for the UF pilot is drawn from sedimentation basin effluent by siphon into a 200 gallon tank that serves as a feed water reservoir for the pilot. The filtrate stream is stored in a 1000 gallon tank for use during backwash cycles. Two parallel wye strainers provide pretreatment of the feed water for removal of large diameter particles and debris. The photograph presented in Figure 1 provides several views of the UF pilot both before and after installation at the WTP.

During normal operation, the UF pilot cycles between forward filtration, backwash, and chemically enhanced backwash (CEB) operation modes in a user defined sequence. The pilot actively filters feed water during a forward filtration cycle producing a filtrate stream. Regular backwashes remove matter that has collected on the fiber surface. During backwashes, filtrate water is first pumped through the feed side of the membrane and then through the filtrate side of the membrane at a flux three times greater than the forward filtration flux. At specified intervals, the pilot will perform a CEB. During a CEB, a chemical such as sodium hypochlorite or citric acid is injected into the backwash stream to remove a targeted foulant, allowed to soak on the membrane fibers, and then rinsed prior to the restart of forward filtration.

Pilot Test Operating Parameters

The goal of the pilot test is to evaluate UF membrane performance on the basis of parameters such as flux rate, backwash frequency, and cleaning schedule to determine a suitable operating condition for the consistent production of filtrate with a turbidity below 0.1 NTU. To accomplish this goal, the pilot will be operated at three separate flux rates defined as Cases 1, 2, and 3. Case 1 calls for a conservative filtration flux of 36.9 gallons/ft^2-day, while Cases 2 and 3 operate at a moderate flux of 49.2 gallons/ft^2-day and a high flux of 61.5 gallons/ft2-day, respectively. Results from Cases 1 and 2 (i.e., the low and moderate flux cases) will be presented. Table 1 provides a summary of the operating parameters that define Cases 1 and 2 in terms of forward filtration and backwash cycles.

Figure 1: Ultrafiltration pilot during factory testing at Harn R/O Systems Inc. (left) and installed at the Lake Manatee Water Treatment Plant in Manatee County (right)

Table 1: Summary of pilot test operating parameters

Testing Case	Process	Water Flux (gfd)	Water Flow (gpm)	Duration (min)
Case 1	Filtration	36.9	11.0	30.0
	Backwash	110.7	33.1	1.0
Case 2	Filtration	49.2	14.7	30.0
	Backwash	147.6	44.1	1.0

Water Quality Summary

As part of the pilot test research, the University collected water samples during regular site visits to the UF pilot and samples of the pilot feed and filtrate streams were taken for analysis in its analytical chemistry laboratories. The water quality parameters of interest include: pH, temperature, conductivity, total suspended solids (TSS), total dissolved solids (TDS), turbidity, alkalinity, total organic carbon (TOC), and dissolved organic carbon (DOC). During the period between March 12 and September 13, the feed water quality to the pilot changed noticeably. Quantifying changes in water quality is important because variations in the aforementioned parameters may impact pilot performance and operations. For the treatment of settled surface water, as is the case at the WTP, seasonal variations in water

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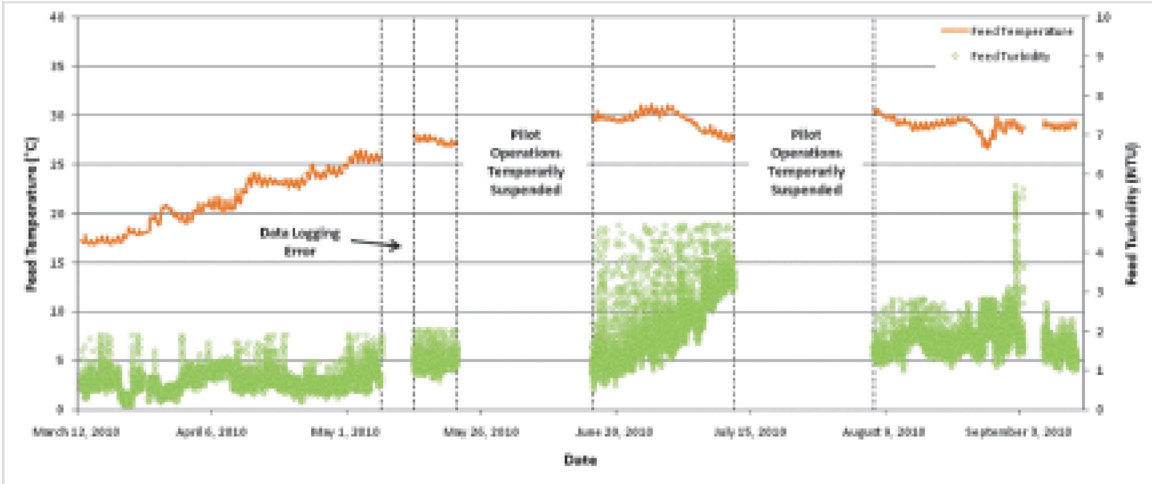
Figure 2: Feed temperature and turbidity vs. date (March 12 – September 13, 2010)



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quality should be taken into account for the development of an operations protocol. Depending on the feed water quality, modifications may need to be made to operational parameters such as backwash frequency, CEB frequency, or CEB chemical type(s).

Figure 2 graphically presents the feed water temperatures and turbidity values recorded by the pilot's onboard equipment and demonstrates the influence that seasonal changes may have on surface water quality. Since the start of pilot operations in early spring 2010, feed water temperatures have generally increased before reaching a peak in early July. The results of the University's laboratory analyses also point to changes in other water quality parameters, such as TOC, DOC, and alkalinity, as shown in Table 2. For the purposes of the pilot test, the water quality data is used as an additional resource for decision making and analysis of pilot performance.

Preliminary Results

The UF pilot is operated as a constant flux (i.e., constant water production) process, meaning that the feed pressure applied to the membrane is increased as necessary to maintain constant filtrate production. In hollow fiber ultrafiltration systems, the term flux refers to the flow of water through the porous membrane fiber with typical units of gallons/ft^2-day or liters/m^2-hour. A major challenge with UF operation is the management of fouling. Typical foulants of concern are organic, biological, or particulate matter. In constant flux operation, membrane surface fouling results in increased feed pressure requirements to maintain production. However, if the UF pilot were to be operated at constant pressure, fouling would manifest itself as a decrease in the flux through the membrane (Cheryan, 1998).

The flux of water varies with changes in both pressure and temperature. For example, feed water temperature influences water viscosity, which means that water will have less resistance to flow at higher temperatures and more resistance to flow at lower temperatures. Therefore, the flux of water through a clean membrane will increase as feed water temperature increases (MWH, 2005). One method for evaluating and monitoring the performance of UF systems is to plot the specific flux, or mass transfer, of water through the membrane fiber, versus the system runtime during filtration. Specific flux is used to assess membrane performance (rather than flux) because it is corrected for both temperature and pressure. By accounting for variability in both temperature and pressure, the specific flux term identifies the impact of fouling on system operations (MWH, 2005). Typical units for specific flux are gallons/ft^2-day-psi or liters/m^2-hour-bar.

The first pilot test period took place from March 12 to April 23, 2010, and utilized the Case 1 operating parameters defined in Table 1. A conservative flux of 36.9 gallons/ft^2-day was chosen for the start of pilot operations in order to: (1) establish a baseline operating condition for comparison with higher flux rates, (2) demonstrate at least one month of stable operation treating settled surface water, and (3) identify potential foulants. During this part of the pilot test, it was assumed that biological or organic fouling might result in a loss of specific flux, so a sodium hypochlorite CEB was performed once per day to recover membrane performance.

Figure 3 is a plot of specific flux, trans-

Table 2: UF pilot water quality data (March 12 – August 30, 2010)

Date	Alkalinity (mg/L as $CaCO_3$)		TOC (mg/L)		DOC (mg/L)	
	Feed	Filtrate	Feed	Filtrate	Feed	Filtrate
1/4	14.5	14.5	---	---	---	---
3/19	9.6	9.6	3.8	3.5	---	---
3/26	12	14.4	3.6	3.1	---	---
2	21.7	21.7	---	---	---	---
4/9	---	---	3.9	3.5	---	---
1/4	---	---	4	3.3	---	---
4/23	---	---	4.5	4.2	4.4	4.4
2/15	17.1	17.1	5.1	4.6	4.8	4.6
5/7	25.8	26.5	---	---	---	---
5/14	20.9	23.7	---	---	---	---
5/21	25.7	23.6	---	---	---	---
6	25	---	---	---	---	---
2/5	30.6	---	5.4	---	---	---
3/11	27	26.3	4.7	4.4	4.5	4.8
6/29	35.3	35.3	4.9	4.7	---	---
1 1/6	31.6	33.1	4.6	4.2	4.2	4.6
4/5	26.5	26.5	5.2	4.5	4.6	4.8
1/2	32.4	30.1	5.6	5	---	---
8/23	7.4	7.4	5.2	4.4	4.6	4.9
4/15	16.9	16.9	---	---	---	---

membrane pressure (TMP), feed temperature, and filtrate production, versus runtime for Case 1 of UF pilot operations. The pilot was able to maintain performance during this test period with recovery from the daily hypochlorite CEBs. Transmembrane pressure also remained relatively constant during Case 1, with values ranging between approximately 1.3 and 1.8 psi. After approximately one month of operating at the Case 1 parameters, it was determined that the membrane had demonstrated an ability to treat the organic surface water at a flux of 36.9 gallons/ft^2-day.

Testing began with the Case 2 flux of 49.2 gallons/ft^2-day on April 23, 2010. As in Case 1, a hypochlorite CEB was performed once per day in addition to the regular backwash cycles. The pilot experienced stable operation for approximately one week before a malfunction of the filtrate pressure transmitter on April 30 and an error in pilot data recording on May 7 resulted in an inability to monitor the TMP or specific flux for a period of approximately two weeks. Figure 4 illustrates the stable performance observed during the first week of testing at the Case 2 condition. The sodium hypochlorite CEBs have a pronounced effect during this initial week of operation.

In May, a fouling event began to affect pilot performance that could not be resolved by sodium hypochlorite CEBs. Figure 4 shows a significant performance decline characterized by a decrease in specific flux and increase in TMP. Pilot operations temporarily stopped on May 21, 2010, at a TMP of approximately 9.5 psi and a specific flux value of 4.2 gallons/ft^2-day-psi. Several extended sodium hypochlorite CEBs were performed in an attempt to restore pilot production, without success. The details of the extended hypochlorite CEBs are outlined in Table 3.

Following the temporary suspension of pilot operations on May 21, it was hypothesized that calcium carbonate ($CaCO_3$) scaling had occurred on the membrane fibers. The Muriatic Acid Fizz Test was performed on a sample of the foulant taken from the top end of the UF membrane at the end-cap and tested positive for $CaCO_3$. Additionally, a metals analysis was performed by UCF using an Inductively Coupled Plasma Spectrometer at its analytical laboratories. Samples were collected from both the ultrafiltration membrane end-cap and the UF pilot feed tank for the purpose of this investigation.

The results of the metals analysis are presented in Table 4. The samples were analyzed for calcium (Ca), magnesium (Mg), aluminum (Al), silica (Si), iron (Fe), manganese (Mn), potassium (K), and barium (Ba). Calcium was the dominant metal present in the samples tested, followed by magnesium. The

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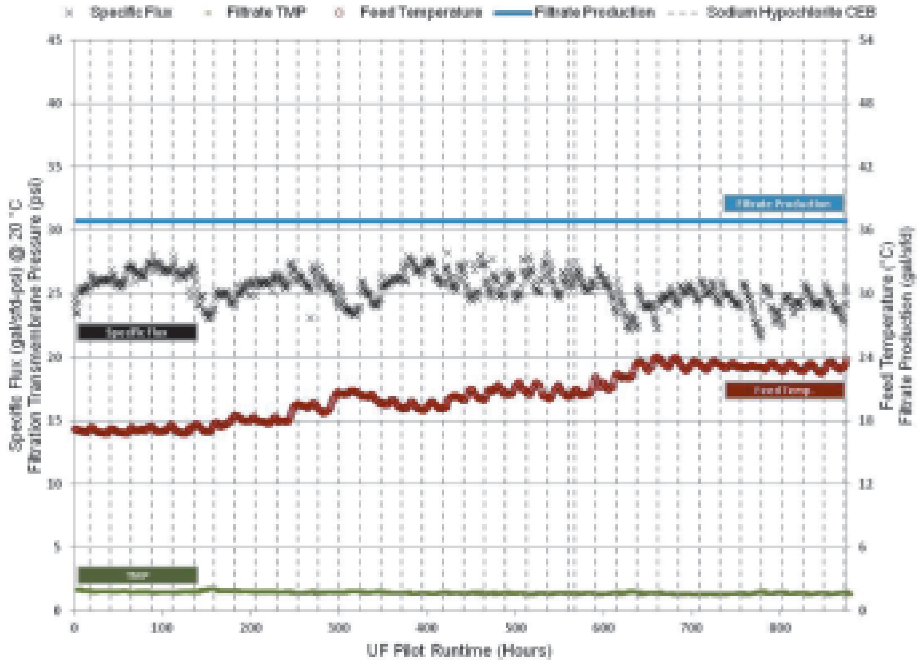

Figure 3: UF pilot performance – Case 1 (March 12 – April 23, 2010)

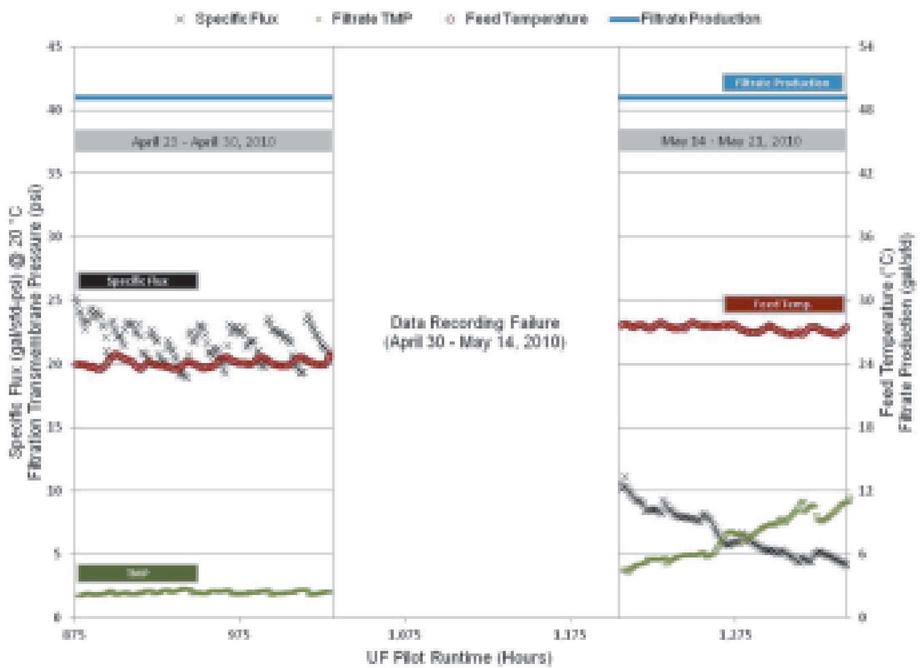

Figure 4: UF pilot performance – Case 2 (April 23 – May 21, 2010)

Table 3: Extended CEB characteristics (May 21, 2010)

Parameter	Extended CEB Attempt #1	Extended CEB Attempt #2
Chlorine Injection Time	60 seconds	90 seconds
BW Flow during Injection	20 gpm	5 gpm
Soak Time	15 minutes	3 hours 45 minutes
Rinse Time	5 minutes	5 minutes

Table 4: UF Pilot Foulant Anaysis

Metal (%)	UF Membrane Sample	Feed Tank Sample
Calcium (%)	18.65	26.62
Magnesium (%)	6.39	5.45
Aluminum (%)	4.15	1.17
Silica (%)	1.11	1.80
Iron (%)	0.14	0.21
Manganese (%)	0.03	0.01
Potassium (%)	0.06	0.13
Barium (%)	0.07	0.03
Solids (%)	69.40	64.59

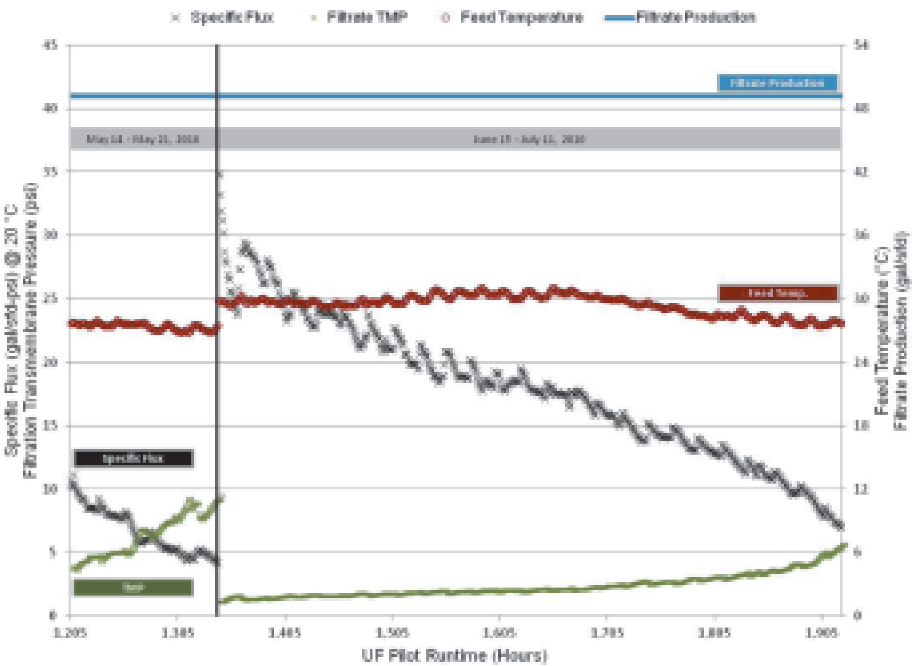

Figure 5: UF pilot performance – Case 2
(May 14 – May 21, June 15 – July 11, 2010)

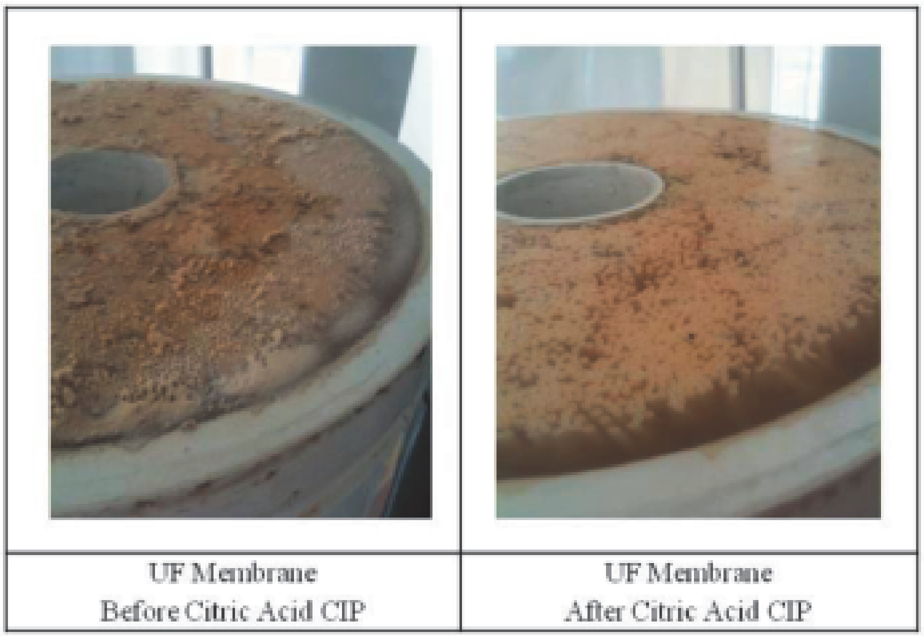

Figure 6: Toyobo UF membrane end-cap before and after first citric acid CIP

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metals analysis did not characterize a significant portion of the total mass of the samples tested, as may be expected with a filtration system treating settled surface water.

In order to remove the foulant, a citric acid chemical cleaning in place (CIP) was conducted on June 8 with two separate batches of citric acid at an approximate strength of 2 percent. The first batch of citric acid was recirculated through the membrane at varying flow rates for approximately 1.5 hours, and the second citric acid batch was used to soak the UF membrane for 1 hour and 20 minutes prior to rinsing. Transmembrane pressure was monitored during the CIP to assess the impact of the citric acid solution on foulant removal.

The citric acid CIP was successful at restoring membrane performance as demonstrated in Figure 5, and Case 2 of the pilot test resumed on June 15, 2010. The photographs of the UF membrane in Figure 6 were taken at the end-cap of the UF pressure vessel and serve as visual confirmation of the effectiveness of the citric acid CIP. The occurrence of significant and detrimental calcium carbonate membrane fouling in the month of May prompted the installation of a citric acid CEB system. However, due to the lead time required for implementing the new system, the citric acid CEB could not be brought online until August 6, 2010. In the interim, it was decided to resume Case 2 pilot operations with the once-per-day hypochlorite CEB to recreate the fouling condition observed previously and gather further information on the rate of performance decline. As the graph of specific flux in Figure 5 indicates, the performance of the membrane gradually declined until membrane fouling postponed further pilot testing on July 11, 2010.

A second citric acid CIP was successfully performed on August 4, 2010, following the installation of the citric acid CEB system. Pilot operations resumed on August 6, 2010, with a once-per-day citric acid CEB step in place of the hypochlorite CEB. Figure 7 shows the specific flux observed at the UF pilot, following the second citric acid CIP. As was observed following the first citric acid CIP, membrane performance was restored by the chemical cleaning. The data also shows that the pilot was able to maintain production without the significant fouling observed previously at the Case 2 flux.

For the majority of Case 2 operations, the focus of the pilot test was the evaluation of membrane fouling trends and implementation of solutions to maintain performance. With the installation of the citric acid CEB to manage the $CaCO_3$ issue, focus shifted to varying CEB combinations and frequencies to help optimize operations at the Case 2 flux of 49.2 gallons/ft^2-day. On August 23, a citric acid CEB was performed, followed by a hypochlorite CEB to study the effects of sequential chemical backwashes on membrane performance. The data presented in Figure 7 indicates that the citric acid CEB/hypochlorite CEB sequence resulted in an increase in the specific flux. Also on August 23, the citric acid CEB frequency was extended to one CEB per every two days of operation. The frequency was further extended on September 3 to one citric acid CEB per four days of operation. Table 5 provides a summary of the CEB sequences tested during Cases 1 and 2.

The integrity of the UF membrane fibers is investigated weekly by performance of pressure decay tests (PDTs). During a PDT, air is pumped into the UF module on either the feed or filtrate side of the membrane until a constant pressure is achieved. The pressure loss is then monitored for a set duration of time and reported in units of psi/minute. For the pilot test at the WTP, PDTs are conducted over a five-minute period. The PDT results, shown in Table 6, do not indicate the presence of broken fibers. Fiber integrity is also monitored by measurement of filtrate turbidity. An average filtrate turbidity of approximately 0.01 NTU was observed during 2650 hours of runtime between March 12 and September 13, 2010.

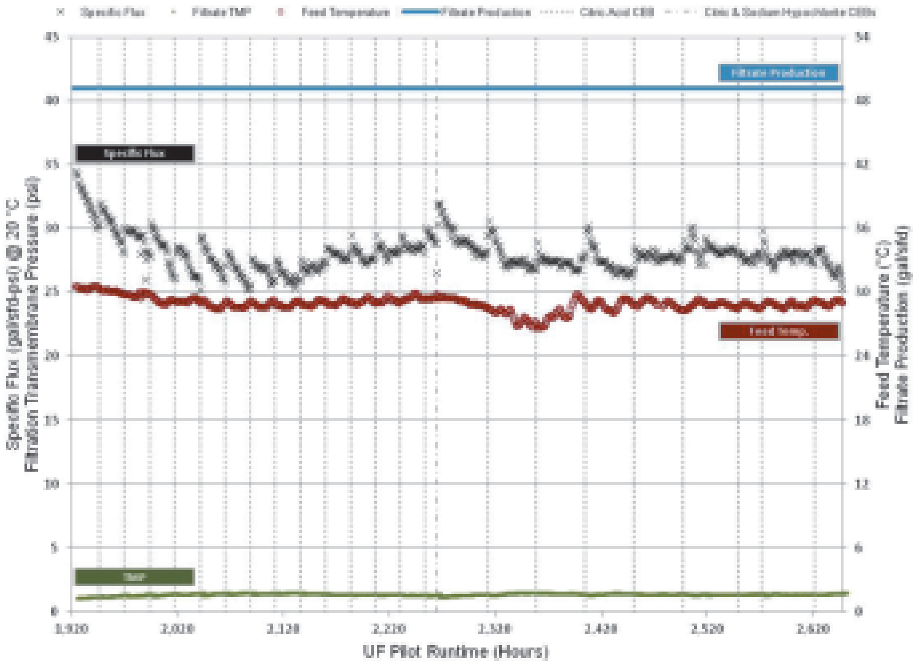

Figure 7: UF pilot performance – Case 2 (August 6 – September 13, 2010)

Observational Conclusions

The UF pilot performed well at the Case 1 flux of 36.9 gallons/ft^2-day, with a once-per-day hypochlorite CEB during the months of March and April. However, it was observed that the once-per-day hypochlorite CEB pro-

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tocol became ineffective at maintaining performance after April 30, 2010. Significant fouling events limited pilot operations until early August. Analysis of the membrane foulant indicated the presence of calcium carbonate scaling on the membrane fibers. A switch to citric acid CEBs allowed for sustained productivity during the pilot testing period of August 6 – September 13, 2010.

As demonstrated in this pilot test, variations in water quality may facilitate the need to modify UF pilot operations. Operational modifications to consider include changes in filtration time, backwash frequency, CEB frequency, and CEB chemical type(s). Potential causes for feed water quality changes include seasonal variations in rainfall volumes and modifications to the operation of upstream processes. The preliminary pilot test results suggest that provisions should be made for the implementation of sodium hypochlorite and citric acid CEBs to manage membrane fouling. These chemicals have demonstrated their usefulness for maintaining membrane productivity at different times during the year. Figure 8 summarizes the pilot performance trends observed during Cases 1 and 2 of pilot testing. The data shows the ability of the UF membrane to maintain constant filtrate production under several fouling scenarios and recover performance through chemical backwashes and cleanings. Additional testing is planned to evaluate other chemicals for use in CEB cycles including sodium hydroxide (caustic).

Table 5: Summary of pilot test CEB sequences (March 12 – September 13, 2010)

Pilot Test Operation Periods	Case	CEB Chemical (s)	CEB Frequency
Mar. 12th – Apr. 23rd, 2010	1	Hypochlorite	Once per day
Apr. 23rd - May 21st, 2010	2	Hypochlorite	Once per day
Jun. 15th – Jul. 11th, 2010	2	Hypochlorite	Once per day
Aug. 6th –Aug. 22nd, 2010	2	Citric Acid	Once per day
Aug. 23rd, 2010	2	Citric Acid and Hypochlorite	Once
Aug. 24th – Sept. 3rd, 2010	2	Citric Acid	Once per two days
Sept. 4th – Sept. 13th, 2010	2	Citric Acid	Once per 4 days

Table 6: Pressure decay test results

Feed PDT		Filtrate PDT	
Date	Pressure Loss	Date	Pressure Loss
---	(psi/min)	---	(psi/min)
06/08/10	-0.03	06/08/10	-0.15
06/15/10	-0.05	06/15/10	-0.15
06/22/10	-0.01	06/22/10	-0.11
06/29/10	-0.01	06/29/10	-0.10
07/06/10	-0.03	07/06/10	-0.09
08/10/10	-0.02	08/06/10	-0.07
08/16/10	-0.02	08/10/10	-0.12
08/23/10	-0.02	08/16/10	-0.12
09/13/10	-0.02	08/30/10	-0.14

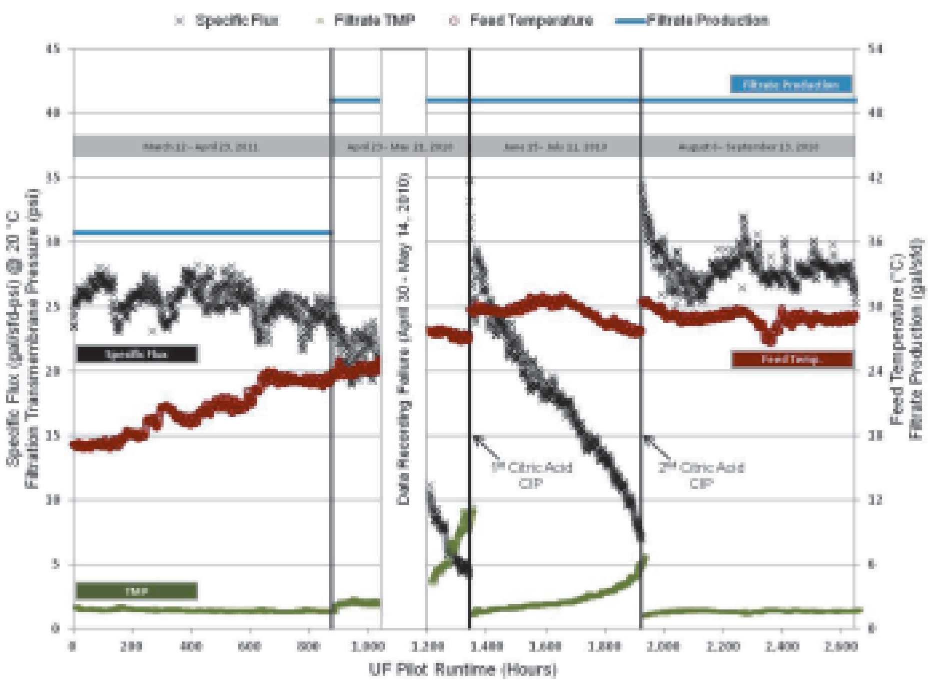

Figure 8: UF pilot performance – Cases 1 & 2 (March 12 – September 13, 2010)

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