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EVALUATION OF REVERSE OSMOSIS SCALING PREVENTION DEVICES AT HIGH RECOVERY

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13. ABSTRACT ***(Maximum 200 words)***

This study evaluated the effectiveness of a magnetic device (MD) and a high voltage capacitance device (HVC) as possible alternatives to the dosing of chemical antiscalants for preventing scaling during reverse osmosis (RO) operation at high product water recovery. The tests were conducted on feedwater to the Bureau of Reclamation's 72-MGD Yuma Desalting Plant located in Yuma AZ. High overall recoveries of greater than 90 percent were achieved by operating a two-stage 4-gal/min RO pilot unit (membrane unit 1 [MU1]) on the concentrate from a 200-gal/min RO unit operating at a water recovery of 70-percent. In these tests, neither the MD nor the HVC were effective in preventing calcium sulfate scaling at 91-percent water recovery. In contrast, the addition of 2 mg/L of sodium hexametaphosphate (SHMP) to MU1 feedwater was successful in avoiding scale at recoveries of 93 percent. Dosing of SHMP (or other chemical antiscalant) remains the recommended method for achieving high recovery operation without scaling at the Yuma Desalting Plant.

14. SUBJECT TERMS--

Reverse osmosis, membrane scaling, scaling prevention, calcium sulfate scale, antiscalant, sodium hexametaphosphate, magnetic water conditioner, Descal-A-Matic, Zeta Rod, Yuma Desalting Plant, Water Quality Improvement Center

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EVALUATION OF REVERSE OSMOSIS SCALING PREVENTION DEVICES AT HIGH RECOVERY

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U.S. Department of the Interior
Bureau of Reclamation
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Environmental Resources Services Division
Water Treatment Engineering and Research Group

Mission Statements

U.S. Department of the Interior

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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LIST OF ACRONYMS

ΔP	pressure differential
AWTR	Advanced Water Treatment Research Program
BRSC	Burns and Roe Services Corporation
CRADA	cooperative research and development agreement
E4	lead element of MU 1 vessel 3B
E7	tail-end element of MU 1 vessel 3B
FS	Fluid Systems
gfd	gallons per square foot per day
gpm	gallons per minute
HR	High Recovery with Antiscalant Addition
HWS	Hydranautics
HVC	high voltage capacitance device
MD	magnetic device
mg/L	milligrams per liter
Minute	Minute No. 242 of the International Boundary and Water Commission
MODE	main outlet drainage extension
MU	membrane unit
P.L.	public law
PS 1	Pilot System 1
PS 2	Pilot System 2
PS 3	Pilot System 3
Reclamation	United States Bureau of Reclamation
River	Colorado River
RO	reverse osmosis
SCADA	supervisory control and data acquisition
SHMP	sodium hexametaphosphate
STC	salt transport coefficient
WQIC	Water Quality Improvement Center
WTC	water transport coefficient
YAO	Yuma Area Office
YDP	Yuma Desalting Plant

EXECUTIVE SUMMARY

The objective of this study was to evaluate the effectiveness of a magnetic device (MD) and a high voltage capacitance device (HVC) as possible alternatives to chemical addition for reducing scaling and improving the performance of reverse osmosis (RO) systems [1]. The control of scaling would enable RO operation at higher recoveries in the treatment of almost all water supplies. The HVC and MD were determined to be ineffective alternatives for reducing RO scaling at high recovery. Significant calcium sulfate scaling was observed with the MD installed on membrane unit 1 (MU 1) feed tank and with the HVC installed on both the suction line to the MU 1 high pressure feed pump and on MU 1 interstage. The overall recovery, where calcium sulfate scaling occurred, was approximately 91 percent. The addition of approximately 2.0 milligrams per liter (mg/L) of sodium hexametaphosphate (SHMP) was successful in avoiding scale at recoveries of approximately 93 percent and is recommended for high recovery operation on main outlet drainage extension (MODE) water.

The MD and HVC were tested at the Water Quality Improvement Center (WQIC). The MD tested was a 316 stainless steel Descal-A-Matic® device, and the HVC tested was the Zeta Rod™ ZR18S. The spiral-wound RO elements used were Desal CD 2540T1078 (2½-inch diameter by 40-inch-long) cellulose acetate elements. The concentrate from Pilot System 1 Fluid Systems RO was the feed source, and the membrane units were operated at an average element flux of 10 gallons per square foot per day (gfd). Response variables include the change in the water transport coefficient (WTC), salt transport coefficient (STC), and second stage pressure differential (ΔP).

During this study, measuring the individual performance of the tail-end element was determined to provide a sensitive and prompt detection of RO scaling. This prompt detection enables the plant engineer to immediately correct the condition(s) that created the scaling environment and prevent further scaling of the RO equipment. Based on these experiences, we recommend that the design of RO membrane equipment for research and production plants should consider including the instrumentation to monitor the performance of some of the lead elements, where degradation and biological fouling may occur, and some of the tail-end elements, where scaling and inorganic fouling may be most severe.

CHAPTER 1
INTRODUCTION

The ability to prevent the formation of scale on RO membranes is critical for the efficient use of this advanced water treatment technology. The economics of operating a brackish RO system usually dictate that the maximum amount of feed water be converted or “recovered” as fresh product water at the minimum cost. Low recovery is rarely an attractive option. However, water recovery for RO systems is limited by the precipitation of sparingly soluble solutes such as silica, barium sulfate, calcium carbonate, and calcium sulfate, which can scale and ruin the membranes [1].

Current techniques to control scaling include softening to remove low solubility solutes (e.g., calcium, barium, and silica) from the feed water, acidification to prevent calcium carbonate scale, and antiscalant chemical addition to keep the solutes in a supersaturated state. Antiscalant chemicals are generally added to RO feed water to prevent precipitation and scaling inside the RO equipment. Although antiscalant chemicals are effective, it is difficult to predict the maximum concentrations of the sparingly soluble solutes in excess of recorded solubility limits that can be tolerated with antiscalant chemicals. Efforts to improve these techniques and development of new technologies have the potential to produce significant cost savings in the RO treatment of water [2].

The industry has developed magnetic and capacitance devices advertised as alternatives to antiscalant chemical addition. The HVC has been shown to significantly reduce the fouling rate in RO systems [3]. The MD has been used to control scale in recirculated water in both open and closed-loop systems [4].

The control of scaling would enable RO operation at higher recoveries in the treatment of almost all water supplies (exceptions include high salinity waters, such as seawater, where recovery is limited by osmotic pressure). Higher recoveries are extremely advantageous because of the more efficient use of water supplies, the decreased volume of concentrate waste to be disposed of, and the potential energy savings [1].

The MD and HVC were tested at the WQIC. The WQIC is located within the United States Bureau of Reclamation (Reclamation) Yuma Area Office (YAO). The mission of the YAO is to protect and enhance the Colorado River's natural and manmade resources while satisfying the water needs of national and international customers. The Yuma Desalting Plant (YDP) and WQIC are components of the YAO.

CHAPTER 2
BACKGROUND

When the YDP was designed, it was based on the most reliable water treatment and desalting technologies available at the time. In the past 30 years, a multitude of advances in RO pretreatment and RO systems have occurred. This test project and the High Recovery with Antiscalant Addition (HR) evaluate some of the advances in water treatment technologies as potential improvements to YDP [5]. Achieving higher recoveries without antiscalant addition is advantageous because of the more efficient use of water supplies, the decreased volume of concentrate waste to be disposed of, and the potential energy savings.

The objectives of the HR study were as follows:

1. Determine system recovery ($R_{SCALING}$) where scaling occurs without SHMP or antiscalant addition.

2. Determine system recovery (R_{SHMP}) where scaling occurs with the addition of 2.0 mg/L SHMP.

3. Determine the minimum dosage rate (C_M) of recommended antiscalants at a system recovery of R_{SHMP}. Start with higher than recommended dosage rates (C_R) and gradually lower the dosage rate until scaling occurs.

4. Determine C_M at higher recoveries or a maximum recovery (R_M) for a short list of antiscalants [6].

Testing related to the first objective of the HR study was used as the initial control for this study.

2.1 Yuma Desalting Plant

The YDP is located on a 24-hectare (60-acre) tract of land about 8 kilometers (5 miles) west of Yuma. It is the world's second largest RO desalting plant. It can produce 275,000 cubic meters (72.4 million gallons) of desalted water per day from a total of 390,000 cubic meters (102.7 million gallons) of drainage water per day. The saline drainage water, from farmlands east of Yuma, flows in a concrete-lined drainage canal to the YDP. The YDP can be expanded to produce 363,000 cubic meters (96 million gallons) per day.

In accordance with a 1944 treaty between the United States and Mexico, the United States is obligated to deliver 1,500,000 acre-feet of Colorado River water to Mexico each year. During the 1960s, the quality of the water delivered to Mexico became so poor that Mexico filed a formal protest. A special commission on Colorado River (River) quality was established in 1973, headed by former Ambassador Herbert Brownell. As a result, Minute No. 242 of the International Boundary and Water Commission (Minute) was adopted. The Minute requires that the United States ensure that the water arriving at Morelos Dam will have an average annual salinity of no more that 115 $\pm$ 30 parts per million over the average annual salinity of water arriving at Imperial Dam. The YDP was conceived by the United States as a permanent solution to meet the provisions of the Minute. The water is used in Mexico for irrigation in the Mexicali Valley.

Construction of the YDP was authorized by Public Law (P.L.) 93-320, Title I, signed June 24, 1974 (as amended by P.L. 96-336). Construction began in 1975 and ended in 1992. Title II of the same act provides for salinity control projects elsewhere in the Colorado River Basin (which includes the Upper and Lower Basins).

The purpose of the YDP is to save water for beneficial use while desalting sufficient drainage returns from the Wellton Mohawk Irrigation and Drainage District in Arizona to maintain salinity levels at Morelos Dam on the River as specified by the Minute.

In May 1992, the YDP was dedicated and started production operations. The YDP was operated at one-third capacity for "shakedown" purposes to test the treatment systems and design. The YDP operated successfully until January 1993, when heavy rains in the Gila River watershed resulted in a 500-year flood event. This flooding caused damage to the drainage canals in the Yuma area, which feed the YDP. At that time, it was placed in ready-reserve status (with an ability to operate within 1 year upon notice of receipt of funding) [7].

2.2 Water Quality Improvement Center

The WQIC is the cornerstone of the National Centers for Water Treatment Technology initiated by Reclamation, the National Water Research Institute, and the U.S. Army. The WQIC serves as a field site to investigate new and improved technologies, including pretreatment associated with desalination. The intent is to make pilot water research and field testing more cost effective and practical for entities such as the United States Government, desalting researchers, universities, water treatment companies, municipalities, private industries, and foreign governments [7]. Reclamation uses cooperative research and development agreements (CRADA) as tools to allow water quality research at the WQIC. Congress authorized CRADA under the Federal Technology Transfer Act of 1986 to enhance and facilitate collaboration between governmental agencies and commercial firms. The mission of the WQIC is to advance the development and transfer of water purification technologies at its state-of-the-art facility through field tests, hands-on training, and implementation. The WQIC is shown in photo 1.

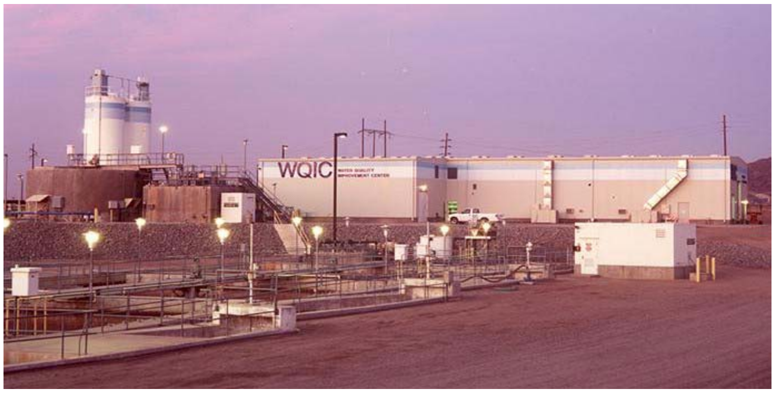

Photo 1.—Water Quality Improvement Center.

The WQIC consists of three main pilot systems and numerous additional pieces of research equipment operated and maintained by Burns and Roe Services Corporation (BRSC). BRSC has been supplying the management and operations services for the YDP and WQIC since 1985. The WQIC equipment used during the HVC testing is discussed in chapter 3 of this report.

Chapter 3
EQUIPMENT

3.1 Magnetic Device

The MD tested at the WQIC was a 316 stainless steel Descal-A-Matic® device. The MD is a non-chemical water treatment technology advertised to eliminate scale buildup and corrosion in pipes and tubes without chemical additives. The MD was developed 20 years ago as a magnetic water conditioner to serve as a simple means of solving scale and corrosion problems. The manufacturer concludes that after exposure to the magnetic field, molecules that cause scale tend to remain in fluid suspension instead of attaching to pipe walls and other surrounding surfaces [8]. The factors unique to the Descal-A-Matic® device are the residence time, proximity of the water in the unit to the magnetic influence (always within 0.5 inch), velocity of the water as it passes through the unit, turbulence created within the unit, and Gauss strength of the magnetic core.

The permanent magnets in the magnetic core are sealed in 1 1/2-inch thin-walled 316 stainless steel tubing with Stay-Brite solder. The water flowing through the MD never comes in direct contact with the magnets. The magnets are a special AlNiCo (aluminum-nickel-cobalt) alloy, which delivers an average Gauss strength of 1,800 gauss at the surface of the 316 stainless steel tubing that contains them. They are cylindrical and are arranged with like poles adjacent to each other. The water enters over a north magnetic field and exits over a south magnetic field.

A circulation skid for the MD was fabricated by BRSC during the second quarter of fiscal year 2000. The skid consisted of a pump, automatic valve, and rotameter with the MD on the discharge of the pump. The skid was fabricated to ensure the minimum velocity of 7 feet per second through the MD was achieved, as recommended by the manufacturer. The manufacturer advised that a flow rate of 19 gallons per minute (gpm) through the MD would achieve the minimum velocity required [9]. The circulation skid is shown in photo 2, and the MD is shown in photo 3.

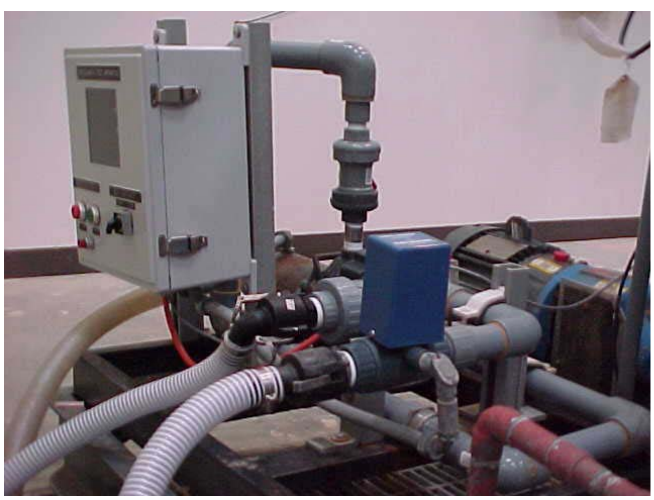

Photo 2.—Circulation Skid for Magnetic Device.

Photo 3.—Magnetic Device.

3.2 High Voltage Capacitance Device

The HVC tested at the WQIC was the Zeta Rod^{TM} ZR18S and is shown in photo 4. The HVC functions by inducing an alteration of the natural surface charge density of dielectric colloidal particles irrespective of the particle composition. The installation of the HVC forms a cylindrical capacitor, much like those pictured in physics texts. Electrochemical dispersion of colloidal organic and inorganic particles, as well as microorganisms, has been practiced for many years to treat the water in small commercial and industrial water systems [10]. The HVC has also been shown effective as a means of preventing biofilm formation on RO membranes [11].

Photo 4.—High Voltage Capacitance Device.

The conducting surfaces are the metallic lining of the HVC and the metal of the pipes or vessels. The ceramic dielectric of the HVC establishes a static electric field within the piping system or the vessel. A direct current power supply charges the capacitor system. The field strength across the water is a function of charge voltage, system dimensions, and the dielectric constant of the water [10].

At sufficiently elevated voltage, the field strength across the water influences the capacitive charge of the particle. The result is a sharp increase in the surface charge of all wetted surfaces [10]. This study evaluated the effectiveness of the HVC as a possible alternative to chemical addition for reducing scaling and improving the performance of RO systems at high recovery rates. The primary field of the HVC (potentials above about 5 kilovolts) extends for about 20 feet in either direction from the electrode surfaces. For a cylindrical capacitor, the total capacitance of the system is given by the equation in figure 1, where:

C	=	capacitance (units)
q	=	charge
v	=	voltage
I	=	length
a, b	=	radii of the electrodes forming the capacitor

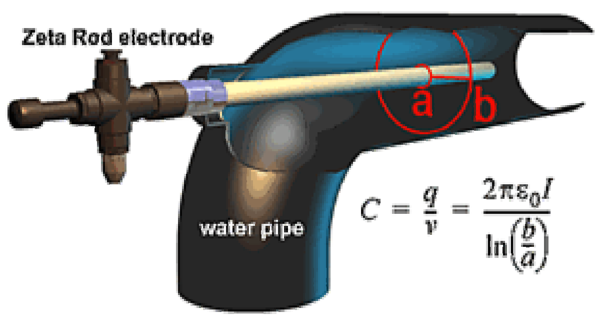

Figure 1.—Total Capacitance - High Voltage Capacitance Device (Courtesy of Zeta Corporation).

3.3 Pilot System 1

Pilot System 1 (PS 1) is a 600-gpm pilot plant, located within the YDP, and is installed as a 1/100th model of the YDP with similar types of equipment and process flows. The PS 1 pretreatment equipment includes a grit basin, intake pumping, solid contact reactor, dual media gravity filters, and clearwell. PS 1 models the YDP for optimization studies, performance verification, personnel training, developmental testing of new systems, and serves as the potable water source for the YAO. This equipment is similar in type and design that was furnished for the YDP so that the results of tests can be readily scaled up and applied to the operation of the YDP. Solids and sludge handling for PS 1 are processed in the equipment furnished for the YDP [7]. The RO desalting equipment was supplied by Hydranautics (HWS) and Fluid Systems (FS) in a 2:1 array as in the YDP. The concentrate from PS 1 FS RO was the feed source for all HR, MD, and HVC tests conducted at the WQIC. The PS 1 FS RO unit is shown in photo 5.

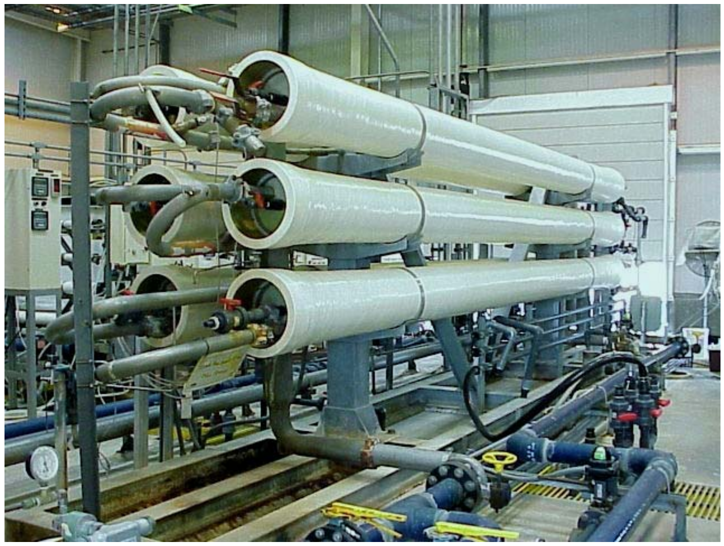

Photo 5.—Fluid Systems Reverse Osmosis Unit.

3.4 Pilot System 2 and 3

The WQIC research pilot systems (PS 2 and PS 3) are each designed for a flow rate of 30 gpm. The basic configuration consists of gravity settling of suspended solids, partial lime-softening and coagulation (with individual rapid mix, precipitator/flocculation, and clarifier components), gravity media filtration, and membrane processes. This configuration can be modified for different tests to omit or bypass any of the above unit processes. In addition, the basic configuration can be modified as needed to connect other unit processes under investigation, such as microfiltration and ultrafiltration. PS 2 and 3 were also designed to model the YDP on a small scale for optimization studies, performance verification, personnel training, and developmental testing of new systems [7]. PS 2 and 3 were installed by BRSC.

The WQIC is configured to supply a wide range of feed waters to the pilot systems. These include Colorado River water, brackish well water, treated and untreated agricultural drainage water from the Wellton Mohawk canal via the MODE, RO concentrate and permeate water from PS 1, and potable water. The MODE is the water source for the YDP.

3.5 Membrane Units

The main purpose of PS 2 and 3 is to evaluate the performance of spiral-wound RO and nanofiltration membrane elements and includes a total of four membrane units (MU), each with a separate feed tank. The MU are designed to operate at recoveries up to 85 percent with 21 spiral-wound 2 ½-inch diameter by 40-inch-long membrane elements in a 2:1 array of seven elements per vessel [7]. The four MU were fabricated by Lakota Engineering, San Diego, California, and installed by BRSC.

Each seven-element vessel consists of a 4-element vessel and a 3-element vessel. Individual permeate flows and conductivities are monitored on the two lead elements, where degradation and biological fouling may occur, and the tail-end element, where scaling and inorganic fouling may be most severe. The permeate characteristics of the other 18 elements are monitored in groups of 3.

The MU high pressure feed pumps utilize variable speed drives to enable operation over a wide flow range of 3 to 12 gpm and a wide pressure range of 60 to 500 pounds per square inch. Automatic control valves are incorporated to ensure precise process control. A typical MU is shown in photo 6.

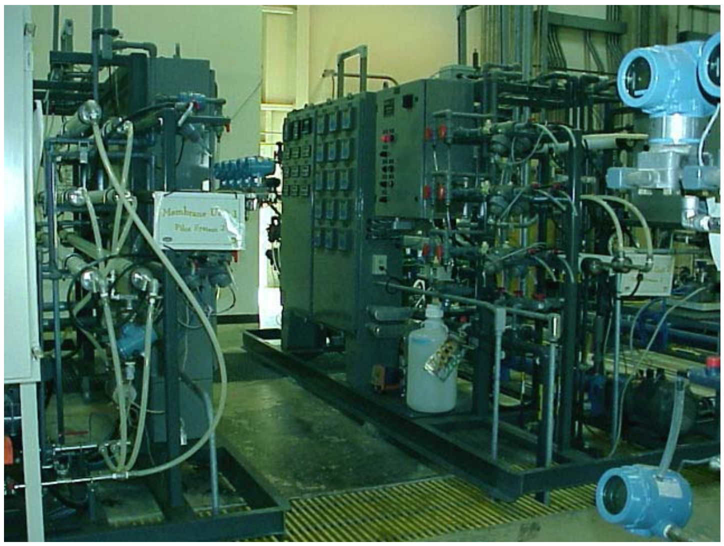

Photo 6.—Membrane Unit.

CHAPTER 4
TEST RESULTS

The objective of the MD and HVC testing was to evaluate the effectiveness of these physical water conditioning devices as possible alternatives to chemical addition for reducing scaling and improving the performance of RO systems. Response variables include the change in the WTC, STC of the tail-end elements, and ΔP. Typically, the tail-end elements will show the first signs of scaling. Once scaling is observed, the system is flushed with PS 1 RO permeate water, and the four tail-end elements removed, bagged, labeled, and placed in cold storage for future autopsy.

A stainless steel 3-inch housing chamber was fabricated for the HVC. The fabrication of the stainless steel housing chamber allowed the flexibility of installing the HVC on high-pressure streams. The HVC was tested on the suction line to MU 1 high pressure feed pump and on MU 1 interstage.

MU 1 and 2 were operated at an average element flux of 10 gallons gfd during the HR, MD, and HVC testing. The spiral-wound elements used during all testing were Desal CD 2540T1078 (2½-inch diameter by 40-inch-long) cellulose acetate elements. These elements are similar to the HWS and FS elements used in PS 1 and YDP RO units. Twenty-one elements are used in a 2:1 array of seven elements per vessel.

4.1 High Recovery with Antiscalant Addition

The HR study was initiated in May 1997. Initial testing was conducted on MU 2. Twenty-one Desal CD 2540T1078 cellulose acetate elements were installed in MU 2. These elements are similar to the HWS and FS elements used in PS 1 and YDP RO units. The feedwater source for MU 2 was PS 1 pretreated MODE water without the addition of SHMP. Initial testing was discontinued in September 1997 because of feedwater supply problems and a pending research project that required the use of the equipment.

During initial testing, MU 2 recoveries exceeding 85 percent were achieved with no signs of scaling. Automatic operation of MU 2, at recoveries exceeding 85 percent, became very sensitive to total concentrate flow rates. As the recovery increased, the total concentrate flow rates decreased, and the total concentrate control valve was unable to maintain a constant recovery. The MU was designed to operate at recoveries up to 85 percent [12].

Due to the successful operation of MU 2 at recoveries exceeding 85 percent, SHMP injection was discontinued on PS 1 HWS and FS RO units in February 1998 [13]. PS 1 HWS and FS RO units operate at an average recovery of 73 and 70 percent, respectively. A safety factor in excess of 12 percent allows for variations in the chemistry of the MODE water without compromising the performance of PS 1 RO units. Eliminating the SHMP injection on PS 1 RO units also allowed PS 1 FS RO concentrate to be used as the feed source for additional HR testing.

HR testing resumed on MU 1 in October 1998. Twenty-one Desal CD 2540T1078 cellulose acetate elements were installed in MU 1. These elements are similar to the HWS and FS elements used in PS 1 and YDP RO units. The feed source for MU 1 was PS 1 FS RO concentrate. Using PS 1 FS RO concentrate allowed the MU 1 total concentrate control valve to operate within normal range. This also enabled higher overall recoveries to be achieved. A flow schematic for HR testing is shown in figure 2.

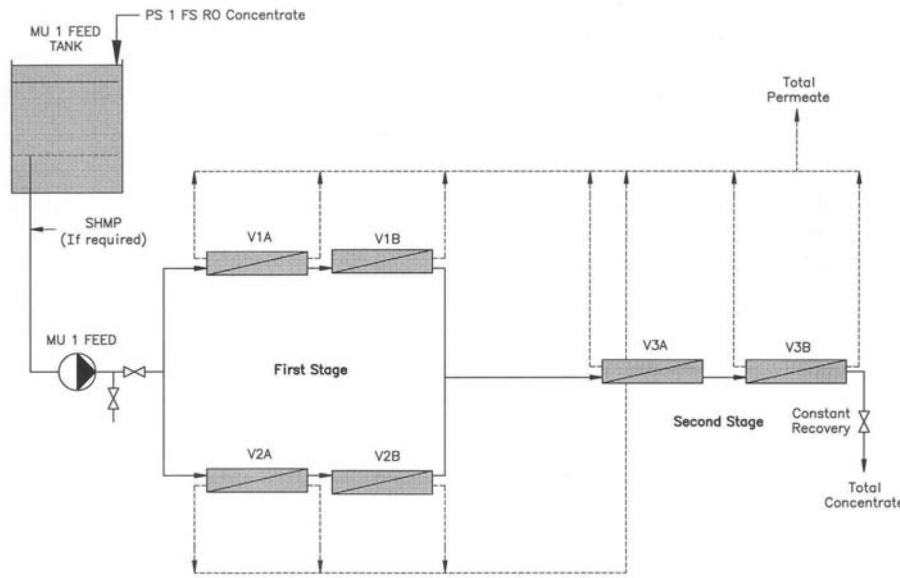

Figure 2.—Flow Schematic - High Recovery.

The overall recovery (R_O) is calculated using the following formula:

$$R_O = R_{FS} + [(1- R_{FS}/100)* R_{MU1}/100]*100$$

The recovery of PS 1 FS RO unit is R_{FS} and the recovery of MU 1 is R_{MU1}. PS 1 FS RO recoveries are based on hourly average permeate and concentrate flows taken from the PS 1 distributed control system. MU 1 recoveries are based on hourly average permeate and concentrate flows taken from the WQIC supervisory control and data acquisition (SCADA) system.

The overall and MU 1 recoveries, for the final 6 weeks of HR testing without the addition of SHMP, are shown in figure 3. During this period, PS 1 FS RO recovery averaged 70.3 percent.

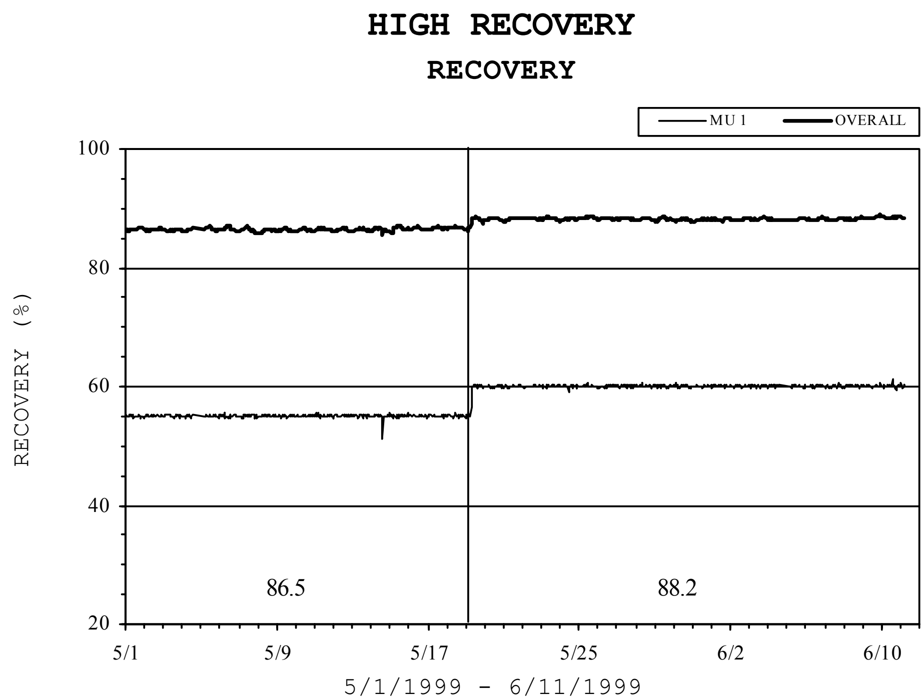

Figure 3.—Recovery - High Recovery.

The WTC data for the tail-end element (E7) of vessel 3 of MU 1 is shown in figure 4 for the final 6 weeks of HR testing without the addition of SHMP. Figure 5 shows the STC data for E7 in vessel 3 of MU 1 for the final 6 weeks of HR testing without the addition of SHMP. Data are entirely calculated from in-line instrument hourly averaged readings recorded in the SCADA. Vessel 3 is the second stage of MU 1 and has a total of seven elements in series. No significant increase in the second stage pressure differential of MU 1 was observed. The WTC for E7 dramatically declined when the overall recovery was increased to approximately 88.2 percent. The rate of decline was approximately 4.0 percent per day. The STC for E7 also showed a dramatic decline when the overall recovery rate was increased to approximately 88.2 percent. The scaling layer contributes to the rejection of the membrane, resulting in the decline of the STC.

The step change observed in the WTC and STC for E7 around June 4, 1999, was related to an unscheduled outage. MU 1 testing was discontinued due to the unavailability of PS 1 FS RO concentrate. PS 1 FS RO unit was shut down due to high feedwater silt density index values. The step change observed is typical for RO units at YDP after an outage.

MU 1 interstage temperature ranged from 21.4 to 31.1 EC, averaging 27.5 EC during the final 6 weeks of HR testing without the addition of SHMP.

On June 11, 1999, MU 1 was shut down due to severe scaling observed in E7 of vessel 3 as shown in figure 4. The four tail-end elements from vessel 3 were removed, and elements four (E4) and E7 were autopsied the following week. Prior to the autopsies, the two elements were drained and weighed. E7 weighed 66 percent more than E4. The autopsy of E4 revealed no

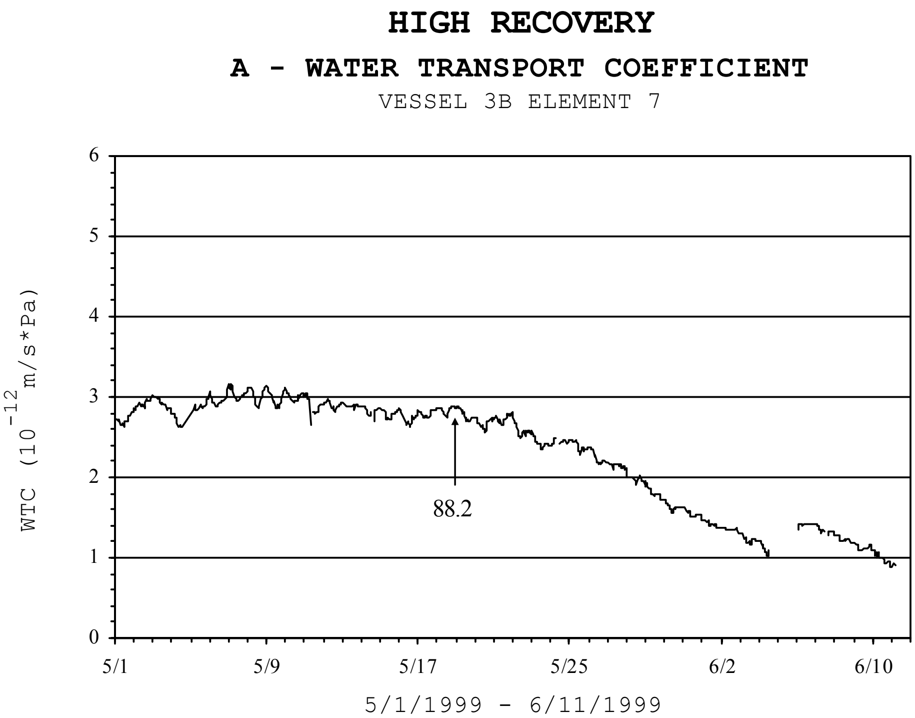

Figure 4.—Calcium Sulfate Scaling - High Recovery.

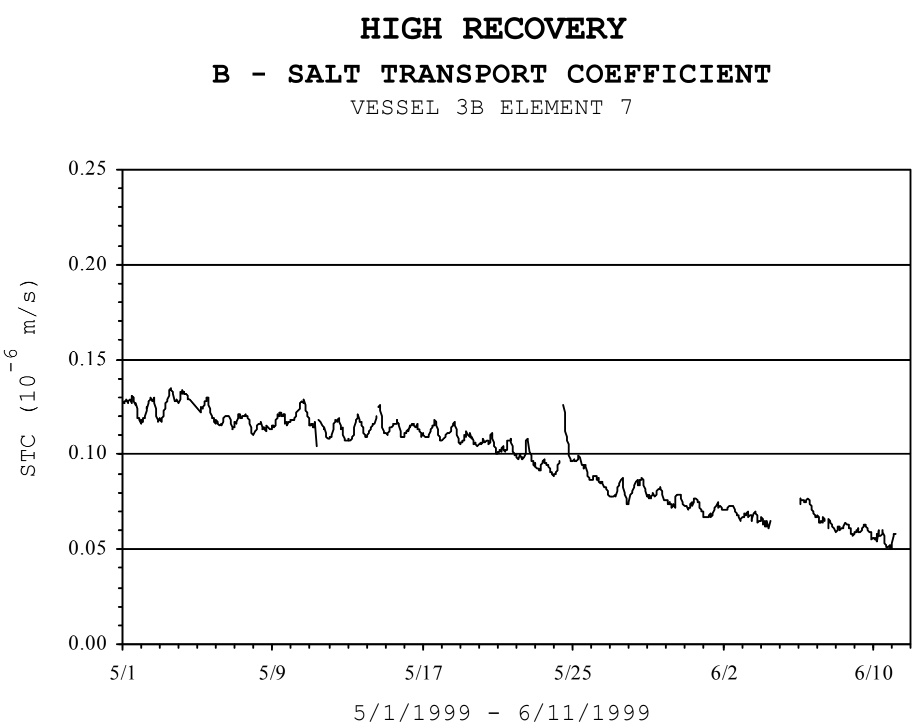

Figure 5.—Water Transport Coefficient - MD Installed on MU 1 Feed Tank.

signs of scaling. The material observed on the membrane surface of E7 was beige, finely powdered material, which is similar to material observed during autopsies performed on YDP RO elements. The feed spacer material of E7 was 60 to 70 percent covered by a white crystalline material, as shown in photo 7. Samples of the white crystalline material were collected, analyzed, and determined to be calcium sulfate [14].

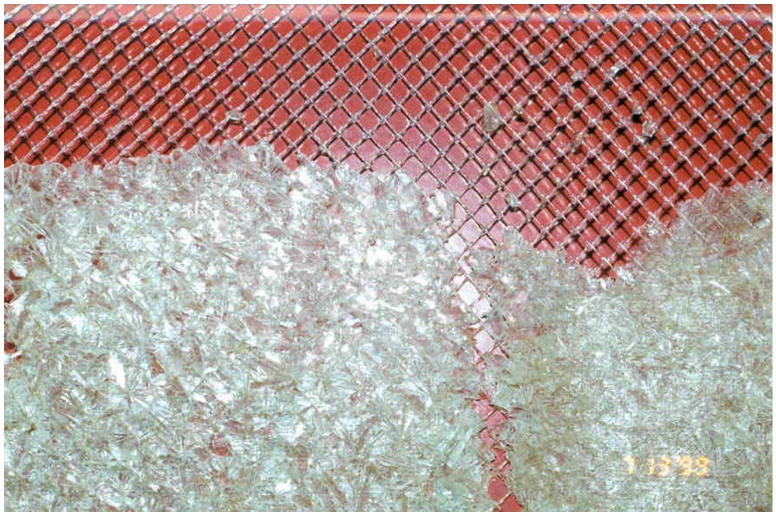

Photo 7.—Calcium Sulfate Scaling - High Recovery.

The overall recovery ($R_{SCALING}$) where calcium sulfate scaling occurred without SHMP or antiscalant addition was determined to be approximately 88 percent. HR testing, without the addition of SHMP, was used as the initial control for the MD and HVC testing.

The WTC data and pressure differential for vessel 3 of MU 1 are shown in figure 6 for the final 6 weeks of HR testing without the addition of SHMP. Vessel 3 is the second stage of MU 1 and has a total of seven elements in series. The WTC for vessel 3 began to gradually decline when the overall recovery rate was increased to approximately 88.2 percent. The rate of decline was approximately 0.3 percent per day.

The second stage pressure differential initially had a step change when the overall recovery was increased to approximately 88.2 percent. The step change can be attributed to the change in flow rate. MU 1 was operated at an average element flux of 10 gfd. As MU 1 recovery was increased, the feed flow rate was decreased to maintain the 10 gfd. No significant increase in the second stage pressure differential of MU 1 was observed when the overall recovery was increased to approximately 88.2 percent.

HIGH RECOVERY

VESSEL 3

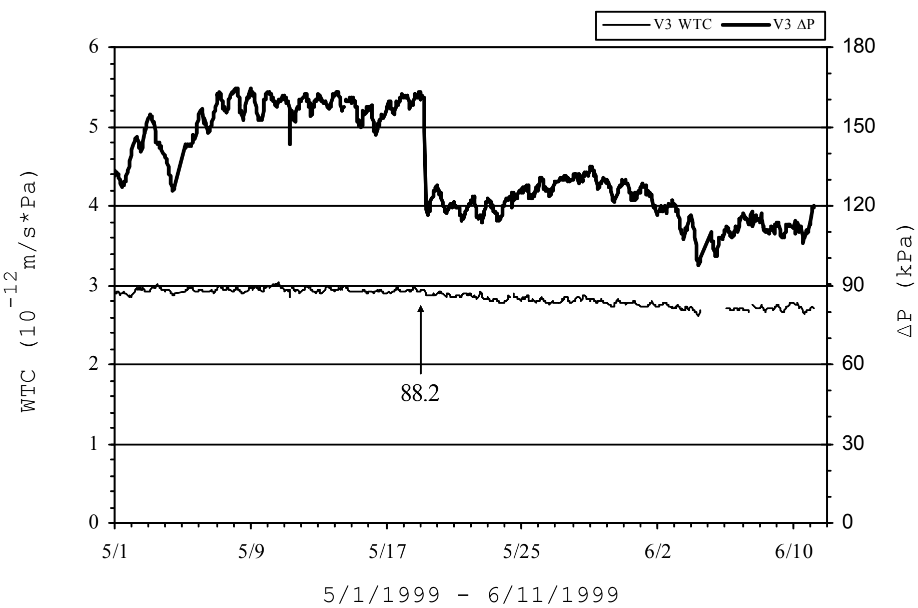

Figure 6.—Recovery - MD Installed on MU 1 Feed Tank.

Four new elements were loaded in the tail-end of MU 1 vessel 3, and testing related to the second objective of the HR study was initiated on June 16, 1999. The objective was to determine the system recovery (R_{SHMP}) where scaling occurs with the addition of 2.0 mg/L SHMP. The original operating parameters for PS 1 and YDP RO units included the addition of 2.0 mg/L of SHMP. Historically, SHMP has been used to inhibit the rate of sulfate precipitation. SHMP has been used to control calcium sulfate at twice its saturation level in the concentrate stream [15]. SHMP was injected prior to MU 1 high-pressure feed pump, as illustrated in figure 2. The overall recovery was gradually increased to over 93 percent, with no signs of scaling [16]. HR testing was terminated during November 2000.

The HR tests provided valuable information for the operation of the YDP. The elimination of SHMP injection at design recoveries for full production YDP operation, with an on-stream factor of 100 percent, will save Reclamation approximately $350,000 per year. The injection of SHMP, at recoveries of 85 percent, appears to provide adequate protection against calcium sulfate scaling.

4.2 Control

The initial testing of the HVC occurred during the first part of 2001. No significant calcium sulfate scaling was observed on MU 1 operating on PS 1 FS RO concentrate at an overall recovery of approximately 87.8 percent with the HVC device installed on the suction line to MU 1 high pressure feed pump.

Repeating the control on MU 1 was recommended to confirm the overall recovery where scaling occurred had not shifted. The HR testing was conducted in 1997, and the MODE water chemistry varies over time. The MODE is the feed source for PS 1 FS RO [16].

During December 2001, the control testing was initiated on MU 1. Twenty-one Desal CD 2540T1078 cellulose acetate elements were installed in MU 1. The feed source for MU 1 was PS 1 FS RO concentrate. The laboratory analyses for PS 1 FS RO feed are shown in table 1.

Table 1.—Inorganic Composition of PS 1 FS RO Feed Water

	06/01/99	02/19/02	04/22/02	05/13/02	07/01/02
Barium (mg/L)	< 0.3	< 0.4	< 0.4	< 0.4	< 0.4
Bicarbonate (mg/L)	5.9	5.8	5.7	4.3	8.9
Calcium (mg/L)	91.2	78.0	68.0	73.0	82.9
Carbonate (mg/L)	0.0	0.0	0.0	0.0	0.0
Chloride (mg/L)	703	655	567	602	641
Iron (mg/L)	< 0.1	< 0.4	< 0.4	< 0.4	< 0.4
Potassium (mg/L)	7.2	7.0	6.0	6.0	7.1
Magnesium (mg/L)	45.3	63.0	48.0	47.9	53.8
Manganese (mg/L)	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
Sodium (mg/L)	636	653	567	570	625
Nitrate (mg/L)	15.0	16.8	15.0	15.0	19.5
Sulfate (mg/L)	907	931	766	809	887
Silicon dioxide (mg/L)	7.0	15.0	8.0	6.0	7.1
Strontium (mg/L)	1.50	1.25	1.15	1.20	1.31
TDS (mg/L)	2,410	2,420	2,030	2,120	2,330
pH	5.6	5.5	5.6	5.1	6.1
Calcium sulfate (% saturated)	11.3	10.3	8.2	9.1	10.7

The barium levels in PS 1 FS RO feed are typically less than 0.01 mg/L. The reason for the < 0.4 mg/L barium values listed in table 1 is related to the dilution factor used by the laboratory. Dilution of the PS 1 FS RO feed samples, when analyzed using the inductively coupled plasma emission optical spectrophotometer instrument, was required due to plugging of the nebulizer and matrix facts related to the high salt content. The calcium sulfate percent saturated values were calculated using Winflows Version 1.2 by Osmonics Desal.

The objective was to determine the overall recovery where calcium sulfate scaling occurs without the MD, HVC, or antiscalant addition. Refer to figure 2 for the flow schematic. This was a repeat of previous HR tests without SHMP or antiscalant addition.

The overall and MU 1 recoveries, for the control, are shown in figure 7. During this period, PS 1 FS RO recovery averaged 69.1 percent. MU 1 was initially operated to achieve an overall recovery that was below where calcium sulfate scaling occurred without SHMP or antiscalant addition. This ensured MU 1 was operating properly before reaching the point where scaling occurred during the HR testing. MU 1 recovery was gradually increased until scaling was observed. The WTC for E7 dramatically declined when the overall recovery was approximately 90.7 percent. The rate of decline was approximately 5.7 percent per day. The actual decline in WTC for E7 began approximately 6 days after the overall recovery was increased to approximately 90.7 percent.

MU 1 interstage temperature ranged from 18.2 to 24.1 °C, averaging 21.6 °C during control testing. The WTC data for E7 in vessel 3 of MU 1 is shown in figure 8 for the control testing.

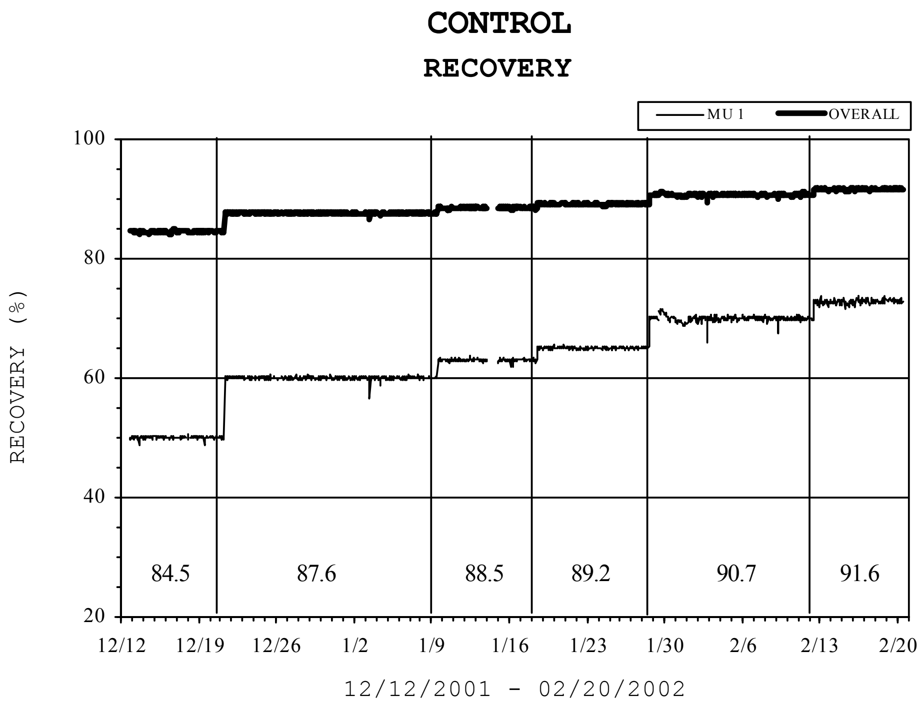

Figure 7.—Recovery – Control.

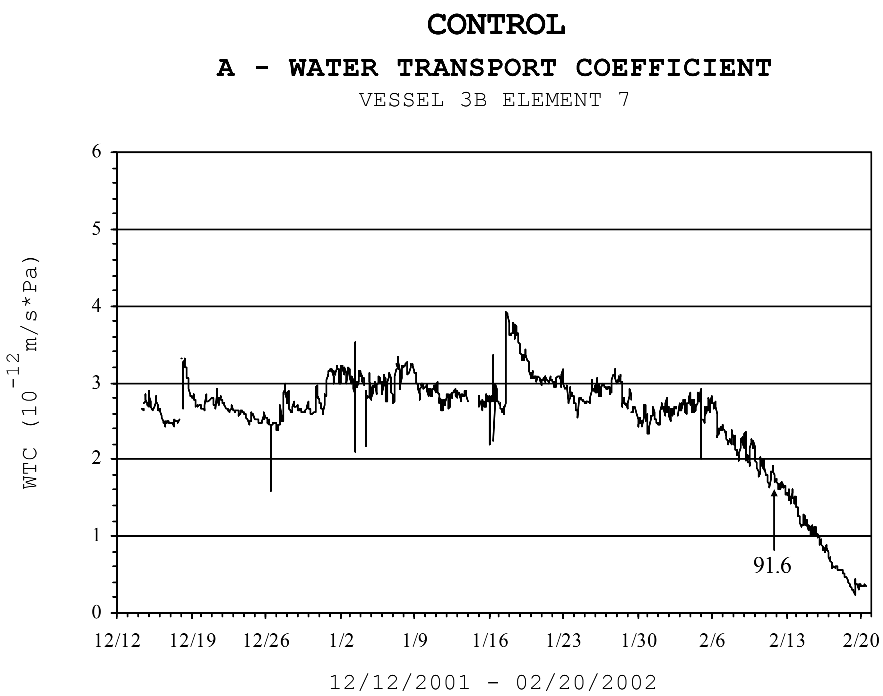

Figure 8.—Water Transport Coefficient – Control

On February 20, 2002, MU 1 was shut down due to severe scaling observed in E7 of vessel 3, as shown in figure 8. The four tail-end elements from vessel 3 were removed and E7 was autopsied in March 2002. The feed spacer material of E7 was over 80 percent covered by a white crystalline material, as shown in photo 8. Samples of the white crystalline material were collected, analyzed, and determined to be calcium sulfate. The material was the same as observed during the HR testing.

Photo 8.—Calcium Sulfate Scaling – Control.

During the control testing, the overall recovery where calcium sulfate scaling occurs without SHMP or antiscalant addition was determined to be approximately 90.7 percent. The increase from 88.2 percent, determined during the HR testing, can be contributed to changes in the MODE water chemistry and the change in performance of the PS 1 FS RO unit in the 2- to 3-year period between the HR and control testing. The laboratory analyses for MU 1 concentrate are shown in table 2.

Table 2.—Inorganic Composition of MU 1 Concentrate

	02/19/02	04/22/02	05/13/02
Treatment	None (control)	HVC installed on MU 1 feed	HVC installed on MU 1 interstage
Overall Recovery (%)	91.6	91.4	91.7
Barium (mg/L)	< 2	< 2	< 2
Bicarbonate (mg/L)	0.0	0.0	0.0
Calcium (mg/L)	917	802	841
Carbonate (mg/L)	0.0	0.0	0.0
Chloride (mg/L)	7,230	6,080	6,550
Iron (mg/L)	< 2	< 2	< 2
Potassium (mg/L)	80	65	70
Magnesium (mg/L)	774	593	598
Manganese (mg/L)	< 0.2	< 0.2	< 0.2
Sodium (mg/L)	7,220	6,090	6,240
Nitrite (mg/L)	98.1	87.0	81.0
Sulfate (mg/L)	11,500	9,300	10,000
Silica (mg/L)	161	89	63
Strontium (mg/L)	15.2	14.0	14.5
TDS (mg/L)	27,800	22,900	24,300
pH	3.9	4.1	4.1
Temperature (°C)	22.6	26.0	27.6
Calcium sulfate (% Saturated)	228	188	203

The calcium sulfate percent saturated for MU 1 concentrate, at an overall recovery of approximately 91.6 percent, was 228 percent and is shown in table 2. The calcium sulfate percent saturated values were calculated using Winflows Version 1.2 by Osmonics Desal. The laboratory analyses in table 2 were taken during the period MU 1 showed signs of scaling. The reason for the < 2 mg/L barium values listed in table 2 is related to the dilution factor used by the laboratory. Dilution of the MU 1 concentrate sample is required due to plugging of the nebulizer and matrix facts related to the high salt content.

4.3 High Voltage Capacitance Device Installed on MU 1 Feed

The HVC was installed on the suction line to MU 1 high-pressure feed pump. Four new Desal CD 2540T1078 cellulose acetate elements were loaded in the tail-end of MU 1 vessel 3, and testing commenced on April 3, 2002. The feed source for MU 1 was PS 1 FS RO concentrate. A flow schematic for this test configuration is shown in figure 9.

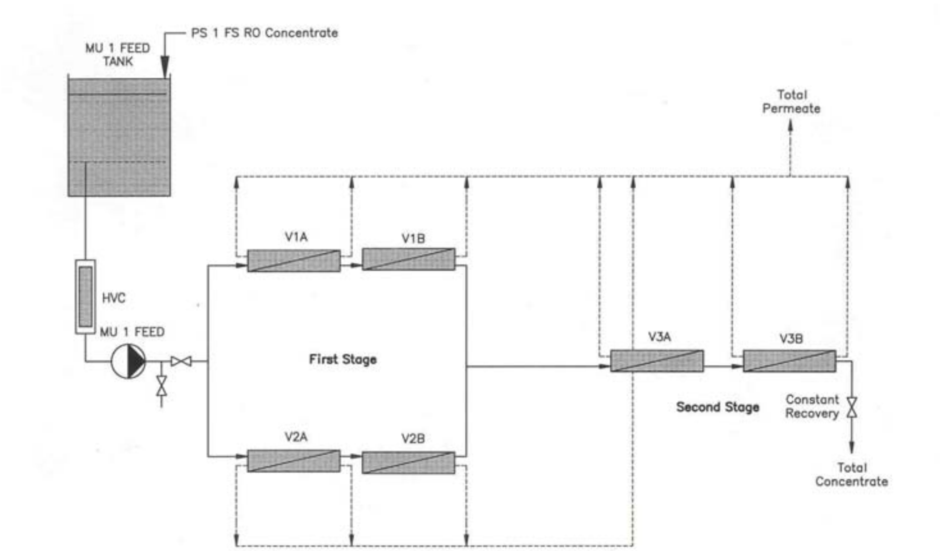

Figure 9.—Flow Schematic - HVC Installed on MU 1 Feed.

The overall and MU 1 recoveries are shown in figure 10. During this period, PS 1 FS RO recovery averaged 68.0 percent. MU 1 was initially operated to achieve an overall recovery that was below where calcium sulfate scaling occurred without SHMP or antiscalant addition. This ensured MU 1 was operating properly before reaching the point where scaling occurred during the control testing. The overall recovery was then increased to approximately 91.4 percent. The WTC for E7 dramatically declined when the overall recovery was increased. The rate of decline was approximately 5.0 percent per day.

MU 1 interstage temperature ranged from 22.2 to 28.1 °C, averaging 25.7 °C during this period. The WTC data for E7 in vessel 3 of MU 1 is shown in figure 11.

On April 26, 2002, MU 1 was secured due to severe scaling observed in E7 of vessel 3, as shown in figure 11. The four tail-end elements from vessel 3 were removed and placed in cold storage. Element E7 was autopsied in May 2002. The feed spacer material of E7 was approximately 50 percent covered by a white crystalline material, as shown in photo 9. Samples of the white crystalline material were collected, analyzed, and determined to be calcium sulfate. The material was the same as observed during the control and HR testing. The calcium sulfate percent saturated for MU 1 concentrate, at an overall recovery rate of approximately 91.4 percent, was 188 percent and is shown in table 2.

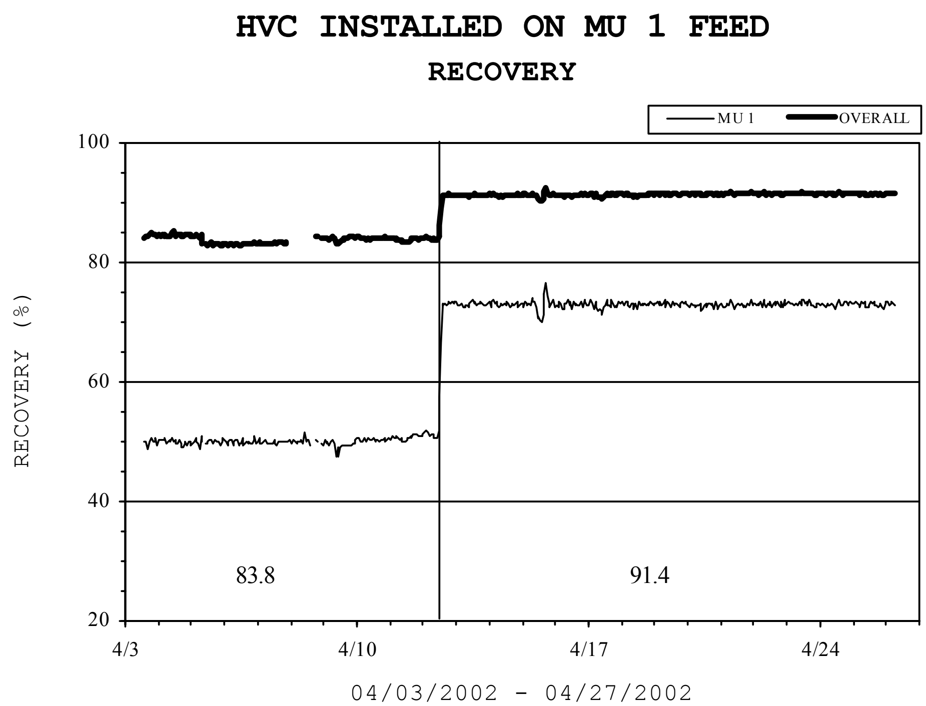

Figure 10.—Recovery - HVC Installed on MU 1 Feed.

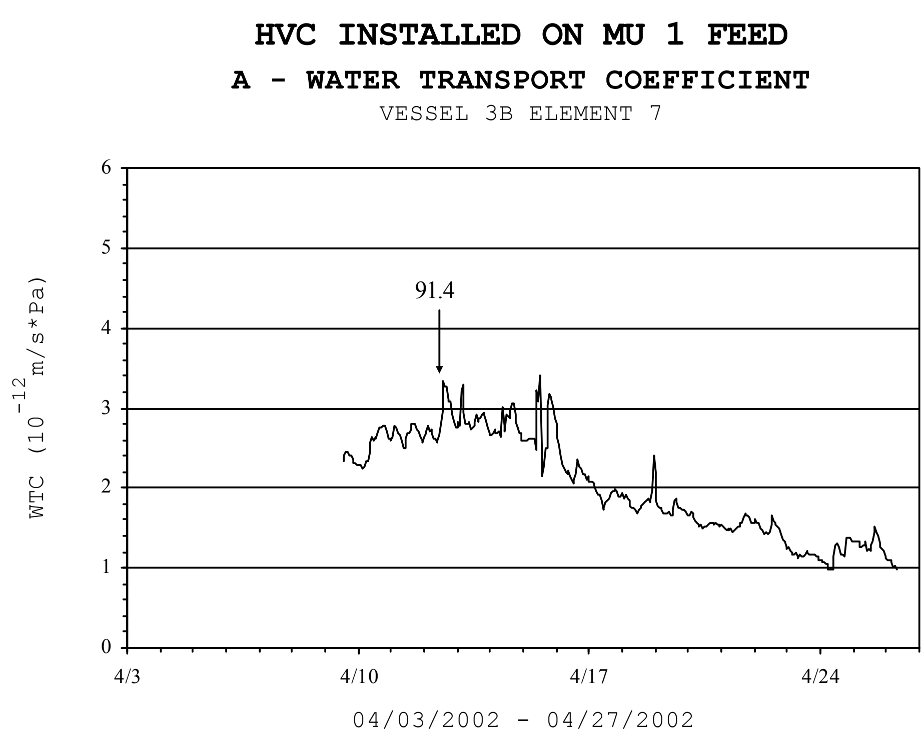

Figure 11.—Water Transport Coefficient - HVC Installed on MU 1 Feed.

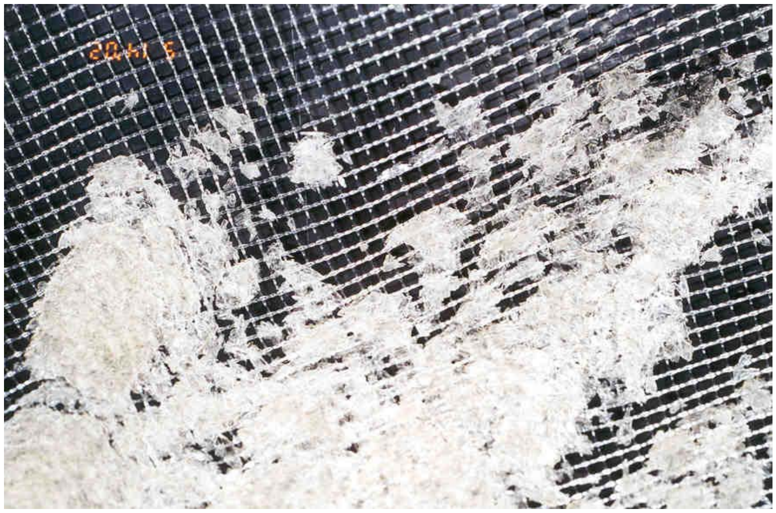

Photo 9.—Calcium Sulfate Scaling - HVC Installed on MU 1 Feed.

4.4 High Voltage Capacitance Device Installed on MU 1 Interstage

The stainless steel 3-inch housing chamber and HVC were installed on MU 1 interstage. Four new Desal CD 2540T1078 cellulose acetate elements were loaded in the tail-end of MU 1 vessel 3, and testing commenced on May 8, 2002. The feed source for MU 1 was PS 1 FS RO concentrate. A flow schematic for this test configuration is shown in figure 12.

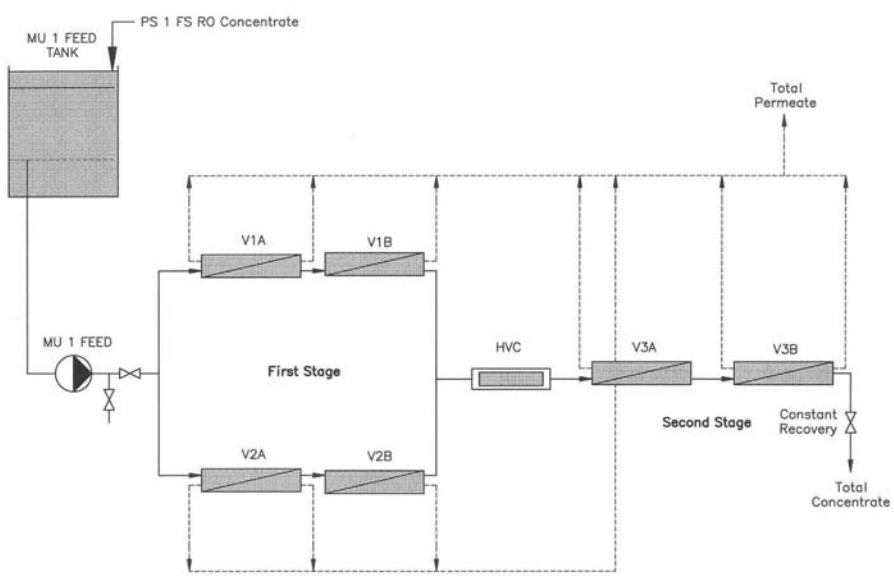

Figure 12.—Flow Schematic - HVC Installed on MU 1 Interstage.

The overall and MU 1 recoveries are shown in figure 13. During this period, PS 1 FS RO recovery averaged 69.5 percent. MU 1 was initially operated to achieve an overall recovery that was below where calcium sulfate scaling occurred without SHMP or antiscalant addition. This ensured MU 1 was operating properly before reaching the point where scaling occurred during the control testing. The overall recovery was then increased to approximately 91.7 percent, and the WTC for E7 dramatically declined. The rate of decline was approximately 13.3 percent per day.

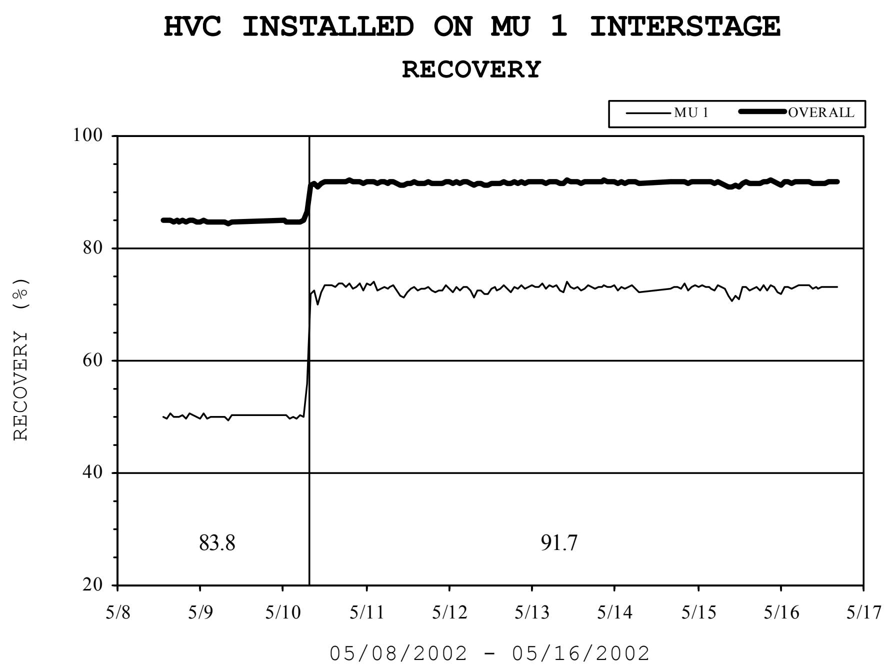

Figure 13.—Recovery - HVC Installed on MU 1 Interstage.

The WTC data for E7 in vessel 3 of MU 1 is shown in figure 14. On May 16, 2002, MU 1 was shut down due to severe scaling observed in E7 of vessel 3, as shown in figure 14. The four tail-end elements from vessel 3 were removed, and element E7 was autopsied. The feed spacer material of E7 was 50 to 60 percent covered by a white crystalline material, as shown in photo 10. Samples of the white crystalline material were collected, analyzed, and determined to be calcium sulfate. The material was the same as observed during the control, HR, and previous HVC testing. The calcium sulfate percent saturated for MU 1 concentrate, at an overall recovery rate of approximately 91.7 percent, was 203 percent and is shown in table 2.

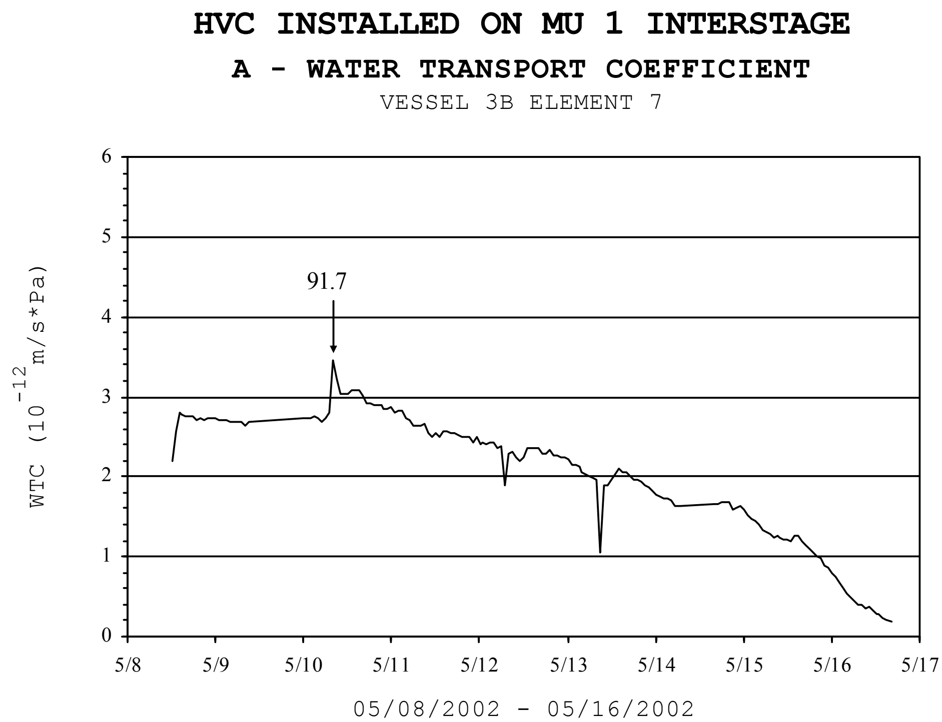

Figure 14.—Water Transport Coefficient - HVC Installed on MU 1 Interstage.

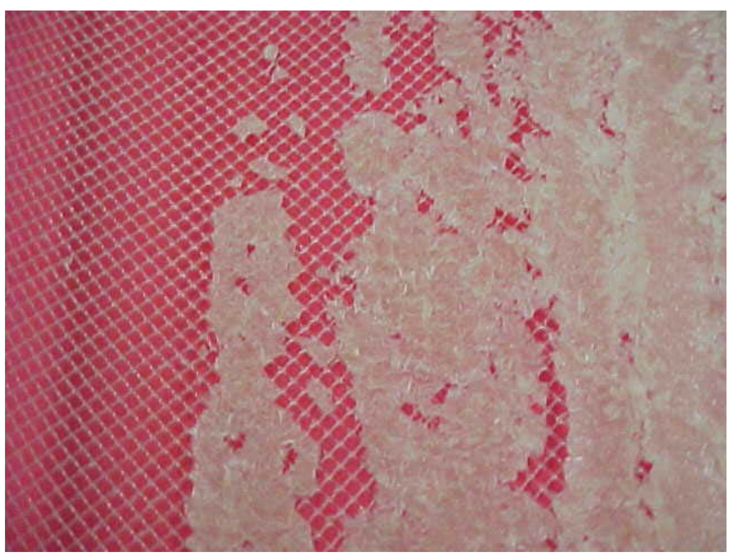

Photo 10.—Calcium Sulfate Scaling - HVC Installed on MU 1 Interstage.

MU 1 interstage temperature ranged from 25.2 to 29.1 °C, averaging 27.4 °C during this period.

4.5 Magnetic Device Installed on MU 1 Feed Tank

The MD and circulation skid were installed on MU 1 feed tank. Four new Desal CD 2540T1078 cellulose acetate elements were loaded in the tail-end of MU 1 vessel 3, and testing commenced on June 24, 2002. The feed source for MU 1 was PS 1 FS RO concentrate. A flow schematic for this test configuration is shown in figure 15.

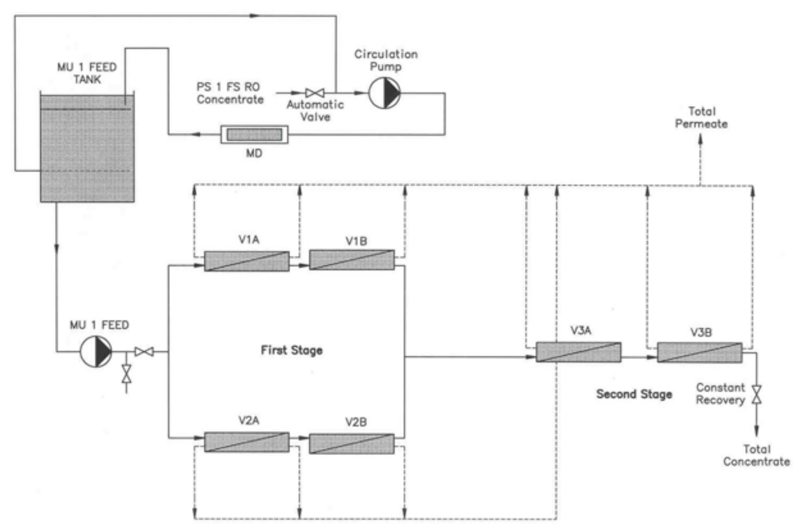

Figure 15.—Flow Schematic - MD Installed on MU 1 Feed Tank.

The overall and MU 1 recoveries are shown in figure 16. During this period, PS 1 FS RO recovery averaged 69.4 percent. MU 1 was initially operated to achieve an overall recovery that was below where calcium sulfate scaling occurred without SHMP or antiscalant addition. This ensured MU 1 was operating properly before reaching the point where scaling occurred during the control testing. During this initial period, E7 permeate conductivity sensor and flow meter were calibrated. The overall recovery was then increased to approximately 91.6 percent, and the WTC for E7 dramatically declined. The rate of decline was approximately 24.6 percent per day.

The WTC data for E7 in vessel 3 of MU 1 is shown in figure 17. On July 5, 2002, MU 1 was shut down due to operational problems with the total concentrate valve and severe scaling observed in E7, as shown in figure 17. The severe scaling occurred prior to the operational problems with the total concentrate valve. The low-pressure concentrate line was completely plugged with scaling material. The low-pressure concentrate line was cleaned, and the four tail-end elements from vessel 3 were removed and element E7 was autopsied. The feed spacer material of E7 was approximately 25 percent covered by a white crystalline material, as shown in photo 11. The accumulation of material was lower than previous tests due to the shorter duration of operation. Samples of the white crystalline material were collected, analyzed, and determined to be calcium sulfate. The calcium sulfate percent saturated for MU 1 concentrate, during operation at an overall recovery of 91.6 percent, was not calculated. MU 1 was shut down prior to the collection of the weekly laboratory samples. MU 1 interstage temperature ranged from 28.6 to 31.0 °C, averaging 29.9 °C during this period.

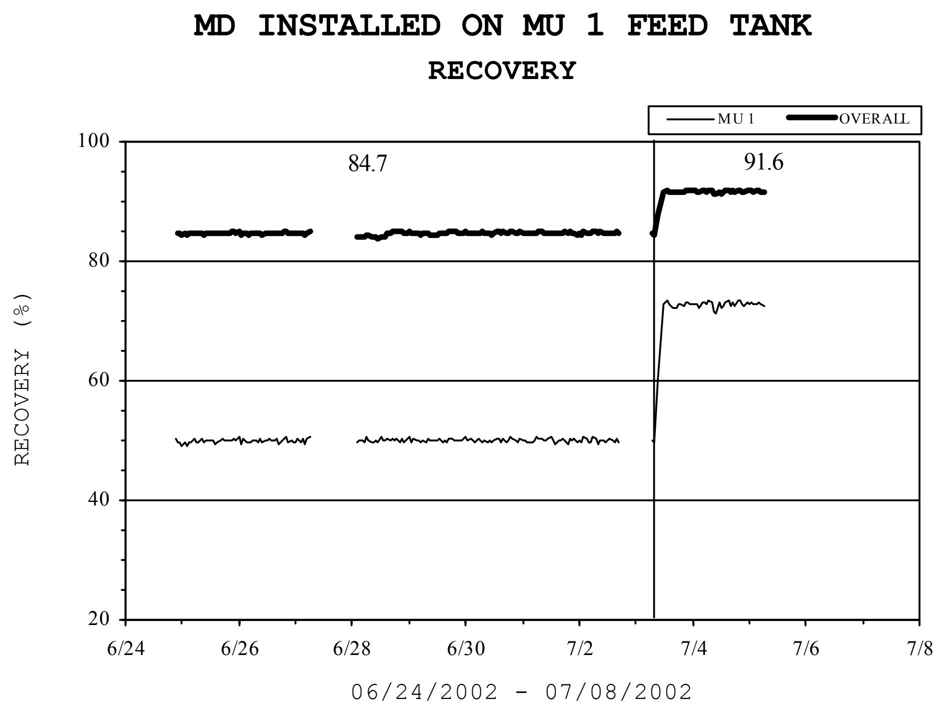

Figure 16.—Recovery - MD Installed on MU 1 Feed Tank.

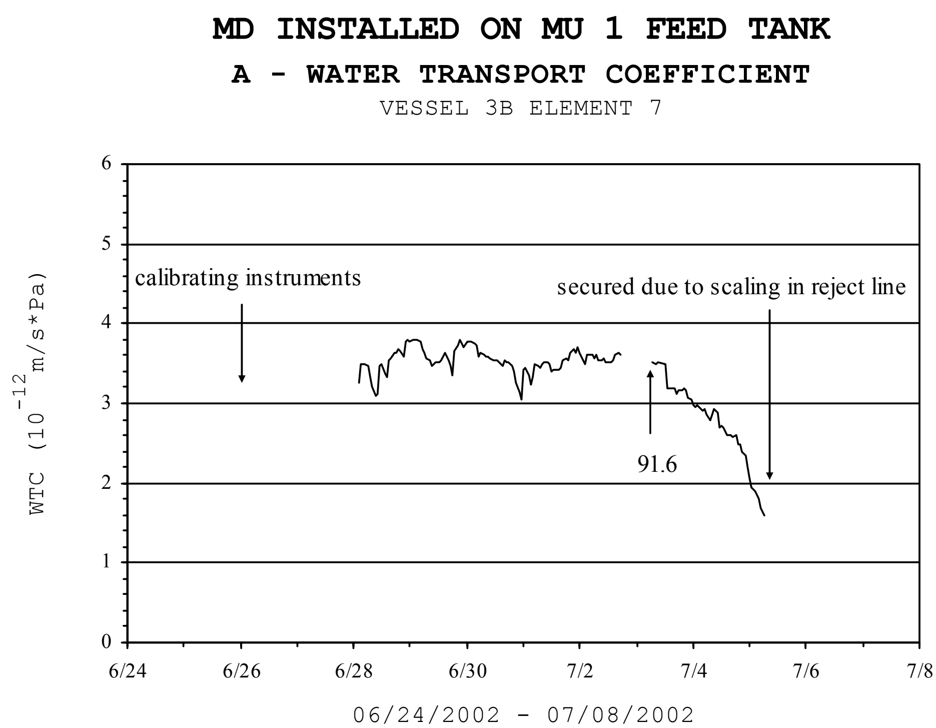

Figure 17.—Water Transport Coefficient - MD Installed on MU 1 Feed Tank.

Photo 11.—Calcium Sulfate Scaling - HVC Installed on MU 1 Feed Tank.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The HVC and MD were determined to be ineffective alternatives for reducing RO scaling at high recoveries on MODE water.

Significant calcium sulfate scaling was observed with the MD installed on MU 1 feed tank and with the HVC installed on both the suction line to MU 1 high-pressure feed pump and on MU 1 interstage. The overall recovery, where calcium sulfate scaling occurred, was approximately 91 percent. Element autopsies indicated the feed spacer material from E7, for both HVC locations and the MD, was at least 25 percent covered by calcium sulfate scaling. The WTC declined dramatically when the overall recovery was increased to approximately 91 percent. The decline in WTC was approximately 5.0 percent per day with the HVC installed on the suction line to MU 1 high-pressure feed pump, approximately 13.3 percent per day with the HVC installed on MU 1 interstage, and approximately 24.6 percent per day with the MD installed on MU 1 feed tank. The decline in WTC for the control was approximately 5.7 percent per day. During HR testing, the overall recovery was gradually increased to over 93 percent, with no signs of scaling with the addition of approximately 2.0 mg/L SHMP. Therefore, of the four operating procedures, the addition of approximately 2.0 mg/L of SHMP was the only procedure successful in avoiding scaling and is recommended for high recovery operation on MODE water.

Measuring the individual performance of the tail-end element provides a sensitive and prompt detection of scaling. This prompt detection enables the plant engineer to immediately correct the condition(s) that created the scaling environment and prevent further scaling of the RO equipment. The rate of decline for vessel 3 WTC was approximately 0.3 percent per day for the HR test without SHMP or antiscalant addition, and the rate of decline for the tail-end element was approximately 4.0 percent per day during this same period. In addition, the WTC for the tail-end element indicated scaling immediately when the overall recovery was increased to approximately 91 percent. In contrast, no clear indication of scaling was evident by vessel 3 WTC.

Based on these experiences, we recommend that the design of RO membrane equipment for research and production plants should consider including the instrumentation to monitor the performance of some of the lead elements, where degradation and biological fouling may occur, and some of the tail-end elements, where scaling and inorganic fouling may be most severe.

CHAPTER 6
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Mr. John Franklin
- San Juan Technical Services, Flora Vista, NM

CHAPTER 7
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