2009-01-01

Treatment of RO Concentrate Using VSEP Technology

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Recommended Citation

Delgado, Guillermo Guadalupe, "Treatment of RO Concentrate Using VSEP Technology" (2009). *Open Access Theses & Dissertations*. 2671.
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TREATMENT OF RO CONCENTRATE USING VSEP TECHNOLOGY

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TREATMENT OF RO CONCENTRATE USING VSEP TECHNOLOGY

by

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THESIS

Presented to the Faculty of the Graduate School of
The University of Texas at El Paso
in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING

Department of Civil Engineering
THE UNIVERSITY OF TEXAS AT EL PASO
December 2009

Acknowledgements

I would like to thank Dr. Anthony Tarquin for giving me the opportunity to work with him in this project and share all his knowledge. I learned many things through these years because of his guidance and support. I would like to thank Dr. Noe Vargas-Hernandez and Dr. Douglas Rittmann for their help in evaluating this thesis.

Thanks to my parents, Laurencio and Lucrecia, for their unconditional support all my life and to my brothers and sisters for being there when I needed them most.

I would like to thank Robert Martinez my co-worker for two years and an important member of the research team in this project.

And last but not least, I would like to express my love and gratitude to her, yes you! For all these years sharing every moment and helping me to walk in this life.

Thanks to all of you and God for making this project possible.

Abstract

The city of El Paso has the largest inland brackish desalination plant in the world. The Kay Bailey Hutchison (KBH) Desalting plant produces 15 million of permeate water every day. Due to the excellent quality of the water, the permeate water is blended with brackish water producing a final volume of 27.5 million gallons of water every day. With an average recovery rate of 80%, the KBH plant produces an average of 3 million gallons of concentrated brackish water that is disposed of via injection wells 23 miles from the plant.

Conventional reverse osmosis (RO) systems are not capable of treating the KBH concentrate due to the high concentrations of dissolved solids. At these concentrations, some of the dissolved solids start to precipitate (i.e. silica for example) causing fouling of membranes.

This project is an analysis of the Vibratory Shear Enhanced Processing (VSEP) to recover fresh water from the KBH concentrate. The characteristics of VSEP to work with high concentrations of suspended solids and high pressures can be used for the KBH concentrate. A VSEP pilot unit was tested to obtain the necessary data in order to make a projection for a large scale treatment system. VSEP was tested under different scenarios (i.e. concentrate with or without suspended solids) to evaluate the efficiency of the unit. A cost analysis was made in order to determine the cost effectiveness of a large scale system capable to treat the KBH concentrate.

The results of this project are presented in the next sections.

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Chapter 1

Introduction

Introduction

El Paso Water Utilities (EPWU), in partnership with Fort Bliss (a U.S. Army installation), owns and operates the largest inland brackish groundwater reverse osmosis (RO) desalting plant in the United States. The Kay Bailey Hutchison (KBH) Desalting plant produces 15 million gallons of water. The permeate water is blended with brackish water to obtain a final volume of 27.5 million gallons of drinking water when it is operated at full capacity.

The KBH plant uses an antiscalant that allows the plant to reach a recovery of 80% of the water treated. Since the procedure is not 100% efficient, the plant produces a concentrate volume of three million gallons per day with a silica concentration of 125 mg/L. At the present time, the concentrate is disposed of via injection wells located 23 miles from the plant.

Preliminary work using well 72 at a pilot plant site (Montana booster Station) showed that it might be possible to recover between 80 and 90% of the RO concentrate using either vibratory shear enhanced processing (VSEP) or a seawater reverse osmosis system (SWRO). This project was undertaken to conduct VSEP studies at the KBH plant to verify that the same results could be obtained using the actual concentrate from the full scale plant as was obtained when using well 72. The results from the VSEP studies at the KBH desalination plant are presented in this report.

Chapter 2

Literature Review

2.1 Membrane Filtration of Drinking Water

The first sand filter used for clarifying drinking water was installed in Paisley Scotland in 1804. Since then, some advances have been made in sand filter design and in the use of coagulation prior to filtration. However, the basic concept has remained the same for nearly 200 years. There has been a trend in recent years towards the use of polymer membranes for treatment of potable water for domestic and industrial use. Significant advances in polymer chemistry within the last 20 years and the use of membranes are becoming more widely accepted. In addition to the membrane itself, significant advances have occurred with respect to the delivery system. New technologies are appearing all the time and membrane systems now offer an effective competitive treatment method option (Johnson 2006 *et al*).

2.2 Membrane Processes

In the membrane processes, separation of a substance from a solution containing numerous substances is possible by the use of a selectively permeable membrane. The solution containing the components is separated from the solvent liquid by the membrane, which must be differently permeable to the components.

Membranes can be classified as four different types according to its size of pore or rejection characteristics. The types of membranes are:

- Microfiltration membranes (MF)
- Ultrafiltration membranes (UF)
- Nanofiltration membranes (NF)
- Reverse osmosis membranes (RO)

Microfiltration membranes have the most open media with pore sizes from 0.1 microns (1×10^{-6} meters) and larger.

Ultrafiltration membranes have a pore range between 0.005 microns and 0.1 microns.

Nanofiltration membranes do not have pores and work by diffusion. NF membranes are designed to remove dissolved solids when present in low to medium concentrations. Multivalent ions present in water are the most common targets for these membranes.

Reverse osmosis membranes, like nanofiltration membranes, do not have pores and work by diffusion. Designed to remove dissolved solids present in water in high concentrations, RO membranes allow water to pass thru but not the solids because the osmotic pressure in the water with more dissolved solids is higher than the pressure in the water with less dissolved solids.

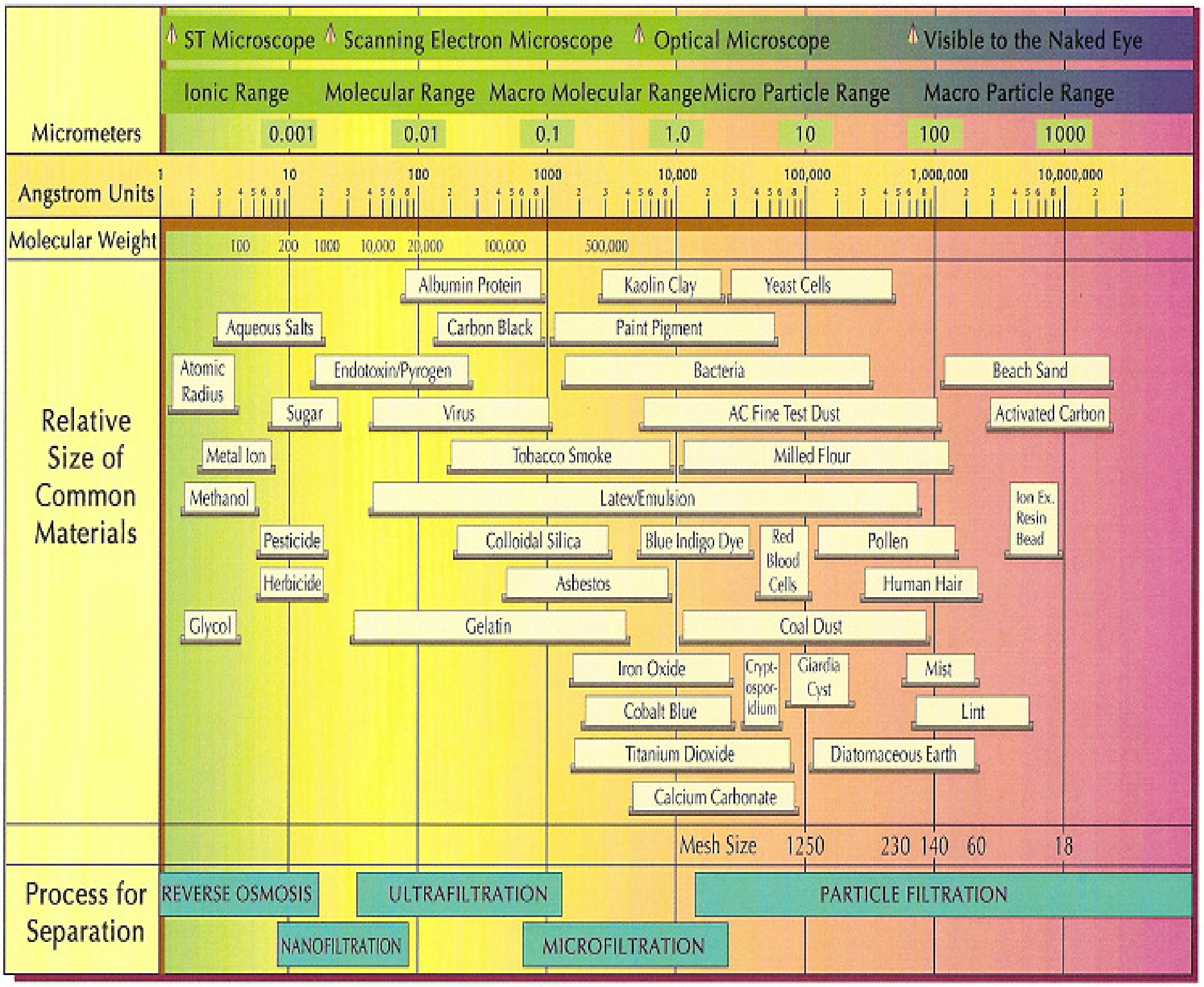
For the purpose of non-brackish water filtration, microfiltration is generally good enough. There is a correlation between pore size and throughput. Generally, the larger the pore is, the higher the flow rate through a given area of membrane. Since filtration of brackish water oftentimes requires removal of silt, suspended particles, bacteria, and other microorganisms, a microfilter is typically used. This type of filter will provide the highest throughput and best economics for a given flow rate. If the water source is especially colored or turbid or if taste complaints are a problem, ultrafiltration can be used which is tighter than microfiltration. UF membranes can remove very small organic matter, humic substances, and even viruses. UF membranes can improve color, taste, and odor of the drinking water.

In the case of commercial bottled water or brackish water filtration, tighter membranes including nanofiltration and reverse osmosis are used. In the case of brackish water, MF or UF would not reduce the high levels of dissolved solids and could not provide filtrate meeting the primary drinking water standards. Brackish water is a term that covers a very broad range of water quality. Brackish water can have anywhere from 1000 ppm to 10,000 ppm of total dissolved solids (TDS). Above 10,000 ppm of TDS, water is considered saline water. The most appropriate membrane for brackish water still depends on the concentration of TDS. For slightly brackish waters, (1,000 to 3,000 ppm), nano-filtration would probably yield an acceptable water quality. For high level brackish water, (>3,000 ppm), reverse osmosis is probably needed as in the case of seawater desalination. Figure 1 shows the filtration spectrum of different particles and the range for the different types of membranes (New Logic Research, Inc., "VSEP Pilot Test Handbook", Figure 1.1).

2.3 Membrane Technology

Advanced treatment utilizing membranes for drinking water is becoming more popular. NF and RO can be used to remove varying degrees of dissolved solids meeting the strict drinking water guidelines. Most membranes used today are made of polymeric materials including: polyamide, polysulfone, regenerated cellulose, kynar (PVDF) and Teflon® (PTFE).

The pore sizes are determined by how well the membrane rejects particles of a known size. The membrane itself allows water to pass through the physical pores or through the matrix of the polymer and does not allow larger molecules or suspended solids to pass. Selection of the proper membrane depends on the separation required.



1 Micron (1 x 10^{-6} Meters) = ~ 4 x 10^{-5} Inches (0.00004 Inches)

1 Angstrom Unit = 10^{-10} Meters = 10^{-4} Micrometers (Microns)

Figure 1: Filtration Spectrum

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2.4 Limitations of Conventional Membranes

Membrane fouling and scaling can significantly increase the cost of a membrane system as well as reduce its efficiency. Because of fouling, elaborate pre-treatment is used ahead of most membrane systems and the solubility limits of various constituents are monitored. The concentration of these constituents is controlled so that the solubility limit is not exceeded, causing precipitation of colloidal materials and mineral scaling of the system. The net effect is that the % recovery of filtered water will be limited by the solubility of sparingly soluble salts and silica. This limitation has been the cause of a great deal of recent development in membrane science. Several approaches have been used to try to minimize the effects of fouling. Polymer chemists are developing many new membranes that have "low fouling" characteristics. Several techniques are used like altering the zeta potential or amount of ionic charge of the membrane surface. Another method is modifying the thermodynamic potential of the membrane surface by using low surface energy materials. These materials reduce the chemical free energy change upon absorption of foulants (Johnson 2006 *et al*).

2.5 Sparingly Soluble Salts

Even with all of these tools, the recovery of these systems can be limited to low levels. This results in a large volume of rejected brine that must be further treated or disposed. Minerals that will precipitate and foul conventional membrane systems as they come out of solution are predominantly composed of divalent metal ions. Monovalent metals such as sodium and potassium are nearly completely soluble, whereas, in the presence of sulfate, phosphate, or carbonate, divalent ions such as calcium, iron, magnesium, barium, strontium, radium, beryllium, lead, and silicon are nearly insoluble.

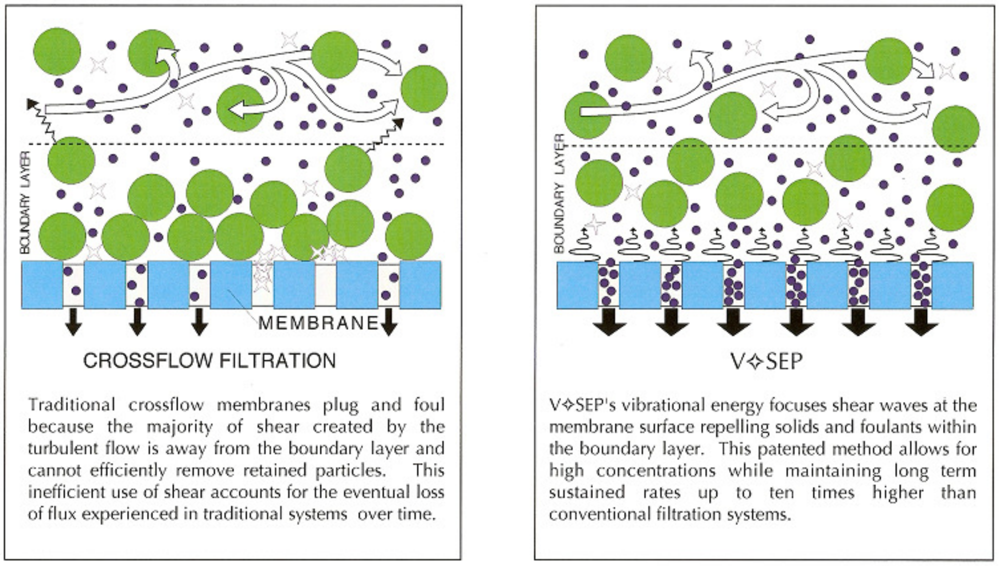
When pressure is applied and reverse osmosis filtration occurs, nearly pure water is forced through the membrane, changing the equilibrium and consequently the concentration of solutes to solvent. If this process continues until the solute reaches its limit of solubility, precipitation is likely to occur. Once precipitation has begun at appropriate nucleation sites, then as more water is removed, more precipitated materials are created. This will continue, as the system will attempt to keep the concentration of solutes at or below the solubility limit. If water is removed by filtration, but not in enough quantity to reach the solubility limit of the solutes, no scaling or precipitation will occur. One primary method used during conventional membrane filtration is to recover water from the system to the point where solubility limits are not reached. The second method is to use antiscalants that either inhibit the growth of crystals or sequester the reagents and thus reduce the available concentration.

2.6 Vibratory Shear Enhanced Processing (VSEP)

VSEP was developed by the company NEW LOGIC *RESEARCH* INC. as an enhanced liquid/solids separation system capable of providing dramatically improved filtration rates over traditional methods.

The industrial VSEP units contain one or several sheets of membranes which are arrayed as parallel disks separated by gaskets. The disk stack is contained within a fiberglass reinforced plastic cylinder. This entire assembly is vibrated in torsional oscillation. The shear generated in a VSEP unit is 150,000 s^{-1}, ten times greater than that achieved in traditional crossflow systems as shown in Figure 2 (New Logic Research, Inc., “VSEP Pilot Test Handbook”, Figure 2.1).

This high shear rate has been shown to significantly reduce or eliminate the susceptibility to fouling for many materials. Beyond the flow induced shear of conventional crossflow filtration, VSEP can produce extremely high shear on the surface on the membrane. This is accomplished by the torsional vibration of a disk plate in resonance within a mass-spring-mass system. The membrane is attached to this plate and moves at an amplitude of ½'' to 1'' peak to peak displacement. The frequency at which the system vibrates is between 50 and 55 Hz. The fluid in the stack remains fairly motionless, creating a highly-focused shear zone at the surface of the membrane. Retained solids at the membrane surface are removed by the shear, allowing for higher operating pressures and increased permeate rates. Feed pressure is provided by a pump, which consistently circulates a new fluid to the filter.



CROSSFLOW FILTRATION

Traditional crossflow membranes plug and foul because the majority of shear created by the turbulent flow is away from the boundary layer and cannot efficiently remove retained particles. This inefficient use of shear accounts for the eventual loss of flux experienced in traditional systems over time.

V✧SEP

V✧SEP's vibrational energy focuses shear waves at the membrane surface repelling solids and foulants within the boundary layer. This patented method allows for high concentrations while maintaining long term sustained rates up to ten times higher than conventional filtration systems.

Figure 2: Crossflow Filtration and VSEP Filtration

In general, a VSEP unit is simply two masses connected by a spring. This is a torsion spring and it is set to resonate at its natural frequency. One mass, the filter pack, is lighter and rides atop the torsion spring. This filter pack contains the membrane(s) and moves at high amplitude. The other mass, the seismic mass, moves with smaller amplitude which is proportional to the ratio of the two masses. The use of two masses in this resonance scheme allows the entire system to resonate without attachment of the device to a rigid surface. Figure 3 shows the main components of the VSEP pilot plant unit (New Logic Research, Inc., “http://www.vsep.com/products/series_lp.html”, 12/15/2009).

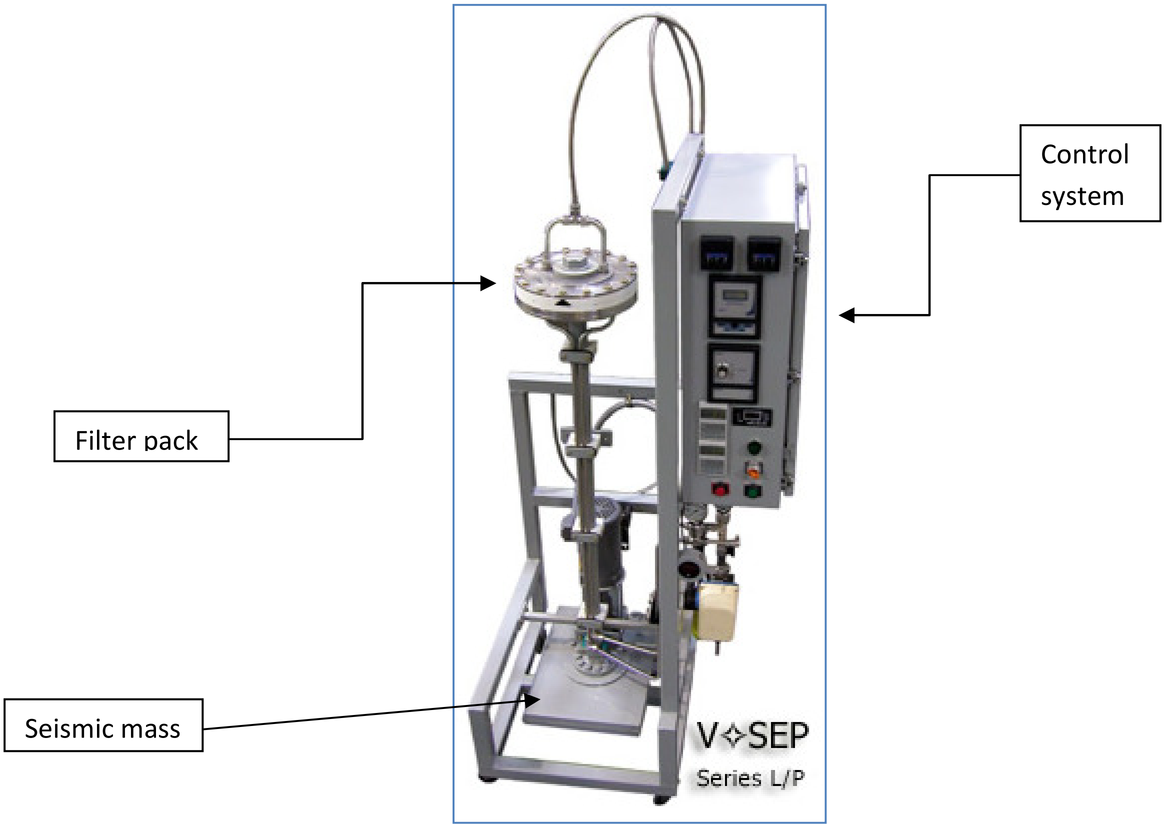


Figure 3: VSEP Pilot Plant Unit

The resonance excitation is provided by an AC motor controlled by a variable frequency, solid state controller. The motor spins an eccentric weight coupled to the seismic mass. Since the eccentricity of the weight induces a wobble, the seismic mass begins to move as the motor speed increases. This energy is transmitted up the torsion spring, inducing the same wobble in the filter pack, however 180^{o} out of phase. As the motor speed approaches the resonance frequency, the amplitude of the moving filter pack reaches a maximum, and greater motor speed will only decrease the amplitude.

VSEP systems are operated in a single pass configuration, which makes them ideal for industrial scale applications consisting of upwards of hundreds of gallons per minute. During single-pass operation, the material enters the top of the filter pack and is progressively dewatered by the membranes as the material passes down through the stack. This establishes a concentration gradient, where the material at the top of the stack is most similar to the feed material, and the material at the bottom of the stack is concentrated reject, having been dewatered as it passes through the filter pack. The concentrated material is essentially extruded from the bottom of the pack. The clear filtrate is removed through the center of the pack from a porous drainage cloth under each membrane sheet. The limit to concentration varies from feed material to feed material but essentially needs to remain flowing as a liquid which can be removed from the outlet pipe.

Figure 4 shows a basic flow diagram of the operation of VSEP.

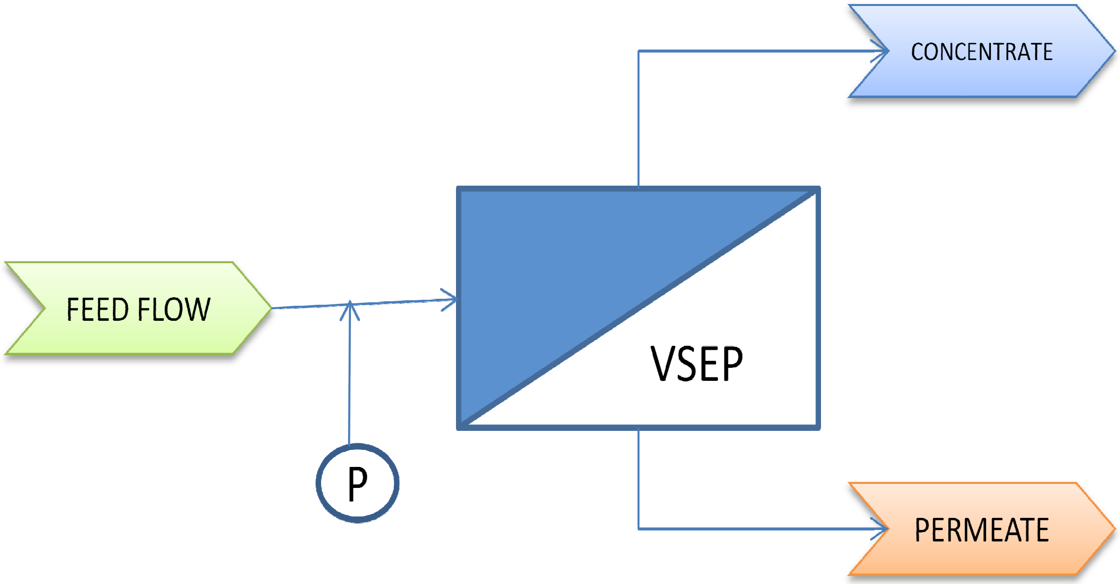


Figure 4: Flow Diagram of VSEP Unit

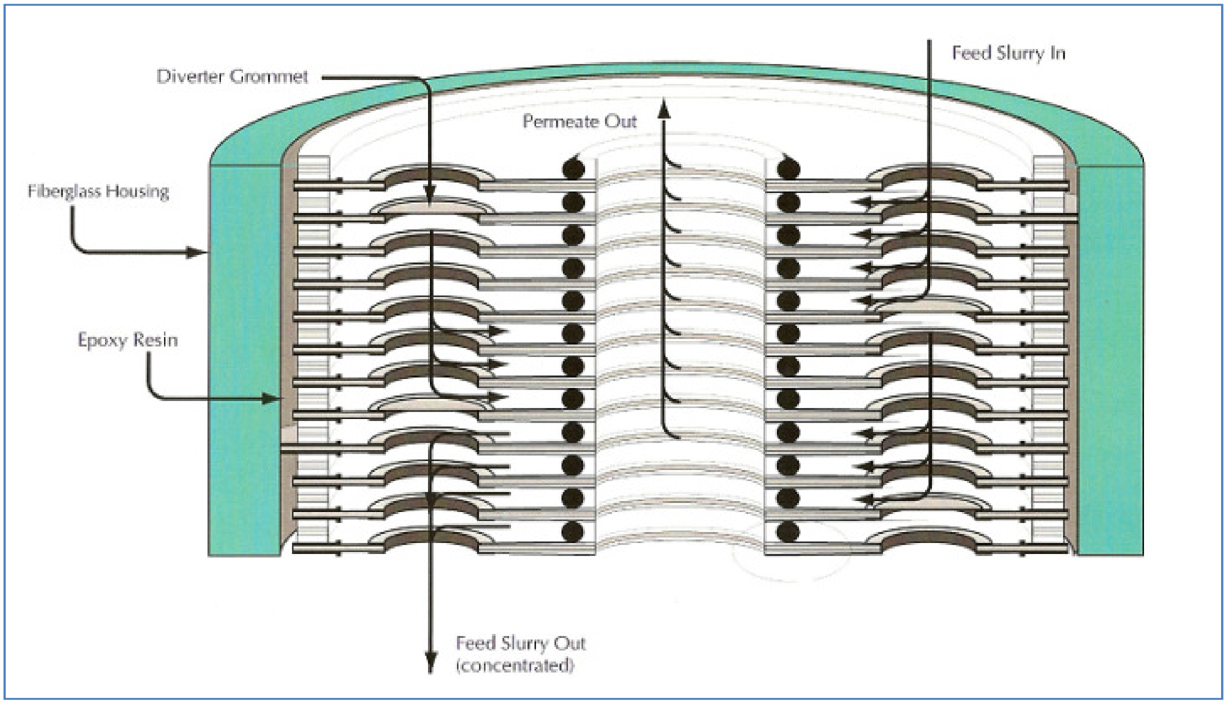


Figure 5: Cross Section of a VSEP Unit Set of Membranes

Figure 5 is a Cross section of a VSEP unit set of membranes. VSEP unit was designed to work with one or more membranes. In the studies made in the KBH desalination plant, only one membrane was used (New Logic Research, Inc., "VSEP Pilot Test Handbook", Figure 2.3).

Chapter 3

VSEP Pilot Plant Studies

VSEP Pilot Plant Studies

As mentioned before, the KBH desalination plant is the largest inland brackish groundwater reverse osmosis desalination plant in the United States. The design allows the plant to treat large amounts of brackish water producing almost 28 million gallons of high quality drinking water every day, but it also produces large amounts of water with high concentrations of dissolved solids.

A problem faced by any inland water desalting facility is what to do with the brine solution that is generated in the reverse osmosis process. The problem is exacerbated when the raw water supply contains substances that could foul membranes if an excessive amount of permeate is extracted from the brackish feed water. In the city of El Paso, the groundwater contains silica (SiO_2) at an average concentration of 25 to 30 mg/L. At this concentration, RO systems will be limited to an efficiency of about 75% (if no antiscalants are used) because above this value, silica will precipitate, fouling the membranes. Since the KBH plant uses an antiscalant, the plant is operated at a recovery rate of 80% which results in a concentrate volume of about 3.0 million gallons per day with a silica concentration of 125 mg/L. The concentrate product is disposed via injection wells located 23 miles from the plant. Table 1 shows the characteristics of the concentrate that is generated at the KBH plant. Note that the average silica concentration exceeds 130 mg/L.

Table 1: KBH Concentrate Analysis

Parameter	2007			2008			2009			% Change '07-'09
	Min	Average	Max	Min	Average	Max	Min	Average	Max	
Cl	2400	4239	8890	265	4699	9710	4840	5089	5540	20.1%
SO_4	453	896	1970	127	1039	2110	1050	1111	1200	23.9%
ALK-P	0	0	0	2.5	6.9	12.5	0	0	0	
ALK-T	266	424	499	18.8	412	498	400	427	445	0.6%
Ba	0.042	0.31	0.48							
B	0.028	0.11	0.17							
CL_2-F	0.05	0.09	0.16	0.05	0.07	0.09				
CL_2-T	0.05	0.11	0.27	0.05	0.06	0.1				
EC	1640	15185	23400	1040	16267	22100	16600	18122	20200	19.3%
Fe	0.03	0.11	0.6	0.03	0.13	0.57	0.03	0.07	0.12	-36.4%
T Hard	1180	1898	3770	528	2089	3030	2050	2291	2430	20.7%
Mn	0.09	0.17	0.23	0.1	0.16	0.21	0.11	0.17	0.22	-0.3%
ortho-P	0.1	0.16	0.27	0.1	0.16	1.26	0.11	0.19	0.49	21.4%
pH	7.5	7.9	8.1	7.1	8.0	8.3	7.6	7.8	8.0	-1.4%
Ca	303	516	1100	376	589	793	281	608	937	17.8%
K	45.5	74	114	4.9	76	99.7	43	113	759	53.4%
Mg	88.8	140	258	0.9	153	208	85.7	161	183	14.9%
Na	208	2398	4220	172	2674	4200	1730	2810	3260	17.2%
Sr	8.74	17.1	30.1							
SiO_2	_		_	28.7	148	228	26.9	131	173	_
TDS	6890	8738	15300	6740	10412	13200	10300	10722	11200	22.7%
CALC-TDS	1070	9867	15200	677	10566	14400	10800	11772	13100	19.3%
Temp	20.5	21.9	24	18.9	24.1	221	23.3	25.4	26.3	15.8%
Turb	0.07	0.22	1.62	0.08	0.85	14.6	0.06	0.30	1.94	34.3%
									Avg =	**15.5%**

Two different studies (Tarquin 2005; Tarquin 2006) showed that it appears to be feasible to recover over 80% of the silica saturated brine concentrate through lime precipitation of the silica and that it might be possible to recover between 80 and 90% of the RO concentrate using either vibratory shear enhanced processing (VSEP) or a seawater reverse osmosis system (SWRO).

The VSEP unit was designed to work with high concentrations of suspended solids and high pressures, but this is one of the first studies when VSEP technology was applied to treat concentrate from a reverse osmosis system. Between 2007 and 2009, The Cache Creek Casino Resort, located among the rolling hills of rural Capay Valley, California, about 70 miles north of San Francisco, implemented a desalination facility to treat recycled water for irrigation of the golf course using VSEP technologies. The TDS concentration of the water treated in this facility is about 1500 mg/L. The concentrate treated in the KBH plant using VSEP had a TDS concentration of 20,000 to 30,000 mg/L as an average. For that reason, it can be considered that this is the first study conducted using VSEP for desalination of water with high concentrations of silica and suspended solids due to precipitation.

For most RO systems, suspended solids are very harmful for the membranes, causing fouling and scaling. VSEP systems are specifically designed to avoid fouling due to the vibratory design that allows the water to flow, but keeps the suspended solids in constant movement, preventing them from plugging the membrane. "In VSEP, no matter how many colloids arrive at the membrane surface, there are an equal number removed as the diffusion layer is limited in size and cannot grow large enough to blind the system. In fact, VSEP is capable of filtration of any liquid solution as long as it remains a liquid. At a certain point, as water or solvent is removed, the solution will reach a gel point. This is the concentration limitation of VSEP" (Johnson 2006 *et al*).

In September of 2006, EPWU began a 4-month pilot test to evaluate the possibility of using VSEP technology to recover a significant amount of water from the RO concentrate without permanently fouling the membranes with silica. The preliminary results from short-term batch tests were very successful, achieving volume reductions of up to 85% with no apparent silica scaling. In fact, there was no precipitation of any type from the concentrate. The study period ended before any tests could be conducted at recoveries high enough to cause precipitation, a condition under which VSEP technology would work efficiently since it was designed to work with solutions with high concentrations of suspended solids. This study was undertaken to investigate the performance of a VSEP unit when suspended solids were present in the concentrate either at the beginning of the process or after precipitation occurred during the treatment process.

3.1 System Components

VSEP Unit: the main component is the VSEP unit itself. This is made up of a frame which supports the vibration drive system and filter pack. The instruments and plumbing are mainly located on the right side of the unit. A cabinet is also included to mount the electrical parts as shown in figure 6 (New Logic Research, Inc., "VSEP Series L/P Operators Manual", page 10).

Figure 6: VSEP System LP Series

Feed Tank: a 15 gallon feed tank was included as part of a complete pilot system package as shown in figure 7 (New Logic Research, Inc., "VSEP Series L/P Operators Manual", page 10). The tank is supported by steel stand-off legs and includes a Teflon ball valve at the outlet. All of the hoses necessary for system installation were also included.

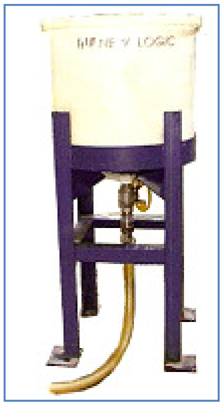


Figure 7: Feed Tank

Pump Station: the standard VSEP pilot unit series L/P includes a feed pump that can be used with a wide variety of fluids. The standard pump station consist of a "hydra-cell", hydraulically balanced, diaphragm pump directly driven by a 2 HP motor. Included are a "y-trap" strainer at the pump inlet, and a "bypass valve" at the pump outlet. Figure 8 is a picture of the VSEP pump station (New Logic Research, Inc., "VSEP Series L/P Operators Manual", page 10).

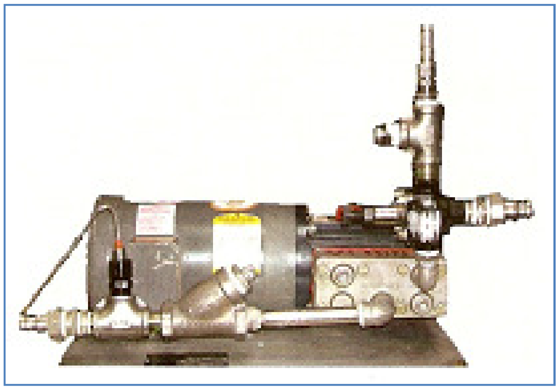


Figure 8: Pump Station

Chapter 4

Procedure

Procedure

The VSEP unit used in this study was a single membrane series LP VSEP system set up to operate in a batch mode. Figure 8 is a schematic of the test system (VSEP Series L/P Operators Manual). Immediately after the system was installed, two RO membranes were tested to determine which one would be used in the extended study. Both membranes were made by Hydronautics Inc., one identified as LFC (Low Fouling Composite), which is a thin-film composite with a molecular weight cutoff size (MWCO) of 30 Daltons (da) and the other identified as ESPA (energy-saving polyamide membrane), a composite polyamide with a MWCO of 40 da. Each membrane was tested for two hours using KBH concentrate as the feed water at a pressure at of 500 psi. The average instantaneous flow rates over the test hours were 78 ml/min and 52 ml/min for the ESPA and LFC membranes, respectively, so the ESPA membrane was selected for the pilot study.

Previous work had shown that concentrate recoveries of at least 70% were possible without precipitating anything from the concentrate. Therefore, in order to reduce the time required to process an entire batch of ten gallons of concentrate, the KBH concentrate was pre-concentrated in a seawater reverse osmosis unit (SWRO) by 25%-66% before it was put into the VSEP feed tank for further concentration. Sulfuric acid was added to the KBH concentrate to lower the pH to below 4.5, in order to eliminate the carbonates present in the water, before it was pretreated in the SWRO unit. During some of the test runs, the antiscalant Pre-treat Plus 0400 from King Lee technologies was added to inhibit precipitation of sulfates. A schematic of the pilot plant is shown in figure 9 (New Logic Research, Inc., "VSEP Series L/P Operators Manual", Figure 10).

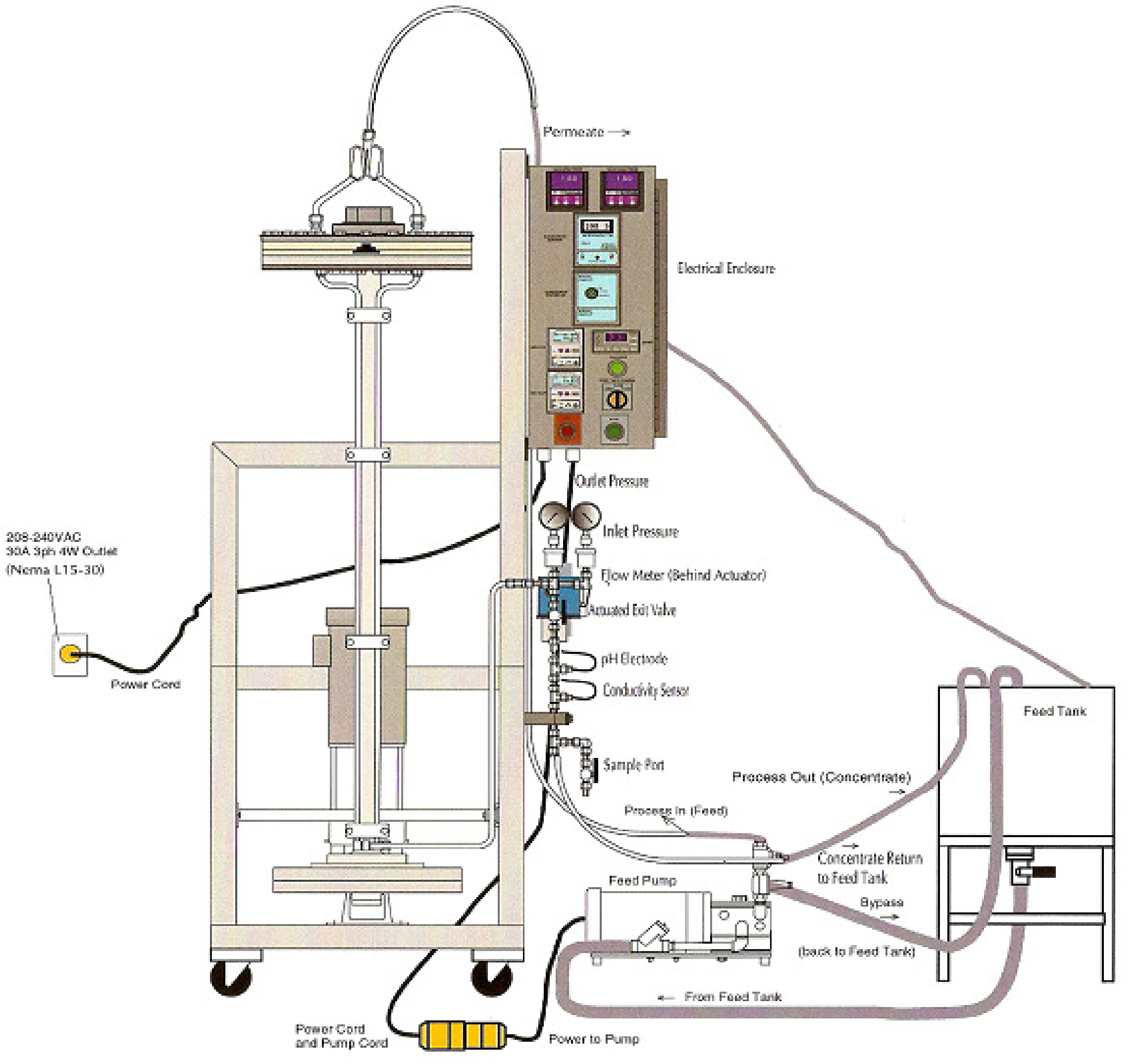


Figure 9: Schematic of Test System

The VSEP unit was tested at pressures between 800 and 900 psi under three different scenarios:

1) No suspended solids in the feed water at the beginning or at the end of a test run.
2) No suspended solids at the beginning of the run, but solids present at the end of a run as a result of precipitation.
3) Precipitated solids present at the beginning of a test run and at the end as a result of precipitation in the pretreatment SWRO unit.

Figure 10 shows a flow diagram of the procedure followed during this study. The results from each of these test conditions are presented in the next section.

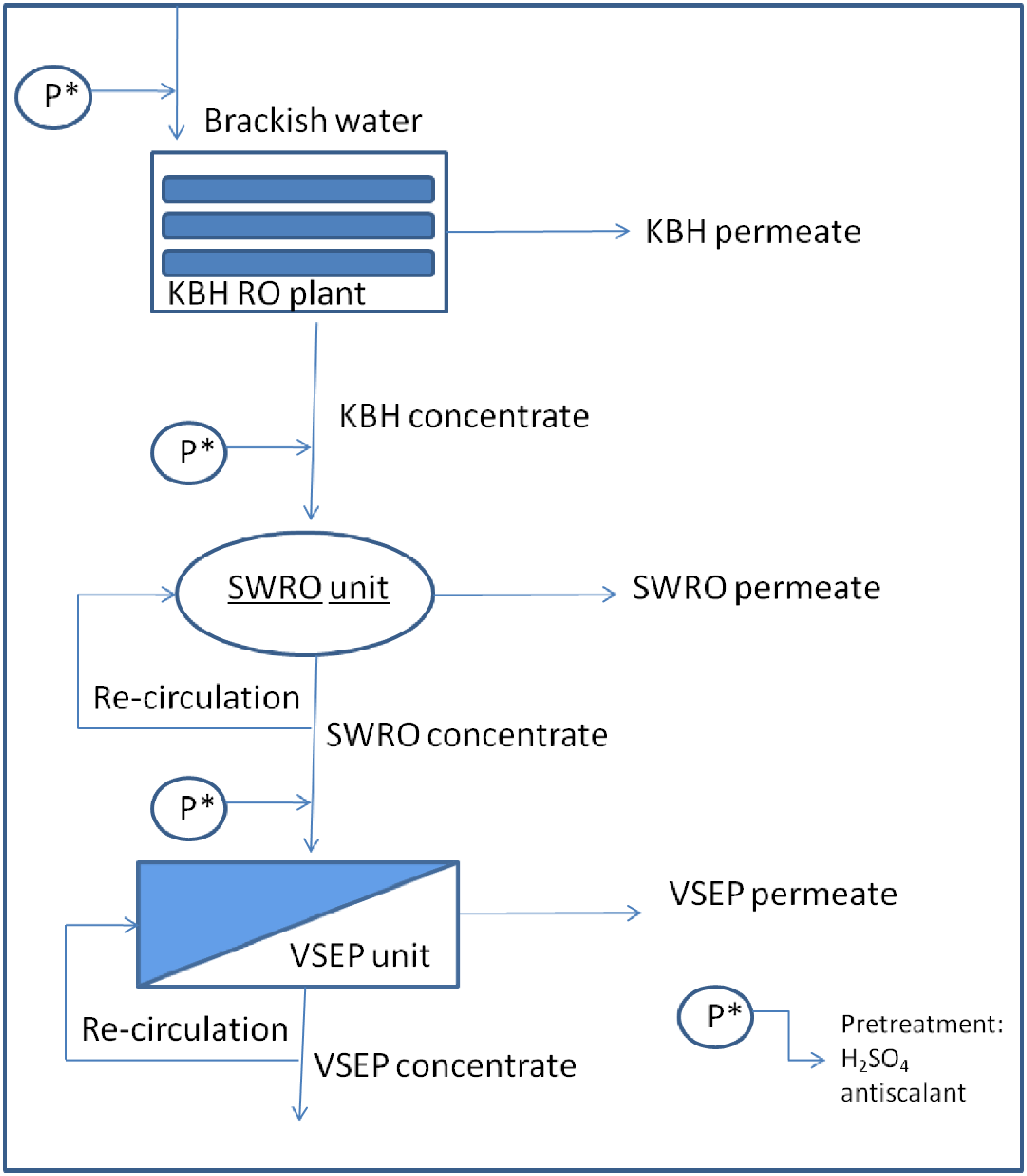


Figure 10: Flow Diagram of the Study Made Using VSEP Technology

Chapter 5

VSEP Test Results

VSEP Test Results

After the VSEP unit was set up and running, a representative from the manufacturer (New Logic Research) operated the unit for the first six days of testing. During that time, usually one batch of concentrate (at a pH just below 4.0 containing an antiscalant to inhibit calcium sulfate precipitation) was treated each day, and the recovery was gradually increased to 75%, where the concentrate conductivity reached about 80,000 µS/cm at the end of the run. There was a precipitate present (as evidenced by cloudiness in the solution) during only one of the runs (a run in which the antiscalant was not added). Samples of the precipitate were taken, dried, and analyzed in the scanning electron microscope to determine the solids concentration. Figure 11 shows the spectrum analysis of the precipitate. It can be seen that there is a large concentration of calcium and sulfur with a small amount of silicon, magnesium and chlorine. For that reason, a further analysis was made in the microscope to determine the weight percentage of the elements present in the precipitate. Figure 12 shows the results of the weight percentage analysis. The analysis shows that the elements with the highest concentration are calcium and sulfur. It can be assumed that the precipitate is primarily calcium sulfate, due to the high concentrations of sulfur and calcium, with a small amount of silica. Figure 13 is a picture of the solids seen at 60 micrometers on the microscope. The membrane was cleaned at the end of each run with a low pH cleaner (NLR 404) followed by a high pH cleaner (NLR 505), each for 45 minutes at approximately 40 ^{0}C. Following each cleaning, the instantaneous flux was checked using fresh water at a pressure of 500 psi, and it stayed at about 90 ml/min (68 gallons/ft^2-day) during the one week test period, indicating that there was no permanent fouling of the membrane. During all of the test runs, the instantaneous flux steadily decreased as the osmotic pressure of the concentrate increased, ending at about 10 ml/min (8 gallons/ft^2-day) at the end of the run.

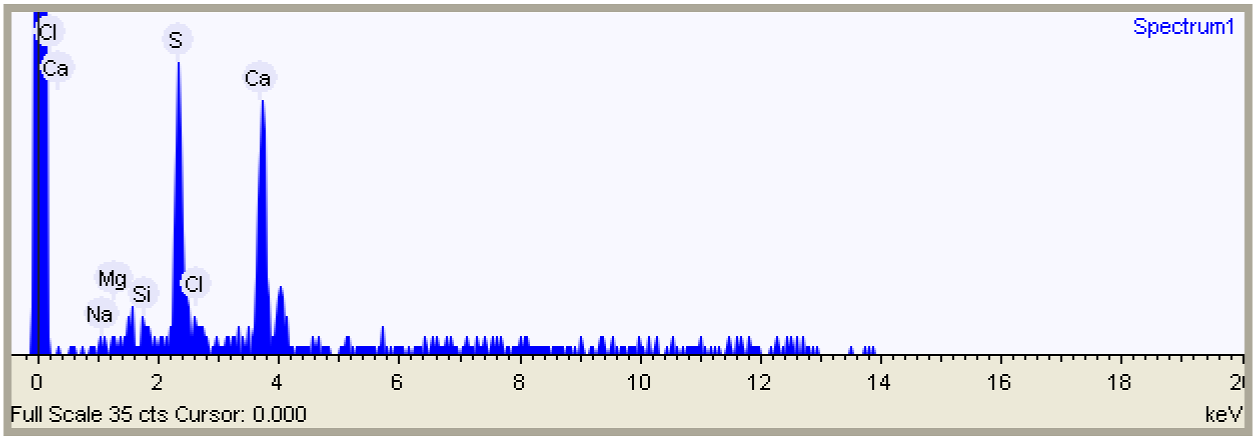


Figure 61: Spectrum Analysis of the Precipitate Present in the VSEP Concentrate

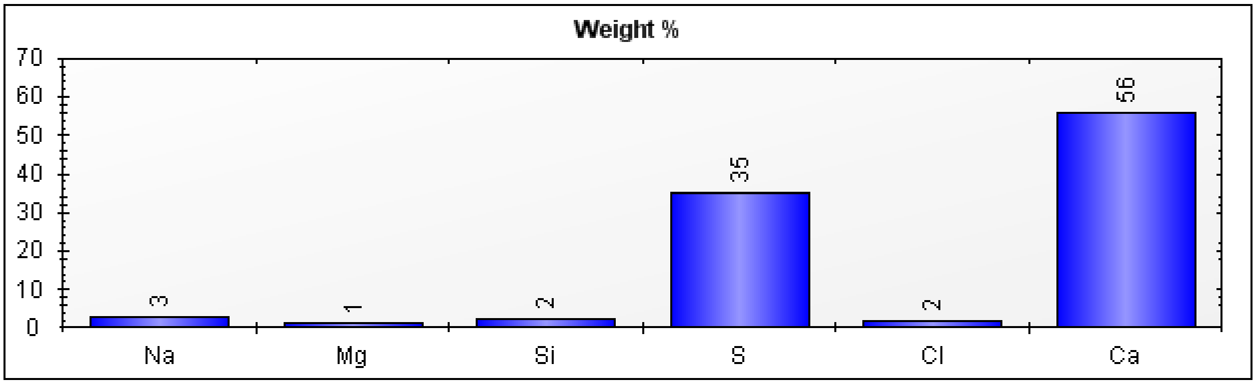


Figure 12: Concentration Analysis of the Precipitate Present in the VSEP Concentrate

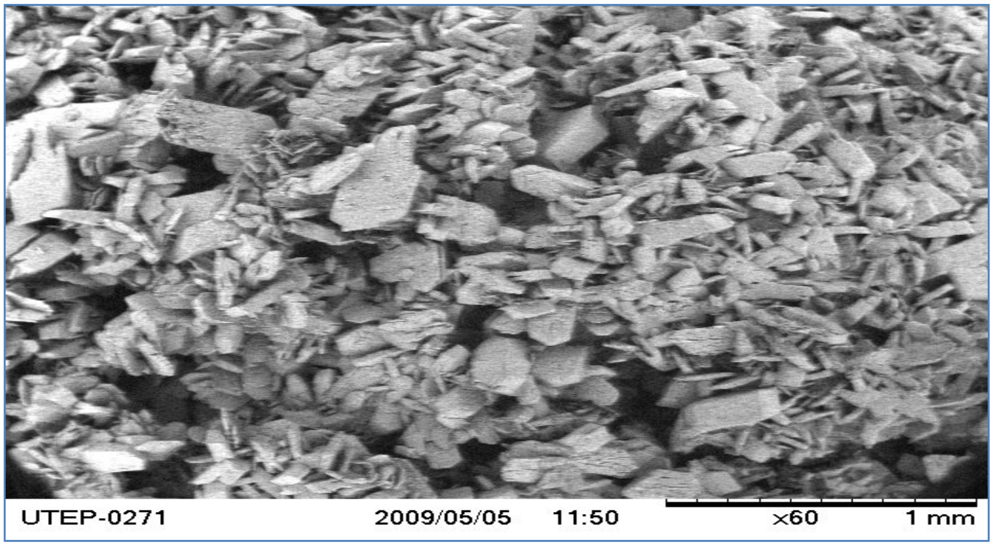


Figure 13: Precipitate Present in the Concentrate Seen at 60 Micrometers

After the initial tests were successfully completed, the VSEP system was tested under conditions wherein a precipitate was present either at the beginning of a test run or at sometime after the start of a run. The results of the first run are shown in Figure 14 (the raw data are in Table A -1 in Appendix A). The conductivity of the feed solution (i.e. RO concentrate from the KBH plant) was 19,700 µS/cm at the start of the run and it increased to almost 78,000 µS/cm when the test was stopped after 570 minutes at a recovery of about 75%. The flux at the start of the batch test was 68 ml/min (64 gallons/ft^2-day), but as the osmotic pressure of the feed solution increased, the flux decreased, ending at less than 13 gallons/ft^2-day when the test was stopped. The first precipitate was evident 520 minutes into the test, when the concentrate conductivity was 72,600 µS/cm, and by the time the test was over, the precipitate was a thick floc. The permeate flow rate did not appear to be affected by the precipitated solids in the feed water during the last 40 minutes of the run, as shown by the lower part of the permeate flow rate line. Even when the test was stopped, the flux at 13 ml/min was still almost 10 gallons/ft^2-day.

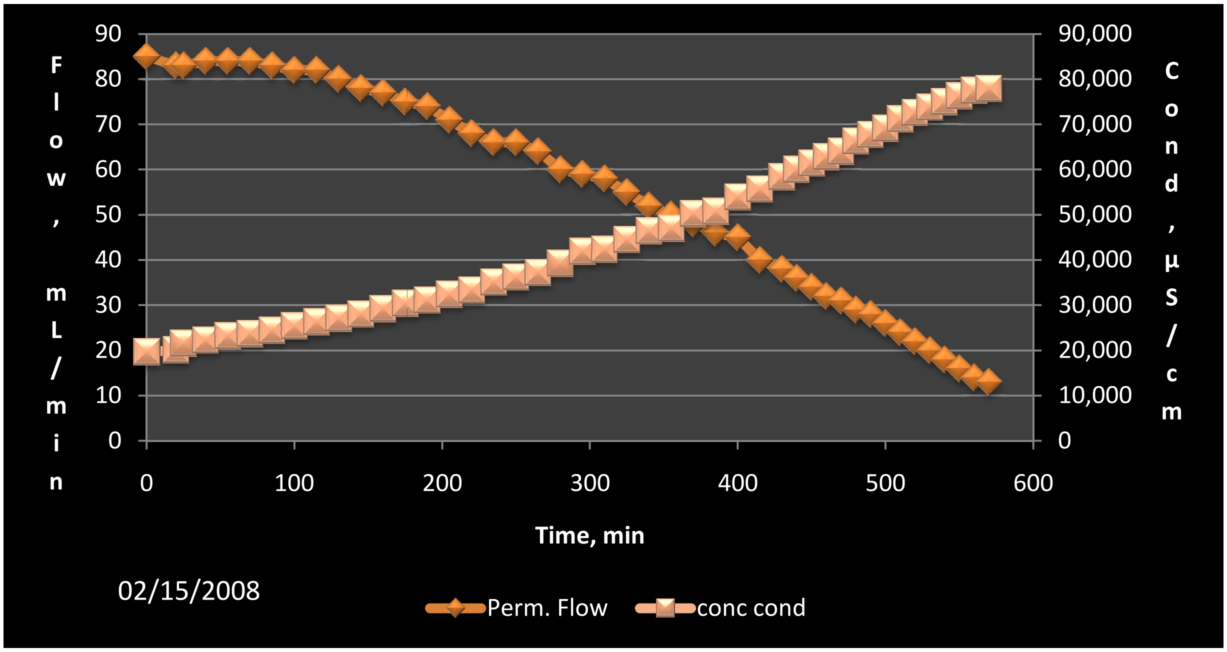


Figure 14: VSEP Perm Flow and Concentrate Conductivity vs Time

The next test run used KBH RO concentrate that was concentrated to 56,000 µS/cm (in a SWRO unit without antiscalant) to reduce the time required to get precipitation in the VSEP unit, but precipitation actually started *before* the concentrate was put into the feed tank of the VSEP unit. The concentrate was transferred to the VSEP feed tank as soon as possible and the SWRO unit was immediately flushed with RO permeate to prevent fouling of the membrane. Figure 15 shows the resulting permeate flows and concentrate conductivities plotted along with the flows and conductivities from the previous run wherein there was no precipitate in the feed water (until near the end of the run). The raw data are in Table A -2-in Appendix A. Since the run with *no precipitate* was started at a feed conductivity of 19,700 µS/cm while the run *with solids* was started at 56,200 µS/cm, the data were shifted by about five hours to get the concentrate conductivities to match up before they were plotted. The higher permeate flow rates at the beginning of the run when solids were present is probably because those flow rates occurred at the beginning of the run, which is a time when flow rates are typically higher because of the chemically cleaned membrane. The presence of solids in the feed water did not seem to have an effect on the permeate flow rate during this run, as shown by the similarity of the two permeate curves at similar concentrate conductivities near the middle of the run. The conductivities of the two concentrates were about the same, even though substances were precipitating from one of them, probably because the amount of ions precipitated from solution was small compared to the amount of ions present, so the difference was likely within the experimental error of the analysis.

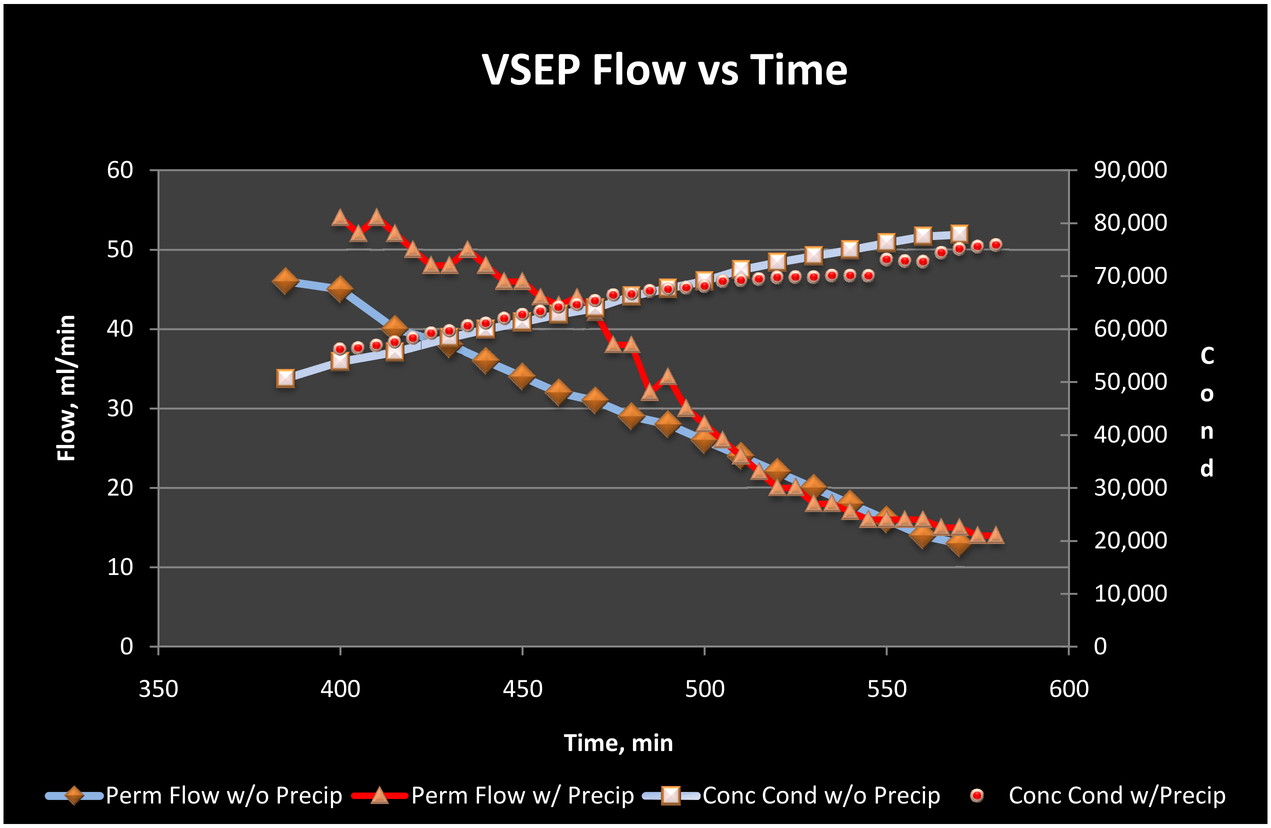


Figure 15: VSEP Permeate Flows with and without Precipitate at Start of Run

Additional tests were conducted using pre-concentrated KBH concentrate and the results are shown in Figure 16. The raw data are presented in Tables A-3, A-4, and A-5 in Appendix A. There was no precipitate in the concentrate at the beginning of each run, where the permeate flow was about 70 ml/min. Precipitation started at different points in each run (roughly at 40 minutes on 3/7, 115 minutes on 3/14, and 60 minutes on 3/21) because the conditions were somewhat different (i.e. different pHs and different initial concentrate conductivities).

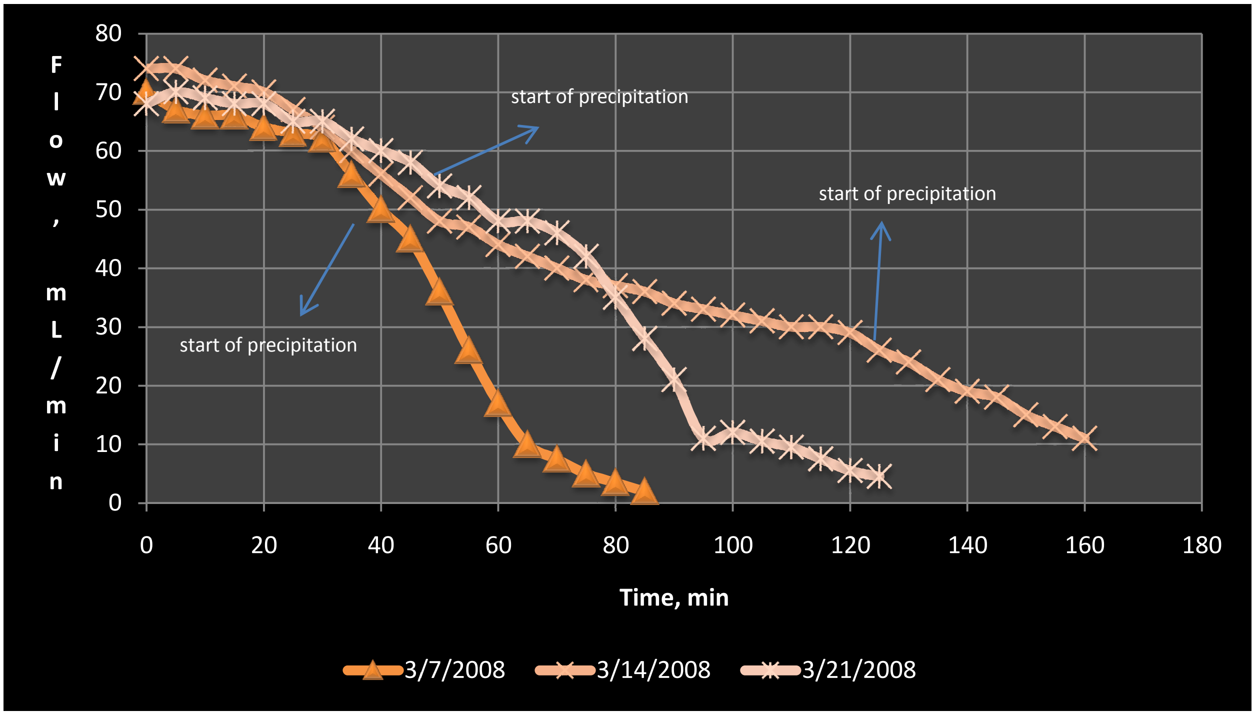


Figure 16: VSEP Permeate Flow Rate Before and After Precipitation Began

Once precipitation began, the flow rate decreased, but the treatment process continued for some time thereafter. At the end of each run, the membranes were chemically cleaned, and the cleaning appears to have been effective as evidenced by the approximate same permeate flow rate at the beginning of each run.

Other tests were conducted with the VSEP unit wherein solids collected from the precipitate of previous runs were added to pre-concentrated KBH concentrate and that solution was treated in the VSEP unit and, in general, the total run times were shortened as the solids concentration in the feed water increased. The membranes were flushed with permeate immediately after each run and in most cases, they were chemically cleaned. However, the instantaneous flow rate with fresh water (immediately after cleaning) slowly decreased as the testing progressed, and although the cleaning raised the flow rate above where it was prior to cleaning, the flow rate kept decreasing with time. Table 2 shows the clean water flow rates of the pilot unit after each run during the test period. By the end of the three-month pilot test period, the clean-water flow rate was about half of what it was when the testing was started. It is not known if the membrane got fouled because the cleaning protocol was not properly followed or if it was not cleaned frequently enough, but the clean-water flow rate definitely indicated that fouling had taken place. Overall, VSEP technology appears to be able to handle water that contains suspended solids, but frequent cleaning may be necessary to maintain an acceptable flux.

Table 2: Flow Rates after Every Test

Date	clean water flow rate	notes
March 7, 2008	45.00 mL/min	flushed after test
March 14, 2008	20.00 mL/min	flushed after test
March 21, 2008	15.00 mL/min	flushed after test
March 25, 2008	18.00 mL/min	no test
April 4, 2008	42.00 mL/min	rinse after test
April 11, 2008	9.00 mL/min	flushed after test
April 11, 2008	40.00 mL/min	cleaned with chemicals
May 2, 2008	150.00 mL/min	new membrane
May 9, 2008	13.00 mL/min	membrane fouled with $CaSO_4$

Chapter 6

Cost Analysis

Cost Analysis

After the VSEP tests were completed, the cost analysis was done for a large scale treatment system capable of treating the three million gallons of concentrate water produced by the KBH desalination plant every day. This analysis consisted of a comparison between all the expenses involved in the installation and operation of VSEP components against the income obtainable with the produced permeate. Table 3 shows the values used in calculating the cost of water using VSEP in a large scale process.

Table 3: Values Used in Calculating Cost of Water

ITEM	VALUE
Excavation & fence amortization time, yrs	20
Equipment life, years	20
Evaporation rate, ft/year*ft^2	4.1667
Excavation, $/yd	$0.11
Pond depth, ft	2
Liner cost, $/ft^2	$0.60
Fence, $/ft	$10.00
Membrane cost, $/ft^2	$45.00
Interest rate, %	5.00%
Water price, $/1000 gal	2.00
Antiscalant feed rate, lb/gal	4.16E-05
H_2SO_4 feed rate, ml/gal	1.00
NaOH feed rate, ml/gal	0.30
Antiscalant cost, $/9 lb gallon	$11.00
H_2SO_4 cost, $/gal	$2.53
NaOH cost, $/gal	$1.21

The VSEP concentrate produced during treatment cannot be disposed of via injection wells like the KBH concentrate. The VSEP concentrate has a dissolved solids concentration well above 10,000 mg/L, the maximum TDS concentration specified in the injection permit. For that reason, the VSEP concentrate was determined to be disposed of in an evaporation pond with an impermeable liner to avoid infiltration through the soil. The pond area is a function of the VSEP concentrate produced during treatment. For that reason, the area required to store the concentrate, if the recovery rates are low, will increase the cost significantly. The cost analysis includes different variables and expenses to be considered according to the recovery rates reached during treatment in order to obtain an accurate projection of the best scenario that can maximize productivity and still be cost effective. These variables can be divided into those involved in the treatment and those involved in the disposal. Figure 17 shows the variables taken in consideration in this analysis.

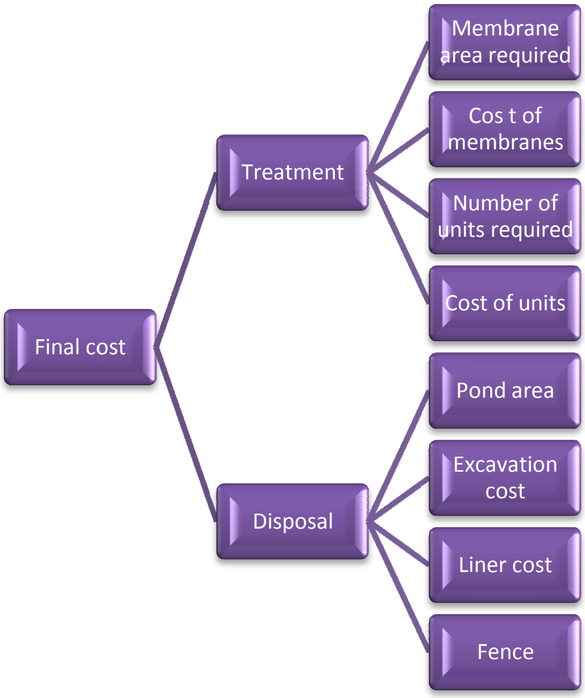


Figure 17: Variables Involved in the Cost Analysis

6.1 Membrane cost and unit selection

It was mentioned before that the cost analysis was made as a function of the recovery rates obtained during production. It is important to mention that the recovery rates are related to the permeate flow which is affected by the amount of solids dissolved in the water and the pressure needed for reverse osmosis to occur. Since the pressure was set at 900 psi, and the amount of solids is increasing constantly as more permeate is obtained, the permeate flux is reduced, increasing the membrane area required to treat the water. VSEP units have a constant membrane area and the only solution to this problem is increasing the number of units needed to treat such volume.

6.1.1 VSEP unit

The VSEP unit selected in this analysis is the i84 VSEP Filtration System. Each unit has a membrane area of 1500 ft^2 with a maximum operating temperature of 70^oC. Each unit has a cost of $220,000, and depending on the recovery rate of operation, at least 30 units are needed to treat the concentrate from the KBH plant. Figure 18 is a picture of the i84 VSEP filtration system (New Logic Research, Inc., “http://www.vsep.com/products/i84.html”, 12/15/2009).

6.1.2 VSEP membranes

The VSEP membrane selected in this project was the ESPA (energy-saving polyamide membrane) with a cost of $45 per ft^2 of membrane area. Each VSEP unit has a membrane area of 1500 ft^2 and the total area required to treat the water depends on the recovery rate of operation. Table 4 shows the membrane cost, the number of units needed, and the initial cost of the VSEP system (the raw data are in Table B-1 in appendix B).

Figure 18: Picture of the i84 VSEP System

6.2 Evaporation pond

Just as the membrane area required for this project is a function of the recovery rate, the evaporation pond that will receive the concentrate is similarly affected. The cost of excavation, the liner and the fence around the pond were calculated according to the expected volumes of concentrate produced with different recovery rates. It is easy to understand that as the recovery rates increase, the cost of the evaporation pond will decrease. However, the cost of operation may increase more than the cost of the pond decreases, rendering the total cost higher and, therefore, not cost effective. The pond has an estimated life of 20 years. Table 5 shows the cost analysis for the evaporation pond (the raw data are in Table B-1 in appendix B).

Table 4: Initial Cost for VSEP Units and Membranes

Flux, gal/day*ft^2	Recovery	Membrane cost	Total units	Units cost
63.15	4.4%	$2,137,613	32	$6,967,035
63.15	5.5%	$2,137,613	32	$6,967,035
63.92	8.8%	$2,112,165	31	$6,884,094
63.92	12.2%	$2,112,165	31	$6,884,094
63.92	15.5%	$2,112,165	31	$6,884,094
63.15	18.8%	$2,137,613	32	$6,967,035
62.39	22.1%	$2,163,681	32	$7,051,999
62.39	25.3%	$2,163,681	32	$7,051,999
60.87	28.5%	$2,217,773	33	$7,228,299
59.35	31.6%	$2,274,639	34	$7,413,640
58.59	34.7%	$2,304,180	34	$7,509,921
57.07	37.7%	$2,365,625	35	$7,710,185
56.31	40.7%	$2,397,593	36	$7,814,377
54.02	43.5%	$2,498,900	37	$8,144,562
51.74	46.3%	$2,609,145	39	$8,503,881
50.22	48.9%	$2,688,210	40	$8,761,574
50.22	51.5%	$2,688,210	40	$8,761,574
48.7	54.1%	$2,772,217	41	$9,035,373
45.65	56.6%	$2,957,031	44	$9,637,731
44.89	58.9%	$3,007,150	45	$9,801,083
44.13	61.2%	$3,058,998	45	$9,970,067
41.85	63.5%	$3,225,852	48	$10,513,889
39.57	65.6%	$3,411,959	51	$11,120,459
38.04	67.6%	$3,548,438	53	$11,565,278
36.52	69.5%	$3,696,289	55	$12,047,164
35	71.4%	$3,856,997	57	$12,570,954
34.24	73.2%	$3,942,708	58	$12,850,309
30.44	74.9%	$4,435,547	66	$14,456,597
28.91	76.4%	$4,668,997	69	$15,217,471
27.39	77.4%	$4,928,385	73	$16,062,886
25.87	78.3%	$5,218,290	77	$17,007,761
24.35	79.2%	$5,544,434	82	$18,070,747
23.59	80.0%	$5,723,286	85	$18,653,674

Table 5: Cost Analysis for the Evaporation Pond

Recovery	Disposable volume ft^3/year	Pond area ft^2	Amort excav,$/yr	Amort liner, $/yr	Amort fencing, $/yr
4.4%	139,807,289	33,553,481	$623,250	$1,615,451	$18,592
5.5%	138,205,411	33,169,033	$616,109	$1,596,941	$18,486
8.8%	133,370,827	32,008,742	$594,557	$1,541,079	$18,159
12.2%	128,507,293	30,841,504	$572,875	$1,484,881	$17,825
15.5%	123,643,760	29,674,265	$551,194	$1,428,684	$17,485
18.8%	118,809,176	28,513,974	$529,642	$1,372,821	$17,139
22.1%	114,032,491	27,367,579	$508,348	$1,317,627	$16,791
25.3%	109,284,756	26,228,132	$487,183	$1,262,768	$16,438
28.5%	104,594,920	25,102,580	$466,276	$1,208,578	$16,081
31.6%	100,020,883	24,004,820	$445,885	$1,155,725	$15,726
34.7%	95,533,694	22,927,903	$425,882	$1,103,877	$15,369
37.7%	91,133,354	21,871,830	$406,265	$1,053,031	$15,011
40.7%	86,819,863	20,836,600	$387,036	$1,003,190	$14,651
43.5%	82,622,170	19,829,162	$368,323	$954,686	$14,293
46.3%	78,598,175	18,863,411	$350,385	$908,189	$13,940
48.9%	74,718,929	17,932,399	$333,091	$863,365	$13,592
51.5%	70,897,581	17,015,283	$316,056	$819,210	$13,240
54.1%	67,134,132	16,112,063	$299,279	$775,724	$12,884
56.6%	63,544,381	15,250,530	$283,276	$734,245	$12,535
58.9%	60,099,378	14,423,735	$267,918	$694,439	$12,190
61.2%	56,712,275	13,610,837	$252,819	$655,301	$11,842
63.5%	53,440,969	12,825,730	$238,236	$617,502	$11,495
65.6%	50,343,362	12,082,310	$224,427	$581,710	$11,157
67.6%	47,390,502	11,373,630	$211,263	$547,590	$10,825
69.5%	44,553,441	10,692,740	$198,616	$514,808	$10,496
71.4%	41,832,178	10,039,642	$186,485	$483,364	$10,170
73.2%	39,197,764	9,407,388	$174,741	$452,924	$9,845
74.9%	36,737,048	8,816,821	$163,771	$424,491	$9,531
76.4%	34,478,979	8,274,889	$153,705	$398,399	$9,233
77.4%	33,050,798	7,932,128	$147,338	$381,897	$9,040
78.3%	31,699,817	7,607,895	$141,315	$366,286	$8,853
79.2%	30,426,034	7,302,190	$135,637	$351,568	$8,673
80.0%	29,210,151	7,010,380	$130,217	$337,519	$8,498

6.3 Energy cost, personnel cost, contingencies and chemicals

This analysis includes the cost of personnel, energy, contingencies and chemicals as needed. For the operation of the system, a group of six technicians is required. The salary was set at \$35,000 per year per employee, making a total of \$210,000 per year. An amount of \$200,000 was included to cover any contingencies that were not accounted for. The cost for chemicals includes sulfuric acid (H_2SO_4) and an antiscalant for pretreatment. These substances have a constant cost per year of \$731,929 and \$55,721, respectively. The VSEP permeate receives treatment with sodium hydroxide (NaOH) to increase the pH to a level that meets the EPA standards for drinking water. The amounts of NaOH to add depends on the volume of permeate produced by the system. It was estimated that one gallon of VSEP permeate needs 0.3 ml of NaOH. Table 6 shows the results of the cost analysis for the energy and NaOH needed.

6.4 Final cost, revenue, and water cost vs. water selling price

The final cost of the project is the sum of all the costs calculated before. The lowest cost of \$6.32 per 1000 gallons occurred at 73% recovery. To determine the cost effectiveness of this project, the revenue was calculated by multiplying the total permeate volume by the estimated selling price of \$2.00 per 1000 gallons. If the revenue and the total cost are compared, the net revenue can be calculated. If the net revenue is negative, the project cost must be compared against the cost of the current concentrate disposal method (i.e. injection) to determine its cost effectiveness. The last column in Table 7 shows the net cost of the process at different recovery rates. The lowest net cost of -\$3,461,115 per year occurs at a recovery of 73%. Thus, compared with the estimated $1,500,000 cost per year for injecting the concentrate, the VSEP system appears to be cost-prohibitive.

Table 6: Energy and NaOH Cost

Recovery	NaOH cost, $/year	Energy cost	Recovery	NaOH cost, $/year	Energy cost
4.4%	$4,655	$40,772	**51.5%**	$54,122	$474,037
5.5%	$5,805	$50,844	**54.1%**	$56,824	$497,699
8.8%	$9,275	$81,241	**56.6%**	$59,400	$520,269
12.2%	$12,767	$111,820	**58.9%**	$61,873	$541,930
15.5%	$16,258	$142,399	**61.2%**	$64,305	$563,226
18.8%	$19,729	$172,796	**63.5%**	$66,653	$583,794
22.1%	$23,158	$202,829	**65.6%**	$68,877	$603,270
25.3%	$26,566	$232,680	**67.6%**	$70,997	$621,836
28.5%	$29,932	$262,167	**69.5%**	$73,033	$639,674
31.6%	$33,216	$290,926	**71.4%**	$74,987	$656,783
34.7%	$36,437	$319,139	**73.2%**	$76,878	$673,347
37.7%	$39,596	$346,806	**74.9%**	$78,644	$688,819
40.7%	$42,692	$373,927	**76.4%**	$80,265	$703,016
43.5%	$45,705	$400,319	**77.4%**	$81,290	$711,996
46.3%	$48,594	$425,620	**78.3%**	$82,260	$720,490
48.9%	$51,379	$450,010	**79.2%**	$83,174	$728,499
			80.0%	$84,047	$736,143

Table 7: Final Cost and Net Revenue

Recovery	Total Permeate, gpd	Total cost	Water Cost, $/1000 gal	Revenue, $/yr	Net Revenue, $/yr	Net water cost, $/1000 gal
25.3%	758,905	$4,583,678	$16.55	$554,001	-$4,029,677	$14.55
28.5%	855,079	$4,575,087	$14.66	$624,208	-$3,950,880	$12.66
31.6%	948,879	$4,569,285	$13.19	$692,681	-$3,876,604	$11.19
34.7%	1,040,897	$4,547,084	$11.97	$759,855	-$3,787,229	$9.97
37.7%	1,131,135	$4,545,722	$11.01	$825,728	-$3,719,994	$9.01
40.7%	1,219,591	$4,526,609	$10.17	$890,301	-$3,636,307	$8.17
43.5%	1,305,673	$4,552,135	$9.55	$953,141	-$3,598,994	$7.55
46.3%	1,388,193	$4,584,852	$9.05	$1,013,381	-$3,571,472	$7.05
48.9%	1,467,744	$4,599,273	$8.59	$1,071,453	-$3,527,820	$6.59
51.5%	1,546,108	$4,564,500	$8.09	$1,128,659	-$3,435,841	$6.09
54.1%	1,623,285	$4,583,063	$7.74	$1,184,998	-$3,398,065	$5.74
56.6%	1,696,900	$4,666,579	$7.53	$1,238,737	-$3,427,843	$5.53
58.9%	1,767,546	$4,666,716	$7.23	$1,290,309	-$3,376,407	$5.23
61.2%	1,837,005	$4,668,457	$6.96	$1,341,014	-$3,327,443	$4.96
63.5%	1,904,090	$4,743,552	$6.83	$1,389,985	-$3,353,566	$4.83
65.6%	1,967,612	$4,832,325	$6.73	$1,436,357	-$3,395,968	$4.73
67.6%	2,028,166	$4,891,204	$6.61	$1,480,561	-$3,410,643	$4.61
69.5%	2,086,346	$4,958,281	$6.51	$1,523,032	-$3,435,248	$4.51
71.4%	2,142,150	$5,034,487	$6.44	$1,563,770	-$3,470,717	$4.44
73.2%	2,196,174	$5,064,322	$6.32	$1,603,207	-$3,461,115	$4.32
74.9%	2,246,636	$5,351,711	$6.53	$1,640,044	-$3,711,666	$4.53
76.4%	2,292,942	$5,477,853	$6.55	$1,673,848	-$3,804,005	$4.55
77.4%	2,322,230	$5,627,883	$6.64	$1,695,228	-$3,932,656	$4.64
78.3%	2,349,934	$5,797,803	$6.76	$1,715,452	-$4,082,351	$4.76
79.2%	2,376,055	$5,991,208	$6.91	$1,734,520	-$4,256,688	$4.91
80.0%	2,400,989	$6,092,533	$6.95	$1,752,722	-$4,339,811	$4.95
80.8%	2,424,736	$6,330,102	$7.15	$1,770,057	-$4,560,045	$5.15
81.6%	2,447,296	$6,457,408	$7.23	$1,786,526	-$4,670,882	$5.23
82.3%	2,468,668	$6,754,323	$7.50	$1,802,127	-$4,952,196	$5.50
83.0%	2,488,456	$7,103,020	$7.82	$1,816,573	-$5,286,446	$5.82
83.6%	2,506,662	$7,517,428	$8.22	$1,829,863	-$5,687,565	$6.22
84.1%	2,523,285	$8,017,051	$8.70	$1,841,998	-$6,175,053	$6.70
84.6%	2,538,325	$8,630,059	$9.31	$1,852,977	-$6,777,082	$7.31
85.1%	2,551,781	$9,398,707	$10.09	$1,862,800	-$7,535,907	$8.09
85.5%	2,563,654	$10,389,396	$11.10	$1,871,468	-$8,517,928	$9.10
85.8%	2,574,340	$10,997,537	$11.70	$1,879,268	-$9,118,269	$9.70

Conclusions

Conclusions

These studies have shown that VSEP technologies have excellent recovery rates for water that conventional RO systems will not be able to treat. The capability of VSEP to maintain filtration even when high concentrations of suspended solids are present in the water is excellent. According to the tests made in March of 2008 (Figure 15), the precipitation of dissolved solids during treatment, due to super saturation, does not affect the permeate flow. Test results showed that VSEP can work with suspended solids present in the water before treatment with no apparent change in the permeate flow (Figure 14). These results showed the capability of VSEP to work under conditions that most RO systems will not be able work at all.

The recovery rates achieved during testing showed that 80% of the KBH concentrate can be recovered using a VSEP system. The KBH plant produces an average of 3 million gallons every day. With these results, an approximate amount of 2.4 million gallons of fresh water can be recovered from the concentrate to help meet El Paso’s water demand.

Even though the VSEP tests showed excellent results, the main factor that affects the viability of a VSEP system for treating the KBH concentrate is the cost effectiveness. According to the cost analysis results, it would not be profitable to recover water from the KBH concentrate with VSEP technology because of the high cost of production. The analysis showed that in order to produce water, the lowest cost is obtained at 73% recovery (Table 7). The lowest cost obtainable is $6.31 per 1000 gallons. If the final cost is compared with the selling price of $2.00, it is clear that is too expensive to produce water and that the investment will not be recovered at any point. The factors that increase the cost considerably are the high cost of membranes, the small membrane area per VSEP unit, thereby requiring many units, and the large amount of energy required to operate at efficient flow rates.

The cost of VSEP membranes is more than ten times greater than conventional RO membranes, with a price of \$45 per ft^2 of membrane (Table 3).

The small membrane area per unit is a factor that increases the final cost. The VSEP system with the highest membrane area has a membrane surface area of 1,500 ft^2. Compared with other RO systems, VSEP has a small membrane area, which is inconvenient when large amounts of water have to be treated like in the case of the KBH plant. The final cost increases when more water needs to be treated because more VSEP units are needed. The lowest cost reached in this study, with a cost of \$6.31 per 1000 gallons and a recovery rate of 73% (Table 7), would require 58 VSEP units. With a cost of \$220,000 per VSEP unit, it makes the final cost prohibitively expensive.

Despite the excellent performance of VSEP, the cost to use this technology renders it unattractive in the application tested here.

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Appendix A

Table A-1

Time, min	Flow, ml/min	Conccentrate Conductivity	pH	
160	77	29,200	3.60	
175	75	30,400	3.64	
190	74	31,100	3.69	
205	71	32,400	3.72	
220	68	33,300	3.76	
235	66	35,100	3.81	
250	66	36,200	3.84	
265	64	37,200	3.88	
280	60	39,300	3.95	
295	59	41,900	3.99	
310	58	42,300	4.02	
325	55	44,500	4.08	
340	52	46,400	4.13	
355	50	47,000	4.18	
370	48	50,200	4.22	
385	46	50,700	4.25	
400	45	53,900	4.28	
415	40	55,700	4.31	
430	38	58,400	4.37	
440	36	60,000	4.39	
450	34	61,400	4.40	
460	32	62,800	4.41	
470	31	64,000	4.43	
480	29	66,300	4.48	
490	28	67,700	4.50	**silica = 660, 730 mg/L = 700 mg/L**
500	26	69,100	4.53	
510	24	71,200	4.57	
520	22	72,600	4.60	slight turbidity evident in conc
530	20	73,800	4.64	
540	18	75,000	4.69	definite turbidity
550	16	76,300	4.74	very turbid
560	14	77,500	4.79	nice floc; can't see stirring bar
570	13	77,900	4.84	
Init vol of conc = 10 gal per cleaning tank (actual vol slightly more)				
Initial pH = 3.30				
Stopped unit at 7:20 pm (570 minutes after start)				
Final mixed perm cond = 1040 uS/cm; pH = 3.36				
Final perm volume = 8.29 gal; final conc volume = 1.32 gal				
Next test: Start w/ 50,000 uS/cm concentrate				

Table A-2

Note: Conc had already precipitated in SWRO before it was put in VSEP						
Time,min	**Pressure**	**Flow, ml/min**	**Conc Cond**	**pH**	**Time, min**	**Flow, ml/min**
0	900	54	56200	5.07	0	93
5	900	52	56400	5.13	20	90
10	900	54	56900	5.26	35	90
15	900	52	57500	5.35	50	89
20	900	50	58300	5.47	65	88
25	900	48	59200	5.54	80	86
30	900	48	59600	5.63	95	84
35	900	50	60600	5.68	110	83
40	900	48	61100	5.73	125	79
45	900	46	62000	5.76	140	75
50	900	46	62700	5.78	155	74
55	900	44	63300	5.79	170	72
60	900	43	64100	5.79	180	70
65	900	44	64600	5.79	195	68
70	900	42	65300	5.79	210	66
75	900	38	66400	5.77	225	63
80	900	38	66600	5.76	240	62
85	900	32	67200	5.76	285	54
90	900	34	67500	5.75	300	56
95	900	30	67800	5.73	315	50
100	900	28	68100	5.73	330	47
105	900	26	69000	5.72	345	46
110	900	24	69200	5.71	360	45
115	900	22	69400	5.72	375	41
120	900	20	69700	5.72	390	37
125	900	20	69800	5.72	405	34
130	900	18	69800	5.72	420	33
135	900	18	70100	5.73	435	29
140	900	17	70100	5.73	450	26
145	900	16	70000	5.73	465	22
150	900	16	73100	5.72	480	18
155	900	16	72800	5.74	495	18
160	900	16	72700	5.73	510	14
165	900	15	74400	5.72	525	11
170	900	15	75100	5.73		
175	900	14	75500	5.74		
180	900	14	75800	5.74		

Table A-3

Constant Pressure @ 900 psi

Init vol of conc = 15,000 ml; Final vol conc = 10,750 ml; Perm vol = 3580 ml

VSEP flow @300 psi after flushing = 45 ml/min

time, min	flow, ml/min	conc cond	pH	
0	70	39800	5.72	
5	67	40800	3.33	
10	66	41600	3.35	
15	66	42100	3.38	
20	64	43300	3.40	
25	63	44000	3.43	
30	62	44400	3.45	
35	56	45300	3.47	
40	50	45800	3.48	maybe precipitate
45	45	46500	3.49	
50	36	46800	3.49	slight cloudiness
55	26	47300	3.51	cloudiness evident
60	17	47400	3.52	
65	10	47600	3.52	definite precipitate
70	7.5	47600	3.52	
75	5	48000	3.52	
80	3.5	48100	3.52	
85	2	48400	3.52	

Table A-4

Constant pressure @ 900 psi

time, min	flow, ml/min	conc cond	pH	temp
0	74	39900	6.84	
5	74	39900	6.93	
10	72	41100	7.04	
15	71	41800	7.12	
20	70	42600	7.17	
25	67	43200	7.18	
30	64	44100	7.19	
35	60	44600	7.2	
40	56	45500	7.22	
45	52	46100	7.23	
50	48	47300	7.26	
55	47	47600	7.27	
60	44	48200	7.3	
65	42	48800	7.32	
70	40	49300	7.34	
75	38	50000	7.36	
80	37	50600	7.38	
85	36	51200	7.4	
90	34	52000	7.42	
95	33	52400	7.43	
100	32	52900	7.45	
105	31	53700	7.45	
110	30	53900	7.48	
115	30	54500	7.49	
120	29	55000	7.5	
125	26	55700	7.5	
130	24	56000	7.51	
135	21	56200	7.52	possible precipitate
140	19	56800	7.52	
145	18	57100	7.53	little cloudy
150	15	57900	7.53	
155	13	58200	7.54	
160	11	58550	7.54	

Final conc not too cloudy- only slightly

Final conc volume = 7500 ml (1.98 gal); Final Perm volume = 6640 ml (1.75 gal)

VSEP perm flow using KBH perm after flushing = 20 ml/min----bad

Note: pH was highest yet. pH on 2/29 was between 5 & 6 and that was longest run (but precipitate was at t=0)

pH on 3/7 was below 4 and that was shortest run

Table A-5

time, min	flow, ml/min	conc cond	pH	Turb	
0	68	44800	6.76	0	
5	70	45200	6.95	0	
10	69	45500	7.05	0	
15	68	46100	7.13	0	
20	68	46400	7.19	0	
25	65	46900	7.24	0	
30	65	47700	7.27	0	
35	62	48200	7.32	0	
40	60	49200	7.36	0	
45	58	50000	7.42	0.2	
50	54	50600	7.45	0.3	
55	52	51100	7.49	0.5	
60	48	51800	7.52	0.6	
65	48	52400	7.53	1	
70	46	52900	7.57	2.2	
75	42	53400	7.59	3.2	
80	35	54100	7.60	4.6	
85	28	54400	7.62	5.2	
90	21	54700	7.65	5.4	
95	11	55200	7.66	5.2	Feed Flow fluctuating between 2-4 gpm
100	12	55900	7.70	4.8	
105	10.5	55700	7.70	4.2	
110	9.5	55700	7.71	3.8	
115	7.5	55400	7.73	3.3	Cond Meter not functioning properly
120	5.5	55500	7.74	2.9	
125	4.5	55800	7.76	2.2	
Final perm vol = 5200 ml; Final conc vol = 11000 ml					
Note: approx 1-1.5 gal of RO-1 conc was in tank when conc from SWRO was added					
Perm flow after flushing was 15 mL/min at 300 psi; 4 days later it was 18 ml/min					
Perm flow after chemical cleaning = 48 ml/min at 300 psi and 25 C					
Silica in conc 4 days later (on 3/25) = 140, 150, 140 mg/L					

Table A-6

Start w/ 15,000 ml SWRO conc; Constant pressure @ 900 psi					
Added 800 ml of precipitate from 3/21/08 (light & fluffy)					
time, min	**flow, ml/min**	**conc cond**	**Temp, C**	**pH**	**Turb**
0	56	54300	28.2	3.56	3.5
5	55	54700	30.1	3.58	3
10	54	55200	31.1	3.62	3.2
15	52	56000	31.5	3.64	3.2
20	48	56500	31.9	3.65	3.6
25	42	57000	32.1	3.65	4.2
30	38	57500	32.2	3.67	4.6
35	35	58200	32.4	3.68	6.6
40	31	58500	31.6	3.67	38
45	30	59200	32.7	3.68	95
50	27	59400	32.7	3.70	160
55	24	59600	32.7	3.69	780
60	20	59700	32.4	3.67	740
65	17.5	59900	32.7	3.67	800
70	16	59700	32.7	3.66	800
75	15	59700	32.7	3.67	780
80	13.5	59700	32.7	3.67	770
85	13	59900	32.5	3.67	770
90	12.5	60100	32.7	3.68	780
95	12.5	60200	32.8	3.68	770
100	12.5	60400	32.7	3.68	760
105	12	60600	32.5	3.69	760
110	11	60800	32.7	3.69	740
115	11.7	61100	32.8	3.70	750
120	11.5	61200	33.0	3.70	790
125	11.2	61500	33.0	3.70	780
130	11	61600	33.0	3.71	760
135	11	61800	33.1	3.72	730
140	10	61900	33.2	3.72	720
145	9.5	62100	33.0	3.72	740
11000 mL of Concentrate					
3,500 mL of Permeate					
After rinsing, flow was 42 mL/min @300psi, Temp 26					
TDS (oven dried) *mixed* sample = 48890, 48590					
TDS (oven dried) *settled* sample = 45020, 45293					

Table A-7

Start w/ 15,000 ml SWRO conc; Init cond = 54200 uS/cm						
Added 400 ml of precipitate from 4/4/08 (pretty thick); pressure = 900 psi						
Time	**elapsed time, min**	**flow, ml/min**	**conc cond**	**Temp, C**	**pH**	**Turb**
9;35	0	54	54800	28.9	3.77	
9:40	5	52	54700	30.8	5.95	0.4
9:45	10	50	54800	32.1	6.19	
9:50	15	47	55000	33.1	6.23	
9:55	20	42	55400	33.3	6.53	
10:00	25	40	55800	33.5	6.6	
10:05	30	34	56100	33.7	6.61	
10:10	35	30	56400	33.9	6.73	
10:15	40	26	57200	34.3	6.77	
10:20	45	19	57400	34.3	6.82	
10:25	50	16	57700	33.5	6.85	
10:30	55	14	58100	33.1	6.85	
10:35	60	11.7	58700	33.2	6.86	
10:40	65	10.5	58300	33.2	6.88	
10:45	70	9.25	58300	33.1	6.89	
10:50	75	8.5	58900	33.1	6.9	
10:55	80	7.8	58700	33	6.95	
11:00	85	6.9	58900	32.9	6.97	
Vol conc = 12540 mL; vol perm = 2086 mL						
Perm flow after flush = 9 mL/min; after chem clean = 40 ml/min @300 psi and 25 C						
Feed turbidity (samples taken to UTEP)						
Time	**Turb**					
9:45	2410					
10:25	1733					
10:30	1883					
10:35	1662					
10:40	1806					
10:45	1543					
10:50	1640					

Table A-8

Constant pressure @ 900 psi				
10 gals				
Cond= 11,990		New NE-90 membrane		
time, min	**flow, ml/min**	**perm cond**	**con cond**	**pH**
0	352	852	11550	7.82
5	332	782	12270	7.9
10	304	804	12460	7.81
15	302	630	13460	8.02
20	284	803	14000	7.96
25	264	694	14590	8.02
30	248	894	15090	8.05
35	232	815	15710	8.11
40	220	738	16170	8.11
45	210	793	16740	8.11
50	192	780	17180	8.12
55	180	815	17660	8.12
60	168	806	18330	8.12
65	148	869	18810	8.15
70	137	889	19410	8.16
75	118	937	21200	8.16
80	110	984	21600	8.18
85	102	998	22000	8.19
90	86	998	22800	8.23
95	84	1131	23300	8.25
100	72	1160	24100	8.26
105	62	1197	24600	8.28
110	52	1242	25300	8.31
115	44	1246	25800	8.3
Concentrate = 7,000 mL				
Perm= 6 gal				
Perm flow after flushing 150 mL/min @ 300 psi temp=25				

Table A-8

Constant pressure @ 900 psi					
Initial Vol=1475 mL					
Initial Cond= 51,000 (from SWRO)					
Added solid CaSO4 (from Home Depot) to Concentrate					
time, min	**flow, ml/min**	**perm cond**	**con cond**	**pH**	**turb**
0	134.0	3980	44600	6.1	8.0
5	128.0	3270	45600	6.29	8.0
10	100.0	3460	46900	6.72	7.0
15	58.0	3670	47800	6.84	6.6
20	32.0	3840	48100	6.92	6.2
25	20.0	3740	48600	6.99	5.8
30	14.5	3760	48900	7.06	5.6
35	12.0	3740	49100	7.12	5.2
40	10.5	3680	49200	7.17	5.0
45	9.5	3610	49400	7.22	4.5
50	9.0	3820	49400	7.25	4.5
Concentrate Vol = 11,350 mL					
Perm Vol= 2,250 mL					
Perm flow after flushing 13 mL/min @ 300 psi temp=25					

Appendix B

Table B-1

Time, min	Flow, ml/min	Flux, gal/day*ft²	Volume	Sum	Recovery	Total volume (gal)
0	85	64.68	0	0.00	0.00%	3000000.00
20	83	63.15	1680	1680.00	4.43%	3000000.00
25	83	63.15	415	2095.00	5.53%	3000000.00
40	84	63.92	1252.5	3347.50	8.83%	3000000.00
55	84	63.92	1260	4607.50	12.16%	3000000.00
70	84	63.92	1260	5867.50	15.48%	3000000.00
85	83	63.15	1252.5	7120.00	18.79%	3000000.00
100	82	62.39	1237.5	8357.50	22.05%	3000000.00
115	82	62.39	1230	9587.50	25.30%	3000000.00
130	80	60.87	1215	10802.50	28.50%	3000000.00
145	78	59.35	1185	11987.50	31.63%	3000000.00
160	77	58.59	1162.5	13150.00	34.70%	3000000.00
175	75	57.07	1140	14290.00	37.70%	3000000.00
190	74	56.31	1117.5	15407.50	40.65%	3000000.00
205	71	54.02	1087.5	16495.00	43.52%	3000000.00
220	68	51.74	1042.5	17537.50	46.27%	3000000.00
235	66	50.22	1005	18542.50	48.92%	3000000.00
250	66	50.22	990	19532.50	51.54%	3000000.00
265	64	48.70	975	20507.50	54.11%	3000000.00
280	60	45.65	930	21437.50	56.56%	3000000.00
295	59	44.89	892.5	22330.00	58.92%	3000000.00
310	58	44.13	877.5	23207.50	61.23%	3000000.00
325	55	41.85	847.5	24055.00	63.47%	3000000.00
340	52	39.57	802.5	24857.50	65.59%	3000000.00
355	50	38.04	765	25622.50	67.61%	3000000.00
370	48	36.52	735	26357.50	69.54%	3000000.00
385	46	35.00	705	27062.50	71.41%	3000000.00
400	45	34.24	682.5	27745.00	73.21%	3000000.00
415	40	30.44	637.5	28382.50	74.89%	3000000.00
430	38	28.91	585	28967.50	76.43%	3000000.00
440	36	27.39	370	29337.50	77.41%	3000000.00
450	34	25.87	350	29687.50	78.33%	3000000.00
460	32	24.35	330	30017.50	79.20%	3000000.00
470	31	23.59	315	30332.50	80.03%	3000000.00

Table B-1 Cont.

Membrane area per unit ft^2	Total membrane area ft^2	Membrane cost	Cost per unit	Total units	Total cost
1500.00	46384.80	$2,087,316.18	$220,000.00	31	$6,803,104.58
1500.00	47502.51	$2,137,612.95	$220,000.00	32	$6,967,034.81
1500.00	47502.51	$2,137,612.95	$220,000.00	32	$6,967,034.81
1500.00	46937.00	$2,112,165.18	$220,000.00	31	$6,884,093.92
1500.00	46937.00	$2,112,165.18	$220,000.00	31	$6,884,093.92
1500.00	46937.00	$2,112,165.18	$220,000.00	31	$6,884,093.92
1500.00	47502.51	$2,137,612.95	$220,000.00	32	$6,967,034.81
1500.00	48081.81	$2,163,681.40	$220,000.00	32	$7,051,998.64
1500.00	48081.81	$2,163,681.40	$220,000.00	32	$7,051,998.64
1500.00	49283.85	$2,217,773.44	$220,000.00	33	$7,228,298.61
1500.00	50547.54	$2,274,639.42	$220,000.00	34	$7,413,639.60
1500.00	51204.00	$2,304,180.19	$220,000.00	34	$7,509,920.63
1500.00	52569.44	$2,365,625.00	$220,000.00	35	$7,710,185.19
1500.00	53279.84	$2,397,592.91	$220,000.00	36	$7,814,376.88
1500.00	55531.10	$2,498,899.65	$220,000.00	37	$8,144,561.82
1500.00	57981.00	$2,609,145.22	$220,000.00	39	$8,503,880.72
1500.00	59738.01	$2,688,210.23	$220,000.00	40	$8,761,574.07
1500.00	59738.01	$2,688,210.23	$220,000.00	40	$8,761,574.07
1500.00	61604.82	$2,772,216.80	$220,000.00	41	$9,035,373.26
1500.00	65711.81	$2,957,031.25	$220,000.00	44	$9,637,731.48
1500.00	66825.56	$3,007,150.42	$220,000.00	45	$9,801,082.86
1500.00	67977.73	$3,058,997.84	$220,000.00	45	$9,970,067.05
1500.00	71685.61	$3,225,852.27	$220,000.00	48	$10,513,888.89
1500.00	75821.31	$3,411,959.13	$220,000.00	51	$11,120,459.40
1500.00	78854.17	$3,548,437.50	$220,000.00	53	$11,565,277.78
1500.00	82139.76	$3,696,289.06	$220,000.00	55	$12,047,164.35
1500.00	85711.05	$3,856,997.28	$220,000.00	57	$12,570,954.11
1500.00	87615.74	$3,942,708.33	$220,000.00	58	$12,850,308.64
1500.00	98567.71	$4,435,546.88	$220,000.00	66	$14,456,597.22
1500.00	103755.48	$4,668,996.71	$220,000.00	69	$15,217,470.76
1500.00	109519.68	$4,928,385.42	$220,000.00	73	$16,062,885.80
1500.00	115962.01	$5,218,290.44	$220,000.00	77	$17,007,761.44
1500.00	123209.64	$5,544,433.59	$220,000.00	82	$18,070,746.53
1500.00	127184.14	$5,723,286.29	$220,000.00	85	$18,653,673.84

Table B-1 Cont.

Disposable volume ft^3/year	Pond area ft^2	Storage volume	Pond cost	Liner cost $/$ft^2$
146292000.00	35109799.12	73146000	$8,127,333.33	$21,065,879.47
139807288.65	33553480.85	69903644.3	$7,767,071.59	$20,132,088.51
138205410.55	33169033.18	69102705.3	$7,678,078.36	$19,901,419.91
133370826.65	32008742.33	66685413.3	$7,409,490.37	$19,205,245.40
128507293.14	30841503.62	64253646.6	$7,139,294.06	$18,504,902.17
123643759.63	29674264.92	61821879.8	$6,869,097.76	$17,804,558.95
118809175.73	28513974.06	59404587.9	$6,600,509.76	$17,108,384.44
114032491.03	27367578.91	57016245.5	$6,335,138.39	$16,420,547.34
109284755.94	26228131.6	54642378	$6,071,375.33	$15,736,878.96
104594920.05	25102579.99	52297460	$5,810,828.89	$15,061,548.00
100020882.59	24004819.78	50010441.3	$5,556,715.70	$14,402,891.87
95533693.93	22927903.12	47766847	$5,307,427.44	$13,756,741.87
91133354.09	21871830.01	45566677	$5,062,964.12	$13,123,098.00
86819863.06	20836600.44	43409931.5	$4,823,325.73	$12,501,960.27
82622170.45	19829162.27	41311085.2	$4,590,120.58	$11,897,497.36
78598175.46	18863411.2	39299087.7	$4,366,565.30	$11,318,046.72
74718928.50	17932399.38	37359464.2	$4,151,051.58	$10,759,439.63
70897580.74	17015283.26	35448790.4	$3,938,754.49	$10,209,169.95
67134132.19	16112062.83	33567066.1	$3,729,674.01	$9,667,237.70
63544381.27	15250529.5	31772190.6	$3,530,243.40	$9,150,317.70
60099378.36	14423735.42	30049689.2	$3,338,854.35	$8,654,241.25
56712274.67	13610837.03	28356137.3	$3,150,681.93	$8,166,502.22
53440969.39	12825730.05	26720484.7	$2,968,942.74	$7,695,438.03
50343361.74	12082310.16	25171680.9	$2,796,853.43	$7,249,386.10
47390502.11	11373629.52	23695251.1	$2,632,805.67	$6,824,177.71
44553440.90	10692740.27	22276720.4	$2,475,191.16	$6,415,644.16
41832178.10	10039642.43	20916089.1	$2,324,009.89	$6,023,785.46
39197764.12	9407388.129	19598882.1	$2,177,653.56	$5,644,432.88
36737047.76	8816820.927	18368523.9	$2,040,947.10	$5,290,092.56
34478978.63	8274888.672	17239489.3	$1,915,498.81	$4,964,933.20
33050798.15	7932128.1	16525399.1	$1,836,155.45	$4,759,276.86
31699816.62	7607895.126	15849908.3	$1,761,100.92	$4,564,737.08
30426034.04	7302189.751	15213017	$1,690,335.22	$4,381,313.85
29210150.66	7010380.075	14605075.3	$1,622,786.15	$4,206,228.05

Table B-1 Cont.

Fence $	Amort excav,$/yr	Amort liner, $/yr	Amort fencing, $/yr
$237,014.09	$652,158.25	$1,690,380.67	$19,018.62
$231,701.47	$623,249.92	$1,615,450.87	$18,592.33
$230,370.25	$616,108.87	$1,596,941.42	$18,485.51
$226,305.08	$594,556.68	$1,541,078.58	$18,159.30
$222,140.51	$572,875.43	$1,484,881.23	$17,825.13
$217,896.36	$551,194.18	$1,428,683.87	$17,484.57
$213,593.91	$529,641.98	$1,372,821.03	$17,139.33
$209,256.13	$508,347.89	$1,317,627.20	$16,791.25
$204,853.63	$487,182.86	$1,262,767.88	$16,437.99
$200,409.90	$466,275.94	$1,208,577.58	$16,081.41
$195,978.86	$445,885.24	$1,155,725.31	$15,725.85
$191,532.36	$425,881.71	$1,103,876.56	$15,369.05
$187,069.31	$406,265.34	$1,053,031.34	$15,010.93
$182,588.50	$387,036.14	$1,003,189.64	$14,651.37
$178,119.79	$368,323.15	$954,685.97	$14,292.79
$173,728.11	$350,384.50	$908,189.35	$13,940.39
$169,386.66	$333,091.12	$863,365.27	$13,592.02
$164,998.34	$316,055.85	$819,210.21	$13,239.89
$160,559.34	$299,278.69	$775,724.16	$12,883.70
$156,207.71	$283,275.86	$734,245.17	$12,534.51
$151,914.37	$267,918.31	$694,438.71	$12,190.00
$147,571.47	$252,818.87	$655,301.27	$11,841.52
$143,252.11	$238,235.65	$617,501.86	$11,494.92
$139,038.47	$224,426.76	$581,709.50	$11,156.81
$134,899.25	$211,263.14	$547,589.67	$10,824.66
$130,799.02	$198,615.74	$514,807.89	$10,495.65
$126,741.58	$186,484.57	$483,364.13	$10,170.07
$122,685.86	$174,740.56	$452,923.90	$9,844.63
$118,772.53	$163,770.88	$424,490.71	$9,530.61
$115,064.42	$153,704.58	$398,399.09	$9,233.07
$112,656.14	$147,337.86	$381,896.69	$9,039.82
$110,329.65	$141,315.29	$366,286.31	$8,853.14
$108,090.26	$135,636.87	$351,567.96	$8,673.44
$105,908.49	$130,216.56	$337,518.62	$8,498.37

Table B-1 Cont.

Annual membrane cost $/year	Amort VSEP units	Personnel cost, $/yr	Contgcies, $/yr
$766,480.38	$545,898.71	$210,000.00	$200,000.00
$784,949.78	$559,052.90	$210,000.00	$200,000.00
$784,949.78	$559,052.90	$210,000.00	$200,000.00
$775,605.14	$552,397.51	$210,000.00	$200,000.00
$775,605.14	$552,397.51	$210,000.00	$200,000.00
$775,605.14	$552,397.51	$210,000.00	$200,000.00
$784,949.78	$559,052.90	$210,000.00	$200,000.00
$794,522.34	$565,870.62	$210,000.00	$200,000.00
$794,522.34	$565,870.62	$210,000.00	$200,000.00
$814,385.40	$580,017.38	$210,000.00	$200,000.00
$835,267.08	$594,889.62	$210,000.00	$200,000.00
$846,114.70	$602,615.46	$210,000.00	$200,000.00
$868,677.76	$618,685.21	$210,000.00	$200,000.00
$880,416.65	$627,045.82	$210,000.00	$200,000.00
$917,617.35	$653,540.71	$210,000.00	$200,000.00
$958,100.47	$682,373.39	$210,000.00	$200,000.00
$987,133.82	$703,051.37	$210,000.00	$200,000.00
$987,133.82	$703,051.37	$210,000.00	$200,000.00
$1,017,981.75	$725,021.73	$210,000.00	$200,000.00
$1,085,847.20	$773,356.51	$210,000.00	$200,000.00
$1,104,251.39	$786,464.25	$210,000.00	$200,000.00
$1,123,290.21	$800,023.97	$210,000.00	$200,000.00
$1,184,560.58	$843,661.65	$210,000.00	$200,000.00
$1,252,900.62	$892,334.43	$210,000.00	$200,000.00
$1,303,016.64	$928,027.81	$210,000.00	$200,000.00
$1,357,309.00	$966,695.64	$210,000.00	$200,000.00
$1,416,322.44	$1,008,725.88	$210,000.00	$200,000.00
$1,447,796.27	$1,031,142.01	$210,000.00	$200,000.00
$1,628,770.80	$1,160,034.76	$210,000.00	$200,000.00
$1,714,495.58	$1,221,089.22	$210,000.00	$200,000.00
$1,809,745.33	$1,288,927.51	$210,000.00	$200,000.00
$1,916,200.94	$1,364,746.78	$210,000.00	$200,000.00
$2,035,963.50	$1,450,043.45	$210,000.00	$200,000.00
$2,101,639.74	$1,496,819.05	$210,000.00	$200,000.00

Table B-1 Cont.

Antiscalant cost, $/year	H_2SO_4 cost, $/year	NaOH cost, $/year	Energy cost	Total permeate, gpd
$55,721.51	$731,928.67	$0.00	$0.00	0.00
$55,721.51	$731,928.67	$4,655.06	$40,772.14	132,981.53
$55,721.51	$731,928.67	$5,804.97	$50,843.83	165,831.13
$55,721.51	$731,928.67	$9,275.48	$81,240.91	264,973.61
$55,721.51	$731,928.67	$12,766.77	$111,820.01	364,709.76
$55,721.51	$731,928.67	$16,258.06	$142,399.12	464,445.91
$55,721.51	$731,928.67	$19,728.57	$172,796.20	563,588.39
$55,721.51	$731,928.67	$23,157.52	$202,829.25	661,543.54
$55,721.51	$731,928.67	$26,565.69	$232,680.28	758,905.01
$55,721.51	$731,928.67	$29,932.29	$262,167.27	855,079.16
$55,721.51	$731,928.67	$33,215.77	$290,926.19	948,878.63
$55,721.51	$731,928.67	$36,436.90	$319,139.05	1,040,897.10
$55,721.51	$731,928.67	$39,595.69	$346,805.86	1,131,134.56
$55,721.51	$731,928.67	$42,692.13	$373,926.61	1,219,591.03
$55,721.51	$731,928.67	$45,705.45	$400,319.29	1,305,672.82
$55,721.51	$731,928.67	$48,594.08	$425,619.85	1,388,192.61
$55,721.51	$731,928.67	$51,378.80	$450,010.33	1,467,744.06
$55,721.51	$731,928.67	$54,121.96	$474,036.77	1,546,108.18
$55,721.51	$731,928.67	$56,823.55	$497,699.17	1,623,284.96
$55,721.51	$731,928.67	$59,400.46	$520,269.46	1,696,899.74
$55,721.51	$731,928.67	$61,873.46	$541,929.66	1,767,546.17
$55,721.51	$731,928.67	$64,304.89	$563,225.82	1,837,005.28
$55,721.51	$731,928.67	$66,653.20	$583,793.91	1,904,089.71
$55,721.51	$731,928.67	$68,876.82	$603,269.88	1,967,612.14
$55,721.51	$731,928.67	$70,996.53	$621,835.77	2,028,166.23
$55,721.51	$731,928.67	$73,033.12	$639,673.58	2,086,345.65
$55,721.51	$731,928.67	$74,986.58	$656,783.31	2,142,150.40
$55,721.51	$731,928.67	$76,877.70	$673,346.99	2,196,174.14
$55,721.51	$731,928.67	$78,644.13	$688,818.56	2,246,635.88
$55,721.51	$731,928.67	$80,265.08	$703,016.00	2,292,941.95
$55,721.51	$731,928.67	$81,290.30	$711,995.58	2,322,229.55
$55,721.51	$731,928.67	$82,260.11	$720,489.78	2,349,934.04
$55,721.51	$731,928.67	$83,174.49	$728,498.59	2,376,055.41
$55,721.51	$731,928.67	$84,047.32	$736,143.36	2,400,989.45

Table B-1 Cont.

Total cost	Revenue, $/yr	Net Revenue, $/yr	Water cost, $/1000 gal
$4,871,586.81	$0.00	-$4,871,586.81	$0.00
$4,844,373.16	$97,076.52	-$4,747,296.64	$99.81
$4,829,837.45	$121,056.73	-$4,708,780.72	$79.79
$4,769,963.77	$193,430.74	-$4,576,533.03	$49.32
$4,725,821.39	$266,238.13	-$4,459,583.26	$35.50
$4,681,672.62	$339,045.51	-$4,342,627.10	$27.62
$4,653,779.97	$411,419.53	-$4,242,360.44	$22.62
$4,626,796.25	$482,926.78	-$4,143,869.47	$19.16
$4,583,677.83	$554,000.66	-$4,029,677.17	$16.55
$4,575,087.45	$624,207.78	-$3,950,879.66	$14.66
$4,569,285.23	$692,681.40	-$3,876,603.83	$13.19
$4,547,083.61	$759,854.88	-$3,787,228.73	$11.97
$4,545,722.29	$825,728.23	-$3,719,994.05	$11.01
$4,526,608.53	$890,301.45	-$3,636,307.08	$10.17
$4,552,134.89	$953,141.16	-$3,598,993.73	$9.55
$4,584,852.21	$1,013,380.61	-$3,571,471.60	$9.05
$4,599,272.91	$1,071,453.17	-$3,527,819.74	$8.59
$4,564,500.04	$1,128,658.97	-$3,435,841.07	$8.09
$4,583,062.92	$1,184,998.02	-$3,398,064.90	$7.74
$4,666,579.34	$1,238,736.81	-$3,427,842.53	$7.53
$4,666,715.95	$1,290,308.71	-$3,376,407.24	$7.23
$4,668,456.72	$1,341,013.85	-$3,327,442.87	$6.96
$4,743,551.93	$1,389,985.49	-$3,353,566.44	$6.83
$4,832,324.98	$1,436,356.86	-$3,395,968.12	$6.73
$4,891,204.40	$1,480,561.35	-$3,410,643.06	$6.61
$4,958,280.79	$1,523,032.32	-$3,435,248.47	$6.51
$5,034,487.15	$1,563,769.79	-$3,470,717.36	$6.44
$5,064,322.23	$1,603,207.12	-$3,461,115.11	$6.32
$5,351,710.63	$1,640,044.20	-$3,711,666.44	$6.53
$5,477,852.80	$1,673,847.63	-$3,804,005.17	$6.55
$5,627,883.28	$1,695,227.57	-$3,932,655.71	$6.64
$5,797,802.53	$1,715,451.85	-$4,082,350.68	$6.76
$5,991,208.48	$1,734,520.45	-$4,256,688.04	$6.91
$6,092,533.20	$1,752,722.30	-$4,339,810.90	$6.95

Curriculum Vita

Guillermo was born in Hidalgo del Parral, Chihuahua., Mexico. The fifth of six offspring of Laurencio Delgado and Lucrecia Gardea. He received his bachelor degree in Chemical Engineering at the Parral Institute of Technology in fall 2005. Then he started his professional career as an engineer in the waste water laboratory of Sta. Maria del Oro, Durango. Later, he entered The University of Texas at El Paso in fall 2007. While pursuing a master's degree in Environmental Engineering, he worked with Dr. John Walton and Dr Anthony Tarquin as their Teacher Assistant. He had the opportunity to work with Dr. Anthony Tarquin as a Research Assistant in several desalination projects in the University of Texas at El Paso and the Kay Baley Hutchison Desalination Plant. He is expecting to continue his studies in the University of Texas at El Paso in order to obtain a Ph. D. in Civil Engineering and keep his search for knowledge in the water treatment area.