Department of Chemical Engineering

Investigations into the effectiveness of large size membrane elements for RO desalination
RO: Water treatment by reverse osmosis

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This thesis is presented for the Degree of

Master of Philosophy (Chemical Engineering)

of

Curtin University

May 2013

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature: ………………………………………….

Date: ………………………...

Acknowledgment

I thank God, the Beneficent, and the Merciful for his help and continuous favours upon me throughout my life.

I like to express my deep gratitude to my Supervisor A/Prof. Hari B. Vuthaluru for his support, valuable technical advice, and cooperation during the course of my thesis; Professor H. Ming Ang for his constant guidance and support during the course of this project. I'd also like to thank my co supervisor Dr. Rupa Vuthaluru for her feedback, advice and constant assistance, her valuable help during my study time is much appreciated.

I acknowledge and express appreciation to the ministry of higher education and scientific research of Iraq for offering me this scholarship to come to Australia and pursue my Masters degree at Curtin University. Special thanks to the Iraqi cultural attaché in Canberra and the head (Mr. Fadhil Farhod) for providing me and my family with the financial during our stay in Australia.

I like to thank Mr. Neil Palmer, CEO of the National Center in Excellence of desalination, Mr. Heip Lee of Osmoflo Pty Ltd for their assistance in arranging my site visits to the Queensland refinery RO plant and allowing me to collect and use the plant data for the purpose of my thesis and for their consistent helps and support.

I thank Michael Akindeju for his valuable support and assistance in the arrangement and reviewing of the thesis and for his suggestions and ideas throughout my studies.

I like to thank my immediate family, especially my wife Shadan Sherzad for her support and care; and to my little daughter Lara who is my hope in this life and the reason for crossing all the challenges.

To my parents Nasruldeen Qader and Khadija Hussien for their prayers and to my two brothers Rawand Kader & Rawen Kader for their encouragements during the hard times and for their interest in my progress all the time, without them this thesis would never have been possible.

Abstract

Although no less than 66% of the earth surface is covered by water, with some statistics indicating that proportion to be about 70%. Of this, fresh water is less than 1%, the balance is salt water. Conversely, the growing population and the associated increasing developments by way of civilised expansion puts unending and nerving stress on the demands and competitions for potable water more than ever before, especially in arid regions where supplies of portable water are hinged on a very limited range of sources, fresh water must be produced at a rate that can cope with both instantaneous and growing demands.

In this research, operational data on Reverse Osmosis application in Sea Water Desalination were acquired for two different membrane system sizes (8 and 16 inches); their performances and effectiveness in terms of specific flux, recovery, salt rejection, pressure drop across membranes components and power consumption were compared.

Upon completion of this research, the 16-inch membrane system was found to outperform the 8-inch system for all criteria evaluated but with wider variability.

- The 16-inch system was found to allow higher flux ranging from 0.13 to 7.69L/m^2/hr/bar compared to the 8-inch membrane system at 0.76 to 2.32 /m^2/hr/bar under similar operating conditions. The monthly averages also showed that the 16-inch system outperformed the 8-inch system at between 0.70 and 77.89 L/m2/hr/bar compared to 0.76 and 2.32 L/m2/hr/bar for the 8-inch system

- Fresh water recovery also showed similar trend with the 16-inch membrane system performing better at between 41.88 and 90.52% compared to those of the 8-inch system at between 45.88 and 76.15%. Conversely, the 16-inch system registered lower pressure drops of between 0.13 and 4.28 bar across its membranes compared to between 1.56 and 5.05 bar for the 8-inch system; this trend is further substantiated by the data on monthly. This implies that lower pumping power requirement to transfer permeates and retentate away from the membrane.

- Salt rejection was higher with the 16-inch system at between 87.23 and 99.97% compared to those of between 93.1 and 99.06% for the 8-inch system, the data showed a wider variability especially in the period between November 2007 and April 2008 with no specific attributable reasons.

- Based on the data and trend observed, the 8-inch system showed less variability and hence more predictable compared to the 16-inch system.

In general and given the observed trend, a mix of both depending on expected outcomes are required to achieve given process objectives. However, deploying the 16-inch system alone requires more investment in control systems to handle the variability.

Comparison of results now provided a knowledge base (compendium) on the effectiveness of small and large size membrane elements for RO desalination presenting a tool for making selective decision for the optimisation of available capital and resource utilisation.

Additionally, an attempt has been made to fit generalized equations for the parameters (Salt Rejection, Specific Flux, Pressure Drop, Recovery and Power Consumption) evaluated for both the 8- and 16-inch membrane modules using polynomial and exponential regression methods. As these correlations are based on reliable and large valuable plant data, they will (when fully developed and tested to cover other membrane sizes) provide firsthand information for water practitioners to predict the likely variations in terms of the parameters of importance to membrane operations and will complement literature efforts on silent alarm approaches in predicting deviation points at which maintenance is required.

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Chapter 1 : Introduction, Objectives and Significance

1. Introduction

Although no less than 66% of the earth surface is covered by water, with some statistics indicating that proportion to be about 70%. Of this, fresh water is less than 1% (Khawaji et al., 2007), the balance is salt water. Conversely, the growing population and the associated increasing developments by way of civilised expansion puts unending and nerving stress on the demands and competitions for potable water more than ever before, especially in arid regions, like Australia, where supplies of portable water are hinged on a very limited range of sources. According to Righton (2009), "recent studies undertaken as part of the Murray Darling Basin Salinity Audit and the National Land and Water Resources Audit have highlighted the decline in the quality of the water sources (Quiggin, 2001)". He concluded that water is the most desired natural elements available and obtainable to human.

The above implies that in order to meet the needs of the increasing population and development, fresh water must be produced at a rate that can cope with both instantaneous and growing demands and has therefore become a priced commodity for the sustenance of life and our way of life.

Dating back to ancient times, mankind has devised a number of ways for purifying and or producing potable water to meet its needs. Foremost amongst which are simple decanting and mesh (membrane) filtration of ground and surface water sources, and in some instances including the use of additives. While those methods were limited to their water sources and failed to prove the removal of microbes, they have provided the bases for the developments and advancement in potable water system solutions from the vastly available salt (sea) water.

Sea water, if used untreated, is not suitable for human or for industrial or agricultural applications. However, different techniques have evolved which separate salts and unwanted materials from sea water and make it suitable for human consumption and irrigation. The phenomenon associated with such techniques is called desalination.

There are several desalination processes and it can be divided into two major groups: Thermal Desalination Technology and Membrane based Desalination Technology; the membrane based desalination commonly relies on Reverse Osmosis (RO). This, and Multi-Stage Flash distillation are widely used commercially and are competitive alternatives with choice based on optimal salinity level of feed water; required product quality; and on the site-specific factors, such as, labour and energy cost. Although thermal desalination is overly energy intensive compared to membrane based desalination processes, it can handle more saline water throughput to produce better quality product water and has longer lifespan. Hence, it seems a better option on a “per-unit” cost and quality scale when capital availability is not an issue and required in a large population density demand scenario (Fritzmann et al., 2007). However, the focus of this research is the application of Reverse Osmosis in Sea Water Desalination with primary objectives as stated below to acquire and use operational data on two different membrane system sizes (8 and 16 inches) to compare their

1. Efficiencies using
    a. Total through put per unit area
    b. Permeates
        i. Water Recovery Percentage
        ii. Quality
        iii. Differential Pressure across the membrane
    c. Rejection percentage
        i. TDS
        ii. Other key elements
    d. Predictability

2. Feasibilities using
    a. Data on efficiencies to determine operating cost per unit area of membrane

b. Required Capital and Operational Cost over a known/given time span based on membrane life.

2. *Significance of the Study*

Based on the comparisons made, this project provides a knowledge base (compendium) on the effectiveness of small and large size membrane elements for RO desalination presenting a tool for making selective decision for the optimisation of available capital and resource utilisation.

Chapter 2 : Literature Review

Fresh water is short in supply in many countries of the world, in some places due to location while in others simply due to population explosion, requirements of enhanced living standards, as well as the expansion of industrial and agricultural activities. This is not so surprising considering that only 0.5% of the total water body on earth is fresh water and hence has become one of many gifts provided by nature to us.

In the many ways man has learnt to conquer the environment, several technologies have been developed to tap into the vastly available, but otherwise unsuitable, water in the oceans, seas and rivers which together represent more than 97% of the earth's major water reservoir and about 66% of the total earth surface (Khawaji et al., 2007).

Sea water, if used untreated, is not suitable for human beings and neither is it suitable for industrial or agricultural applications. However, different techniques have evolved which separate salts and unwanted materials from sea water and make it suitable for human consumption and irrigation. The phenomenon associated with such techniques is called desalination.

2.1 Desalination

There are several desalination processes and they can generally be divided into two groups; Thermal Desalination Technology and Membrane based Desalination Technology; of these, the Reverse Osmosis (RO) and Multi-Stage Flash distillation are widely used commercially with selection depending on the feed water salinity, required product quality and on the site-specific factors, such as, labour and energy cost. On a final analysis, "Thermal Desalination" is more energy intensive compared to membrane based desalination processes, but can handle more saline water and deliver higher quality product water (Fritzmann et al., 2007); some factors to be considered in the selection of which technology to use are discussed below.

2.2 Factors affecting Desalination Technology Selection

Performance Ratio: Regardless of scale, the energy utilisation for any plant of major consideration and may be difficult to evaluate except on a ratio basis (i.e. energy/unit input or energy/output). In terms of output, the Performance Ratio is defined as the ratio of the amount of freshwater produced to the amount of energy consumed. This ratio becomes of more importance in countries or locations where the cost of energy is high (Stikker, 2002).

Plant Costs: Even with low performance ratio, the total cost of a plant and its component units often sway decisions; a low performing ratio plant with low capital cost is definitely the preference in all cases. However, a compromise between performance ratio and plat cost may sometimes be necessary especially when the cost of running the plant over a time period is put into consideration (Peters and Timmerhaus, 1991).

Feedwater: The performance of a plant largely depends on defined boundary conditions and operating envelop. Of these, the composition of the feed water is vital and should be well established for the choice of technology to be sound and valid as it determines the overall process route, type and magnitude of pre-treatment required and the treatment for the rejects (Andrianne and Alardin, 2003).

Site Location: The availability of appropriate (size and scale) real estate for the plant is also a major factor to consider. It determines pumping and storage requirements and ultimately there is a cost associated. The nearer the location is the feedwater source, the better but this often means farness to settlements and labour, hence a compromise is often required (Ondrey, 2005).

Other factors: Other factors include the availability of long term technical support for troubleshooting and de-bottlenecking, availability of spare parts and repairs.

2.3 Thermal Processes

Thermal processes are mainly deployed in large commercial applications due to their huge energy consumption, comprising of technologies such as Multistage Flash Distillation (MSF), Multi effect distillation (MED) and Vapour Compression (VC).

The associated energy consumption of Thermal Processes are independent of the salinity and are hence practical to be deployed for sea water applications with huge throughput where membrane technologies may not be an outright choice based on efficiency.

a) Multi-Stage Flash (MSF) Distillation

In Multi-Stage Flash (MSF) desalination, the feed water is heated to the super-critical temperature under pressure and then flashed in a chamber maintained slightly below the saturation vapour pressure of the water. A fraction of the water content flashes into steam and is stripped off the suspended brine as it passes through a mist eliminator. The steam stream condenses on the outer surface of the tubing and drips off as liquid into trays as fresh water. The uncollected steam that condenses on the inside of the tubes preheats the brine vapour in each stage which acts to remove the latent heat of condensation. This operation is referred to as the heat recovery step of the MSF shown in Figure 2-1 below (El-Dessouky, et al. 1998).

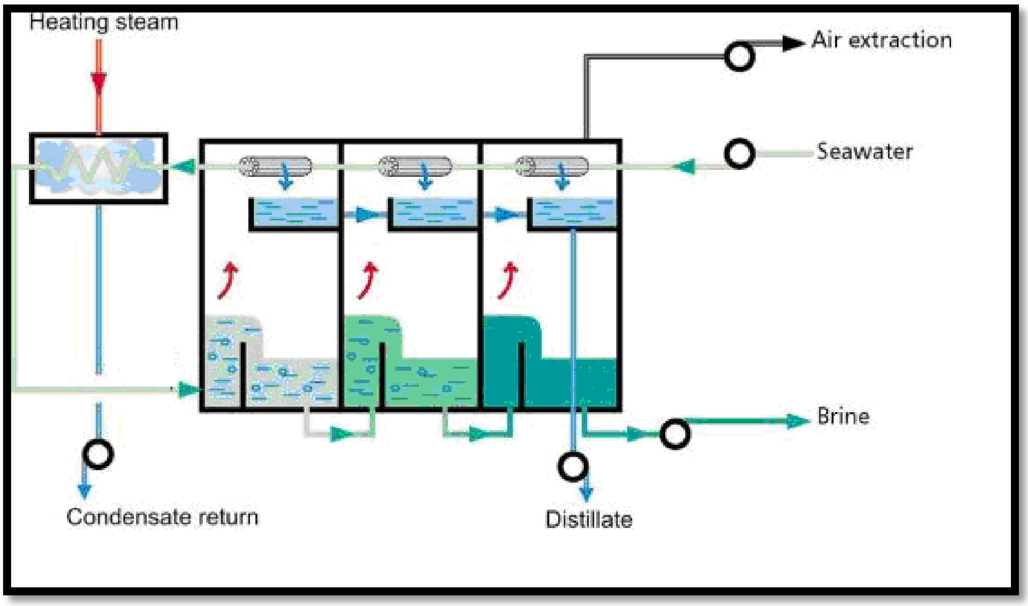

Figure 2-1: The Multistage Flash Distillation Process (El-Dessouky, et al. 1998)

Some of the advantages of the MSF process include the following

1. Large Throughput
2. Performance independent of feedwater salinity
3. Energy consumption independent of feedwater salinity
4. Produces high quality fresh water product
5. Minimum pre-treatment required
6. The plant can be pinched and or integrated with another process to act as heat sink.

Some disadvantages of the technology includes

1. It requires huge capital to establish
2. It requires considerable level of skilled labour to operate
3. The fresh water recovery (yield) ratio is low (El-Dessouky, et al. 1999).

b) Multiple Effect Distillation (MED)

The Multiple Effect Distillation (MED) process involves reducing the operating pressure at each stage of the process to cause the feedwater to undergo multiple boiling without external heat addition.

The initiating heat is supplied by process steam or vapour generated by a boiler fed into a series of tubes and allowed to condense to give off the heat content with the tube surface acting as heat transfer interface. That heat given off elevates the surface temperature of the tubes causing the feedwater in contact at the surface to evaporate. The evaporated water collects into the next stage where it condenses by losing its latent heat which is in turn used to heat a portion of the remaining feedwater at the next lower pressure stage (Wade, 2001) as depicted in Figure 2-2 below. This arrangement is repeated in series until the final stage where there the "Carnot Engine" efficiency limits heat transfer (Ophir and Lokiec, 2005).

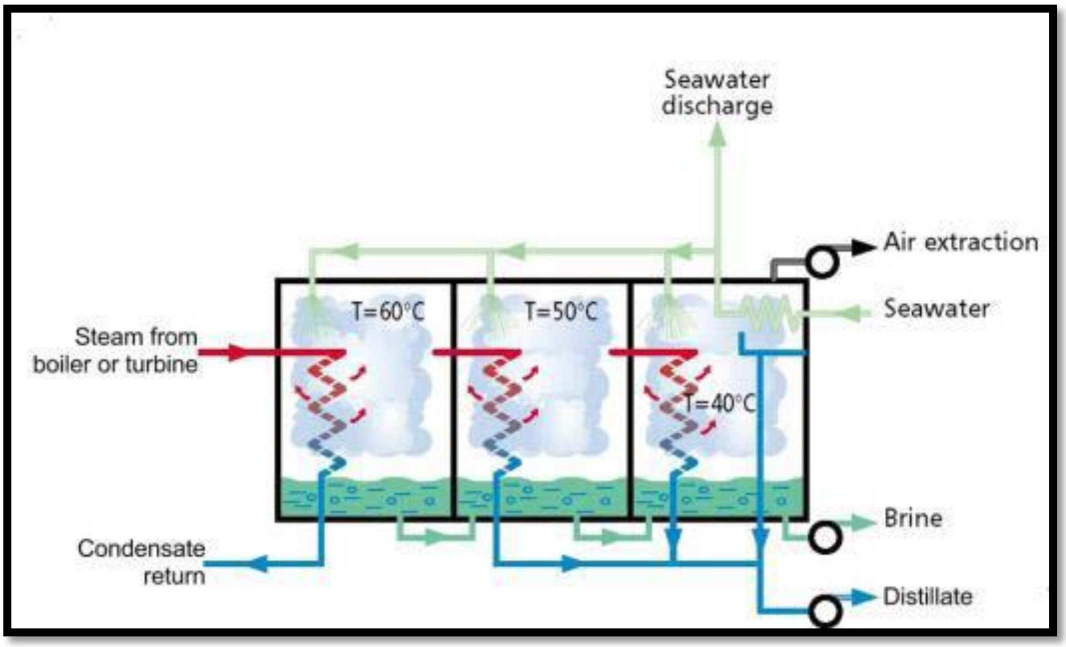

Figure 2-2: The Multiple Effect Distillation Process (Ophir and Lokiec, 2005)

According to Righton (2009), "The major difference in the MED and the MSF process is the role of flashing steam in the MED process which is not as important as the condensing steam in the MSF. The condensing steam evaporates the feed seawater in each effect. In a MED process the steam produced in one effect is passed on to the next effect operating at a much lower pressure and temperature as compared to the previous effect. Hence the MED consumes less power in comparison to the MSF process (Green and Schwarz, 2002)".

Some of the advantages of the MED process include the following

1. The fresh water product is of extremely high quality
2. The technology can process both biologically laden water and feedwater with suspended matter.
3. It does not require as much energy as the MSF
4. Pre-treatment requirement are minimum

Some disadvantages of the technology includes

1. Huge capital cost
2. Fresh water product requires cooling
3. The fresh water recovery (yield) ratio is low, but higher than in MSF

c) *The Vapour Compression (VC) Process*

Vapour Compression (VC) process depicted in Figure 2-3 below is typically used to extract heat which is then recycled in the process (Darwish and El-Dessouky, 1996). As applied for desalination, the VC continuously recycles the latent heat in the evaporation condensation stages similar to that of the MSF except that the vapour produced during the evaporation of brine is not condensed separately; a compressor is used to return the condensate to the steam side of the same evaporator in which it originated. This forms a heat transfer surface on the steam side of the same evaporator and gives out latent heat to evaporate more fresh water from the brine solution. Conversely, the energy required for the evaporation is sourced from a vapour compressor which raises the temperature of the vapour by compressing the volume to establish the driving force for the transfer of heat from vapour to brine (Darwish and El-Dessouky, 1996).

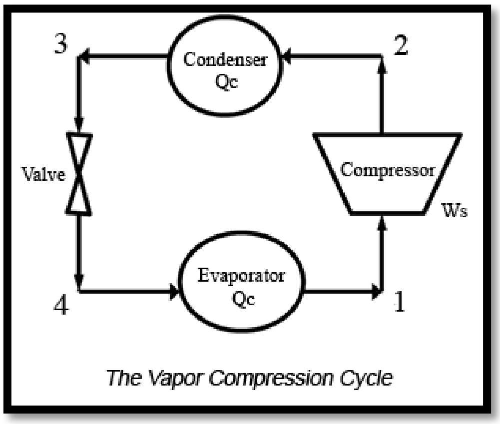

Figure 2-3: Vapour Compression Utility Marketing Corporation, 2011 (utility.com.ph)

Some of the advantages of the VC process include the following

1. The Vapour Compression system is very compact and can be made portable
2. The freshwater recovery (yield) is high
3. The freshwater product is of high quality
4. The energy requirement is low
5. It requires minimum pre-treatment

Some disadvantages of the technology includes

1. The compressors which are the major components of the system are expensive

2. Auxiliary heating is required to pre-heat the feedwater
3. It requires expertise to operate

d) *The Electrodialysis Process*

According to Xu and Huang (2008), Electrodialysis (ED) involves the movement of water through a filtering medium using low voltage direct current (DC) electric field as main driving force to overcome the membrane resistance and pump the pre-treated water through the electrodialysis cells. Righton (2009) reported that “the main components of an ED cell depicted in Figure 2-4 below are large number of narrow compartments through which feedwater is pumped. These compartments are separated using membranes that are permeable to either positive ions (cations) or negative ions (anions). The DC electrical field directs the cations and anions through the membrane to form two specific sections of water. These sections are the electrolyte enriched wastewater and the electrolyte depleted product water. Non-ionic particles and bacteria will pass through the cell along with product water and this will require further treatment before it can be used domestically or for industry purposes”.

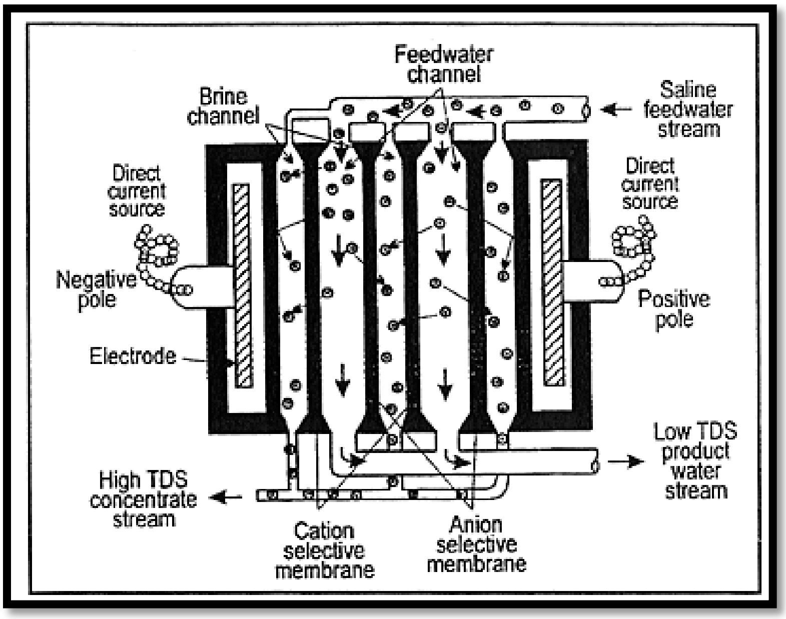

Figure 2-4: The Electrodialysis Process (Pilat, 2001)

A basic electrodialysis unit consist of a membrane stack comprising of pairs of cells bound together by electrodes on the outside. The feedwater are fed into a feed distributor to distribute feed to all the cells in parallel paths in a continuous flow. The membrane cells' pores are small and requires pre-treatment of the feedwater to remove suspended matters relatively about the size of the pores that can cause blockages; sometimes additives may also be added to the streams in the stack to reduce the effects of scaling (Pilat, 2001).

Veerman, et al. 2009 reported recent developments which further enhance the efficiency of the ED process. One such development is the Electrodialysis Reversal (EDR). This addition to the existing ED process involves a reversal stream of water flow to break up and flush out build-up of scales and slime on the cells thus preventing scaling and fouling. This addition to the ED process allows the unit to operate with fewer pre-treatment chemicals which are needed to prevent scaling.

Some of the advantages of the ED process include the following

1. High fresh water recovery (85-94%) is achievable with a single stage
2. Feedwater with high level of suspended solids can be treated using the ED
3. Energy consumption is dependent on salinity of feed water
4. The ED membranes can last for up to 10months longer compared to those of Reverse Osmosis
5. ED membranes are immune to bacterial and silica scaling
6. The ED process can be operated at a low pressure

Some disadvantages of the technology includes

1) The ED cell membranes require periodic cleaning with specific chemicals
2) Leakages around the membrane stacks are possible
3) The ED is not suitable for sources with high levels of bio-contaminants

2.3 Reverse Osmosis

Osmosis is the movement of water molecules, through a semi-permeable membrane, from an area of low solute concentration to an area of higher solute concentration until the concentration of both sides of membrane becomes equal. The membrane separating the two solutions is permeable to water molecules and impermeable to solute molecules. This phenomenon will also take place if the pressure on both sides of the membrane is different, as long as the pressure difference ΔP between the concentrated side and the dilute side is not larger than a certain critical value called Osmotic Pressure difference (ΔΠ) which depends on the difference of the respective concentrations. Under this condition when pressure differential is lower that the Osmotic Pressure difference, concentration remains the driving force; but if the pressure differential ΔP is larger than ΔΠ, pressure becomes more significant and the direction of flow will reverses to move water molecules from an area of higher solute concentration to an area of lower solute concentration. This philosophy is used in Reverse Osmosis (RO) operations depicted in Figure 2-5 below. Hence, reverse osmosis involves keeping the pressure differential across the membranes above the osmotic pressure of the specific membrane, this is used as a manipulated variable for recovery and for self-cleaning of the membranes.

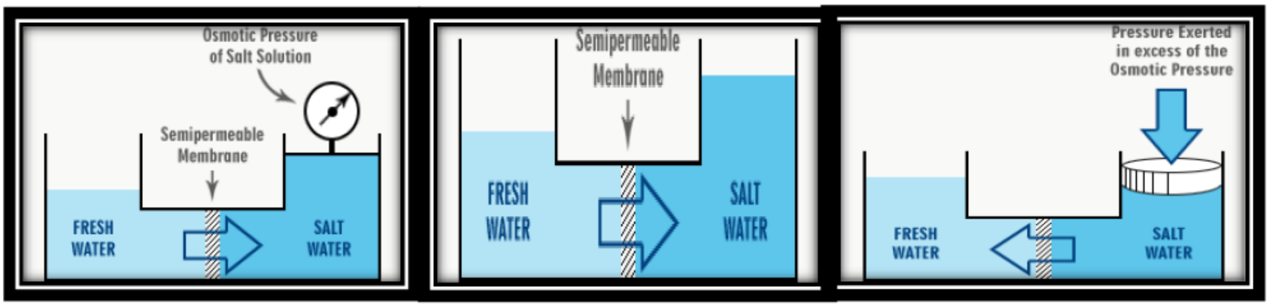

Figure 2-5: Natural Osmosis, Osmotic Equilibrium and Reverse Osmosis (http://www.novatron.com.au)

The Osmotic pressure can be calculated using the Van't Hoff equation which is given as:

$$\boldsymbol{\Pi = RT \sum_{1}^{i} x_i} \qquad \textbf{2-1}$$

where Π: is the osmotic pressure (kPa)

T is the temperature (K)

R is the universal gas constant

X_i is the concentration of all the dissolved salts present in the solution

2.4 Desalination by Reverse Osmosis

In Reverse Osmosis (RO) an external pressure in excess of the osmotic pressure of the sea water is applied which makes the natural direction of flow for the water through a semi-permeable membrane reversed. The reject stream has a higher salt concentration as compared to permeate (product stream). To create the required pressure, a high pressure pump operating at between 60 to 80 Bar is used to feed the sea water into the RO plant, this is the major energy intensive step in sea water RO process. However the pressure requirement to treat brackish water is considerably lower (about 15 bars) compared to that required in desalination of sea water (Fritzmann et al., 2007). Even with the high pressure pumping, the energy requirement of RO desalination process is less than that of comparable Thermal process; nonetheless, the membrane performance is a critical consideration associated with this technology. The performance diminishes with time due to the deposition of solute on the membrane surface, termed as fouling and scaling, resulting in decreased permeate flux and increased the energy requirement. Typically, anti-scalants are used to reduce the impact and the membranes are backwashed at regular intervals to enhance performance.

A typical large Sea water RO plant consists of four major components:-

- Feed water pre-treatment
- High pressure pumping
- Membrane separation
- Post treatment

2.4 Pre-treatment

Feed water pre-treatment is an essential process in all RO systems. The goal of the pre-treatment processes is to prevent or reduce scaling. Solutes are concentrated as water is removed from the feed stream, and the resulting concentration can be higher than the solubility product of different kinds of salts. Without pre-treatment, these salts can precipitate onto the membrane surface and scale down the efficiency of the membrane. Subsequent to the precipitation step, the feed is filtered to remove suspended particles upto approximate size of the membrane pores (John et al. 2005).

2.5 *High pressure pumping*

After scale control and pre filtration, which are the two main pre-treatment processes the feed water is pressurized with feed pumps. The feed water pressure ranges from 5 to 10 bar (73 - 145 psi) for NF membranes, from 10 to 30 bar (145 to 430 psi) for low-pressure and brackish water RO, and from 55 to 85 bar (800 to 1200 psi) for seawater RO. The membrane arrays can consist of one or more stages that may be concentrate stage or permeate stage. A manufacturer, Ultrapure Water® (1996), the optimum operating pressure is given by

$$P = -2\sigma cos\theta/r \qquad \textbf{2-2}$$

where P is the optimal operating pressure

σ is the surface tension of water

θ is the contact angle

R is the radius of the pores of the micro-porous membrane

2.6 *Membrane separation*

Although product quality is relatively lower in Membrane separation processes, they are more widely used in industry as compared to the thermal processes because of their low energy consumption, flexible design and installation. By design, the permeable membranes selectively inhibit the passage of dissolved salts while allowing the product water to pass through. Applying pressure to the membrane assembly, in excess of the osmotic pressure, results in a freshwater product stream and concentrated brine reject stream. However, some soluble salts break through the membrane and remains in the product water (Cheremisinoff, 2002). Calcium and Magnesium salts do improve the taste, but the overall objective is to limit breakthrough to the insipient point. Typical target product water quality using OSMOFLO® (2009) membrane system is shown in Table 1 below.

Table 2-1: Typical Target Product Water Quality (OSMOFLO®, 2009)

	Parameter	Units	Acceptable Limits
1	Total Dissolved Solids (prior to pH adjustment)	mg/L	≤ 150 for ≤ 8500mg/L TDS wastewater
			≤ 180 for ≥ 8500mg/L TDS wastewater
2	Calcium & Magnesium Hardness	mg/L CaCO3	≤ 15 (weekly requirement)
			≤ 20 (maximum allowable daily value)
3	Ammonia (total)	mg/L	≤ 25
4	TOC (non-volatile)	mg/L	≤ 1
5	Silica	mg/L	≤ 5
6	Sulphate	mg/L	≤ 100
7	pH		7.0 – 8.0

Achieving the target product water quality depends largely on the ability of the membrane to reject ions which in turn depends on the type of membrane used and the materials from which it is made. Usually, reverse osmosis membranes are made from cellulose acetate, cellulose triacetate and aromatic polyamide resins. Generally and according to Righton (2009), "ions of low charge are more difficult to reject as compared to higher charged ions. Flow through a semi permeable membrane is directly proportional to the net pressure across the membrane. The net pressure is the difference in the inlet pressure and the sum of the osmotic pressure and the pressure in the treated water storage container. The membrane is assumed to behave like a dense liquid layer. Ions and water are assumed to be soluble in the membrane material with pressure driving both of them though the membrane at their own unique rate".

He further reported that, the diffusion rate of water molecules through the membrane material is much higher than of the ions through the membrane (Rowzee, 2005). He concluded that an efficient RO membrane system must have sufficiently large surface area to process a large amount of feedwater; this is reflected in the design of the RO membrane modules. Of the several architecture available, the Hollow fibre and the Spiral wound are the most commonly used because they provide considerably large surface areas but in a relatively small volume. These membranes, tubular membranes and the "plate and frame" membrane are described further below.

a) *The Hollow Fibre Membrane*

As depicted in Figures 2-6 and 2-7, the hollow fibre membrane is typically a bundle of several thousands of 0.5-1.0mm diameter fibres spun into an open-ended U-tube membrane element usually with its own potted in an epoxy tube sheet; the other end of the fibre bundle is sealed in epoxy to prevent short circuiting of feed stream to the concentrate stream. The assemblage is cased in a pressure vessel with pressurised feedwater distributed from a co-centre tube. Under pressure, permeates pass through the membrane as the water flows radially through the bundle and over the fibres and is collected at the tube sheet end of the vessel (Noble and Stern, 1995). The hollow fibre membranes have a high packing density and requires low pumping power, while cleaning is achieved using a backwash. However, damage of a single fibre leads to replacement of the entire bundle which is expensive.

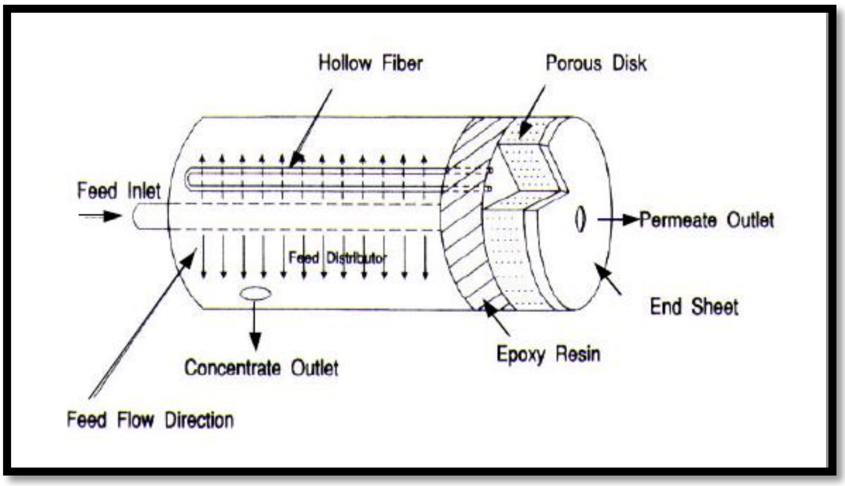

Figure 2-6: A Hollow Fibre Membrane (Noble and Stern, 1995)

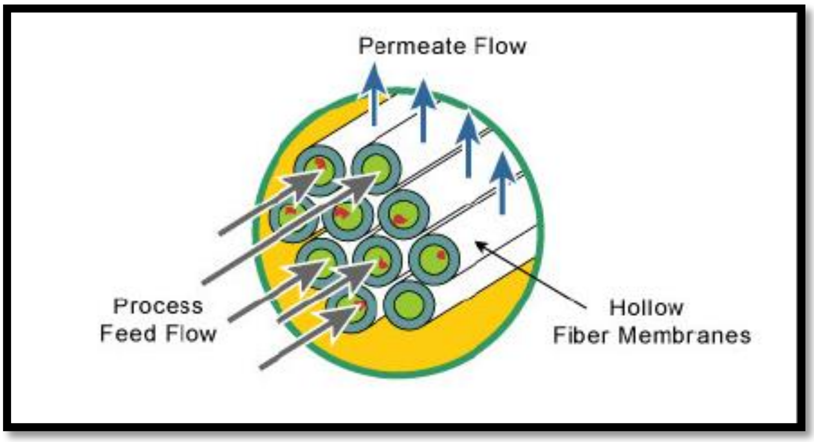

Figure 2-7: Cross Section of a Hollow Fibre Membrane (Noble and Stern, 1995)

b) The Spiral Wound Membrane

Figures 2-8 and 2-9 show the general schematic and cross section of a spiral wound membrane respectively; the membranes are cast in sheet form and attached to materials such as sail cloth of cellulosic membranes and/or a non-woven polyester web. Two of these sheets are placed back to back and separated by a spacing fabric that acts as a permeate channel. The configuration is such that two sides and one end of this assembly are joined together to form an envelope with the open end of this envelope connected to the permeate tube around which the envelope is wrapped to form the spiral with a brine concentrate seal is fixed to one end (Nicolaisen, 2003); with an inert mesh wrapped along the rib to separate the membrane surfaces and maintain the feed stream channel height and provide some rigidity for the structure.

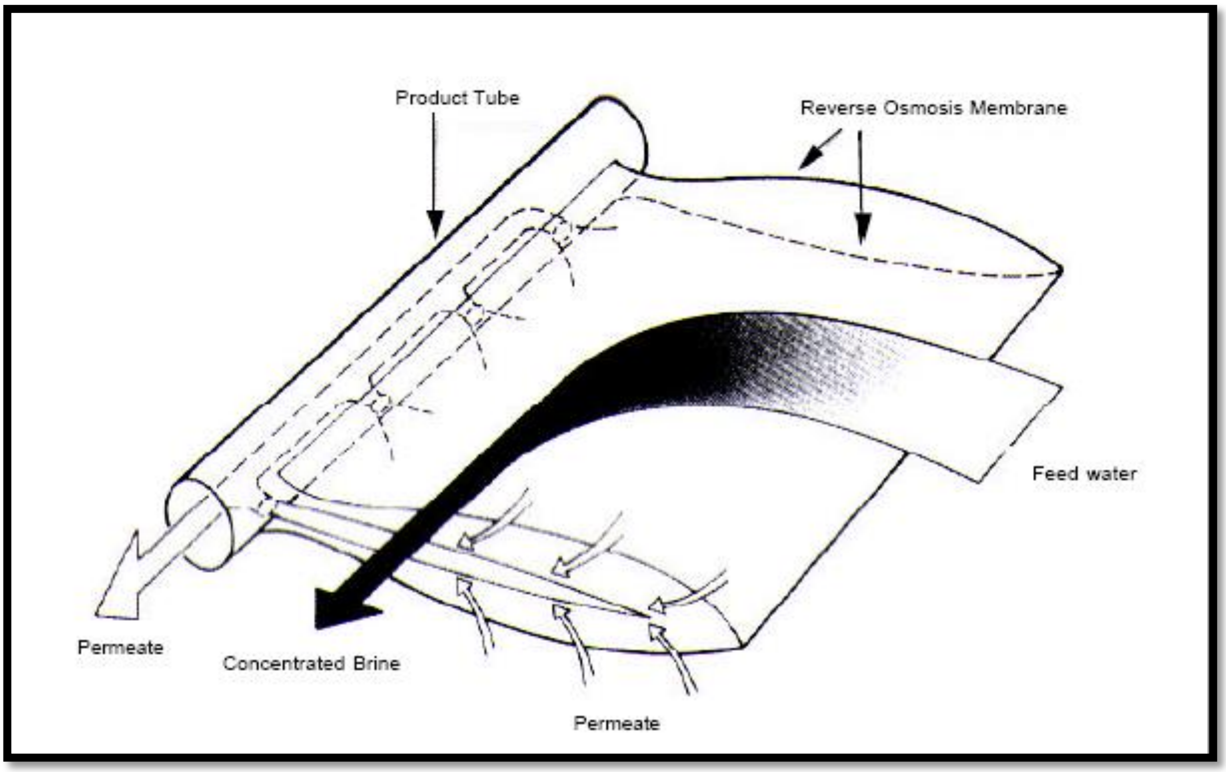

Figure 2-8: Spiral Wound Membrane (Nicolaisen, 2003)

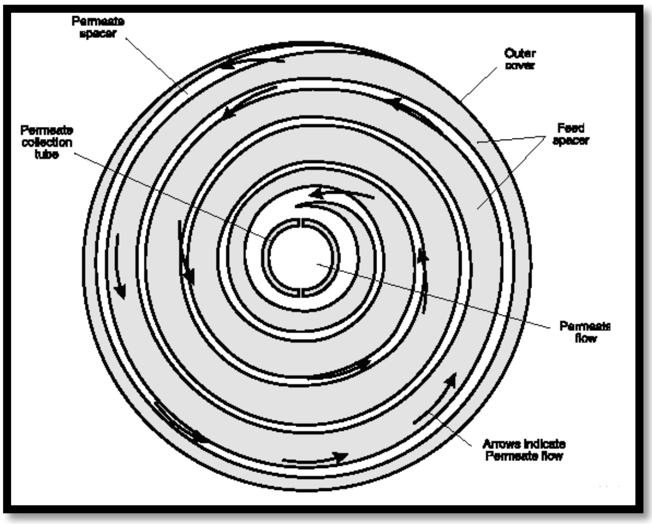

Figure 2-9: Cross Section of a Spiral Wound Membrane (Nicolaisen, 2003)

The elements are placed in a cylindrical vessel with the feed and the concentrate flowing through the feed side channels in a straight axial path parallel to the direction of the permeate collection tube. Under pressure, permeates penetrates the membrane and spirals its way to the centre collecting in the permeate tube, while the remaining water passes from the element into the concentrate end of the vessel. Arranging the units in series within the pressure vessel, the concentrate stream from one unit feeds the next until (typically 6^{th} of 7^{th} unit) the differential concentration of salts in the vicinity of the membrane becomes large enough for back transport to begin sand concentration gradient begins to drive the flow.

c) The Tubular Membranes Figure

Figure 2-10 below shows a tubular membrane system which is one of the earliest architecture used for desalination. Structurally, it is similar to the shell and tube filtration unit with the membrane, in a tubular form, on the inside of a pressure tight porous support tube. The feed solution flows through the inside and the permeate flows through the tube wall into the shell side. Several of this membrane tubes are placed in a pressure shell container to form a unit. Unlike the hollow fibre, the tubular membrane system is easier to clean and to replace a damage unit. On the other hand, the system requires has a higher energy requirements for pumping large volumes of feedwater, hence higher capital costs, and low membrane surface area per unit volume (Lawson and Lloyd, 1997).

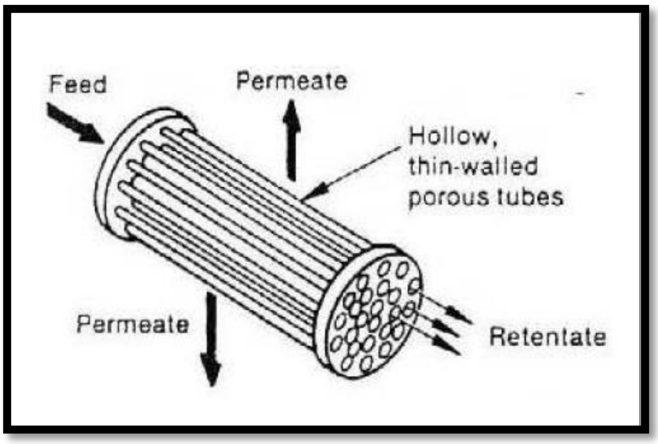

Figure 2-10: A tubular membrane (Lawson and Lloyd, 1997)

d) The Plate and Frame Membranes

Figure 2-11 below depicts the plate and frame membrane and is similar to the plate and frame filtration unit. In this architecture, the membrane sheets, spacers and support plates are alternately stacked and the supports forms a flow channel for the permeate water. The system is fed from the middle and outwards allowing the entire membrane surface to be covered by the feed stream; and permeate is collected from each support plate. Righton (2009) reported that "recent innovations have increased the packing densities for new design of plate and frame membranes. He also commented that maintenance on plate and frame membranes systems are a lot easier due to the nature of their assembly. The system offers high recoveries with their long feed channels and are used to treat feed streams that often cause fouling problems (Nunes and Peinemann, 2001)".

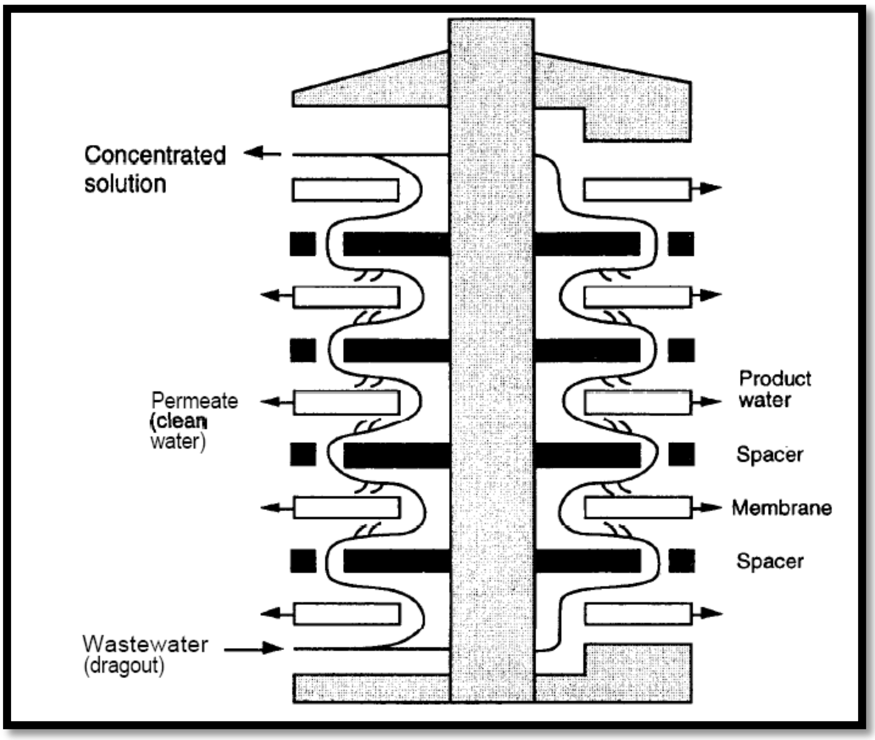

Figure 2-11: A plate and Frame Membrane (Nunes and Peinemann, 2001)

2.7 *Post-treatment and stabilization*

The fresh water product (as is the total case with Thermal processes), although of high quality are bland to taste as they contain low dissolved Calcium and Magnesium salts, can aid pipeline corrosion, hence a post treatment step to re-harden the product is necessary. Controlled dosages of Calcium and Magnesium salts are dissolved in the product stream for stabilization and its further chlorinated to disinfect any micro-organisms that may still be present in the stream. The pH values and CO_2 content are also adjusted to within allowable thresholds.

2.8 Fouling and scaling

Fouling and scaling is a major issue in RO operation. This is because of the build-up of unwanted solids and biomass on the membrane surface resulting in less permeate flux, higher pressure drop across the membrane, higher energy requirement and short membrane life. The ions present in water that causes scaling (or inorganic fouling) are Calcium, Magnesium, Sulphate, Silica, Iron and Barium (Potts et al., 1981). To prevent scaling and fouling, anti-scalants are used as additives. Anti-scalants used in reverse osmosis typically come as colourless to pale yellow liquid with mild odour. They are available from various manufacturers and can consist of varied proportions of acids and water (Osmo Flo®).

2.9 Factors Affecting Reverse Osmosis Performance

As indicated in the penultimate section, RO systems are designed and operated for over a long nominal period of time and can withstand the effect of fouling and scaling. However and over time, fouling and scaling impacts on the performance of the RO system. The degree of such impact depends on factors such

1. The characteristics of the feed water
2. Type of membrane used, and
3. The pre-treatment procedures carried

The influence of these factors is indicated by how well the system is able to reject ions which is mathematically expressed as

$$\boldsymbol{Ion\ Rejection = 1 - \frac{C_f}{C_p}} \qquad \textbf{2-3}$$

where Cp is the ion concentration in the permeate, and

Cf is the ion concentration in the feed water.

A performing RO system will have "ion rejection" ranging from 0.95 to 0.99 for various ions present in the feedwater (Bartels et al, 2010) as given in the Table 2-2 below. However, this build-up of ions on the membrane also affects the performance of the membrane and requires pulsed or periodic flushing. The increase of salt concentration on the membrane surface can be estimated by the percentage of the build-up of salts along the membrane surface as follows:

$$\% \, \boldsymbol{ion\ build\ up} = \frac{\boldsymbol{i_f - i_c - i_p}}{\boldsymbol{i_f}} * \mathbf{100} \qquad \textbf{2-4}$$

where i_f is the total ions in the feed

i_c is the total ions in the reject stream

i_p is the total ions in the product stream

Table 2-2: Summary of Ion Rejections for various constituents in Feed Water (Bartels et al, 2010)

	Singapore - ESPA2+	CA, USA - ESPA2	CA2, USA - ESPA2	Singapore - LFC1	CA3, USA - ESPA2	CA4, USA - LFC1	CA4, USA - ESPA2	CA5, USA - ESPA2	Singapore MBR-RO ESPA2LD
Temp C	32	25	27.8	25	25	22	22	25	31
Flux	18.6 lmh	20 lmh	19.3 lmh	15.8 lmh	20 lmh	18 lmh	18 lmh	20.3 lmh	21 lmh
Recovery	80%	85%	85%	75%	80%	75%	75%	81.2%	75%
Ca	99.98%	99.99%	99.98%	99.89	99.98%	99.99%	99.95%	99.98%	99.90%
Mg		99.99%	99.99%	99.88	99.95%	99.99%	99.96%	99.99%	
Na	98.70%	99.36%	99.00%	98.46	99.16%	98.97%	99.26%	99.13%	
K		99.65%	99.30%	98.98	99.26%			99.21%	
NH4	98.35%	98.47%	97.20%	98.52	98.71%	97.63%	97.71%		
HCO3		98.27%	97.35%		95.61%	98.39%	97.96%	98.44%	
SO4	99.98%	99.74%	99.70%	99.93	99.93%	99.86%	99.82%	99.97%	
Cl	99.22%	99.59%	99.30%	98.79	99.37%	99.34%	99.62%	99.53%	
F				93.22	93.96%			85.13%	
NO3	97.58%	94.15%	95.10%	96.64	95.54%	94.32%	96.00%	93.45%	97.00%
B	26.25%			65.10					
SiO2	99.04%	99.71%	99.80%	98.21	99.17%	99.25%	99.55%	99.78%	98.60%
TOC	99.73%	99.70%	99.52%	99.64	97.93%	98.23%	98.28%	99.02%	99.70%
TDS		99.23%				99.23%	99.34%		98.90%
P				99.73	99.73%	99.99%	99.99%	99.46%	99.70%
TKN					98.35%				
Org N					96.67%				

while the overall water recovery of the system is calculated using

$$\% \, \boldsymbol{Recovery} = \frac{\boldsymbol{P_f}}{\boldsymbol{P_f + R_f}} * \mathbf{100} \qquad \textbf{2-5}$$

where P_f is the permeate flow rate, and

R_f is the reject flow rate

2.10 Concentration Polarization

Over time as solutes or ion build up on the surface of the membrane; the solids accumulate to concentrations that exceed their concentrations in the feedwater in a phenomenon known as concentration polarization (Kim and Hoek, 2005). This phenomenon creates a boundary layer and the thickness of the layer depends on the turbulence of the feedwater flow. Increase in the turbulence will reduce the thickness of the boundary layer and reduce concentration polarization (Kumar et al. 2006).

This formation of a boundary layer creates a concentration gradient in the vicinity of the membrane surface with back transport of the foulant occurring due to diffusion; however, this disappears as soon as the pressure is relaxed. The larger the boundary layer the slower is the back diffusion of the suspended solids. The concentration polarization is given as:

$$Concentration\ polarisation = \frac{C_m - C_p}{C_b - C_p} = \frac{J_w}{k} \qquad 2\text{-}6$$

where Cm = Solute concentration in the vicinity of the membrane wall

Cp = Permeate concentration

Cb = Feed concentration

Jw = Solvent Water flux

k = Mass transfer coefficient

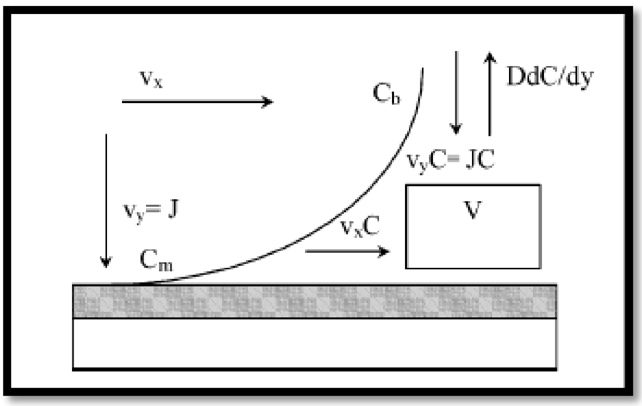

Figure 2-12: Concentration Polarization in the RO Membrane (Kumar, et al. 2006)

According to Sobana and Panda (2010), concentration polarization leads to a local

1. Increase in solute flux through the membrane because of increased concentration gradient across the membrane;
2. Decrease in water flux due to increased osmotic pressure at the membrane wall
3. Exhibition of changed membrane separation properties
4. Precipitation of the solute if the surface concentration exceeds its solubility limit, leading to scaling or particle fouling of the membrane and reduced water flux, and
5. Particulate or colloidal materials in the feed starts blocking the membrane surface that reduces water flux, and enhances membrane fouling.

To reduce concentration polarization, turbulence at the vicinity of the membrane have been shown to be of significant factor (Sobana and Panda, 2010); same are true for increasing the flow rate, assembling an intensifier for general turbulent flow, impulse and agitating methods, periodic depressurization of membrane tube, flow reversal, pre-coating of membrane surfaces and modification of membrane polymeric structure. In addition to these methods for limiting the concentration polarization, an adequate pre-treatment will ensure the control of fouling and scaling coupled with regular membrane cleaning (Kosutic and Kunst, 2002). Righton (2009) reported some techniques to measure the concentration polarization build up during operation. He noted that "a simple technique was proposed by Sutzkover et al (2010) for determining the mass transfer coefficient and concentration polarization in a RO system".

Sutzkover added that "the technique was based on evaluation of the permeate flux decline induced by the addition of a salt solution to an initially salt-free water feed. Since the net pressure driving force is influenced by the level of the osmotic pressure prevailing on the membrane surface, the magnitude of flux decline enables the evaluation of membrane surface concentration, and hence the determination of the mass transfer coefficient k. Hence, the value of k can be determined simply from the osmotic pressures of the saline feed and permeate respectively by measuring the permeate flux of the salt-free water, and the permeate flux of the saline solution (Sutzkover, et al. 2000)". In an earlier work, "Kim and Hoek (2005) compared the analytical concentration polarization models to a rigorous concentration polarization model and experimental concentration polarization data. The numerical concentration polarization model was developed to enable local description of permeate flux and solute rejection in cross flow reverse osmosis separations. They concluded that the predictions of local concentration polarization; permeate flux and solute rejection by film theory and the numerical model agreed well for realistic ranges of RO process operating conditions".

2.11 Cake Formation Theory

As concentration polarization occurs, there is a local cake formation in the vicinity of the membrane surface causing fouling and scaling. These have been shown by the results of various studies and experiments conducted which has led to the conclusion on a new source of decline in salt rejection being enhanced osmotic pressure due to formation of a cake. This occurs basically as a combination of a back diffusion of salt ions and altered cross flow hydrodynamics within colloidal deposit layers (Hoek and Elimelech, 2003).

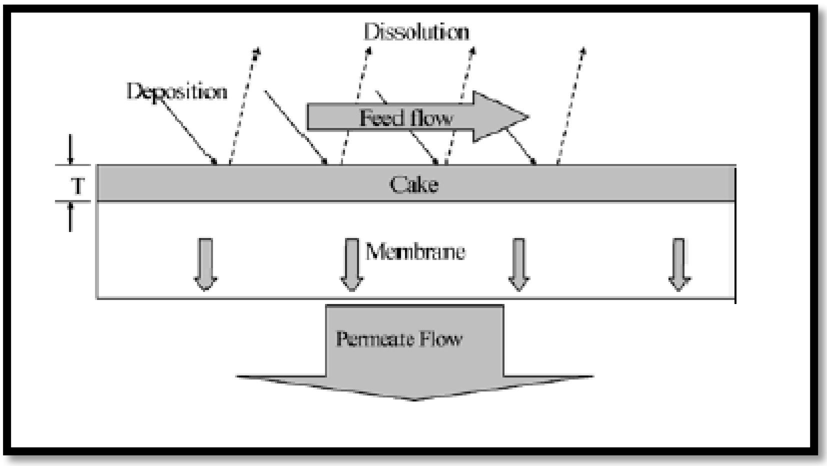

Figure 2-13: Cake Formation Theory (Che-Jen Lin, et al. 2005)

In their report, Lin et al (2005) explained the cake formation theory by looking at the decline in permeate flux across the membrane. From the schematics presented in Figure 2-13, the feed water flows along the surface of the membrane from one end to the other; the concentrate is collected at the other end from the feed, and the filtrate passes through the membrane as permeate. They reported that the permeate flux declined during the early stages of cake formation and then gradually levelled off as time progressed before finally reaching a steady state ultimate flux when the rate of solid deposition is balanced by "back dissolution".

Blatt, et al. (1970) in their early work on the effect of cake formation in flux, studied the transition from pressure dependent flux region to the pressure independent flux region and limiting flux region. They concluded that the transition occurs at lower pressure when low resistance membranes, lower mass transfer coefficients and high feed concentrations are used.

2.12 Current Gap

Johnson and Busch (2009) presented engineering issues with Reverse Osmosis module design; otherwise, there are no widely reported performance and efficiency comparisons between small and large membrane components and hence there are no general process selection heuristics or rule of thumbs associated with the use of either. It is therefore the objective of this research to initiate such by acquiring and analysing actual operating data from an existing plant as a case study; and thereafter to make some general process optimisation recommendations.

2.13 Case Application

United utilities Australia's Osmoflo® systems (2009) at the Townsville, Queensland that deployed Koch membranes were used as case study for this research. The plant has two trains of feedwater fed into four 8-inch membrane units mounted on two skids, two apiece operating at 15bar feed pressure, 6.6bar average osmotic pressure, 2.2 L/m2/hr/bar, 99% salt rejection and 59% recovery with 1.86kWh/kL power consumption at 1.7bar average pressure drop across the membranes . The retentate collects and feeds into four skids of four 16-inch membrane units in parallel operating at 15bar feed pressure, 6.5bar average osmotic pressure, 1.9 L/m2/hr/bar, 98% salt rejection and 78%

recovery with 1.81kWh/kL power consumption at 1.5bar average pressure drop across the membranes.

The 16-inch system retentate is further processed in another set of 16-inch membrane units before all permeates are re-combined for post processing, stabilization and storage.

According to Palmer and Bedem (2003), the use of antiscalant at the refinery water recovery facility (WRF) enhanced recovery to about 90% even though the RO system was operating outside of the accepted operating envelope. This may be unsustainable if other dependencies change or become unstable, and therefore the stability and responses of the 8- and 16-inch systems making up the nickel plant WRF need to be examined.

Chapter 3 : Methodology and Data Acquisition

For ongoing efforts (Johnson and Busch, 2009) in addressing the engineering issues with Reverse Osmosis module designs (i.e. feed rate allowable because of the associated feed spacers, connection systems, train size, element loading, etc.) to be adequately benchmarked, a performance comparison between different sizes especially a size with known and accepted levels need to be done; the 8-inch membrane component is ideal.

To achieve an unbiased comparison, a large pool of data covering at least 3 years generated from an actual operating plant was acquired and analysed, hence saving time and resources on the rigours and drudges associated with the experimental stage of data generation from a local laboratory which may in the end not be an accurate reflection of plant operations. The data were sorted to obtain information such that there are information for both the 8-inch and 16-inch systems under consideration for the period covering July 2004 to September 2008 as presented in the sample Table 3-3 to 3-4, and Tables A-1 to A-29 of the appendix; furthermore, monthly averages are presented in Tables 3-4 and 3-5. These data are used for the following parametric analysis:

1. Normalized specific flux (L/h/m^2/bar)
2. Salt rejection (%)
3. Recovery (%)
4. Power consumption (kWh/kL)
5. Differential pressure (bar)

At the plant, brackish wastewater (with intermediate salinity level between those of Sea water and ground water typified in Table 3-1) from the nickel refinery operations of Queensland Nickel Pty Ltd near Townsville in North Queensland is unsuitable for direct reuse in the refinery. This water has traditionally been stored in tailings ponds for evaporation or directly discharged to Halifax Bay under strict environmental authority control and with extensive monitoring. However due to persisting dry conditions QNPL reviewed its water management strategy in 1999 and decided to develop an 11 ML/d water recycling facility to treat the wastewater with the objective of eliminating marine discharge and reduce new water consumption.

Following the success of pilot plant trials, the Water Recycling Facility was commissioned in December 2000.

Table 3-1: Typical Feedwater Composition (Osmoflo®, 2009)

	Parameter	Units	Typical	Maximum
1	Temperature	°C	20–32	35
2	pH		4.0–6.0	3.2 (min), 8.5 (max)
3	Total Suspended Solids	mg/L	0–20	Not Advised
4	Turbidity	NTU	2–10	15
1	Total Dissolved Solids	mg/L	3000–7500	9750
2	Conductivity @ 25°C	µS/cm	4000–9000	11700
3	Bicarbonate	mg/L CaCO3	10–20	25
4	Carbonate	mg/L CaCO3	< 1	1.3
5	Ammonia (total)	mg/L	400–800	1300
6	Total Organic Carbon	mg/L	5–10	12
7	Silica	mg/L	20–60	78
8	Chloride	mg/L	180–400	520
9	Fluoride	mg/L	0.5–4.0	5.5
10	Sulphate	mg/L	3500–5000	6500
11	Nitrate	mg/L	4–10	61
12	Iron (soluble)	mg/L	< 0.1–0.5	0.7
13	Iron (Fe2+)	mg/L	< 0.05	0.07
14	Iron (Fe3+)	mg/L	< 0.1	0.13
15	Manganese	mg/L	3–15	20
16	Magnesium	mg/L	400–700	910
17	Calcium	mg/L	30–100	130
18	Sodium	mg/L	75–140	350
19	Nickel	mg/L	0.15–0.6	0.8
20	Cobalt	mg/L	0.04–0.25	0.33
21	Potassium	mg/L	10–15	30
22	Barium	mg/L	0.02–0.08	0.40
23	Strontium	mg/L	0.4–0.6	0.7

"The facility was provided as part of a design-build-operate agreement between United Utilities Australia and Queensland Nickel Pty Ltd. The facility was designed and constructed by O'Donnell Griffin Water Technologies of Adelaide and includes Memcor hollow fibre microfiltration (from OSMOFLO) and the novel Grahamtek electromagnetic antiscaling desalination technology which is built in to 16 inch diameter RO pressure vessels arranged as a two stage concentrator. An additional conventional first stage reverse osmosis plant using eight inch diameter pressure vessels was also installed to operate in parallel with the GrahamTek plant to increase overall plant throughput and to provide a comparison with the GrahamTek technology. This conventional plant operates at lower recovery and its concentrate is recycled by blending with the GrahamTek RO feed. A 40 hectare evaporation pond has been constructed for brine disposal. United Utilities operated the facility for QNPL under a ten year alliance agreement" (Palmer et al, 2005).

The wastewater was reported to have salinity in the range 5,500 – 7,500 mg/L TDS and contains significant amounts of ammonia, sulphate, magnesium and silica. It also had soluble trace amounts of barium and strontium salts. Seasonal changes in the rate of evaporation at the tailings pond caused significant variations to the overriding chemistry of the. For instance, rapid reduction of pH causing high concentrations of ferrous iron was observed and was mitigated by incorporating spray aeration, intermittent pH monitoring and correction using caustic soda followed in a shallow intermediate pond located between the active tailings pond and the water recycling facility.

In their summary, Palmer et al (2005) state that "since commencement of operation in 2000, the Water Recovery Facility (WRF) has removed some 5,500 ML of raw water from the tailings pond complex, and supplied 4,600 ML of treated water to the QNPL refinery. 900 ML of reject has been transferred to the evaporation ponds. Dry weather conditions over the past three years have limited further water recycling opportunities from the tailings pond system.

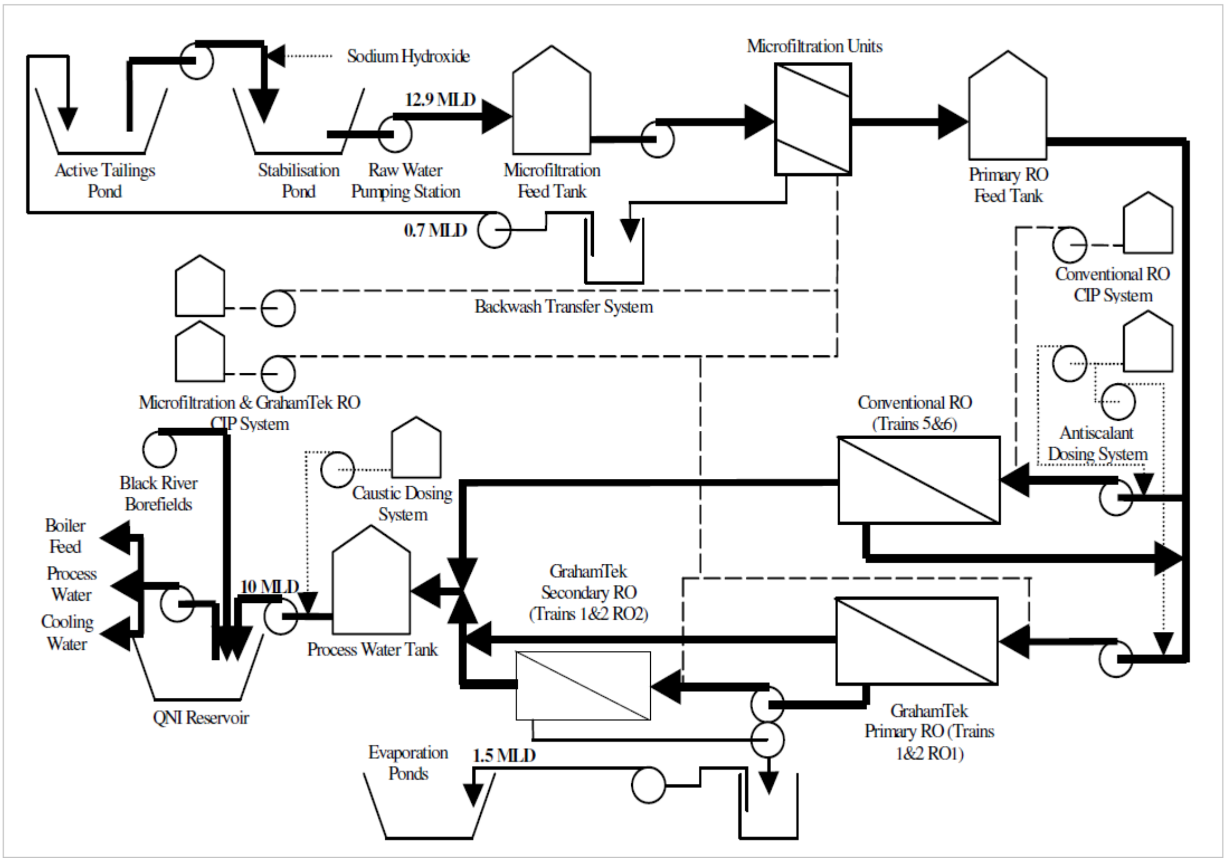

Figure 3-1: Schematic of the Remediated WRF (Palmer et al, 2005)

The original WRF was able to operate sustainably with regular cleaning, but unable to meet warranted flow requirements. The WRF was substantially remediated in 2004 to reduce flux and increase cross flow. A chemical antiscalant dosing system and a clean-in-place system were also added to the facility.

Sustainable operation of the secondary reverse osmosis system, part of the GrahamTek plant (Figure 3-1), has continued despite the operating conditions being significantly outside of the accepted reverse osmosis operating envelope, apparently as a result of the effect of the EMF antiscaling system". This has enabled the facility to operate at up to 90% fresh water recovery (quality typified in Table 3-2) but still prone to future reductions in efficiencies considering the varying conditions and current operations outside of the RO operating envelop. It is in view of this that a performance comparison between the 8-inch and 16-inch system is paramount as a ready handy tool to generate process alternatives and insight for plant expansion or module configuration.

Table 3-2: Typical Feedwater Composition (Osmoflo®, 2009)

	Parameter	Units	Acceptable Limits
1	Total Dissolved Solids (prior to pH adjustment)	mg/L	≤ 150 for ≤ 8500mg/L TDS wastewater
			≤ 180 for ≥ 8500mg/L TDS wastewater
2	Calcium & Magnesium Hardness	mg/L CaCO3	≤ 15 (weekly requirement)
			≤ 20 (maximum allowable daily value)
3	Ammonia (total)	mg/L	≤ 25
4	TOC (non-volatile)	mg/L	≤ 1
5	Silica	mg/L	≤ 5
6	Sulphate	mg/L	≤ 100
7	pH		7.0 – 8.0

Table 3-3: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
27 Mar 2004	1.66	2.07	98.98	64.96	14.13	1.14	2.27	98.78	79.92	13.18
28 Mar 2004	1.67	2.05	98.97	64.99	14.25	1.14	2.28	98.80	79.88	13.43
29 Mar 2004	1.66	2.04	98.97	64.97	14.28	1.13	2.26	98.80	79.78	13.51
30 Mar 2004	1.68	2.06	98.98	64.95	1.11	1.12	2.25	98.82	79.78	1.06
1 Apr 2004	1.68	2.06	98.97	65.20	1.13	1.15	2.12	98.36	77.35	1.20
2 Apr 2004	1.68	1.99	98.94	65.08	1.14	1.11	2.21	98.75	79.82	1.06
3 Apr 2004	1.69	2.02	98.95	65.01	1.15	1.11	2.17	98.75	79.28	1.09
4 Apr 2004	1.70	1.99	98.94	65.04	1.16	1.10	2.16	98.76	79.21	1.11
5 Apr 2004	1.70	1.98	98.93	64.99	1.17	1.10	2.15	98.77	79.08	1.12
21 Apr 2004	1.67	2.07	98.93	64.95	1.15	4.28	77.69	99.80	86.59	1.15
22 Apr 2004	1.67	2.05	98.92	65.01	1.16	1.10	2.46	98.65	82.45	1.16
23 Apr 2004	1.68	2.03	98.91	64.93	1.17	1.09	2.39	98.64	82.85	1.13
30 Apr 2004	1.75	2.00	98.88	63.86	1.19	1.28	2.97	99.16	82.52	1.06
6 May 2004	1.81	2.32	98.94	61.63	1.11	1.29	3.04	98.74	79.85	0.97
7 May 2004	1.71	2.20	98.84	64.67	1.14	1.20	3.02	99.23	80.74	0.94
10 May 2004	1.70	2.16	98.84	64.31	1.12	1.18	2.97	99.17	80.31	0.90
28 May 2004	1.73	2.20	98.82	64.94	1.14	1.26	2.91	99.02	80.72	0.98
29 May 2004	1.73	2.12	98.77	64.97	1.17	1.26	2.72	98.83	80.28	1.05
30 May 2004	1.75	2.09	98.73	64.92	1.21	1.28	2.70	98.82	80.17	1.08
31 May 2004	1.77	2.04	98.70	64.95	1.24	1.27	2.68	98.84	80.01	1.12
1 Jun 2004	1.77	2.03	98.71	65.04	1.23	1.26	2.67	98.87	79.81	1.12
2 Jun 2004	1.76	2.02	98.74	64.98	1.22	1.27	2.68	98.90	79.68	1.11
3 Jun 2004	1.76	2.04	98.77	64.95	1.22	1.25	2.67	98.89	79.67	1.11
4 Jun 2004	1.75	2.04	98.76	65.07	1.19	1.24	2.68	98.87	79.69	1.09
5 Jun 2004	1.75	2.04	98.77	65.07	1.21	1.24	2.69	98.87	79.79	1.10
6 Jun 2004	1.77	2.03	98.79	65.05	1.22	1.22	2.65	98.87	79.64	1.12

Table 3-4: Monthly averages performance index for 8-inch membrane system

Row Labels	Average of Pressure Drop (bar)	Average of Flux (L/m2/hr/bar)	Average of Salt rejection (%)	Average of Recovery (%)	Average of Power Consumption (kWh/kL)
April 2004	1.69	2.02	98.93	64.90	1.16
April 2005	1.82	1.79	98.53	64.51	1.55
April 2006	2.42	1.13	97.74	58.92	1.86
April 2007	2.55	1.07	98.04	58.61	1.95
August 2004	2.09	1.80	98.58	64.73	1.49
August 2005	1.91	1.58	98.36	59.77	1.71
August 2006	2.67	1.07	97.89	54.94	2.09
August 2007	3.22	0.98	98.28	57.55	2.19
December 2005	2.34	1.34	98.14	61.07	1.77
December 2006	2.27	1.28	98.52	57.12	1.95
December 2007	4.29	1.13	97.71	61.81	1.91
February 2005	1.95	1.70	98.55	64.23	1.29
February 2006	2.54	1.23	98.59	57.07	1.66
February 2007	2.22	1.12	98.18	60.49	1.67
February 2008	4.45	0.80	94.03	60.28	1.92
January 2005	1.92	1.70	98.86	60.61	1.34
January 2006	2.38	1.25	98.09	60.96	1.75
January 2008	3.58	0.86	97.83	58.65	2.00
July 2004	1.99	1.87	98.72	65.18	1.39
July 2005	1.96	1.79	98.32	53.65	1.72
July 2006	2.58	0.98	97.66	50.75	2.07
July 2007	2.93	1.10	97.73	54.00	2.40
June 2004	1.81	1.96	98.79	64.97	1.27
June 2005	2.02	1.71	98.52	59.92	1.61
June 2006	2.49	0.99	97.64	50.28	2.14
June 2007	2.75	1.12	97.98	51.54	2.33
March 2004	1.67	2.06	98.98	64.97	10.94
March 2005	2.02	1.70	98.50	64.37	1.42
March 2007	2.50	1.04	98.33	60.14	1.75
March 2008	3.51	0.76	96.57	57.36	2.06
May 2004	1.74	2.16	98.81	64.34	1.16
May 2005	2.24	1.74	98.57	61.71	1.72
May 2006	2.16	1.09	97.68	57.50	1.91
May 2007	2.72	1.13	97.91	58.58	2.04
November 2005	2.28	1.40	98.17	60.82	1.75
November 2006	2.20	1.30	98.50	60.35	1.84
November 2007	4.35	1.10	97.88	57.70	2.09
October 2005	2.13	1.45	98.40	60.61	1.65
October 2006	3.09	1.15	98.54	56.93	2.10
October 2007	3.75	1.07	98.36	55.07	2.09
September 2004	2.01	1.76	98.60	64.92	1.45
September 2005	1.85	1.53	98.57	59.86	1.59
September 2006	2.95	1.15	98.41	55.98	2.08
September 2007	3.56	1.00	98.32	57.32	2.11
Grand Total	**2.62**	**1.29**	**98.19**	**58.70**	**1.90**

Table 3-5: Monthly averages performance index for 16-inch membrane system

Row Labels	Average of Pressure Drop (bar)	Average of Flux (L/m2/hr/bar)	Average of Salt rejection (%)	Average of Recovery (%)	Average of Power Consumption (kWh/kL)
April 2004	1.48	10.70	98.85	81.02	1.12
April 2005	1.49	2.18	99.28	80.34	1.14
April 2006	1.59	1.64	98.74	82.36	1.20
April 2007	1.66	1.47	98.88	74.33	1.85
August 2004	1.25	2.49	98.91	81.99	1.23
August 2005	1.82	1.80	99.03	81.36	1.44
August 2006	1.38	1.45	98.66	82.83	2.15
August 2007	2.16	1.55	98.56	72.51	2.42
December 2005	1.63	2.02	98.68	82.43	1.48
December 2006	1.59	1.58	98.76	79.36	1.89
December 2007	1.47	1.32	98.47	72.49	2.48
February 2005	1.55	2.51	97.68	82.56	1.21
February 2006	1.79	1.75	99.31	81.10	1.22
February 2007	1.57	1.52	98.94	80.14	1.25
February 2008	- 3.42	1.21	99.25	68.20	2.43
January 2005	1.19	2.48	99.22	82.51	1.21
January 2006	1.69	1.72	98.85	82.39	1.42
January 2008	0.07	1.69	98.79	74.42	1.98
July 2004	1.09	2.44	98.46	79.96	1.19
July 2005	1.79	1.91	98.73	79.23	1.51
July 2006	1.22	1.45	98.69	83.24	1.56
July 2007	1.84	1.41	98.55	71.05	3.21
June 2004	0.86	4.06	98.64	78.43	1.16
June 2005	1.15	2.04	99.19	81.59	1.02
June 2006	1.71	1.49	98.77	81.41	1.49
June 2007	1.58	1.41	98.32	54.95	3.42
March 2004	1.13	2.26	98.80	79.84	10.30
March 2005	1.47	2.41	99.35	81.87	1.10
March 2007	1.70	1.42	99.11	80.34	1.37
March 2008	1.94	0.72	91.28	69.12	2.66
May 2004	1.25	2.86	98.95	80.30	1.00
May 2005	1.49	2.12	99.26	76.95	1.18
May 2006	1.66	1.56	98.90	82.51	1.26
May 2007	1.54	1.54	98.78	55.65	2.65
November 2005	1.71	1.88	99.05	82.49	1.42
November 2006	1.59	1.60	98.87	79.18	2.30
November 2007	1.67	1.50	98.51	74.84	2.61
October 2005	1.74	2.02	99.17	82.17	1.34
October 2006	1.83	1.41	98.85	77.05	2.16
October 2007	1.78	1.51	98.40	75.24	2.36
September 2004	1.35	2.32	99.07	82.76	1.44
September 2005	1.78	1.92	99.28	82.10	1.41
September 2006	1.37	1.63	98.74	77.76	1.63
September 2007	1.89	1.51	98.27	75.09	2.47
Grand Total	**1.51**	**1.90**	**98.70**	**77.26**	**1.86**

The observed trends resulting from the operations of both the 8-inch and 16-inch membrane systems are discussed in Chapter 4.

Chapter 4 : Results and Discussion

The data presented in Tables 3-1 to 3-3 and Tables A-1 to A-29 of the appendix were selected such that the information for both the 8- and 16-inches system were for the same period and on the same basis for each parameter to enable fair comparison of performances as discussed below.

4.1 Specific Flux

Figure 4-1 below shows the scattered plot for the specific flux for both the 8- and 16-inches membrane systems. The 16-inch system was found to allow higher flux ranging from 0.13 to 77.69 L/m^2/hr/bar compared to the 8-inch membrane system at 0.76 to 2.32 L/m^2/hr/bar under similar operating conditions. The monthly averages presented in Figure 4-2 also showed that the 16-inch system outperformed the 8-inch system at between 0.70 and 77.89 L/m^2/hr/bar compared to 0.76 and 2.32 L/m^2/hr/bar for the 8-inch system. Both of these produce much more in excess of the minimum requirement of 500L/day for such systems (URS, 2002) for economic feasibility.

The performance of the 16-inch system is better because it has in excess of 4 times active area compared to the 8-inch system (Johnson and Busch, 209) and can hence be ran to produce more permeate that the 8-inch module. As expected however and as seen in Figures 4-1 and 4-2, the specific flux decreased gradually over the years reflecting the age of the membrane units and the increasing salinity of the bay water due to waste discharge in the vicinity of feed water uptake.

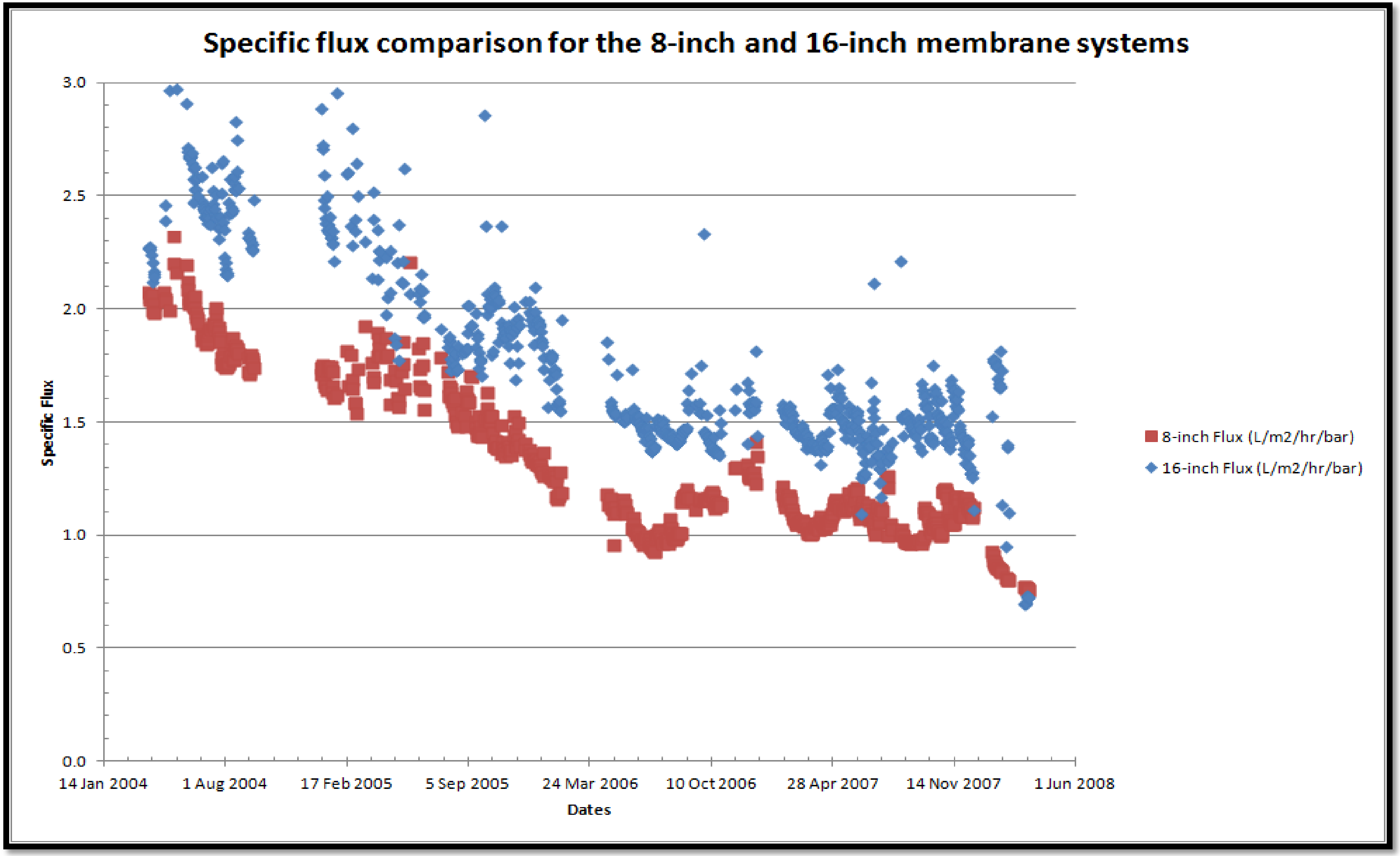

Figure 4-1: Specific flux comparison

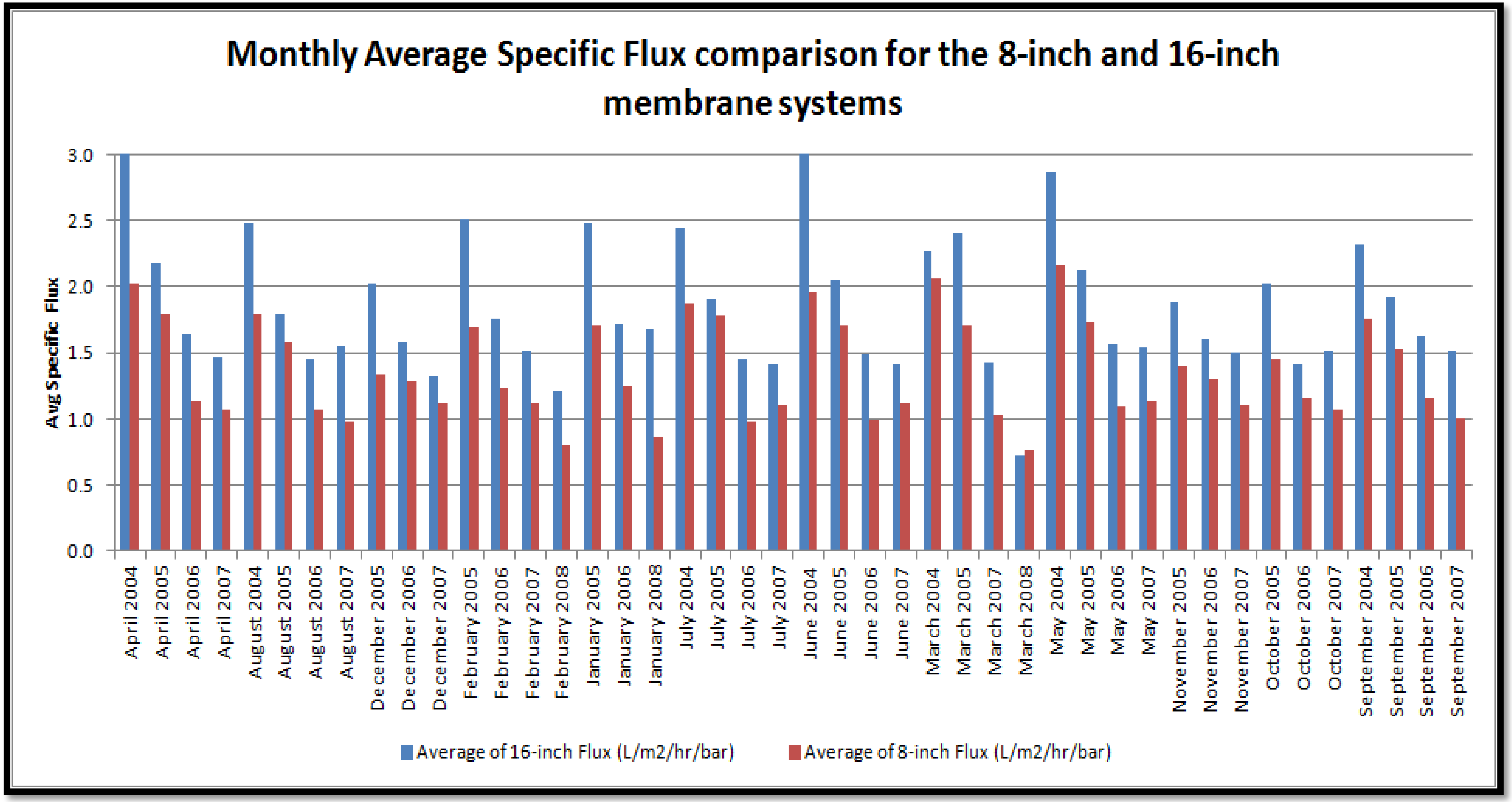

Figure 4-2: Specific flux comparison (Monthly Averages)

4.2 Pressure Drop

Conversely, the 16-inch system registered lower pressure drops of between 0.13 and 4.28 bar across its membranes as shown in Figure 4-3 below compared to between 1.56 and 5.05 bar for the 8-inch system representing an average of 57% increase in pressure drop compared to the 16-inch module. This is due to improved membrane stability and permeates spacer technology deployed in the 16-inch module because thicker spacers can be used without necessarily compromising the effective active area. This trend is further substantiated by the data on monthly averages shown in Figure 4-4. This implies that lower pumping power requirement to transfer permeates and retentate away from the membrane. Both of the systems are well within the designed pressure drop limits (OSMOFLO, 2009).

The plant experienced unusual pressure drops in late 2007 due to membrane scaling and fouling, but was adequately addressed with plant wide turnaround maintenance.

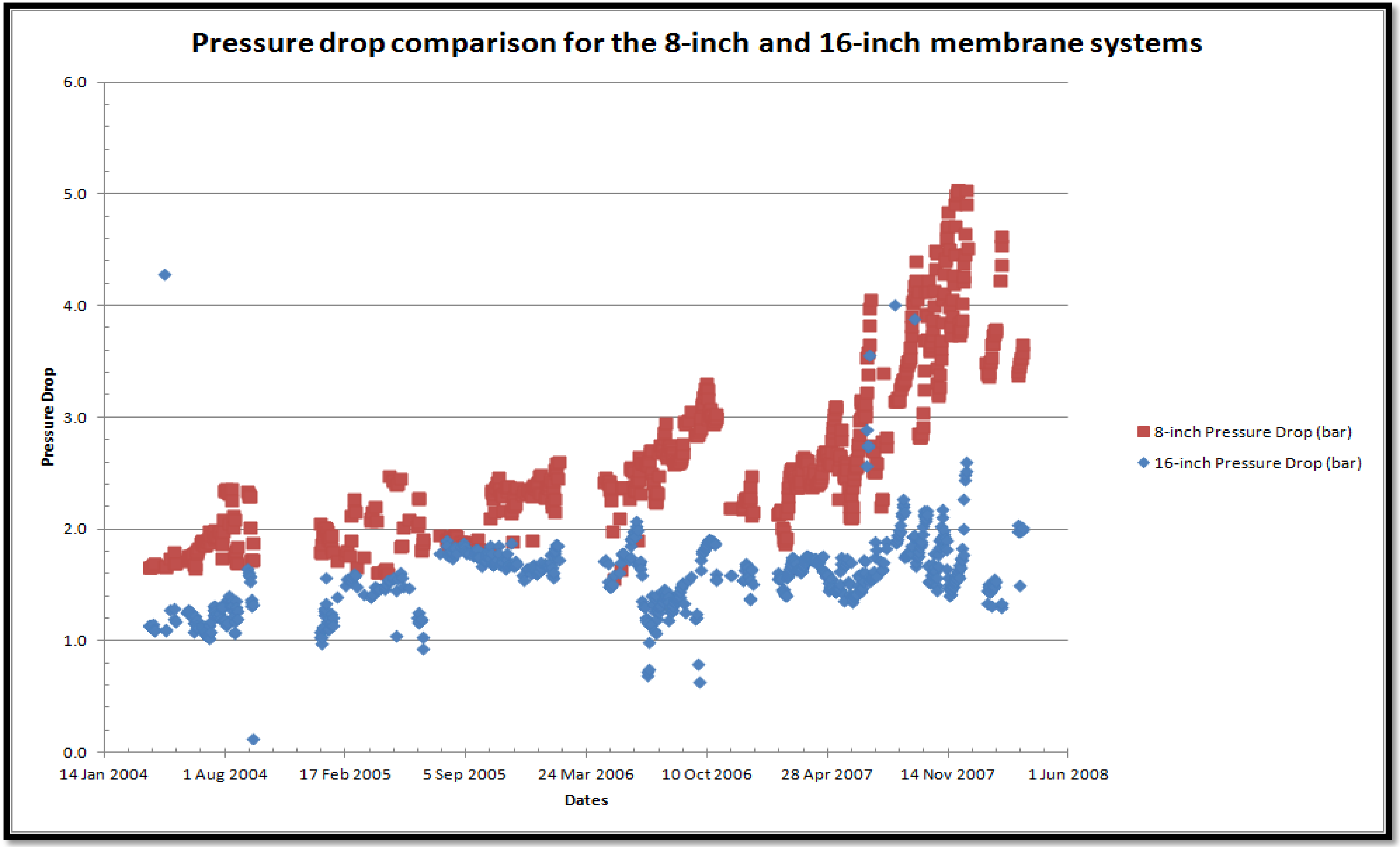

Figure 4-3: Pressure drop comparison

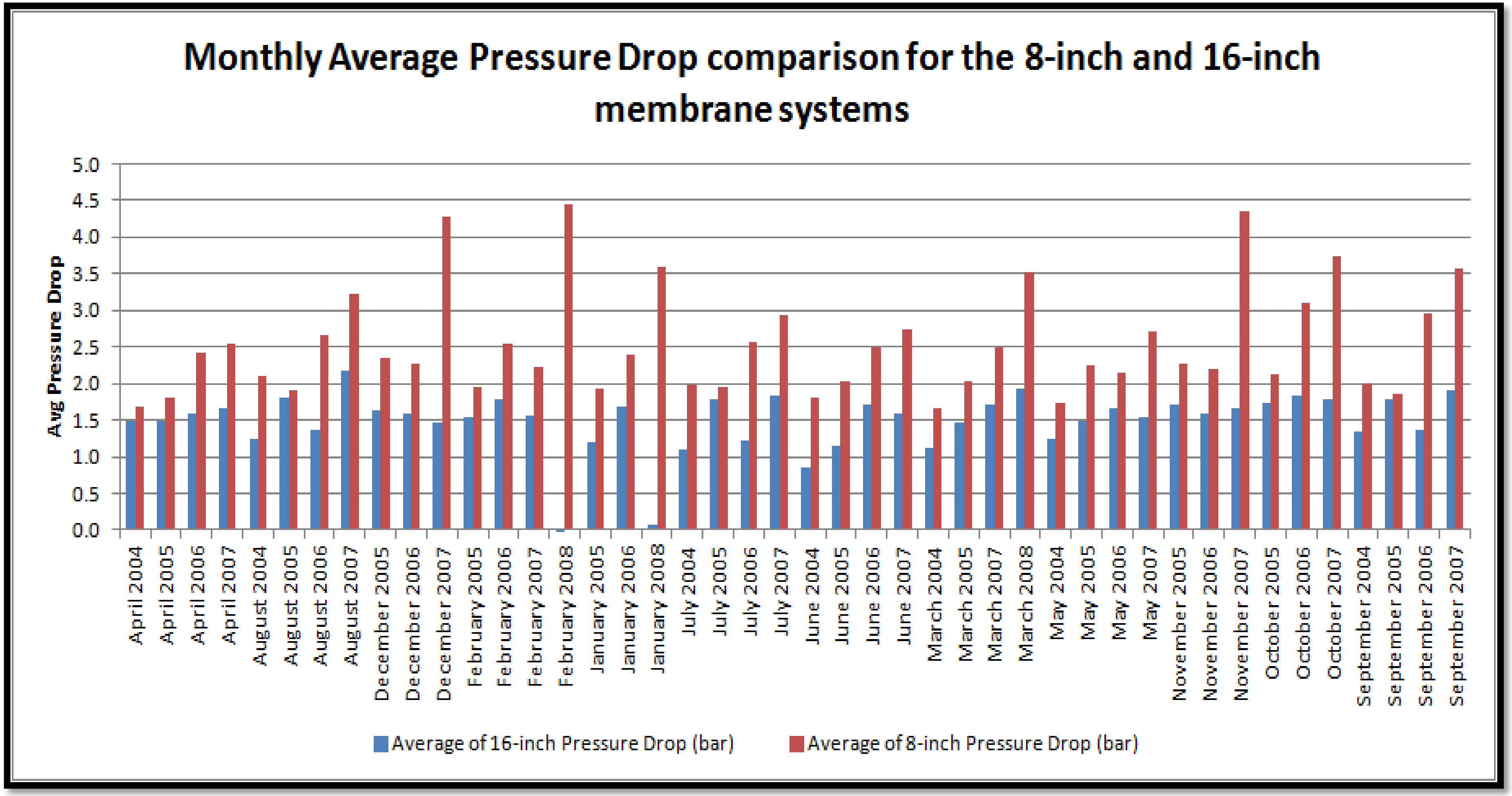

Figure 4-4: Pressure drop comparison (Monthly Averages)

4.3 Salt Rejection

Although on a general note, Salt rejection is higher with the 16-inch system at between 87.23 and 99.97% as depicted in Figure 4-5 and Figure 4-6 compared to those of between 93.1 and 99.06% for the 8-inch system, the data showed a wider variability especially in the period between November 2007 and April 2008 with no specific attributable reasons. These results are in agreement with the 95-99% range prescribed by Bartel et al (2010), Sobana and Panda (2010), Righton (2009) and URS (2002).

The trends observed are typical and agree with literature (Johnson and Busch, 2009); in general, the larger the membrane module the more permeate that can be pushed through and the higher the total salt rejected.

The variations experienced in late 2007 are attributable to imperfect mixing which caused Osmotic penalty and led to increased pressure drops in the same period which according to Johnson and Busch (2009) also “promotes scaling at the membrane surface, and increases the rate of deposition of certain foulants”.

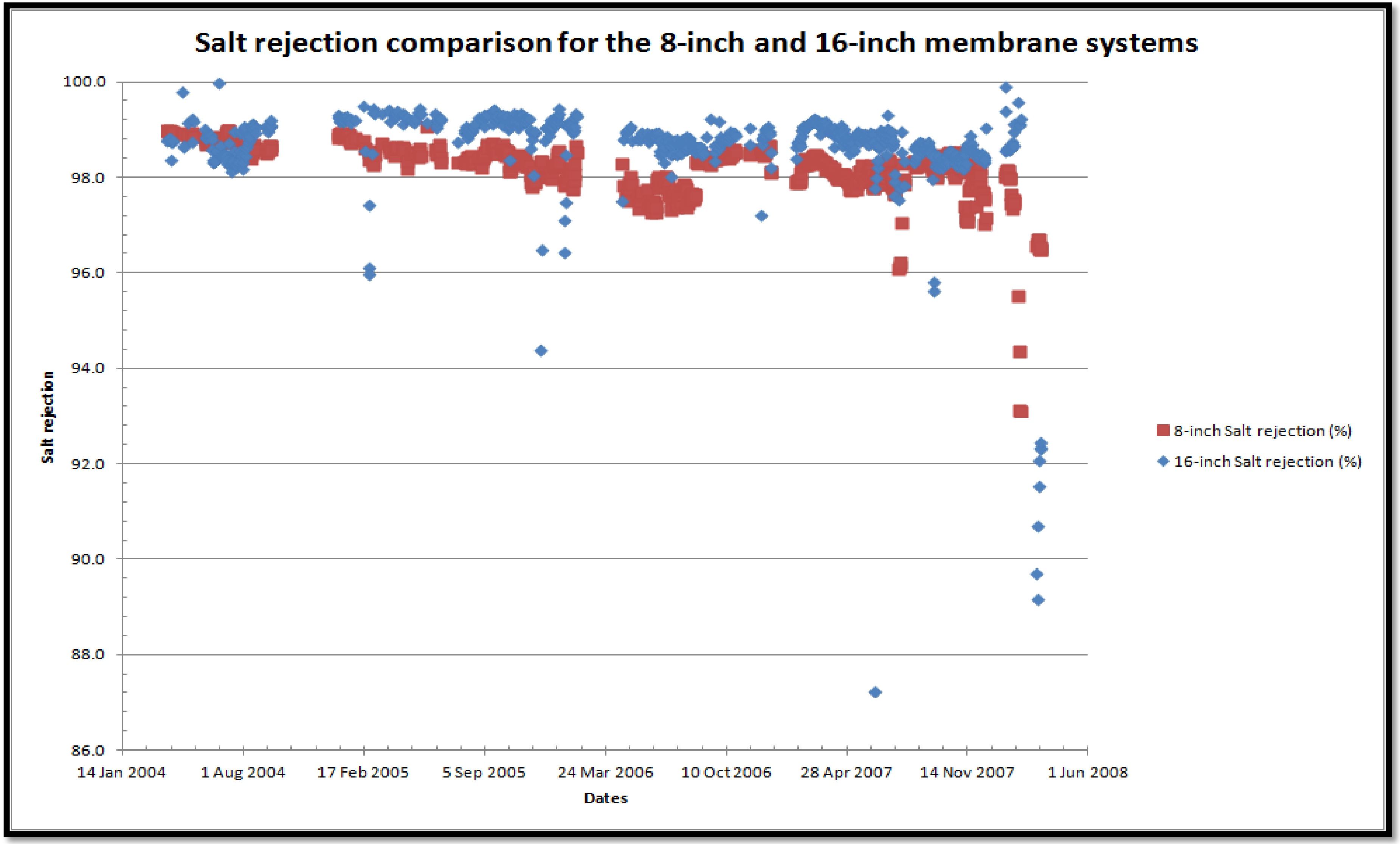

Figure 4-5: Salt rejection comparison

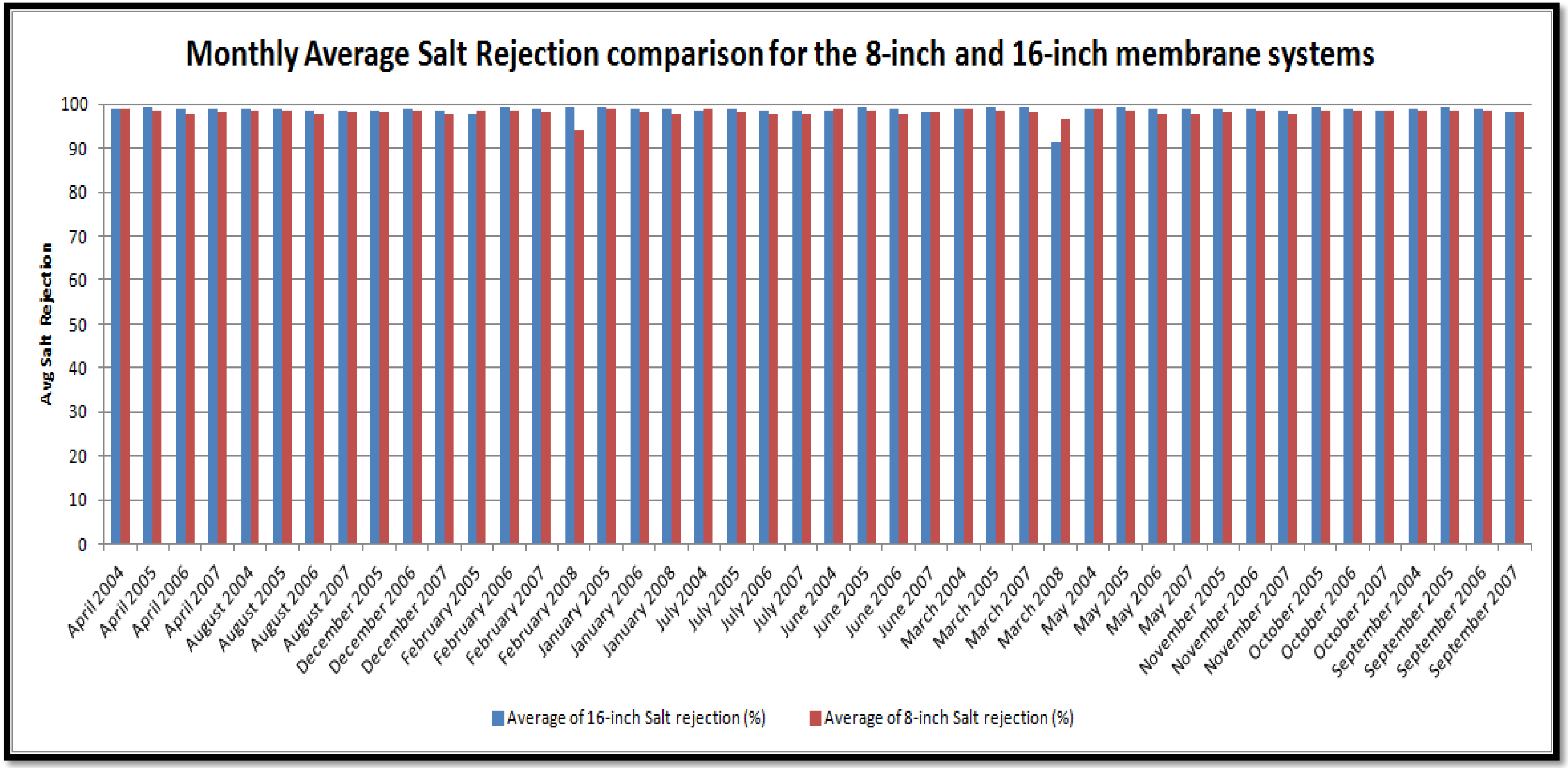

Figure 4-6: Salt rejection comparison (Monthly Averages)

4.4 Recovery

As presented in Figures 4-7 and 4-8 below, fresh water recovery also showed similar trend with the 16-inch membrane system performing better at an average of 8% higher recovery between 41.88 and 90.52% compared to those of the 8-inch system at between 45.88 and 76.15%. The results outperforms minimum operating boundary recommended by URS (2002).

The better performance of the 16-inch is due to the larger active area which allows more permeate to be pumped through; while the general lower recoveries in late 2007 was due to improper mixing.

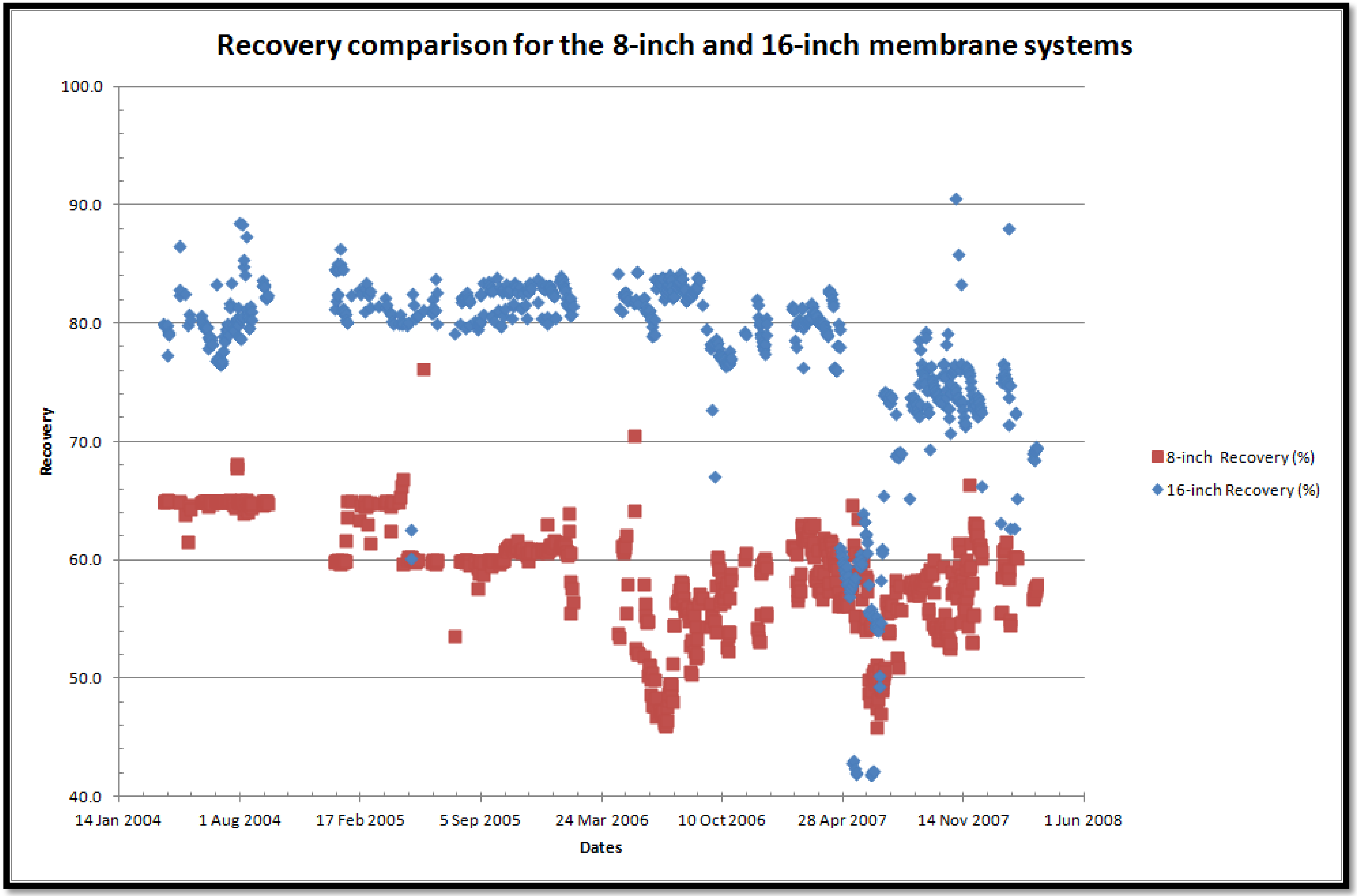

Figure 4-7: Recovery comparison

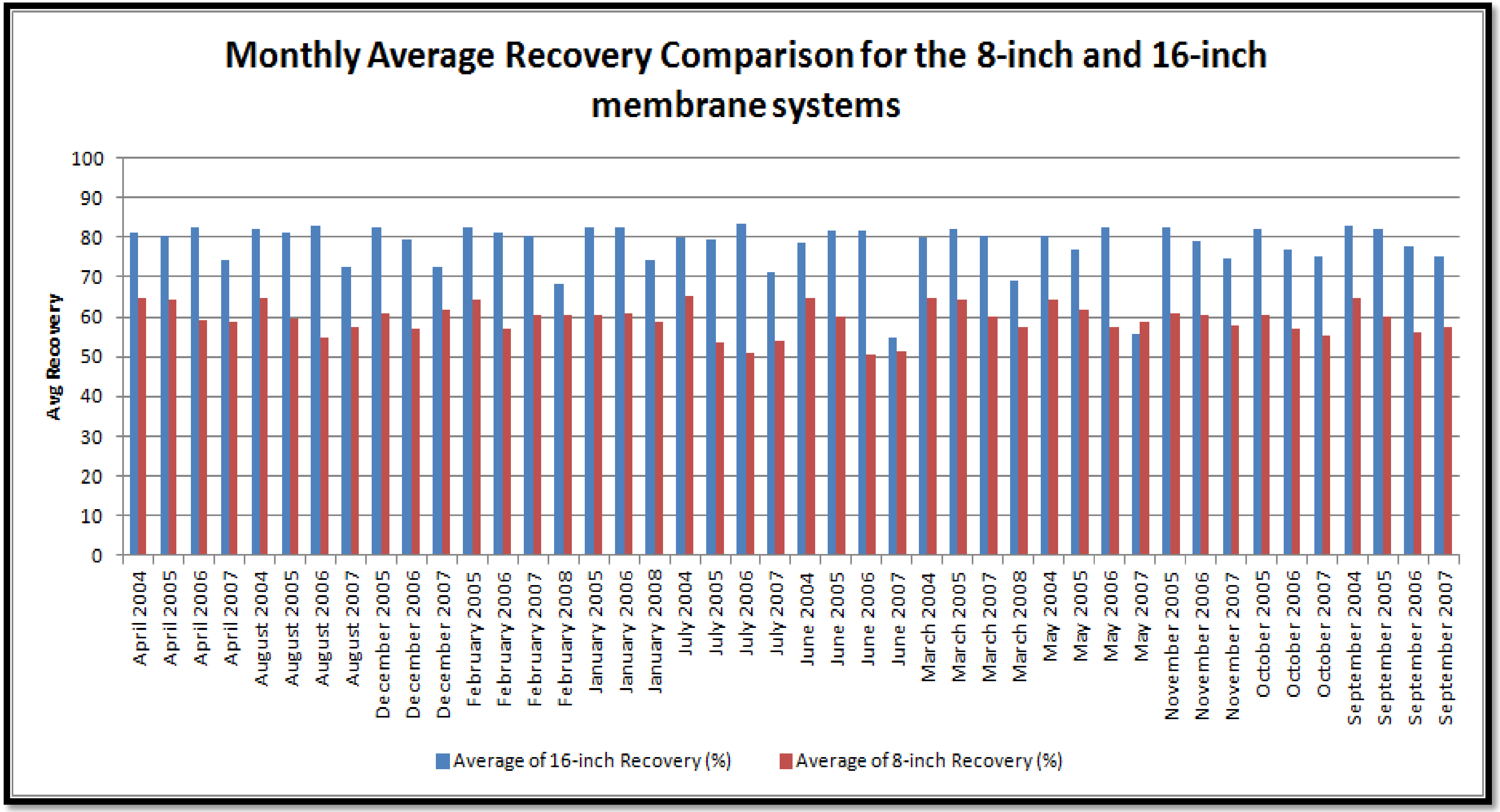

Figure 4-8: Recovery comparison (Monthly Averages)

4.5 Power Consumption

Conversely, the 16-inch system consumed less power compared to the 8-inch system as shown in Figures 4-9 and 4-10. The 16-inch system consumed between 0.77 and 13.51kW/kL compared to between 1.11 and 14.28kW/kL for the 8-inch system. This has direct proportionality implication on operating cost. Pricing power according to Queensland Origin's tariff 41 at 0.11A$/kWh, these results show that operating cost associated with power alone [0.122 – 14.18A$/kL for the 8-inch system and 0.085 – 2.59 A$/kL for the 16-inch system] outstrips the recommended total operating cost (OPEX) for such plants (URS, 2002) in absolute terms. When indexed at the 2.8% average inflation rate in Australia (CPI, 2012) from 2002 to 2012 presented in Table 4-1 below, the recommended total OPEX gave between 0.86 – 1.98A$/kL which is still lower than the cost of actual power consumption alone.

The 16-inch module's 10% better performance is attributable to improve hydraulic balance in low-pressure RO systems (Bartels, 2008; Johnson, 2005; Kihara, 2003); whereas the imperfect mixing which led to fouling affected the 16-inch more and hence the poorer performance in late 2007.

Table 4-1: Australian Inflation History (RI, 2012)

Year	mar	jun	sep	dec	ann
2012	1.6%	1.2%	2%	2.2%	1.7%
2011	3.3%	3.6%	3.5%	3.1%	3.4%
2010	2.9%	3.1%	2.8%	2.7%	2.8%
2009	2.5%	1.5%	1.3%	2.1%	1.8%
2008	4.2%	4.5%	5%	3.7%	4.4%
2007	2.4%	2.1%	1.9%	3%	2.3%
2006	3%	4%	3.9%	3.3%	3.5%
2005	2.4%	2.5%	3%	2.8%	2.7%
2004	2%	2.5%	2.3%	2.6%	2.3%
2003	3.4%	2.7%	2.6%	2.4%	2.8%
2002	2.9%	2.8%	3.2%	3%	3%

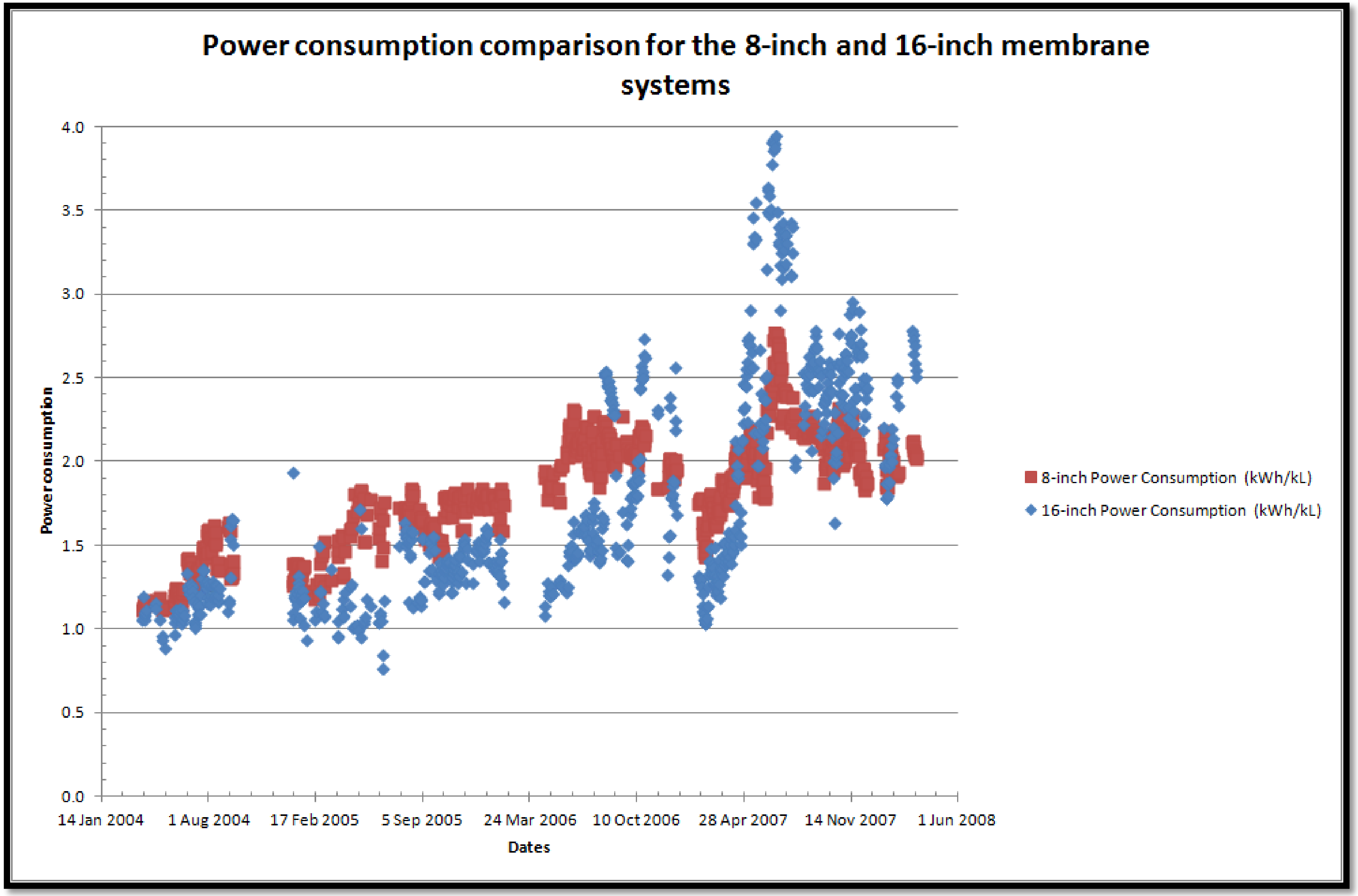

Figure 4-9: Power consumption comparison

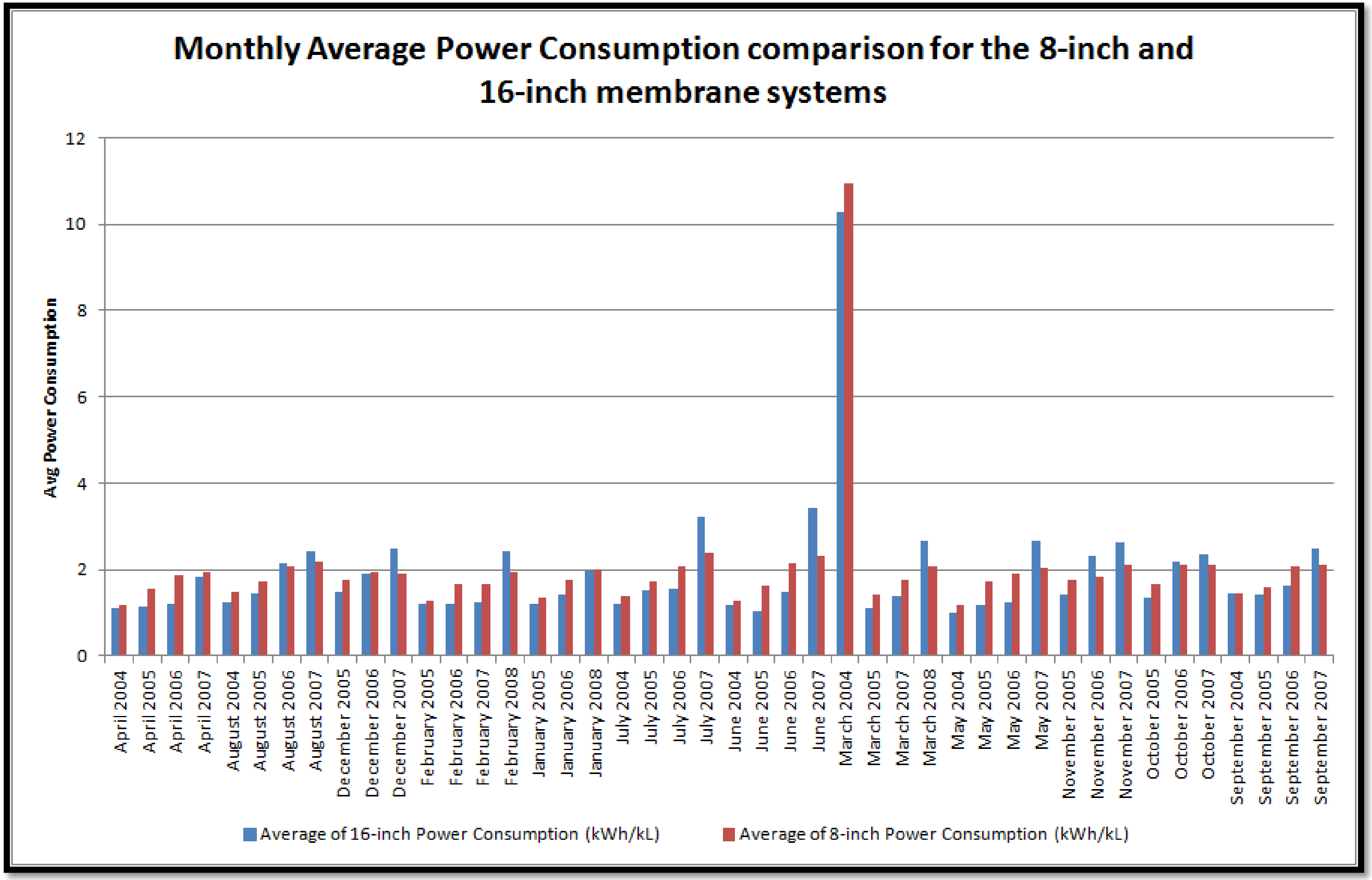

Figure 4-10: Power consumption comparison (Monthly Averages)

4.6 Results and Discussions

Although the 16-inch system outperforms the 8-inch system for all parameters evaluated, the 16-inch system presented a wider variability and hence can easily become unstable. By implication, the narrower bands presented by the 8-inch system suggests better controllability.

From the above results, it is evident that the 8-inch system is more suitable in situations where plant-wide automatic controls are not available as it delivers performances within a trackable narrower band but with lower outputs, whereas the 16-inch system is more applicable where a robust central distributed control system is deployed and typically for much larger throughputs where both instantaneous and overall demands are high.

Except for high demands however, the capital cost associated with the increase in estate requirement, control system and storages will outstrip the cost savings in operating cost due to lower power consumption if a 16-inch system is deployed where there are no matching instantaneous and overall demand for product.

The observed trend and performances for both the 8- and 16-inches system are generally within the stipulated requirements, except for power consumption, given in URS' report on economic and technical assessment of desalination technologies in Australia: with particular reference to National Action Plan Priority Region (2002) presented in Table 4-2 below.

Table 4-2: URS report on economic and technical assessment of desalination technologies in Australia: with particular reference to National Action Plan Priority Region (URS, 2002)

Parameter	**Seawater RO**	**Brackish RO**	**Multi Effect Distillation**	**Electrodialysis Reversal**
Feed Water Salinity (mg/L TDS)	> 32,000	< 32,000	> 35,000	3,000 – 12,000
Product Water Salinity (mg/L TDS)	< 500	<200	<10	<10
Minimum Product Water Volume	500 L/day	500 L/day	120kL/day	90 kL/day
% Recovery	≤30	≥80	40 – 65	> 90
Energy Required	Electrical Energy	Electrical Energy	Electrical Energy or Waste Heat Energy	Electrical Energy or Waste Heat Energy
Capital Cost [A$/(L/day of product water)]	1,600 – 2,500	600 – 1,800	2,500 – 3,900	570 – 3,250
Operating Cost (A$/kL)	1.89 – 2.20	0.65 – 1.50	With Waste Heat: 0.55 – 0.95 Without Waste Heat: 1.8 – 2.80	1.00 – 2.80

4.7 Formulation of Generalized Correlations

Preliminary attempts were made to fit generalized equations for the parameters (Salt Rejection, Specific Flux, Pressure Drop, Recovery and Power Consumption) evaluated for both the 8- and 16-inch membrane modules using polynomial and exponential regression methods; however these were inconclusive and will be recommended for future.

In the attempt, extreme conditions and data points were pruned (Kleinbam, et al 1998) to reduce the overall noise levels and by finding the least square estimates for the unknown variables, single equations were developed using gradient points for each membrane parameter's data considered. Using the equation for the 8- and 16-inches for each parameter as a pair, they were grafted together to form sub-models and least squares were estimated to develop single equations for each parameter for power consumption, salt rejection and specific flux as presented in Equations 4-1 to 4-3; while lumped parameter regression was used to obtain the correlations for pressure drop and recovery as presented in Equations 4-4 and 4-5.

The exercise yielded for

1. **Power Consumption**

$$\boldsymbol{P_2 = 10^{-58}\left(\left(\frac{ln(p_1)}{0.0006}\right) + 38,376.54\right)^{12.673}} \qquad 4\text{-}1$$

Where P2 and P1 are the Power Consumption (kWh/kL) for the 16-inch and 8-inch systems respectively with R2 value of 0.426 and within ±0.25 average variation compared to actual data points. Table 4-3 present the actual and predicted values for the 16-inch power consumption for few data points, showing good match between the actual and predicted values.

Table 4-3: Actual and predicted trend for 16-inch membrane power consumption

8-inch Power Consumption (kWh/kL)	16-inch Power Consumption (kWh/kL)	Predicted 16-inch Power Consumption (kWh/kL)	Variance
1.39	1.23	1.48	-0.25
1.14	1.09	1.33	-0.24
1.67	1.40	1.64	-0.24
2.16	1.69	1.88	-0.19
2.17	1.71	1.89	-0.18
1.23	1.21	1.39	-0.18
1.78	1.53	1.70	-0.17
1.63	1.45	1.62	-0.17
1.72	1.52	1.67	-0.15
1.79	1.57	1.70	-0.14
1.93	1.64	1.77	-0.13
1.45	1.39	1.52	-0.13
1.76	1.56	1.69	-0.12
1.22	1.27	1.38	-0.12
1.70	1.55	1.66	-0.11
1.68	1.54	1.65	-0.10
2.10	1.80	1.86	-0.06
2.08	1.80	1.85	-0.05
2.07	1.80	1.84	-0.04
2.03	1.79	1.82	-0.04
1.52	1.53	1.56	-0.03
1.74	1.64	1.68	-0.03
1.54	1.54	1.57	-0.03
2.21	1.88	1.91	-0.03
1.84	1.71	1.73	-0.02
1.76	1.91	1.69	0.23
2.56	2.30	2.06	0.24
1.99	2.04	1.80	0.24
1.87	1.98	1.74	0.24
1.76	1.94	1.69	0.25

2. Specific Flux

$$\boldsymbol{S_2 = 0.0003{S_1}^2 + 0.0194S_1 + 2.3058} \qquad 4\text{-}2$$

Where S_2 and S_1 are the Specific Flux (L/m2/hr/bar) for the 16-inch and 8-inch systems respectively with R^2 value of 0.7695 and within |10%| average variation compared to actual data point. Table 4-4 present the actual and predicted values for the 16-inch specific flux for few data points, showing good match between the actual and predicted values.

Table 4-4: Actual and predicted trend for 16-inch membrane specific flux

8-inch Flux (L/m2/hr/bar)	16-inch Flux (L/m2/hr/bar)	Predicted 16-inch Flux (L/m2/hr/bar)	Variance
2.07	2.27	2.35	-3%
2.05	2.28	2.35	-3%
2.04	2.26	2.35	-4%
2.06	2.25	2.35	-4%
1.99	2.21	2.35	-6%
2.02	2.17	2.35	-8%
1.99	2.16	2.35	-9%
1.98	2.15	2.35	-9%
2.05	2.46	2.35	5%
2.03	2.39	2.35	2%
2.05	2.58	2.35	9%
2.02	2.47	2.35	5%
2.06	2.53	2.35	7%
1.98	2.58	2.35	9%
1.96	2.53	2.35	7%
1.95	2.50	2.34	6%
1.94	2.58	2.34	9%
1.88	2.48	2.34	5%
1.87	2.46	2.34	5%
1.88	2.44	2.34	4%
1.88	2.43	2.34	4%
1.87	2.41	2.34	3%
1.86	2.41	2.34	3%
1.85	2.41	2.34	3%
1.85	2.42	2.34	3%

3. Salt Rejection

$$\mathrm{SR}_2 = 0.0001\mathrm{SR}_1{}^2 - 0.003\mathrm{SR}_1 + 98.897 \qquad \text{4-3}$$

Where SR2 and SR1 are the Salt Rejection (%) for the 16-inch and 8-inch systems respectively with R2 value of 0.421 and within |1%| average variation compared to actual data point. Table 4-5 present the actual and predicted values for the 16-inch Salt Rejection for few data points, showing good match between the actual and predicted values.

Table 4-5: Actual and predicted trend for 16-inch membrane salt rejection

8-inch Salt rejection (%)	16-inch Salt rejection (%)	Predicted Salt Rejection (%)	Variance
98.98	98.78	99.58	-1%
98.97	98.80	99.58	-1%
98.97	98.80	99.58	-1%
98.98	98.82	99.58	-1%
98.97	98.36	99.58	-1%
98.94	98.75	99.58	-1%
98.95	98.75	99.58	-1%
98.94	98.76	99.58	-1%
98.93	98.77	99.58	-1%
98.93	99.80	99.58	0%
98.92	98.65	99.58	-1%
98.91	98.64	99.58	-1%
98.88	99.16	99.58	0%
98.94	98.74	99.58	-1%
98.84	99.23	99.58	0%
98.84	99.17	99.58	0%
98.82	99.02	99.58	-1%
98.77	98.83	99.58	-1%
98.73	98.82	99.58	-1%
98.70	98.84	99.58	-1%
98.71	98.87	99.58	-1%
98.74	98.90	99.58	-1%
98.77	98.89	99.58	-1%
98.76	98.87	99.58	-1%
98.77	98.87	99.58	-1%

4. Pressure Drop

$$Pd_2 = 1.0228 Pd_1{}^{0.25} \qquad \text{4-4}$$

Where P_{d1} and P_{d2} are the Pressure Drops (bar) for the 16- and 8-inches system respectively with R^2 value of 0.3523 and within |5%| average variation compared to actual data point. Table 4-6 present the actual and predicted values for the 16-inch Pressure Drop for few data points, showing good match between the actual and predicted values.

Table 4-6: Actual and predicted trend for 16-inch membrane pressure drop

8-inch Pressure Drop (bar)	16-inch Pressure Drop (bar)	Predicted 16-inch Pressure Drop (bar)	Variance
1.66	1.14	1.16	-2%
1.67	1.14	1.16	-3%
1.66	1.13	1.16	-3%
1.68	1.12	1.16	-4%
1.68	1.15	1.16	-1%
1.70	1.18	1.14	4%
1.79	1.16	1.16	1%
1.65	1.17	1.14	3%
1.79	1.19	1.16	4%
1.80	1.15	1.16	-1%
1.82	1.12	1.16	-4%
1.84	1.11	1.16	-5%
1.91	1.14	1.17	-3%
1.89	1.12	1.17	-5%
1.98	1.15	1.18	-4%
1.95	1.17	1.18	-1%
1.97	1.23	1.18	5%
1.95	1.22	1.18	4%
1.99	1.20	1.18	2%
1.99	1.19	1.18	1%
2.09	1.18	1.19	-1%
2.35	1.18	1.22	-4%
2.36	1.19	1.23	-4%
2.13	1.23	1.20	3%
2.09	1.17	1.19	-2%
1.99	1.18	1.18	0%
1.95	1.19	1.18	2%
1.92	1.15	1.17	-3%
1.93	1.17	1.17	-1%
1.95	1.18	1.18	0%
1.81	1.15	1.16	-1%
2.04	1.21	1.19	2%
2.07	1.16	1.19	-3%
2.28	1.17	1.22	-4%
2.29	1.26	1.22	4%
1.82	1.19	1.16	3%
1.83	1.20	1.16	3%

5. Recovery

$$R = 2.5041\left(\frac{S}{P_d}\right)^2 + 7.179\left(\frac{S}{P_d}\right) + 53.777 \qquad 4\text{-}5$$

Where *R*, *S* and P_d are the Recoveries (%), Specific Flux (L/m2/hr/bar) and Pressure Drop (bar) respectively for the system with R^2 value of 0.225 and within |4%| average variation compared to actual data point. Table 4-7 present the actual and predicted values for the 16-inch Recovery for few data points, showing good match between the actual and predicted values.

Table 4-7: Actual and predicted trend for 16-inch membrane Recovery

8-inch Specific flux (S)	8-inch Pressure drop (P_d)	S/P_d	8-inch Recovery (%)	Predicted Recovery (%)	Variance
2.07	1.66	1.25	64.96	66.60	-3%
2.05	1.67	1.23	64.99	66.41	-2%
2.04	1.66	1.23	64.97	66.36	-2%
2.06	1.68	1.23	64.95	66.35	-2%
2.06	1.68	1.23	65.20	66.39	-2%
1.99	1.68	1.19	65.08	65.87	-1%
2.02	1.69	1.20	65.01	65.93	-1%
1.99	1.70	1.17	65.04	65.65	-1%
1.98	1.70	1.17	64.99	65.58	-1%
2.07	1.67	1.24	64.95	66.53	-2%
2.05	1.67	1.22	65.01	66.32	-2%
2.03	1.68	1.21	64.93	66.14	-2%
2.00	1.75	1.14	63.86	65.21	-2%
2.20	1.71	1.29	64.67	67.20	-4%
2.16	1.70	1.27	64.31	66.98	-4%
2.20	1.73	1.27	64.94	66.93	-3%
2.12	1.73	1.23	64.97	66.38	-2%
2.09	1.75	1.19	64.92	65.90	-2%
2.04	1.77	1.15	64.95	65.41	-1%
2.03	1.77	1.15	65.04	65.35	0%
2.02	1.76	1.15	64.98	65.34	-1%
2.04	1.76	1.16	64.95	65.45	-1%
2.04	1.75	1.17	65.07	65.54	-1%
2.04	1.75	1.17	65.07	65.54	-1%

4.8 Potential Usefulness of the Correlations

As these correlations are based on reliable and large valuable plant data, they will (when fully developed and tested to cover other membrane sizes) provide firsthand information for water practitioners to predict the likely variations in terms of the parameters of importance to membrane operations and will complement the silent alarm approach (Saad, 2005) in predicting deviation points at which maintenance is required.

Chapter 5 : Conclusions and Recommendations

In this research, operational data on Reverse Osmosis application in Sea Water Desalination were acquired for two different membrane system sizes (8 and 16 inches); their performances and effectiveness in terms of specific flux, recovery, salt rejection, pressure drop across membranes components and power consumption were compared as follows:

1. Efficiencies using
    a. Total through put per unit area
    b. Permeates
        i. Water Recovery Percentage
        ii. Quality
        iii. Differential Pressure across the membrane
    c. Rejection percentage
        i. TDS
        ii. Other key elements
    d. Predictability
2. Feasibilities using
    a. Data on efficiencies to determine operating cost per unit area of membrane
    b. Required Capital and Operational Cost over a known/given time span based on membrane life.

The data acquired were pruned such that there were data for both modules to cover the period under consideration for each parameter. These comparisons which to date does not exist is expected to become a ready compendium and handy tool for process decisions and providing insight and better understanding of the variability in the tested parameters of paramount importance in Reverse Osmosis operations and can lead to cost reductions by making appropriate process selection decisions based on the finding, herewith summarized in Table 5-1.

The study has provided sufficient and valuable analysis of data collected in the plant over the years leading to the possible implementation of large size membrane modules for RO operations.

Table 5-1: Summary of Parameters

Membrane size		***8-inch***	***16-inch***
Specific flux (L/m^2/hr/bar)		*0.76 – 2.32*	*0.13 – 77.69*
Pressure drop (bar)		*1.56 – 5.05*	*0.13 – 4.28*
Salt Rejection (%)		*93.1 – 99.06*	*87.23 – 99.97*
Recovery (%)		*45.88 – 76.15*	*41.88 – 90.52*
Power consumption (kW/kL)		*1.11 –14.28*	*0.77 – 13.5*
Costs	*Operating Expenses (A$/kL)*	*0.12 – 14.18*	*0.085 – 2.59*
	Capital expenditure (A$/kL)	• *At least 4 modules required for every 1 module of 16-inch due to permissible flux to meet similar demands* • *Narrow product quality variability and hence simple control system is sufficient for the plant*	• *Only1 module required for every 4 modules of the 8-inch system.* • *Wide product quality variability and hence more complex control system will be required for the plant*
Maintenance issues		*Less maintenance and simpler control. More end caps but less spacers*	*More maintenance and more complex control Less end caps but more spacers*
Merits		*Narrower product quality variability*	*Wider product quality variability*
Demerits		*Allows only 25% flux compared to the 16 inch module.*	*Allows only 400% flux compared to the 8 inch module.*
Optimal scenario		*Less variability and hence better quality predictability*	*More variability and hence less quality predictability.*

Upon completion of this research and using similar basis for data analysed, the 16-inch membrane system was found to outperform the 8-inch system for all criteria evaluated but with wider variability as presented in Chapter 4 and summarized below:

1. Efficiencies:
    a. The 16-inch system was found to allow higher flux ranging from 0.13 to 7.69L/m^2/hr/bar compared to the 8-inch membrane system at 0.76 to 2.32 L/m^2/hr/bar under similar operating conditions. The monthly averages also showed that the 16-inch system outperformed the 8-inch system at between 0.70 and 77.89 L/m^2/hr/bar compared to 0.76 and 2.32 L/m^2/hr/bar for the 8-inch system
    b. Fresh water recovery also showed similar trend with the 16-inch membrane system performing better at between 41.88 and 90.52% compared to those of the 8-inch system at between 45.88 and 76.15%. Conversely, the 16-inch system registered lower pressure drops of between 0.13 and 4.28 bar across its membranes as shown in Figure 4-3 below compared to between 1.56 and 5.05 bar for the 8-inch system; this trend is further substantiated by the data on monthly averages shown in Figure 4-4. This implies that lower pumping power requirement to transfer permeates and retentate away from the membrane.
    c. Salt rejection was higher with the 16-inch system at between 87.23 and 99.97% as depicted in Figure 4-5 and Figure 4-6 compared to those of between 93.1 and 99.06% for the 8-inch system, the data showed a wider variability especially in the period between November 2007 and April 2008 with no specific attributable reasons.
    d. Based on the data and trend observed, the 8-inch system showed less variability and hence more predictable compared to the 16-inch system.
2. In general and given the observed trend, a mix of both depending on expected outcomes are required to achieve given process objectives. However because of the wider product quality variability, deploying the 16-inch system alone requires stricter control and hence more investment in control systems.

Therefore the following overall process configurations are recommended for optimisation and cost minimisation.

1. The 16-inch membrane system should be a preferred option when and where adequate control system is in place.
2. The 8-inch membrane system should be a preferred option where only limited centralised control is feasible.
3. The 8-inch membrane system should be the first choice for small scale production.
4. Using the 8-inch membrane system at the front-end followed by the 16-inch systems can be a low-capital alternative to deploying an expensive control system where there is huge demands for product. This nonetheless, a centralised control system should be implemented over time.
5. The 16-inch with adequate control system, or a mix using 8-inch at the front end with retentate fed into the 16-inch system, should be the preferred option where there are huge instantaneous and overall demands for product.
6. It should be noted the capital cost associated with the increase in estate requirement, control system and storages will outstrip the cost savings in operating cost due to lower power consumption if a 16-inch system is deployed where there are no matching instantaneous and overall demand for product.

The general correlations developed from reliable and large valuable plant data used for this research, will (when fully developed and tested to cover other membrane sizes) provide firsthand information for water practitioners to predict the likely variations in terms of the parameters of importance to membrane operations and will complement the silent alarm approach in predicting deviation points at which maintenance is required.

Recommendation for future work

1. The effect of cake formation and the limit permissible before concentration polarization occurs, on the membrane surfaces should be investigated for possible impact on specific flux, pressure drop and recovery, looking specifically at

    a. The effective mass transfer required to limit the permissible before concentration polarization around the permeate spacers.
    b. Optimal spacers required to avoid excessive pressure drop and osmotic penalty.

2. Substantive work on investigating, extending and testing the generalized correlations to predict the performances of the 8- and 16-inches membrane elements. Attempt should thereafter be made to generalize the correlations to cover most RO system designs and configurations.

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Appendix

Table A-1: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
7 Jun 2004	1.78	2.01	98.82	64.99	1.22	1.21	2.62	98.88	79.62	1.13
8 Jun 2004	1.79	2.05	98.84	64.55	1.19	1.16	2.58	98.78	78.84	1.12
9 Jun 2004	1.70	2.02	98.83	64.84	1.16	1.08	2.47	98.58	77.87	1.11
10 Jun 2004	1.65	2.06	98.83	64.88	1.14	1.17	2.53	98.38	78.54	1.06
11 Jun 2004	1.69	2.01	98.82	65.01	1.17	1.23	2.63	98.32	78.95	1.04
12 Jun 2004	1.79	1.98	98.82	65.01	1.21	1.19	2.58	98.35	78.77	1.06
13 Jun 2004	1.80	1.96	98.82	64.99	1.22	1.15	2.53	98.34	78.55	1.10
14 Jun 2004	1.82	1.95	98.83	64.97	1.23	1.12	2.50	98.34	78.26	1.12
15 Jun 2004	1.84	1.94	98.83	64.85	1.24	1.11	2.58	98.56	78.24	1.09
21 Jun 2004	1.89	1.86	98.73	65.00	1.42	- 6.16	40.45	99.97	83.30	1.34
22 Jun 2004	1.91	1.89	98.72	64.88	1.42	1.14	2.59	98.65	76.86	1.26
23 Jun 2004	1.89	1.88	98.72	65.01	1.40	1.12	2.48	98.44	76.92	1.26
24 Jun 2004	1.88	1.87	98.75	64.98	1.38	1.10	2.46	98.46	77.10	1.24
25 Jun 2004	1.87	1.88	98.80	65.04	1.35	1.08	2.44	98.46	77.13	1.22
26 Jun 2004	1.86	1.88	98.82	64.95	1.33	1.07	2.43	98.45	76.95	1.21
27 Jun 2004	1.88	1.87	98.81	65.01	1.36	1.07	2.41	98.44	76.63	1.24
28 Jun 2004	1.90	1.86	98.80	64.95	1.39	1.08	2.41	98.47	76.57	1.27
29 Jun 2004	1.91	1.85	98.81	65.01	1.40	1.08	2.41	98.49	76.63	1.28
30 Jun 2004	1.90	1.85	98.84	65.05	1.37	1.05	2.42	98.48	76.69	1.26
1 Jul 2004	1.90	1.86	98.86	64.95	1.33	1.04	2.41	98.49	76.88	1.24
2 Jul 2004	1.89	1.88	98.91	65.04	1.29	1.06	2.38	98.46	77.50	1.20
3 Jul 2004	1.89	1.91	98.95	65.02	1.27	1.07	2.43	98.40	77.73	1.17
4 Jul 2004	1.98	1.90	98.95	65.02	1.29	1.15	2.40	98.28	78.90	1.04
5 Jul 2004	1.93	1.91	98.99	64.98	1.25	1.03	2.38	98.37	78.58	1.04
6 Jul 2004	1.89	1.91	98.99	65.03	1.23	1.08	2.45	98.30	78.50	1.03
7 Jul 2004	1.95	1.91	98.98	65.04	1.26	1.17	2.63	98.73	79.54	1.02

Table A-5-2: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
10 Jul 2004	1.94	1.94	98.74	64.99	1.34	1.32	2.52	98.12	79.95	1.09
11 Jul 2004	1.94	1.92	98.74	64.94	1.35	1.28	2.47	98.31	79.54	1.14
12 Jul 2004	1.97	1.91	98.75	64.98	1.36	1.23	2.42	98.32	79.01	1.16
13 Jul 2004	2.00	1.93	98.76	65.02	1.35	1.31	2.45	98.34	79.83	1.14
14 Jul 2004	1.92	1.93	98.78	65.01	1.30	1.27	2.41	98.35	81.72	1.10
15 Jul 2004	1.93	1.98	98.81	65.11	1.28	1.24	2.51	98.54	81.33	1.09
16 Jul 2004	1.94	2.01	98.79	64.96	1.28	- 1.69	3.04	98.95	83.38	1.21
19 Jul 2004	1.95	1.92	98.70	64.85	1.40	1.22	2.31	98.25	79.81	1.31
20 Jul 2004	1.97	1.90	98.65	65.02	1.45	1.24	2.36	98.22	79.55	1.35
21 Jul 2004	1.99	1.87	98.60	64.87	1.49	1.24	2.41	98.31	79.53	1.37
22 Jul 2004	1.99	1.86	98.60	64.70	1.49	1.20	2.37	98.31	79.35	1.35
24 Jul 2004	1.94	1.79	98.51	64.48	1.47	1.29	2.52	98.55	80.17	1.29
25 Jul 2004	1.88	1.76	98.42	67.81	1.48	1.33	2.65	98.92	80.34	1.27
26 Jul 2004	1.75	1.75	98.36	68.12	1.45	1.30	2.66	98.96	80.39	1.25
27 Jul 2004	1.99	1.80	98.62	64.89	1.42	1.19	2.39	98.49	79.82	1.28
28 Jul 2004	2.09	1.79	98.60	64.88	1.45	1.18	2.35	98.45	81.32	1.16
29 Jul 2004	2.35	1.78	98.57	64.97	1.56	1.18	2.23	98.19	78.94	1.20
30 Jul 2004	2.36	1.76	98.55	64.98	1.58	1.19	2.21	98.32	88.55	1.29
31 Jul 2004	2.37	1.74	98.53	64.93	1.60	1.15	2.18	99.00	78.86	1.27
1 Aug 2004	2.36	1.75	98.57	65.12	1.58	1.15	2.16	99.02	78.75	1.27
2 Aug 2004	2.35	1.75	98.59	65.00	1.56	1.14	2.16	99.06	80.30	1.18
3 Aug 2004	2.34	1.76	98.59	64.87	1.54	1.17	2.15	98.43	80.51	1.19
4 Aug 2004	2.35	1.76	98.61	64.98	1.55	1.37	2.47	98.60	88.40	1.15
5 Aug 2004	2.33	1.77	98.60	63.98	1.55	1.37	2.42	98.66	84.81	1.26
6 Aug 2004	2.06	1.79	98.61	64.81	1.47	1.41	2.58	98.85	85.41	1.20
9 Aug 2004	2.33	1.85	98.60	64.74	1.56	1.32	2.45	98.74	84.18	1.29

Table A-5-3: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
10 Aug 2004	2.37	1.79	98.53	65.09	1.62	1.36	2.43	98.78	87.35	1.27
11 Aug 2004	2.27	1.77	98.54	64.37	1.54	1.31	2.44	98.86	81.23	1.20
12 Aug 2004	2.02	1.87	98.40	64.06	1.52	1.27	2.58	99.08	80.91	1.21
13 Aug 2004	2.13	1.78	98.49	64.85	1.58	1.23	2.56	99.07	80.57	1.27
14 Aug 2004	2.09	1.78	98.53	64.96	1.50	1.17	2.53	98.99	80.32	1.27
15 Aug 2004	1.80	1.82	98.65	64.95	1.36	1.07	2.59	99.12	79.61	1.26
16 Aug 2004	1.76	1.81	98.65	64.72	1.36	1.09	2.52	99.01	79.69	1.27
17 Aug 2004	1.71	1.84	98.68	64.79	1.36	1.36	2.83	99.10	81.42	1.17
18 Aug 2004	1.82	1.82	98.62	64.58	1.36	1.30	2.75	99.09	81.04	1.18
19 Aug 2004	1.85	1.82	98.62	64.48	1.40	1.27	2.61	99.04	81.04	1.21
20 Aug 2004	1.71	1.80	98.58	64.77	1.35	1.20	2.54	98.94	80.29	1.25
6 Sep 2004	2.35	1.79	98.51	64.63	1.61	1.65	2.34	99.05	83.70	1.11
7 Sep 2004	2.32	1.72	98.53	65.04	1.64	1.62	2.32	99.09	83.20	1.18
8 Sep 2004	2.30	1.71	98.58	65.03	1.60	1.59	2.31	99.06	83.20	1.16
9 Sep 2004	2.30	1.72	98.57	64.84	1.58	1.58	2.32	99.01	83.30	1.32
10 Sep 2004	2.02	1.78	98.58	64.78	1.39	1.53	2.27	98.97	83.09	1.54
11 Sep 2004	1.74	1.80	98.66	64.95	1.30	1.37	2.30	99.05	82.24	1.63
12 Sep 2004	1.73	1.78	98.68	65.02	1.31	1.35	2.29	99.07	82.17	1.65
13 Sep 2004	1.73	1.77	98.68	65.00	1.32	1.32	2.27	99.07	82.11	1.67
14 Sep 2004	1.74	1.76	98.65	65.02	1.34	1.33	2.26	99.08	82.22	1.66
15 Sep 2004	1.88	1.74	98.59	64.85	1.40	0.13	2.49	99.21	82.40	1.51
4 Jan 2005	2.06	1.71	98.83	59.97	1.39	1.08	3.01	99.26	81.23	1.94
5 Jan 2005	1.80	1.74	98.90	59.82	1.28	1.04	2.89	99.29	84.63	1.10
6 Jan 2005	1.79	1.75	98.91	59.92	1.26	0.98	2.71	99.18	84.47	1.06
7 Jan 2005	1.87	1.73	98.91	60.01	1.28	1.04	2.73	99.26	81.96	1.19
8 Jan 2005	1.95	1.74	98.93	59.97	1.30	1.13	2.59	99.25	82.53	1.21

Table A-5-4: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
9 Jan 2005	1.97	1.73	98.93	60.02	1.32	1.12	2.48	99.22	82.42	1.24
10 Jan 2005	2.00	1.68	98.87	60.00	1.37	1.24	2.45	99.18	85.06	1.18
11 Jan 2005	2.02	1.66	98.87	59.99	1.39	1.27	2.40	99.20	84.85	1.19
12 Jan 2005	2.02	1.66	98.86	59.79	1.39	1.29	2.38	99.21	84.55	1.16
13 Jan 2005	2.01	1.64	98.84	59.68	1.38	1.57	2.35	99.17	85.00	1.22
14 Jan 2005	2.02	1.72	98.87	59.90	1.37	1.34	2.50	99.24	86.27	1.33
15 Jan 2005	1.99	1.75	98.86	60.03	1.36	1.18	2.37	99.23	81.17	1.28
16 Jan 2005	1.97	1.74	98.88	59.99	1.35	1.11	2.36	99.23	81.06	1.26
17 Jan 2005	1.95	1.73	98.88	59.94	1.34	1.19	2.34	99.22	80.86	1.23
18 Jan 2005	1.93	1.73	98.91	60.00	1.31	1.12	2.36	99.23	84.60	1.07
19 Jan 2005	1.91	1.74	98.91	59.84	1.29	1.10	2.41	99.29	81.30	1.18
20 Jan 2005	1.92	1.73	98.90	59.94	1.32	1.15	2.32	99.19	81.11	1.21
21 Jan 2005	1.93	1.75	98.90	59.92	1.33	1.17	2.32	99.20	81.04	1.21
22 Jan 2005	1.95	1.72	98.87	59.92	1.36	1.18	2.29	99.19	80.76	1.23
23 Jan 2005	1.83	1.66	98.77	61.71	1.37	1.24	2.29	99.17	80.28	1.19
24 Jan 2005	1.81	1.63	98.73	63.64	1.37	1.21	2.35	99.24	80.06	1.19
25 Jan 2005	1.81	1.61	98.75	65.04	1.37	1.15	2.21	99.16	80.08	1.03
31 Jan 2005	1.72	1.62	98.82	65.01	1.23	1.39	2.96	99.20	82.40	0.94
14 Feb 2005	1.78	1.82	98.77	63.45	1.18	1.50	2.60	99.49	82.85	1.07
17 Feb 2005	1.81	1.66	98.61	64.73	1.26	1.55	2.61	98.56	82.56	1.12
23 Feb 2005	1.77	1.80	98.57	64.53	1.21	1.55	2.37	96.11	81.03	1.50
24 Feb 2005	1.91	1.69	98.52	65.03	1.29	1.53	2.80	97.42	82.99	1.23
25 Feb 2005	2.13	1.65	98.37	64.59	1.39	1.56	2.28	95.98	83.43	1.23
28 Feb 2005	2.28	1.59	98.43	63.05	1.44	1.58	2.40	98.49	82.52	1.12
2 Mar 2005	2.18	1.58	98.31	64.76	1.46	1.60	2.35	99.43	82.40	1.16
4 Mar 2005	2.17	1.54	98.26	64.87	1.52	1.59	2.65	99.37	82.74	1.08

Table A-5-5: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
5 Mar 2005	1.67	1.73	98.49	61.44	1.25	1.49	2.50	99.34	81.34	1.09
17 Mar 2005	1.76	1.92	98.73	64.75	1.29	1.42	2.30	99.35	81.45	1.36
29 Mar 2005	2.11	1.77	98.63	64.76	1.43	1.40	2.14	99.41	81.34	1.05
30 Mar 2005	2.08	1.70	98.57	65.01	1.47	1.40	2.40	99.35	82.16	0.97
31 Mar 2005	2.17	1.68	98.53	65.01	1.53	1.41	2.52	99.17	81.64	0.96
6 Apr 2005	2.21	1.79	98.46	64.57	1.56	1.49	2.13	99.34	80.84	1.13
8 Apr 2005	2.08	1.89	98.62	62.51	1.55	1.47	2.35	99.24	80.74	1.09
9 Apr 2005	1.62	1.87	98.62	64.95	1.31	1.47	2.22	99.29	80.76	1.08
10 Apr 2005	1.62	1.82	98.63	65.03	1.33	1.45	2.26	99.33	80.18	1.19
11 Apr 2005	1.63	1.79	98.63	64.86	1.47	1.46	2.25	99.39	79.99	1.23
21 Apr 2005	1.64	1.87	98.63	64.91	1.60	1.47	1.98	99.32	79.99	1.26
22 Apr 2005	1.63	1.79	98.63	65.41	1.55	1.49	2.23	99.13	80.76	1.15
24 Apr 2005	1.66	1.80	98.57	66.29	1.60	1.51	2.06	99.31	79.97	1.28
27 Apr 2005	1.61	1.58	98.17	66.83	1.68	1.54	2.26	99.22	80.19	1.01
28 Apr 2005	2.49	1.69	98.35	59.77	1.81	1.55	2.08	99.25	80.00	1.03
5 May 2005	2.46	1.73	98.50	60.11	1.70	1.56	1.88	99.21	79.89	1.03
6 May 2005	2.44	1.68	98.51	60.33	1.75	1.56	1.85	99.21	80.06	1.00
10 May 2005	2.41	1.61	98.53	60.29	1.80	1.45	2.21	99.14	62.52	1.72
11 May 2005	2.42	1.60	98.53	60.12	1.82	1.05	1.78	99.22	60.09	1.61
12 May 2005	2.42	1.57	98.50	60.18	1.83	1.55	2.38	99.24	82.52	0.96
16 May 2005	2.46	1.72	98.43	60.05	1.78	1.60	2.12	99.36	81.63	1.04
18 May 2005	1.85	1.85	98.61	59.83	1.52	1.61	2.12	99.35	80.38	1.06
19 May 2005	1.87	1.75	98.54	59.90	1.52	1.56	2.22	99.45	80.66	1.08
21 May 2005	2.02	1.65	98.46	60.11	1.68	1.48	2.62	99.34	80.68	1.19
30 May 2005	2.10	2.21	99.06	76.15	1.77	1.48	2.07	99.14	81.09	1.15
14 Jun 2005	2.04	1.83	98.58	59.89	1.54	1.21	2.07	99.32	80.92	1.05

Table A-5-6: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	**Pressure Drop (bar)**	**Flux (L/m2/hr/bar)**	**Salt rejection (%)**	**Recovery (%)**	**Power Consumption (kWh/kL)**	**Pressure Drop (bar)**	**Flux (L/m2/hr/bar)**	**Salt rejection (%)**	**Recovery (%)**	**Power Consumption (kWh/kL)**
15 Jun 2005	2.07	1.73	98.55	59.81	1.61	1.16	2.10	99.03	82.00	1.05
16 Jun 2005	2.28	1.66	98.48	59.95	1.69	1.17	2.04	99.10	80.92	1.11
17 Jun 2005	2.29	1.65	98.51	60.05	1.73	1.26	2.16	99.21	81.32	1.09
20 Jun 2005	1.82	1.85	98.70	59.71	1.41	1.19	1.97	99.24	81.18	1.06
21 Jun 2005	1.83	1.75	98.62	59.94	1.48	1.20	2.08	99.24	83.74	0.77
22 Jun 2005	1.88	1.64	98.44	59.92	1.65	1.04	1.98	99.20	82.64	0.85
23 Jun 2005	1.92	1.55	98.31	60.06	1.75	0.94	1.97	99.22	80.01	1.18
21 Jul 2005	1.96	1.79	98.32	53.65	1.72	1.79	1.91	98.73	79.23	1.51
1 Aug 2005	1.91	1.73	98.35	59.90	1.68	1.90	1.84	98.94	79.92	1.57
2 Aug 2005	1.92	1.66	98.31	59.92	1.72	1.85	1.86	98.98	82.14	1.64
3 Aug 2005	1.91	1.61	98.29	59.97	1.72	1.79	1.86	99.02	81.87	1.60
4 Aug 2005	1.88	1.62	98.35	59.99	1.68	1.78	1.88	99.06	82.06	1.55
5 Aug 2005	1.86	1.65	98.43	60.01	1.62	1.76	1.78	98.89	82.32	1.50
6 Aug 2005	1.89	1.63	98.40	60.01	1.67	1.78	1.73	98.83	82.20	1.53
7 Aug 2005	1.92	1.59	98.35	60.00	1.71	1.80	1.76	98.92	82.02	1.56
8 Aug 2005	1.94	1.60	98.38	60.03	1.71	1.80	1.82	99.02	82.18	1.53
9 Aug 2005	1.95	1.57	98.37	60.03	1.72	1.81	1.75	98.94	82.13	1.54
10 Aug 2005	1.91	1.60	98.42	59.86	1.68	1.74	1.78	98.96	79.58	1.17
11 Aug 2005	1.89	1.60	98.45	59.98	1.65	1.79	1.81	98.94	82.41	1.43
12 Aug 2005	1.90	1.61	98.45	60.04	1.68	1.80	1.81	98.97	82.59	1.46
13 Aug 2005	1.94	1.53	98.33	60.01	1.77	1.83	1.75	98.97	82.12	1.54
14 Aug 2005	1.96	1.51	98.28	60.00	1.82	1.84	1.73	98.99	81.90	1.58
15 Aug 2005	1.96	1.50	98.30	59.97	1.84	1.84	1.73	99.03	81.82	1.60
16 Aug 2005	1.95	1.49	98.31	60.01	1.83	1.83	1.74	99.06	81.91	1.59
17 Aug 2005	1.94	1.48	98.31	59.62	1.79	1.79	1.84	99.12	79.82	1.14
25 Aug 2005	1.90	1.54	98.40	59.90	1.67	1.85	1.81	99.26	80.20	1.17

Table A-5-7: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
29 Aug 2005	1.90	1.53	98.34	59.33	1.71	1.88	1.81	99.20	79.49	1.20
30 Aug 2005	1.86	1.48	98.20	57.68	1.64	1.86	1.83	99.24	79.87	1.19
31 Aug 2005	1.87	1.64	98.40	58.96	1.65	1.85	1.82	99.22	79.98	1.19
1 Sep 2005	1.87	1.60	98.42	60.00	1.66	1.84	1.83	99.19	80.23	1.15
2 Sep 2005	1.87	1.59	98.44	60.00	1.67	1.81	1.90	99.06	80.21	1.18
3 Sep 2005	1.87	1.58	98.47	59.98	1.67	1.80	2.02	99.28	82.41	1.55
4 Sep 2005	1.85	1.59	98.52	59.99	1.65	1.78	2.02	99.32	82.46	1.54
7 Sep 2005	1.84	1.71	98.70	58.75	1.56	1.78	1.93	99.31	80.73	1.29
8 Sep 2005	1.84	1.70	98.63	59.81	1.54	1.79	1.93	99.32	83.42	1.29
16 Sep 2005	1.83	1.51	98.72	60.04	1.50	1.77	1.84	99.11	83.52	1.36
17 Sep 2005	1.85	1.48	98.68	59.95	1.55	1.78	1.98	99.38	83.18	1.46
18 Sep 2005	1.88	1.45	98.61	60.02	1.62	1.81	1.89	99.39	82.81	1.54
19 Sep 2005	1.88	1.44	98.61	60.04	1.62	1.82	1.87	99.40	82.76	1.52
20 Sep 2005	1.88	1.44	98.60	59.91	1.63	1.83	1.81	99.41	80.72	1.35
21 Sep 2005	1.92	1.53	98.64	59.73	1.52	1.82	1.74	99.27	80.58	1.36
22 Sep 2005	1.83	1.48	98.51	59.55	1.55	1.76	1.78	99.19	83.04	1.49
23 Sep 2005	1.83	1.45	98.50	60.00	1.59	1.76	1.78	99.26	82.82	1.55
24 Sep 2005	1.83	1.44	98.50	59.95	1.61	1.75	1.77	99.28	82.73	1.56
25 Sep 2005	1.82	1.44	98.51	59.99	1.61	1.76	1.71	99.28	80.16	1.48
30 Sep 2005	1.80	1.51	98.62	59.97	1.54	1.67	2.86	99.29	83.90	1.30
3 Oct 2005	1.82	1.51	98.62	60.01	1.53	1.72	2.37	99.30	81.09	1.22
4 Oct 2005	1.81	1.63	98.69	59.73	1.43	1.71	1.98	99.08	80.96	1.24
5 Oct 2005	1.79	1.56	98.59	60.00	1.48	1.71	2.07	99.23	83.04	1.34
6 Oct 2005	1.80	1.53	98.51	60.01	1.51	1.76	2.02	99.23	79.71	1.36
7 Oct 2005	1.80	1.52	98.47	59.98	1.52	1.79	2.01	99.22	79.90	1.40
8 Oct 2005	1.80	1.50	98.46	60.03	1.53	1.81	2.00	99.23	82.68	1.39

Table A-5-8: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
9 Oct 2005	1.79	1.51	98.51	60.01	1.49	1.80	2.01	99.25	82.79	1.36
10 Oct 2005	1.78	1.53	98.56	60.03	1.46	1.79	2.05	99.28	82.90	1.34
11 Oct 2005	1.79	1.53	98.57	60.04	1.45	1.75	2.06	99.27	82.98	1.33
12 Oct 2005	1.81	1.53	98.52	60.04	1.46	1.74	1.80	99.01	80.70	1.28
14 Oct 2005	2.11	1.45	98.22	60.82	1.67	1.85	1.82	98.37	81.25	1.32
15 Oct 2005	2.36	1.41	98.12	60.84	1.78	1.79	2.10	99.04	83.34	1.36
16 Oct 2005	2.33	1.40	98.14	60.95	1.79	1.69	2.08	99.11	82.80	1.36
17 Oct 2005	2.32	1.39	98.18	61.05	1.79	1.68	2.07	99.14	82.79	1.37
18 Oct 2005	2.28	1.40	98.26	60.95	1.76	1.68	2.06	99.20	82.70	1.39
19 Oct 2005	2.16	1.42	98.31	60.76	1.71	1.69	2.03	99.21	82.63	1.41
20 Oct 2005	2.32	1.39	98.28	61.18	1.78	1.69	2.03	99.24	82.66	1.42
21 Oct 2005	2.36	1.38	98.31	61.03	1.79	1.70	2.03	99.27	82.67	1.43
22 Oct 2005	2.38	1.39	98.35	61.25	1.76	1.71	2.03	99.29	82.74	1.41
23 Oct 2005	2.39	1.39	98.40	61.31	1.75	1.71	2.04	99.33	82.84	1.41
24 Oct 2005	2.43	1.39	98.39	61.00	1.79	1.73	1.86	99.17	80.43	1.40
27 Oct 2005	2.48	1.36	98.33	61.01	1.78	1.85	2.37	99.31	81.46	1.22
28 Oct 2005	2.36	1.49	98.46	61.06	1.67	1.78	1.94	99.03	81.75	1.23
29 Oct 2005	2.36	1.41	98.34	60.93	1.74	1.68	1.92	99.11	83.41	1.29
30 Oct 2005	2.37	1.39	98.37	60.76	1.78	1.70	1.88	99.17	83.16	1.32
31 Oct 2005	2.32	1.38	98.39	61.03	1.79	1.70	1.89	99.25	83.05	1.34
1 Nov 2005	2.31	1.38	98.44	61.18	1.77	1.72	1.91	99.31	83.04	1.36
2 Nov 2005	2.32	1.38	98.45	61.14	1.78	1.73	1.91	99.34	82.79	1.39
3 Nov 2005	2.30	1.37	98.42	61.09	1.82	1.71	1.90	99.31	82.66	1.39
4 Nov 2005	2.18	1.35	98.35	61.68	1.81	1.71	1.87	99.30	82.61	1.42
8 Nov 2005	2.38	1.41	98.42	60.83	1.74	1.64	1.93	99.23	83.11	1.35
9 Nov 2005	2.39	1.37	98.36	60.74	1.78	1.73	1.84	99.21	81.37	1.28

Table A-5-9: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
10 Nov 2005	2.35	1.39	98.32	60.69	1.73	1.79	1.77	99.16	81.25	1.33
11 Nov 2005	2.39	1.36	98.25	60.73	1.78	1.68	1.91	99.25	82.67	1.45
12 Nov 2005	2.39	1.36	98.23	60.78	1.79	1.68	1.90	99.22	82.59	1.44
13 Nov 2005	2.40	1.37	98.26	60.97	1.79	1.68	1.88	99.21	82.54	1.44
17 Nov 2005	2.15	1.53	98.23	60.61	1.59	1.88	1.90	99.21	81.59	1.35
18 Nov 2005	2.17	1.44	98.03	60.37	1.70	1.68	2.01	98.99	80.43	1.49
19 Nov 2005	2.23	1.40	97.88	61.16	1.80	1.69	1.95	99.00	82.91	1.53
20 Nov 2005	1.90	1.46	98.08	60.00	1.59	1.68	1.69	98.62	82.84	1.51
21 Nov 2005	2.21	1.40	97.88	60.61	1.75	1.67	1.92	98.93	82.65	1.54
22 Nov 2005	2.30	1.39	97.80	60.65	1.80	1.68	1.84	98.81	82.64	1.51
24 Nov 2005	2.23	1.50	98.10	60.62	1.70	1.71	1.76	98.04	83.41	1.28
25 Nov 2005	2.37	1.42	97.89	61.03	1.79	1.68	1.96	98.94	83.31	1.42
26 Nov 2005	2.38	1.40	97.91	60.73	1.84	1.69	1.93	98.96	82.97	1.49
6 Dec 2005	2.32	1.41	98.34	60.78	1.73	1.59	2.04	94.39	81.80	1.40
7 Dec 2005	2.35	1.37	98.33	60.66	1.77	1.54	3.20	96.49	83.81	1.28
13 Dec 2005	2.33	1.38	98.09	61.03	1.74	1.64	2.04	98.76	80.43	1.47
14 Dec 2005	2.36	1.36	98.03	60.80	1.76	1.65	1.99	99.04	83.36	1.46
15 Dec 2005	2.37	1.35	98.02	60.83	1.76	1.65	1.98	99.05	83.22	1.48
16 Dec 2005	2.36	1.34	98.01	60.92	1.77	1.65	1.95	99.06	83.02	1.50
17 Dec 2005	2.35	1.33	98.01	60.89	1.79	1.65	1.93	99.06	82.89	1.53
20 Dec 2005	2.34	1.36	98.11	60.91	1.71	1.60	1.84	98.89	83.21	1.42
21 Dec 2005	2.38	1.34	98.03	60.73	1.77	1.64	1.91	99.03	80.22	1.52
22 Dec 2005	2.30	1.34	98.00	60.66	1.80	1.67	2.10	99.19	80.50	1.49
23 Dec 2005	1.91	1.32	97.96	63.06	1.80	1.68	1.99	99.00	80.00	1.52
24 Dec 2005	2.38	1.33	98.13	60.90	1.84	1.68	1.94	99.05	83.14	1.49
25 Dec 2005	2.40	1.32	98.24	60.83	1.81	1.66	1.94	99.15	83.15	1.47

Table A-5-10: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
26 Dec 2005	2.38	1.32	98.27	61.10	1.76	1.64	1.96	99.17	83.20	1.47
27 Dec 2005	2.37	1.31	98.23	61.30	1.75	1.64	1.95	99.14	83.14	1.49
28 Dec 2005	2.37	1.31	98.20	61.17	1.77	1.63	1.93	99.12	82.91	1.53
29 Dec 2005	2.39	1.32	98.24	61.34	1.75	1.61	1.94	99.12	82.83	1.52
30 Dec 2005	2.40	1.31	98.22	61.28	1.76	1.61	1.93	99.12	82.73	1.55
31 Dec 2005	2.43	1.31	98.25	61.10	1.77	1.61	1.91	99.13	82.59	1.57
1 Jan 2006	2.42	1.29	98.29	61.10	1.80	1.62	1.87	99.16	82.44	1.61
2 Jan 2006	2.34	1.28	98.38	61.73	1.79	1.62	1.86	99.25	82.41	1.60
3 Jan 2006	2.49	1.28	98.51	61.27	1.79	1.62	1.84	99.31	82.34	1.57
4 Jan 2006	2.49	1.26	98.57	61.42	1.80	1.66	1.79	99.35	80.60	1.40
5 Jan 2006	2.33	1.36	98.33	61.59	1.71	1.70	1.73	99.43	80.47	1.40
13 Jan 2006	2.29	1.28	97.84	61.00	1.80	1.69	1.57	96.43	83.57	1.40
14 Jan 2006	2.29	1.27	97.86	61.45	1.79	1.68	1.69	97.11	83.80	1.39
15 Jan 2006	2.38	1.27	97.92	61.22	1.77	1.67	1.80	97.49	83.97	1.35
16 Jan 2006	2.38	1.26	97.91	61.17	1.78	1.67	1.78	98.47	83.82	1.37
17 Jan 2006	2.38	1.25	97.92	61.26	1.77	1.67	1.78	99.08	83.74	1.39
18 Jan 2006	2.37	1.26	97.98	61.19	1.73	1.66	1.80	99.10	83.46	1.37
19 Jan 2006	2.41	1.26	98.02	61.38	1.73	1.66	1.80	99.13	83.04	1.37
20 Jan 2006	2.44	1.25	98.06	61.41	1.72	1.69	1.79	99.15	82.96	1.39
21 Jan 2006	2.43	1.25	98.01	61.24	1.72	1.71	1.73	99.12	82.92	1.39
22 Jan 2006	2.46	1.24	98.00	61.19	1.73	1.77	1.72	99.13	82.72	1.41
23 Jan 2006	2.24	1.27	98.17	60.63	1.60	1.66	1.73	99.15	82.15	1.36
24 Jan 2006	2.21	1.27	98.21	60.72	1.59	1.59	1.73	99.17	81.74	1.33
25 Jan 2006	2.34	1.26	98.16	60.72	1.66	1.57	1.71	99.15	81.64	1.33
26 Jan 2006	2.44	1.24	98.07	60.38	1.76	1.61	1.65	99.09	81.44	1.41
27 Jan 2006	2.17	1.17	97.76	63.98	1.80	1.83	1.57	98.95	81.58	1.54

Table A-5-11: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
28 Jan 2006	2.27	1.16	97.77	62.53	1.80	1.78	1.57	98.94	81.65	1.46
29 Jan 2006	2.55	1.17	97.95	60.68	1.84	1.82	1.59	98.99	81.90	1.46
30 Jan 2006	2.50	1.18	98.08	58.23	1.80	1.87	1.59	99.08	82.18	1.41
31 Jan 2006	2.60	1.18	98.28	55.55	1.80	1.86	1.60	99.26	80.72	1.28
1 Feb 2006	2.46	1.28	98.66	57.60	1.59	1.86	1.55	99.34	80.77	1.27
4 Feb 2006	2.61	1.19	98.52	56.54	1.74	1.73	1.96	99.27	81.42	1.17
20 Apr 2006	2.43	1.18	98.28	53.84	1.91	1.71	1.86	97.50	84.22	1.09
21 Apr 2006	2.47	1.13	97.83	53.54	1.94	1.72	1.78	98.81	81.22	1.15
26 Apr 2006	2.41	1.16	97.59	61.18	1.78	1.69	1.59	98.96	81.03	1.28
27 Apr 2006	2.44	1.12	97.57	60.83	1.83	1.54	1.58	98.94	82.28	1.23
28 Apr 2006	2.44	1.12	97.62	60.69	1.85	1.48	1.56	98.97	82.56	1.21
29 Apr 2006	2.41	1.12	97.67	60.94	1.85	1.49	1.55	98.99	82.55	1.22
30 Apr 2006	2.36	1.09	97.66	61.45	1.85	1.48	1.55	99.00	82.64	1.21
1 May 2006	2.39	0.96	97.52	61.06	1.85	1.48	1.54	99.02	82.63	1.20
2 May 2006	2.26	1.11	97.88	62.18	1.85	1.49	1.53	99.02	82.58	1.22
3 May 2006	1.99	1.12	98.02	55.59	1.85	1.50	1.54	99.06	82.34	1.26
5 May 2006	1.56	1.10	97.86	57.99	1.93	1.59	1.72	98.77	81.89	1.22
16 May 2006	2.10	1.16	97.57	64.23	1.83	1.62	1.51	98.78	81.72	1.28
17 May 2006	1.64	1.11	97.35	70.61	1.76	1.70	1.51	98.83	81.79	1.30
19 May 2006	2.37	1.14	97.51	52.56	1.95	1.78	1.51	98.80	82.03	1.30
20 May 2006	2.38	1.11	97.62	52.22	1.98	1.78	1.54	98.89	84.35	1.27
21 May 2006	2.38	1.10	97.68	52.11	1.98	1.78	1.53	98.92	84.31	1.27
22 May 2006	2.38	1.09	97.70	52.10	1.98	1.79	1.53	98.93	81.74	1.26
31 May 2006	2.27	1.03	97.76	51.86	2.06	1.73	1.74	98.93	82.20	1.22
2 Jun 2006	2.57	1.08	97.48	57.99	2.03	1.75	1.56	98.73	82.18	1.26
3 Jun 2006	2.55	1.05	97.40	56.34	2.12	1.86	1.54	98.80	81.51	1.39

Table A-5-12: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
4 Jun 2006	2.54	1.03	97.39	55.29	2.19	1.92	1.52	98.84	81.08	1.44
5 Jun 2006	2.54	1.02	97.40	54.90	2.21	1.93	1.51	98.86	80.94	1.47
6 Jun 2006	2.54	1.00	97.27	54.79	2.22	1.92	1.51	98.87	80.97	1.47
7 Jun 2006	2.52	1.02	97.40	54.89	2.18	1.94	1.51	98.88	80.99	1.46
8 Jun 2006	2.40	1.01	97.45	50.29	2.19	1.98	1.52	98.90	80.99	1.50
9 Jun 2006	2.35	1.01	97.46	50.71	2.18	1.97	1.52	98.88	80.97	1.50
10 Jun 2006	2.36	1.01	97.50	51.15	2.14	1.93	1.53	98.87	81.12	1.46
11 Jun 2006	2.36	1.01	97.50	51.10	2.13	1.94	1.53	98.87	81.17	1.47
12 Jun 2006	2.35	0.99	97.43	49.88	2.24	2.03	1.50	98.88	80.58	1.58
13 Jun 2006	2.44	0.98	97.41	48.68	2.31	2.07	1.49	98.90	80.28	1.65
14 Jun 2006	2.44	0.98	97.27	47.72	2.30	1.99	1.48	98.92	79.73	1.42
15 Jun 2006	1.91	0.97	97.37	50.54	2.04	1.69	1.47	98.85	78.95	1.44
16 Jun 2006	2.45	0.98	97.87	47.75	2.08	1.69	1.47	98.91	79.06	1.43
17 Jun 2006	2.53	0.98	97.98	47.91	2.06	1.68	1.47	98.92	79.20	1.43
18 Jun 2006	2.66	0.97	98.03	47.79	2.10	1.71	1.45	98.94	79.03	1.46
19 Jun 2006	2.64	0.95	97.77	48.28	2.11	1.72	1.45	98.77	80.33	1.46
20 Jun 2006	2.32	0.97	97.93	49.97	2.08	1.65	1.47	98.77	83.74	1.45
21 Jun 2006	2.60	0.98	97.84	48.44	2.12	1.59	1.42	98.55	82.94	1.47
22 Jun 2006	2.60	1.00	97.90	46.80	2.10	1.36	1.52	98.48	83.62	1.59
23 Jun 2006	2.60	0.98	97.89	47.16	2.11	1.31	1.48	98.53	83.64	1.59
27 Jun 2006	2.60	0.98	97.87	47.40	2.14	1.30	1.48	98.31	83.66	1.61
28 Jun 2006	2.58	0.97	97.84	47.32	2.05	1.22	1.45	98.52	83.50	1.59
29 Jun 2006	2.60	0.96	97.92	47.22	2.07	1.19	1.43	98.64	83.36	1.61
30 Jun 2006	2.61	0.95	98.01	47.02	2.10	1.16	1.40	98.77	83.17	1.63
1 Jul 2006	2.59	0.95	98.02	47.10	2.09	0.70	1.38	98.76	83.92	1.60
2 Jul 2006	2.58	0.95	98.00	47.14	2.09	0.73	1.37	98.85	83.86	1.59

Table A-5-13: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
3 Jul 2006	2.57	0.95	97.94	47.23	2.08	0.75	1.37	98.85	83.83	1.56
4 Jul 2006	2.63	0.94	97.83	46.52	2.14	0.99	1.38	98.76	82.91	1.61
5 Jul 2006	2.69	0.93	97.69	46.20	2.20	1.14	1.38	98.74	82.04	1.69
6 Jul 2006	2.71	0.93	97.63	46.07	2.21	1.14	1.39	98.73	82.25	1.69
7 Jul 2006	2.72	0.92	97.62	46.13	2.20	1.16	1.39	98.67	82.63	1.66
9 Jul 2006	2.51	1.00	97.41	46.46	2.08	1.41	1.48	98.01	82.85	1.57
10 Jul 2006	2.45	0.99	97.32	47.58	2.05	1.33	1.49	98.49	83.25	1.54
11 Jul 2006	2.42	0.99	97.58	48.19	2.00	1.32	1.52	98.71	83.33	1.53
12 Jul 2006	2.35	1.00	97.59	48.80	1.96	1.27	1.51	98.71	83.81	1.48
13 Jul 2006	2.25	1.02	97.68	49.54	1.94	1.09	1.51	98.74	84.09	1.45
14 Jul 2006	2.27	1.02	97.66	49.35	1.96	1.07	1.50	98.76	83.96	1.48
15 Jul 2006	2.25	1.01	97.71	49.52	1.93	1.37	1.50	98.69	83.56	1.49
16 Jul 2006	2.26	1.01	97.73	49.53	1.92	1.40	1.50	98.75	83.70	1.47
17 Jul 2006	2.32	1.00	97.61	48.56	2.03	1.27	1.48	98.74	83.08	1.58
18 Jul 2006	2.34	0.98	97.53	48.07	2.14	1.19	1.47	98.76	82.70	1.65
19 Jul 2006	2.48	0.99	97.37	51.32	2.18	1.26	1.45	98.80	82.13	1.68
20 Jul 2006	2.69	0.97	97.43	54.49	2.27	1.31	1.51	98.46	82.31	1.77
21 Jul 2006	2.76	0.96	97.63	54.58	2.27	1.31	1.50	98.53	82.30	1.73
25 Jul 2006	2.72	0.99	97.48	56.41	2.07	1.44	1.47	98.50	83.09	1.51
26 Jul 2006	2.71	0.98	97.66	56.48	2.08	1.38	1.46	98.68	83.14	1.54
27 Jul 2006	2.77	0.97	97.75	56.59	2.08	1.35	1.45	98.77	83.30	1.53
28 Jul 2006	2.82	0.97	97.65	56.66	2.03	1.38	1.44	98.72	83.54	1.48
29 Jul 2006	2.86	0.97	97.79	57.04	1.98	1.46	1.45	98.79	83.55	1.47
30 Jul 2006	2.88	0.99	97.73	57.53	1.95	1.45	1.44	98.75	84.04	1.41
31 Jul 2006	2.95	0.96	97.87	57.30	1.97	1.41	1.43	98.79	84.20	1.41
1 Aug 2006	2.68	1.07	97.77	58.25	1.84	1.40	1.44	98.75	84.25	1.41

Table A-5-14: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
2 Aug 2006	2.67	1.03	97.82	58.01	1.91	1.44	1.44	98.79	83.74	1.47
3 Aug 2006	2.65	1.03	97.78	58.07	1.91	1.38	1.43	98.82	83.82	1.43
4 Aug 2006	2.68	1.02	97.76	57.63	1.98	1.19	1.42	98.84	83.78	1.48
5 Aug 2006	2.72	1.01	97.39	56.83	2.05	1.39	1.45	98.58	82.69	1.60
6 Aug 2006	2.76	1.00	97.45	56.28	2.12	1.35	1.42	98.63	82.58	1.68
7 Aug 2006	2.76	0.99	97.51	55.92	2.21	1.30	1.43	98.78	83.04	1.64
8 Aug 2006	2.75	0.99	97.56	55.74	2.24	1.28	1.43	98.82	82.89	1.66
9 Aug 2006	2.73	0.98	97.58	55.80	2.24	1.27	1.41	98.80	81.97	2.52
10 Aug 2006	2.70	0.98	97.56	55.88	2.23	1.26	1.41	98.75	82.07	2.53
11 Aug 2006	2.69	0.98	97.58	55.88	2.23	1.28	1.41	98.73	81.98	2.54
12 Aug 2006	2.68	0.99	97.64	55.99	2.22	1.31	1.41	98.70	82.06	2.55
13 Aug 2006	2.63	0.99	97.68	56.01	2.17	1.32	1.41	98.68	82.10	2.53
14 Aug 2006	2.62	1.00	97.54	55.49	2.14	1.38	1.41	98.64	82.32	2.46
15 Aug 2006	2.59	1.00	97.61	54.87	2.15	1.35	1.42	98.62	82.32	2.49
16 Aug 2006	2.60	1.01	97.53	52.85	2.15	1.40	1.41	98.58	82.46	2.46
17 Aug 2006	2.60	1.01	97.57	50.61	2.16	1.37	1.42	98.65	82.26	2.46
18 Aug 2006	2.61	1.01	97.66	50.37	2.16	1.37	1.43	98.63	82.24	2.49
19 Aug 2006	2.61	1.01	97.62	53.23	2.14	1.36	1.44	98.53	82.51	2.45
20 Aug 2006	2.61	1.14	98.32	55.22	2.11	1.38	1.44	98.59	82.47	2.43
21 Aug 2006	2.60	1.15	98.33	55.60	2.07	1.43	1.46	98.60	82.78	2.38
22 Aug 2006	2.60	1.16	98.41	55.89	2.06	1.39	1.47	98.62	82.76	2.39
23 Aug 2006	2.61	1.17	98.30	55.35	2.08	1.39	1.46	98.56	82.76	2.37
24 Aug 2006	2.61	1.17	98.37	52.39	2.04	1.44	1.47	98.61	82.96	2.35
25 Aug 2006	2.64	1.18	98.38	54.41	2.01	1.49	1.47	98.62	82.98	2.31
26 Aug 2006	2.65	1.18	98.38	51.82	2.00	1.48	1.47	98.64	83.12	2.29
27 Aug 2006	2.69	1.18	98.41	51.88	1.99	1.51	1.47	98.64	83.00	2.29

Table A-5-15: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
28 Aug 2006	2.70	1.18	98.47	52.13	1.97	1.52	1.48	98.64	83.14	2.29
29 Aug 2006	2.78	1.21	98.44	53.34	1.97	1.51	1.58	98.48	83.87	1.92
31 Aug 2006	2.97	1.17	98.38	56.36	2.10	1.33	1.64	98.56	83.90	1.50
1 Sep 2006	2.95	1.16	98.40	57.16	2.10	1.25	1.56	98.49	83.65	1.45
6 Sep 2006	2.98	1.17	98.46	56.83	2.03	1.54	1.72	98.86	81.55	1.47
12 Sep 2006	3.07	1.11	98.26	54.45	2.27	1.58	1.58	99.24	79.52	1.71
19 Sep 2006	2.85	1.15	98.42	56.37	2.12	1.20	1.59	98.34	77.94	1.63
20 Sep 2006	2.85	1.16	98.39	54.41	2.10	1.22	1.54	98.52	78.30	1.42
21 Sep 2006	2.86	1.16	98.36	55.39	2.07	1.24	1.54	98.65	78.34	1.42
22 Sep 2006	2.85	1.16	98.36	55.26	2.04	0.79	1.76	98.70	72.67	1.51
26 Sep 2006	2.88	1.15	98.43	54.89	2.03	0.63	2.34	99.18	67.10	1.69
27 Sep 2006	2.91	1.15	98.47	54.86	2.04	1.64	1.46	98.62	78.22	1.73
28 Sep 2006	3.00	1.16	98.45	54.00	2.06	1.73	1.46	98.71	78.76	1.79
29 Sep 2006	3.11	1.16	98.39	57.91	2.06	1.81	1.45	98.77	78.65	1.80
30 Sep 2006	3.13	1.16	98.49	60.26	2.02	1.79	1.53	98.84	78.40	1.88
1 Oct 2006	3.13	1.17	98.48	60.13	2.03	1.81	1.44	98.75	78.42	1.80
2 Oct 2006	3.19	1.16	98.54	59.40	2.03	1.81	1.44	98.76	77.87	1.87
3 Oct 2006	3.20	1.16	98.57	59.31	2.04	1.81	1.44	98.74	77.36	1.87
4 Oct 2006	3.22	1.15	98.58	59.23	2.05	1.83	1.42	98.78	77.30	1.89
5 Oct 2006	3.27	1.16	98.56	56.31	2.04	1.84	1.42	98.81	77.19	1.88
6 Oct 2006	3.31	1.16	98.55	56.65	2.02	1.84	1.41	98.81	77.06	1.88
7 Oct 2006	3.26	1.18	98.58	58.51	2.04	1.86	1.40	98.81	77.22	1.81
8 Oct 2006	3.25	1.18	98.67	56.99	2.05	1.89	1.38	98.79	77.26	1.79
9 Oct 2006	3.18	1.19	98.63	57.55	2.01	1.89	1.38	98.80	77.22	1.80
10 Oct 2006	3.00	1.19	98.65	57.66	1.97	1.89	1.39	98.86	76.94	1.93
11 Oct 2006	3.03	1.17	98.60	57.11	2.04	1.92	1.37	98.84	76.59	2.01

Table A-5-16 : Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
12 Oct 2006	3.06	1.15	98.58	56.47	2.13	1.90	1.44	98.85	76.83	1.93
13 Oct 2006	3.09	1.14	98.54	56.87	2.15	1.90	1.37	98.76	77.01	1.89
14 Oct 2006	3.01	1.12	98.41	57.47	2.16	1.89	1.37	98.86	76.63	2.03
15 Oct 2006	3.03	1.13	98.46	57.70	2.14	1.89	1.38	98.91	76.46	2.44
16 Oct 2006	3.03	1.15	98.46	58.12	2.14	1.90	1.37	98.95	76.82	2.45
17 Oct 2006	3.01	1.15	98.48	52.75	2.18	1.89	1.38	98.89	76.75	2.50
18 Oct 2006	2.98	1.13	98.47	52.38	2.21	1.89	1.37	98.90	76.60	2.58
19 Oct 2006	2.95	1.14	98.45	53.58	2.19	1.88	1.37	98.87	76.72	2.52
20 Oct 2006	2.97	1.13	98.50	53.99	2.19	1.88	1.36	98.94	76.50	2.54
21 Oct 2006	2.99	1.14	98.54	53.99	2.18	1.87	1.36	98.94	76.69	2.51
22 Oct 2006	3.00	1.14	98.54	56.81	2.13	1.61	1.55	98.91	77.64	2.65
23 Oct 2006	3.00	1.14	98.58	58.95	2.10	1.55	1.46	98.93	77.01	2.74
24 Oct 2006	3.04	1.13	98.53	58.38	2.16	1.55	1.50	98.87	77.10	2.63
16 Nov 2006	2.20	1.29	98.52	60.05	1.83	1.59	1.56	98.70	79.25	2.32
17 Nov 2006	2.20	1.30	98.47	60.65	1.84	1.59	1.65	99.04	79.10	2.29
6 Dec 2006	2.19	1.31	98.58	54.32	1.84	1.55	1.41	97.21	82.06	1.33
7 Dec 2006	2.21	1.30	98.55	54.06	1.91	1.55	1.68	98.69	81.60	1.44
8 Dec 2006	2.25	1.28	98.52	53.52	1.97	1.56	1.64	98.80	80.61	1.56
9 Dec 2006	2.28	1.26	98.50	53.15	2.01	1.63	1.59	98.83	79.83	2.33
10 Dec 2006	2.28	1.26	98.50	53.11	2.01	1.69	1.55	98.85	80.04	1.57
11 Dec 2006	2.29	1.26	98.46	55.48	2.01	1.70	1.55	98.91	79.21	2.39
12 Dec 2006	2.28	1.25	98.51	58.93	1.99	1.68	1.58	99.01	79.11	1.79
13 Dec 2006	2.27	1.25	98.53	59.13	1.98	1.66	1.57	99.00	78.88	1.79
14 Dec 2006	2.29	1.26	98.58	59.56	1.95	1.66	1.59	98.95	78.50	1.81
15 Dec 2006	2.28	1.26	98.63	59.68	1.93	1.63	1.59	98.99	78.15	1.86
16 Dec 2006	2.25	1.27	98.64	59.83	1.91	1.58	1.59	99.03	78.00	1.89

Table A-5-17: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
17 Dec 2006	2.26	1.27	98.67	59.98	1.90	1.55	1.59	99.07	77.83	1.88
18 Dec 2006	2.29	1.28	98.65	60.16	1.90	1.38	1.57	98.94	78.30	1.75
19 Dec 2006	2.39	1.25	98.67	59.81	1.94	1.37	1.56	98.95	77.43	2.57
20 Dec 2006	2.48	1.23	98.65	59.37	2.01	1.65	1.82	98.91	80.41	2.20
21 Dec 2006	2.13	1.41	98.12	55.39	1.94	1.64	1.59	98.53	80.01	2.25
22 Dec 2006	2.16	1.35	98.10	55.61	1.95	1.51	1.44	98.22	79.06	1.69
2 Feb 2007	2.14	1.22	97.89	61.18	1.75	1.61	1.56	98.39	81.28	1.33
3 Feb 2007	2.14	1.18	97.90	61.23	1.75	1.56	1.58	98.64	81.44	1.29
4 Feb 2007	2.15	1.17	97.93	61.07	1.77	1.56	1.57	98.72	81.27	1.31
5 Feb 2007	2.16	1.15	97.91	61.02	1.77	1.56	1.55	98.74	81.16	1.31
6 Feb 2007	2.16	1.14	97.90	61.14	1.77	1.57	1.54	98.73	81.20	1.31
7 Feb 2007	2.18	1.13	97.89	61.01	1.78	1.58	1.53	98.73	78.62	1.26
8 Feb 2007	2.16	1.12	97.90	60.51	1.77	1.55	1.50	98.66	78.04	1.22
9 Feb 2007	2.03	1.15	97.98	58.18	1.63	1.45	1.50	98.67	79.86	1.14
10 Feb 2007	2.01	1.16	98.11	56.62	1.57	1.46	1.53	98.83	79.93	1.11
11 Feb 2007	1.99	1.17	98.22	57.04	1.52	1.47	1.54	98.88	79.94	1.10
12 Feb 2007	1.94	1.18	98.32	57.54	1.46	1.44	1.56	98.97	80.19	1.07
13 Feb 2007	1.91	1.18	98.31	57.84	1.43	1.42	1.58	99.06	80.32	1.04
14 Feb 2007	1.88	1.16	98.33	57.83	1.43	1.41	1.57	99.07	80.29	1.04
15 Feb 2007	1.91	1.16	98.39	57.40	1.46	1.41	1.55	99.07	80.13	1.06
16 Feb 2007	1.94	1.15	98.36	58.93	1.49	1.40	1.54	99.08	80.03	1.08
17 Feb 2007	2.15	1.11	98.27	63.02	1.59	1.57	1.55	99.07	81.31	1.14
18 Feb 2007	2.21	1.11	98.30	62.86	1.62	1.58	1.53	99.04	81.27	1.15
19 Feb 2007	2.30	1.09	98.26	62.32	1.68	1.59	1.51	99.05	76.34	1.26
20 Feb 2007	2.38	1.08	98.27	61.87	1.74	1.61	1.49	99.05	79.67	1.33
21 Feb 2007	2.43	1.07	98.28	61.86	1.76	1.63	1.48	99.07	80.02	1.41

Table A-5-18: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
22 Feb 2007	2.48	1.07	98.30	61.78	1.78	1.65	1.48	99.09	80.18	1.41
23 Feb 2007	2.52	1.07	98.31	61.70	1.79	1.67	1.47	99.10	80.20	1.37
24 Feb 2007	2.54	1.06	98.31	61.67	1.80	1.69	1.46	99.11	80.14	1.42
25 Feb 2007	2.55	1.05	98.28	61.66	1.81	1.72	1.45	99.12	80.13	1.48
26 Feb 2007	2.55	1.05	98.31	61.82	1.76	1.73	1.46	99.14	80.25	1.33
27 Feb 2007	2.54	1.05	98.34	62.07	1.75	1.75	1.45	99.16	80.24	1.38
28 Feb 2007	2.52	1.05	98.38	62.12	1.73	1.74	1.45	99.17	80.26	1.40
1 Mar 2007	2.50	1.05	98.39	62.35	1.72	1.74	1.44	99.18	80.38	1.37
2 Mar 2007	2.48	1.05	98.42	62.55	1.69	1.73	1.45	99.19	80.35	1.27
3 Mar 2007	2.45	1.06	98.45	62.88	1.66	1.71	1.45	99.20	80.48	1.50
4 Mar 2007	2.43	1.06	98.49	63.06	1.63	1.70	1.46	99.21	80.57	1.33
5 Mar 2007	2.41	1.06	98.46	62.89	1.63	1.70	1.45	99.18	80.46	1.28
6 Mar 2007	2.38	1.06	98.46	61.05	1.61	1.64	1.49	99.18	81.69	1.21
7 Mar 2007	2.38	1.06	98.47	60.85	1.63	1.64	1.48	99.20	81.48	1.23
8 Mar 2007	2.38	1.06	98.46	60.70	1.67	1.65	1.45	99.19	81.05	1.32
9 Mar 2007	2.43	1.05	98.41	61.58	1.70	1.65	1.43	99.14	80.95	1.24
10 Mar 2007	2.50	1.04	98.32	63.01	1.73	1.65	1.44	99.11	80.86	1.29
11 Mar 2007	2.46	1.04	98.31	60.25	1.72	1.65	1.43	99.09	80.77	1.42
12 Mar 2007	2.40	1.04	98.31	58.36	1.70	1.63	1.45	99.10	80.83	1.28
13 Mar 2007	2.44	1.05	98.38	58.67	1.68	1.62	1.38	98.89	80.90	1.19
14 Mar 2007	2.54	1.05	98.40	58.67	1.71	1.63	1.46	99.14	80.72	1.36
15 Mar 2007	2.62	1.03	98.38	58.29	1.79	1.65	1.43	99.14	80.50	1.37
16 Mar 2007	2.66	1.02	98.35	57.59	1.88	1.67	1.42	99.12	80.24	1.33
17 Mar 2007	2.64	1.01	98.30	58.97	1.90	1.69	1.40	99.11	80.14	1.36
18 Mar 2007	2.64	1.01	98.30	60.93	1.88	1.71	1.40	99.12	80.05	1.52
19 Mar 2007	2.62	1.01	98.28	59.15	1.88	1.73	1.39	99.12	80.07	1.44

Table A-5-19: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
20 Mar 2007	2.61	1.00	98.31	57.45	1.87	1.75	1.39	99.13	80.02	1.32
21 Mar 2007	2.61	1.01	98.32	57.51	1.87	1.76	1.39	99.15	80.04	1.52
22 Mar 2007	2.62	1.01	98.30	57.55	1.86	1.75	1.39	99.11	80.06	1.39
23 Mar 2007	2.62	1.01	98.31	57.27	1.87	1.75	1.40	99.15	80.06	1.43
24 Mar 2007	2.60	1.01	98.15	56.68	1.83	1.76	1.41	99.17	79.91	1.40
26 Mar 2007	2.52	1.03	98.22	58.95	1.76	1.75	1.40	99.10	80.06	1.45
27 Mar 2007	2.44	1.04	98.22	61.95	1.78	1.75	1.38	99.01	79.72	1.47
28 Mar 2007	2.42	1.04	98.18	61.40	1.76	1.75	1.38	98.96	79.74	1.40
29 Mar 2007	2.40	1.04	98.21	61.02	1.75	1.74	1.39	98.96	79.52	1.42
30 Mar 2007	2.39	1.05	98.23	61.22	1.74	1.74	1.39	98.97	79.38	1.58
31 Mar 2007	2.39	1.05	98.22	61.30	1.74	1.72	1.40	98.96	79.19	1.51
1 Apr 2007	2.41	1.05	98.20	61.09	1.76	1.72	1.40	98.96	78.99	1.44
2 Apr 2007	2.47	1.04	98.14	60.40	1.84	1.73	1.39	99.00	79.06	1.55
3 Apr 2007	2.52	1.02	98.14	59.88	1.91	1.73	1.38	98.99	82.85	1.40
4 Apr 2007	2.55	1.03	98.16	57.47	1.91	1.73	1.38	99.01	82.72	1.57
5 Apr 2007	2.51	1.07	98.17	58.14	1.86	1.74	1.37	99.04	82.67	1.46
6 Apr 2007	2.40	1.08	98.11	61.65	1.82	1.74	1.32	98.88	82.50	1.48
7 Apr 2007	2.41	1.06	98.07	61.44	1.85	1.71	1.43	98.63	82.57	1.47
8 Apr 2007	2.40	1.06	98.07	61.44	1.88	1.69	1.44	98.91	82.46	1.52
9 Apr 2007	2.42	1.05	98.04	61.07	1.93	1.70	1.42	98.93	82.05	1.56
10 Apr 2007	2.44	1.04	98.00	60.64	1.99	1.71	1.41	98.92	81.67	1.60
11 Apr 2007	2.42	1.04	97.99	60.21	2.02	1.72	1.39	98.92	81.48	1.75
12 Apr 2007	2.42	1.03	97.97	59.99	2.03	1.73	1.38	98.92	76.29	2.13
13 Apr 2007	2.43	1.03	97.96	59.74	2.06	1.74	1.39	98.84	76.24	1.98
14 Apr 2007	2.44	1.04	97.98	59.67	2.08	1.74	1.38	98.83	76.18	1.92
15 Apr 2007	2.47	1.04	97.96	59.53	2.07	1.75	1.38	98.81	76.04	1.91

Table A-5-20: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
16 Apr 2007	2.50	1.05	98.02	58.25	2.04	1.75	1.38	98.85	76.04	2.08
17 Apr 2007	2.59	1.06	98.06	59.29	2.00	1.76	1.39	98.99	76.09	1.94
18 Apr 2007	2.64	1.05	98.08	60.73	1.97	1.64	1.72	99.09	78.09	1.57
19 Apr 2007	2.67	1.06	98.07	57.33	1.96	1.63	1.46	98.66	78.10	1.64
20 Apr 2007	2.68	1.05	98.06	56.13	1.96	1.62	1.54	98.99	80.00	1.51
21 Apr 2007	2.71	1.05	98.09	56.35	1.96	1.62	1.54	99.02	79.57	1.56
22 Apr 2007	2.69	1.07	98.09	56.61	1.96	1.61	1.56	98.92	78.04	1.71
23 Apr 2007	2.71	1.08	98.05	56.55	1.97	1.58	1.66	98.88	61.11	2.14
24 Apr 2007	2.69	1.08	98.01	56.72	1.98	1.60	1.56	98.82	60.69	2.13
25 Apr 2007	2.68	1.10	97.97	56.53	1.98	1.60	1.55	98.75	60.33	2.24
26 Apr 2007	2.69	1.09	97.95	56.49	1.99	1.59	1.56	98.79	60.27	2.47
27 Apr 2007	2.64	1.12	97.97	56.15	1.95	1.52	1.54	98.79	59.84	2.32
28 Apr 2007	2.57	1.14	97.94	56.26	1.91	1.46	1.56	98.76	59.55	2.33
29 Apr 2007	2.60	1.14	97.93	56.30	1.91	1.47	1.56	98.72	59.28	2.46
30 Apr 2007	2.60	1.15	97.91	56.39	1.91	1.48	1.56	98.68	59.10	2.52
1 May 2007	2.59	1.16	97.87	56.42	1.90	1.50	1.56	98.62	58.89	2.45
2 May 2007	2.70	1.15	97.76	56.85	1.98	1.56	1.54	98.49	58.54	2.56
3 May 2007	2.81	1.13	97.72	56.84	2.06	1.56	1.62	98.65	57.99	2.73
4 May 2007	2.88	1.13	97.75	56.26	2.09	1.50	1.73	98.75	59.41	2.24
5 May 2007	2.92	1.13	97.76	56.20	2.12	1.47	1.66	98.69	58.69	2.60
6 May 2007	2.99	1.13	97.78	58.32	2.11	1.45	1.63	98.69	58.10	2.75
7 May 2007	3.04	1.13	97.82	59.10	2.11	1.45	1.61	98.72	57.42	2.71
8 May 2007	3.09	1.13	97.88	58.57	2.15	1.44	1.57	98.55	56.94	2.91
9 May 2007	3.11	1.12	97.89	57.97	2.16	1.44	1.53	98.59	57.79	2.56
10 May 2007	3.11	1.12	97.90	57.65	2.18	1.46	1.61	98.85	57.62	2.70
12 May 2007	2.69	1.11	97.85	57.88	2.13	1.47	1.51	98.87	57.79	2.66

Table A-5-21: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
13 May 2007	2.28	1.11	97.76	64.65	2.04	1.47	1.50	98.90	42.83	3.47
14 May 2007	2.54	1.11	97.87	61.34	2.07	1.47	1.50	98.90	58.13	2.57
15 May 2007	2.66	1.11	97.94	60.45	2.08	1.46	1.50	98.95	43.06	3.31
16 May 2007	2.63	1.12	98.00	60.63	1.99	1.50	1.47	98.89	42.36	3.35
17 May 2007	2.67	1.14	98.13	55.38	2.03	1.63	1.43	98.73	58.51	2.18
18 May 2007	2.81	1.13	98.12	54.44	2.11	1.75	1.48	98.88	41.98	3.56
19 May 2007	2.90	1.12	98.09	58.58	2.05	1.69	1.48	98.88	42.07	3.34
22 May 2007	2.50	1.13	98.05	63.59	1.88	1.42	1.57	98.81	59.97	1.98
23 May 2007	2.47	1.18	98.26	58.75	1.79	1.36	1.54	98.91	59.54	1.98
25 May 2007	2.47	1.15	97.92	60.47	1.94	1.68	1.47	98.83	60.49	2.18
26 May 2007	2.61	1.14	97.90	58.96	2.01	1.68	1.49	98.90	60.00	2.23
27 May 2007	2.58	1.13	97.94	58.60	2.05	1.71	1.46	98.91	59.43	2.67
28 May 2007	2.54	1.12	97.92	56.78	2.04	1.75	1.42	98.86	59.64	2.42
31 May 2007	2.38	1.13	97.97	59.91	1.97	1.53	1.53	98.70	64.00	2.09
1 Jun 2007	2.12	1.20	98.10	58.53	1.84	1.41	1.54	98.85	63.31	2.13
2 Jun 2007	2.21	1.17	98.06	54.41	1.88	1.51	1.54	98.84	63.25	2.19
3 Jun 2007	2.31	1.15	98.04	54.11	1.88	1.70	1.48	98.69	62.22	2.38
4 Jun 2007	2.10	1.21	98.24	55.27	1.78	1.39	1.55	98.87	62.26	2.22
5 Jun 2007	2.12	1.20	98.25	58.65	1.78	1.40	1.55	98.92	62.08	2.38
6 Jun 2007	2.21	1.19	98.15	58.39	1.83	1.35	1.53	98.85	61.59	2.26
7 Jun 2007	2.38	1.15	98.04	57.45	1.96	1.37	1.51	98.87	60.59	2.50
8 Jun 2007	2.45	1.11	97.87	49.95	2.17	1.40	1.47	98.83	57.98	2.52
9 Jun 2007	2.51	1.09	97.82	48.74	2.31	1.41	1.45	98.88	55.68	3.15
10 Jun 2007	2.58	1.07	97.79	48.08	2.37	1.42	1.43	98.90	55.37	3.63
11 Jun 2007	2.56	1.10	97.79	54.29	2.30	1.42	1.39	98.74	55.39	3.50
12 Jun 2007	2.57	1.11	97.85	54.35	2.28	1.41	1.26	97.77	41.88	3.64

Table A-5-22: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
13 Jun 2007	2.58	1.13	97.93	54.49	2.27	1.41	1.10	87.23	41.95	3.60
14 Jun 2007	2.64	1.15	97.98	49.00	2.28	1.42	1.27	97.98	55.84	3.48
15 Jun 2007	2.71	1.14	97.93	49.92	2.35	1.50	1.37	98.66	55.34	3.52
16 Jun 2007	2.77	1.11	97.94	50.39	2.45	1.59	1.27	98.21	42.20	4.35
17 Jun 2007	2.85	1.12	98.08	50.76	2.41	1.59	1.26	98.33	42.11	4.33
18 Jun 2007	2.99	1.11	98.03	50.17	2.47	1.57	1.27	98.37	55.02	3.91
19 Jun 2007	3.00	1.10	98.04	50.17	2.48	1.44	1.32	98.61	54.54	3.78
20 Jun 2007	3.15	1.10	98.05	49.55	2.46	1.48	1.32	98.67	54.26	4.01
21 Jun 2007	3.16	1.12	98.04	51.19	2.59	1.46	1.44	98.97	55.16	3.86
22 Jun 2007	3.10	1.10	98.00	45.88	2.73	1.48	1.41	98.84	54.59	3.93
23 Jun 2007	3.16	1.13	97.85	47.53	2.77	1.61	1.39	98.95	54.10	3.90
24 Jun 2007	3.08	1.11	97.85	48.27	2.60	1.53	1.39	98.95	54.36	3.88
25 Jun 2007	3.07	1.08	97.86	49.85	2.52	1.73	1.39	98.92	54.07	3.95
26 Jun 2007	3.07	1.07	97.89	50.71	2.49	1.71	1.42	98.96	50.20	4.11
27 Jun 2007	3.01	1.08	97.92	50.73	2.57	1.60	1.40	98.89	49.28	4.32
28 Jun 2007	3.14	1.09	97.91	49.15	2.66	1.61	1.33	98.75	54.69	4.47
29 Jun 2007	3.54	1.09	98.02	47.07	2.76	2.90	1.68	98.75	58.31	3.50
30 Jun 2007	3.23	1.07	97.98	49.03	2.71	2.57	1.47	98.48	60.93	3.30
1 Jul 2007	3.40	1.06	98.09	49.20	2.70	2.74	1.56	98.83	60.78	3.41
2 Jul 2007	3.59	1.05	98.22	49.65	2.67	2.76	1.52	98.90	60.58	3.32
3 Jul 2007	3.66	1.04	98.30	50.05	2.62	3.57	2.12	99.32	65.49	3.36
4 Jul 2007	3.84	1.03	98.36	50.36	2.53	1.58	1.60	99.00	74.01	2.91
5 Jul 2007	3.98	1.02	98.36	50.94	2.50	1.53	1.45	98.94	74.20	3.18
6 Jul 2007	4.07	1.00	98.35	50.68	2.56	1.55	1.41	98.99	74.16	3.26
7 Jul 2007	2.76	1.12	98.07	56.67	2.23	1.56	1.41	98.83	74.09	3.10
8 Jul 2007	2.73	1.10	98.13	56.43	2.26	1.56	1.36	98.76	73.97	3.30

Table A-5-23: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
9 Jul 2007	2.71	1.10	98.09	56.08	2.28	1.58	1.36	98.88	73.70	3.43
10 Jul 2007	2.70	1.12	98.06	55.55	2.39	1.59	1.36	98.97	73.66	3.16
11 Jul 2007	2.53	1.05	97.81	54.03	2.43	1.61	1.30	98.62	73.68	3.38
12 Jul 2007	2.52	1.06	97.81	53.89	2.43	1.63	1.30	98.70	73.67	3.27
13 Jul 2007	2.52	1.09	97.78	54.04	2.41	1.75	1.23	98.76	73.34	3.36
14 Jul 2007	2.52	1.12	97.71	56.33	2.39	1.89	1.17	97.92	73.25	3.36
15 Jul 2007	2.60	1.11	97.66	55.67	2.42	1.83	1.32	97.61	73.94	3.19
16 Jul 2007	2.60	1.10	97.65	56.23	2.39	1.58	1.47	98.06	73.72	3.31
23 Jul 2007	2.21	1.25	96.10	58.31	2.24	1.72	1.38	97.54	72.35	3.13
24 Jul 2007	2.28	1.24	96.14	57.35	2.20	1.64	1.35	97.81	68.82	3.43
25 Jul 2007	2.28	1.26	96.22	55.94	2.23	1.64	1.39	97.79	68.98	3.11
26 Jul 2007	2.79	1.21	97.05	51.83	2.26	1.63	1.33	98.53	68.87	3.41
27 Jul 2007	3.40	1.00	98.30	50.96	2.39	1.71	1.33	98.97	68.72	3.26
31 Jul 2007	2.75	1.05	97.85	57.86	2.18	1.89	1.35	98.34	69.12	2.02
1 Aug 2007	2.83	1.03	97.95	55.77	2.28	1.83	1.41	97.83	69.02	1.97
16 Aug 2007	3.15	1.00	98.33	57.76	2.15	4.01	2.21	98.60	65.18	2.54
17 Aug 2007	3.16	1.00	98.35	58.18	2.15	1.88	1.53	98.31	73.78	2.23
18 Aug 2007	3.16	1.02	98.23	58.06	2.14	1.89	1.52	98.60	73.73	2.30
19 Aug 2007	3.15	1.00	98.28	58.01	2.19	1.92	1.52	98.67	73.23	2.34
20 Aug 2007	3.19	1.00	98.22	57.69	2.22	1.95	1.44	98.39	73.07	2.47
22 Aug 2007	3.16	0.98	98.24	57.05	2.21	1.99	1.53	98.46	72.70	2.52
23 Aug 2007	3.17	0.97	98.27	57.33	2.18	1.96	1.53	98.72	73.88	2.45
24 Aug 2007	3.27	0.97	98.31	57.59	2.17	1.99	1.53	98.65	73.59	2.52
25 Aug 2007	3.26	0.97	98.34	57.67	2.16	2.05	1.54	98.72	73.30	2.43
26 Aug 2007	3.30	0.97	98.35	57.91	2.16	2.12	1.53	98.75	73.17	2.54
27 Aug 2007	3.32	0.97	98.35	58.31	2.16	2.14	1.54	98.63	73.21	2.64

Table A-5-24: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
28 Aug 2007	3.35	0.97	98.32	57.81	2.17	2.20	1.53	98.70	72.82	2.53
29 Aug 2007	3.35	0.97	98.32	57.51	2.21	2.23	1.51	98.72	72.46	2.58
30 Aug 2007	3.32	0.97	98.32	57.10	2.27	2.27	1.50	98.71	72.12	2.59
31 Aug 2007	3.33	0.96	98.33	57.06	2.27	2.15	1.50	98.53	74.92	2.08
1 Sep 2007	3.35	0.96	98.35	57.42	2.24	1.76	1.49	98.57	78.60	2.44
2 Sep 2007	3.40	0.97	98.33	57.74	2.22	1.76	1.48	98.66	77.83	2.43
3 Sep 2007	3.43	0.97	98.34	58.15	2.17	1.78	1.50	98.62	73.12	2.43
4 Sep 2007	3.48	0.97	98.39	58.29	2.16	1.77	1.48	98.66	76.59	2.60
5 Sep 2007	3.49	0.97	98.42	58.03	2.18	1.78	1.47	98.69	76.03	2.68
6 Sep 2007	3.51	0.97	98.44	58.06	2.17	1.79	1.47	98.63	75.83	2.68
7 Sep 2007	3.51	0.97	98.40	57.67	2.19	1.79	1.46	98.61	75.76	2.76
8 Sep 2007	3.52	0.97	98.35	57.85	2.19	1.80	1.45	98.66	75.54	2.79
9 Sep 2007	3.55	0.97	98.37	58.26	2.16	1.80	1.46	98.71	75.31	2.70
10 Sep 2007	3.64	0.97	98.41	58.34	2.16	1.81	1.47	98.74	74.95	2.68
11 Sep 2007	3.74	0.97	98.43	58.24	2.17	1.81	1.44	98.61	79.27	2.30
12 Sep 2007	3.82	0.97	98.38	58.46	2.16	1.79	1.51	98.56	78.79	2.46
13 Sep 2007	3.92	0.97	98.24	58.67	2.15	1.85	1.51	98.55	74.32	2.56
14 Sep 2007	4.03	0.97	98.26	58.78	2.14	1.93	1.52	98.49	72.98	2.54
15 Sep 2007	4.06	0.98	98.17	55.54	2.15	1.94	1.49	98.44	72.50	2.55
16 Sep 2007	4.12	0.98	98.17	55.92	2.16	1.94	1.40	97.95	72.48	2.61
17 Sep 2007	4.19	0.97	98.21	59.29	2.13	3.89	1.47	95.81	69.39	2.52
19 Sep 2007	4.23	0.97	98.25	58.86	2.14	1.68	1.37	95.61	76.28	2.16
20 Sep 2007	4.42	0.96	98.11	58.84	2.12	1.71	1.67	98.24	76.37	2.19
22 Sep 2007	4.07	0.98	98.06	58.88	2.07	1.75	1.65	98.36	75.39	2.36
23 Sep 2007	4.13	1.00	98.00	54.70	2.10	1.76	1.63	98.29	75.18	2.24
24 Sep 2007	2.86	1.13	98.48	60.04	1.87	1.80	1.58	98.21	74.81	2.35

Table A-5-25: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
25 Sep 2007	2.83	1.10	98.41	57.31	1.96	1.85	1.62	98.45	74.59	2.38
26 Sep 2007	2.83	1.10	98.41	54.32	1.99	1.89	1.57	98.30	73.96	2.37
27 Sep 2007	2.83	1.10	98.40	54.27	1.98	1.90	1.59	98.30	74.28	2.30
28 Sep 2007	2.85	1.10	98.41	54.34	1.98	1.87	1.57	98.20	74.31	2.39
29 Sep 2007	2.87	1.10	98.42	54.47	1.97	1.89	1.56	98.33	74.15	2.41
30 Sep 2007	2.93	1.09	98.37	54.34	1.99	1.96	1.53	98.37	73.87	2.43
1 Oct 2007	3.05	1.07	98.35	53.95	2.04	2.02	1.49	98.27	73.97	2.48
2 Oct 2007	3.25	1.06	98.30	53.34	2.16	2.12	1.44	98.21	73.54	2.54
3 Oct 2007	3.43	1.02	98.26	53.24	2.15	2.14	1.43	98.34	73.51	2.60
4 Oct 2007	3.69	1.02	98.24	53.82	2.10	2.16	1.42	98.32	73.55	2.42
5 Oct 2007	3.94	1.02	98.25	54.41	2.04	2.07	1.43	98.26	73.71	2.57
6 Oct 2007	4.13	1.01	98.18	54.28	2.04	2.10	1.44	98.30	73.39	2.43
7 Oct 2007	3.71	1.05	98.36	53.52	2.00	2.17	1.42	98.28	73.51	2.53
8 Oct 2007	3.91	1.04	98.42	53.97	2.08	2.14	1.41	98.35	73.26	2.42
9 Oct 2007	4.15	1.03	98.43	54.29	2.14	1.68	1.76	98.42	75.54	2.16
10 Oct 2007	4.23	1.03	98.35	54.44	2.13	1.67	1.65	98.43	76.63	1.91
11 Oct 2007	4.13	1.03	98.27	59.50	1.97	1.53	1.63	98.32	76.48	2.01
12 Oct 2007	3.61	1.08	98.51	55.42	1.95	1.52	1.63	98.50	75.87	2.21
13 Oct 2007	3.62	1.05	98.51	54.66	2.03	1.54	1.60	98.51	75.50	2.30
14 Oct 2007	3.65	1.05	98.52	54.30	2.10	1.54	1.59	98.55	74.41	1.65
15 Oct 2007	3.68	1.04	98.48	53.98	2.13	1.59	1.54	98.50	78.22	2.00
16 Oct 2007	3.75	1.02	98.46	53.55	2.19	1.60	1.53	98.54	73.70	2.04
17 Oct 2007	3.80	1.02	98.48	53.63	2.18	1.64	1.52	98.54	72.86	2.06
18 Oct 2007	3.88	1.02	98.48	53.74	2.18	1.70	1.52	98.52	79.18	2.18
19 Oct 2007	4.01	1.01	98.40	53.27	2.22	1.79	1.50	98.52	72.78	2.59
20 Oct 2007	4.15	1.00	98.28	52.68	2.28	1.66	1.49	98.41	71.99	2.58

Table A-5-26: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
21 Oct 2007	4.34	0.99	98.10	52.61	2.32	1.63	1.52	98.45	70.74	2.48
22 Oct 2007	4.50	1.00	98.08	53.02	2.28	1.50	1.60	98.47	74.07	2.78
23 Oct 2007	4.48	1.01	97.99	54.67	2.19	1.50	1.51	98.45	74.95	2.58
24 Oct 2007	3.46	1.19	98.47	59.04	2.01	1.46	1.48	98.29	75.77	2.42
25 Oct 2007	3.32	1.19	98.46	57.24	2.03	1.57	1.50	98.41	75.76	2.40
26 Oct 2007	3.23	1.19	98.47	57.26	2.01	1.67	1.51	98.47	75.91	2.60
27 Oct 2007	3.20	1.20	98.52	57.54	1.99	1.78	1.46	98.35	76.04	2.36
28 Oct 2007	3.28	1.20	98.54	57.65	1.98	1.85	1.42	98.24	76.14	2.51
29 Oct 2007	3.40	1.19	98.51	57.96	1.99	1.91	1.41	98.30	76.48	2.41
30 Oct 2007	3.53	1.18	98.37	58.04	2.00	1.92	1.47	98.39	90.52	2.33
31 Oct 2007	3.63	1.18	98.22	58.13	2.00	1.93	1.49	98.41	74.56	2.54
1 Nov 2007	3.70	1.17	98.17	57.74	2.02	2.02	1.46	98.42	74.19	2.57
2 Nov 2007	3.85	1.12	98.26	57.14	2.03	2.11	1.42	98.40	73.71	2.65
3 Nov 2007	4.07	1.07	98.22	56.85	2.08	2.18	1.40	98.40	73.52	2.65
4 Nov 2007	4.13	1.07	98.31	59.44	2.06	1.96	1.44	98.30	73.78	2.65
5 Nov 2007	4.29	1.06	98.30	61.40	2.05	1.99	1.39	98.19	85.87	2.55
6 Nov 2007	4.44	1.05	98.38	60.72	2.05	1.84	1.41	98.19	73.45	2.61
7 Nov 2007	4.41	1.06	98.27	57.77	2.07	1.92	1.69	98.46	76.02	2.34
8 Nov 2007	4.59	1.05	98.11	54.74	2.11	1.90	1.67	98.52	83.33	2.27
9 Nov 2007	4.70	1.05	97.40	54.76	2.10	1.82	1.64	98.48	76.58	2.54
10 Nov 2007	4.62	1.06	97.15	58.83	2.03	1.64	1.53	98.28	73.31	2.75
11 Nov 2007	4.72	1.06	97.10	58.35	2.12	1.57	1.62	98.61	73.38	2.88
12 Nov 2007	4.85	1.05	97.07	57.87	2.16	1.48	1.64	98.69	72.72	2.76
13 Nov 2007	4.51	1.13	97.21	56.33	2.24	1.51	1.60	98.69	72.17	2.76
14 Nov 2007	3.99	1.17	97.09	55.70	2.25	1.40	1.60	98.64	71.71	2.71
15 Nov 2007	3.85	1.17	97.37	55.93	2.28	1.42	1.58	98.65	71.27	2.96

Table A-5-27: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
16 Nov 2007	3.74	1.17	97.72	57.60	2.16	1.46	1.56	98.67	71.53	2.92
17 Nov 2007	3.82	1.17	97.76	59.24	2.09	1.46	1.60	98.75	76.38	2.31
18 Nov 2007	3.92	1.16	97.81	60.03	2.11	1.50	1.64	98.88	76.28	2.23
19 Nov 2007	4.06	1.13	97.96	56.86	2.17	1.49	1.56	98.70	75.95	2.38
20 Nov 2007	4.20	1.11	98.17	54.47	2.15	1.49	1.49	98.57	76.11	2.44
21 Nov 2007	4.29	1.10	98.24	57.51	2.07	1.52	1.47	98.56	76.22	2.45
22 Nov 2007	4.47	1.09	98.29	59.27	2.04	1.54	1.46	98.56	75.85	2.39
23 Nov 2007	4.72	1.09	98.24	66.44	2.08	1.57	1.45	98.56	75.61	2.63
24 Nov 2007	4.92	1.08	98.23	59.46	2.08	1.59	1.44	98.55	75.12	2.69
25 Nov 2007	4.99	1.08	98.13	61.41	2.08	1.57	1.44	98.49	74.61	2.66
26 Nov 2007	5.01	1.08	98.04	58.06	2.11	1.55	1.44	98.46	74.03	2.67
27 Nov 2007	5.05	1.10	97.86	53.21	2.08	1.60	1.42	98.46	73.44	2.66
28 Nov 2007	5.03	1.08	97.40	53.05	2.03	1.62	1.38	98.44	73.17	2.64
29 Nov 2007	3.86	1.16	97.97	55.43	1.94	1.64	1.36	98.44	72.97	2.90
30 Nov 2007	3.78	1.16	98.06	55.32	1.94	1.68	1.32	98.42	72.83	2.80
1 Dec 2007	3.74	1.15	98.13	62.80	1.92	1.57	1.41	98.40	73.23	2.71
2 Dec 2007	3.78	1.16	98.19	63.18	1.90	1.65	1.40	98.45	73.37	2.72
3 Dec 2007	3.81	1.16	98.17	62.48	1.94	1.74	1.36	98.41	73.12	2.65
4 Dec 2007	3.88	1.14	98.04	62.20	1.95	1.84	1.31	98.41	73.06	2.64
5 Dec 2007	4.03	1.13	97.82	63.00	1.96	1.73	1.43	98.42	72.31	2.51
6 Dec 2007	4.22	1.12	97.61	62.05	1.95	1.78	1.41	98.50	72.12	2.47
7 Dec 2007	4.38	1.11	97.56	62.11	1.96	2.01	1.35	98.47	73.87	2.19
8 Dec 2007	4.27	1.13	97.71	61.06	1.85	2.27	1.31	98.45	73.63	2.27
9 Dec 2007	4.47	1.12	97.68	61.22	1.83	2.44	1.28	98.46	73.33	2.30
10 Dec 2007	4.66	1.11	97.58	61.34	1.86	2.49	1.28	98.41	72.98	2.51
11 Dec 2007	4.92	1.09	97.53	61.05	1.88	2.53	1.28	98.32	72.66	2.43

Table A-5-28: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
12 Dec 2007	5.04	1.08	97.03	60.22	1.91	2.61	1.26	98.38	72.48	2.38
13 Dec 2007	4.52	1.12	97.17	60.77	1.87	- 5.55	1.11	99.05	66.25	2.44
14 Jan 2008	3.50	0.93	98.09	55.54	2.08	- 11.98	1.53	99.89	63.10	2.21
15 Jan 2008	3.41	0.91	98.02	55.65	2.18	1.33	1.78	99.40	75.50	1.98
16 Jan 2008	3.39	0.88	98.02	58.56	2.11	1.45	1.77	98.54	75.05	1.99
17 Jan 2008	3.41	0.87	98.10	59.61	1.95	1.51	1.76	98.60	75.75	1.88
18 Jan 2008	3.37	0.88	98.16	60.74	1.87	1.48	1.77	98.57	76.65	1.79
19 Jan 2008	3.40	0.87	98.16	60.93	1.85	1.44	1.77	98.57	76.48	1.79
20 Jan 2008	3.50	0.86	98.12	61.05	1.85	1.45	1.75	98.62	76.13	1.81
21 Jan 2008	3.51	0.86	97.99	59.62	1.95	1.44	1.75	98.57	75.71	1.87
22 Jan 2008	3.55	0.86	97.99	59.21	1.93	1.31	1.75	98.61	75.34	1.89
23 Jan 2008	3.66	0.85	97.96	61.57	2.03	1.46	1.70	98.59	75.09	1.98
24 Jan 2008	3.67	0.85	97.65	58.89	2.05	1.48	1.67	98.62	74.88	1.99
25 Jan 2008	3.68	0.85	97.47	59.13	2.07	1.49	1.66	98.65	74.64	2.04
26 Jan 2008	3.74	0.85	97.34	59.30	2.06	1.50	1.65	98.70	73.72	2.05
27 Jan 2008	3.76	0.84	97.52	59.13	2.02	1.56	1.66	98.73	71.43	2.01
28 Jan 2008	3.79	0.84	97.48	58.50	1.98	1.49	1.82	98.95	88.10	2.10
29 Jan 2008	3.78	0.84	97.54	55.05	1.97	1.53	1.73	98.66	74.80	2.20
30 Jan 2008	3.80	0.84	97.46	54.59	2.00	- 8.74	1.14	99.12	62.73	2.14
6 Feb 2008	4.24	0.81	95.52	60.33	1.91	- 10.88	0.95	99.58	62.66	2.40
7 Feb 2008	4.37	0.81	94.36	60.31	1.92	1.31	1.39	99.11	72.41	2.51
8 Feb 2008	4.55	0.80	93.13	60.29	1.93	1.34	1.40	99.09	72.46	2.48
9 Feb 2008	4.63	0.80	93.10	60.17	1.94	- 5.43	1.10	99.23	65.26	2.35
7 Mar 2008	3.38	0.77	96.57	56.77	2.11	2.04	0.70	89.70	69.08	2.79
8 Mar 2008	3.42	0.77	96.63	56.86	2.12	1.98	0.70	90.70	68.58	2.77
9 Mar 2008	3.47	0.77	96.70	57.08	2.09	1.49	0.71	89.17	68.44	2.65

Table A-5-29: Actual operating Data covering July 2004 – September 2008 (NCED, 2012)

	8-inch Membrane System					16-inch Membrane System				
Dates	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)	Pressure Drop (bar)	Flux (L/m2/hr/bar)	Salt rejection (%)	Recovery (%)	Power Consumption (kWh/kL)
10 Mar 2008	3.50	0.77	96.70	57.35	2.06	1.98	0.73	91.54	69.24	2.73
11 Mar 2008	3.53	0.77	96.52	57.54	2.03	1.99	0.74	92.07	69.30	2.70
12 Mar 2008	3.55	0.76	96.47	57.48	2.05	1.99	0.73	92.35	69.33	2.59
13 Mar 2008	3.59	0.76	96.48	57.79	2.03	2.00	0.73	92.30	69.55	2.56
14 Mar 2008	3.66	0.76	96.53	58.01	2.02	2.02	0.73	92.44	69.47	2.51