Optimising Membrane Performance – Practical Experiences

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INTRODUCTION

Europe is an expanding market for reverse osmosis (RO) technology used extensively for treating brackish water, seawater and wastewater sources. Membranes are now seen as a viable option for future potable supply in some areas of the UK.

Regulators within the European Community are imposing stricter water quality standards. To comply with these tougher regulations and discharge constraints, the use of membranes will significantly increase in this new Millennium.

The financial implications of operating reverse osmosis membrane systems below optimum performance levels can be considerable. Many large municipal plants have been constructed on a 'build own and operate' (BOO) basis. The water costs to the end user, normally a municipality or large industrial user, is crucial. This cost is usually the primary decisive factor for selecting the water production process. In recent years, membrane desalination has become a more viable option in many countries. Recently, finished costs for BOO potable water from seawater have ranged from as low as $0.50 to $1.00 per cubic metre. Table 1 gives an example of the contribution to total operating costs for a municipal seawater system.

One the most significant contributors to the supply cost is pumping expenditure, due to the requirement for high feedwater pressures. This, however, can be minimised by the use of energy recovery systems and suitable pre-treatment to maximise the water production and minimise membrane fouling. Poor performance results in higher feedwater consumption and the need for frequent cleaning. This means increased energy and consumable costs; therefore, the OEM is always under pressure to design systems that operate at optimum efficiency.

Table 1 — *Example of seawater RO system costs*

	Percentage of total cost
Capital recovery	18.6%
Scale inhibition	5.8%
Membrane replacement	5.8%
Cleaning chemicals	1.1%
Low pressure pumps	4.8%
High pressure pumps	12.1%
Operating labour	46.2%
Maintenance	5.6%

There are computer packages available that can evaluate and compare the major factors contributing to total RO operating cost. These programmes compare chemical dosing and energy costs, and assess their ability to increase overall plant efficiency (Figure 1).

The major factors that affect membrane performance are:

- Condition of the raw water supply
- Effectiveness of pre-treatment procedures
- System operating parameters
- Degree of plant maintenance and continuous monitoring
- Responsiveness of plant operators to significant performance changes
- The rate and degree of fouling

Membrane fouling is the most common reason for performance problems. The effects are often reduced membrane productivity, poor salt rejection characteristics and increasing pressure differential across the membranes.

PC - Optimise

Run Date: 28-Jun-99	Optimisation 100% Complete			
Run Identification	**An Interesting Test Water**			V. 1.11
	With PermaCare Programme			**Actual Conditions**
Summary of Costs of Design Operation	**$/1,000 gal Product**		**$/year**	**$/year**
Energy Cost – Hi Press Pump	$	0.387	$ 203,533	$ 207,686
Brine Disposal Cost	$	1.920	$ 1,009,152	$ 1,009,152
Raw Water Cost	$	0.167	$ 87,600	$ 87,600
Membrane Replacement	$	0.254	$ 133,333	$ 400,000
Cleaning Costs	$	0.005	$ 2,500	$ 5,000
AntiScale Cost	$	0.136	$ 71,507	$ 78,924
Acid/NaCl Cost	$	–	$ –	$ 9,701
Totals	**$**	**2,869**	**$ 1,507,625**	**$ 1,798,063**
Potential Savings with PermaCare Treatment Programme – $/yr	**$**	**0.55**	**$ 290,438**	

Selected Design Conditions	**Values**	**Units**	
Permeate/Product Flow Rate	1,000.00	gpm	1,000.00
Recovery	**75.0%**	**Percent %**	**75.0%**
Feed Flow Rate	1,333.3	gpm	1,333.3
Estimated differential pressure lost	20.0	psi	25.0
Estimated Pressure adjusted for PI & dP	288.8	psi	293.8
Cleanings/year	2.0	Number	4.0
Membrane lifetime – years	3.0	Years	1.0
Feed pH	8.10	pH units	
Treated feed pH	8.10	pH units	
Acid Type Used	No Acid	Text	H_2SO_4 – 96%
Acid/NaCl Dose – ppm 100% basis	–	ppm	22.1
Acid/NaCl usage (100% basis)	–	lb/day	354
Acid/NaCl usage (100% basis)	–	lb/year	129,349
Recommended PermaCare product	PermaTreat® 191		Current Product
Limiting % with PermaTreat	89.3% – LSI	% of Max SI	????
Recommended/Actual Feed ppm	3.40	ppm	3.75
Concentrate Concentration (ppm inhibitor)	13.59	ppm	15.00
Daily Usage	54.42	lb/day	60.06
Yearly Usage	19,863	lb/year	21,923
Summary at Design Conditions			
Power Required	258	kW	263
Permeate/Product produced	525,600	Gal/year	525,600
Raw Water used	700,800,000	Gal/year	700,800,000
Brine to disposal	175,200,000	Gal/year	175,200,000

Figure 1 — ***Process Optimisation Programme***

MONITORING OF PRE-TREATMENT PLANT

One of the most crucial aspects for ensuring trouble-free operation is the regular monitoring of feedwater conditions throughout the pre-treatment system and inspection of associated equipment and pipework (Table 2). Analysing samples of feedwater at each treatment stage enables a good assessment to be made of existing plant conditions. Careful inspection of pipework, dosing tanks and cartridge filters can identify the presence of biofilm slime requiring sanitisation procedures to prevent continued widespread microbiological growth. If a poor scale inhibition programme is in use or the pre-treatment has failed, visual inspection may reveal colloidal particles, iron or inorganic scale on the micron cartridge filters. These are always positioned immediately prior to membrane filtration.

Closer plant monitoring could prevent many system failures. Regular monitoring should be routine with data taken and plotted either electronically or by hand. Graphs should be prepared, dated and filed appropriately with any unusual or erratic results highlighted with explanations and comments. Important parameters include pressure drop, output, pH, temperature, conductivity and TOC. Computerised data logging packages incorporate alarm systems to alert the operator when parameters have exceeded fixed limits.

CHEMICAL PRE-TREATMENT TO INHIBIT SCALES

Feedwater quality determines allowable plant operating conditions, which will dictate the optimum system recovery and overall production rate. It is necessary to make a full and detailed water analysis to identify all major anions and cations that contribute to scale formation and general fouling. The major scaling/fouling ions are calcium, magnesium, bicarbonate, sulphate, silica, iron and barium.

Many natural waters will deposit calcium carbonate on the membrane surface if untreated. Calcium carbonate scaling potential is determined by the Langelier Saturation Index (LSI), or the Stiff & Davis Saturation Index (S&DSI) for high ionic strength waters. The risk of other scalants, such as calcium

Table 2 — *Pre-treatment failures*

Reason for Failure	Indicators	Monitoring
Poor scale inhibition	Increased ΔP due to scale formation on membranes, usually at the back end	Check antiscalant dosing equipment and monitor changes in water quality, softener failure
Poor sanitisation	Biofilm on pipework, cartridge filters and membrane; increased ΔP	Monitor sand filters, GAC, planktonic micro-counts in feedwater; check biocide dosing levels and inspect dosing tanks for biogrowth
High iron content	Visible iron loading on cartridge filters	Look for signs of pipework corrosion, ferric breakthrough from media beds or failure of media filters
High organic content	Organic matter on cartridge filter and membrane inlet	Feedwater composition, review flocculation procedures, monitor feedwater colour/humics and TOC
Colloidal breakthrough	Colloidal particles fouling the micron filters and membranes	Measure SDI & turbidity, check condition of cartridge filters, eliminate media filter fines
Fouling by GAC fines	Carbon fines foul micron filters and membranes	Check washing procedure to remove fines
Overdosed flocculant	Severe loss of flux, cationic flocculant can irreversibly foul membrane surface	Check dosing levels and detect excess traces prior to membranes
Presence of residual chlorine	Membrane damage, high permeate conductivity and sudden increase in flux	Use Redox meters, check bisulphite dosing levels and positioning of injection point, chlorine test kit
Sand filter breakthrough	Sand and colloidal fouling of cartridge filters and membranes	Check wash procedures to remove fines
Failed acid dosing	Rapid scale formation, fast increase in ΔP	Check acid dose rate, feed pH and increasing ΔP; inspect cartridge filters for $CaCO_3$
Climatic/seasonal change	High microbiological loading, biofilm slimes on cartridge filters	Planktonic microbiological counts, look for evidence of biofilms on filters and at the membrane inlet

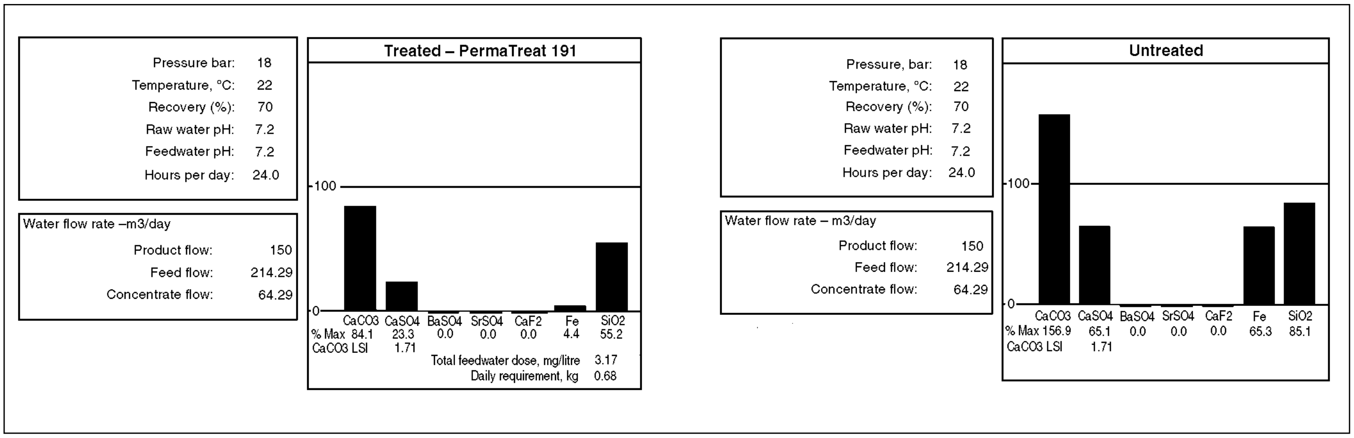

Figure 2 — *Scaling Potential of RO brine with and without Antiscalant A*

sulphate and silica, is determined by measuring their ionic concentration against their known solubility products (Ksp values). Scaling results in increased pressure drop and the need for greater feed pressure to maintain constant product water output.

Dosing of chemical antiscalant reduces the risk of scaling and allows elimination of acid dosing, while maintaining plant efficiency and optimum conversion rates.

The use of an effective antiscalant will allow plant recovery to be increased to a brine LSI of up to +2.6 compared to a limitation of LSI +1.0 when using a commodity antiscalant such as SHMP or zero in an untreated system. Computer prediction programmes are available from some chemical suppliers to calculate scaling potential of a range of water sources. The software allows accurate recommendations for antiscalant addition. The effect of antiscalant on scaling potential is illustrated in Figure 2 for a brine of LSI +2.01. The graph for the treated brine conditions indicates that the plant recovery of 70% could be increased further if plant design limitations allow. At 70% recovery, 3.4 ppm Antiscalant A is required to be dosed to the feedwater.

As shown in Figure 2, dosing of the phosphonate-based antiscalant allows safe operation of the RO plant with brine concentration of scaling species considerably in excess of normal solubility limits.

MINIMISING FOULING

BIOFOULING CONTROL

Most RO systems suffer biofouling to some degree, although this does not always severely affect performance as some biofilms remain within tolerable levels or have a high level of porosity, therefore, not severely affecting the permeate flux. Biofouling potential should always be anticipated and measures taken to prevent and control biogrowth. This may require maintenance cleaning with a non-oxidising biocide or for non-potable applications, intermittent biocide 'shock dosing' on-line. Laboratory analysis can be used to characterise the fouling and propose the appropriate methods of control.

Biofilm material can be scraped from fouled membrane samples for microbiological analysis consisting of basic identifications and enumeration of bacteria, fungi and yeasts. Most membrane biofilms contain both bacterial and fungal species. The physical structure of biofilms found in membrane systems can be 'gel'-like or 'slimy and adhesive' with some consisting of a large ratio of polysaccharide slime to viable micro-organisms. Membrane biofilms investigated in our laboratory often contain between 10^3 and 10^8 colony forming units (cfu) of bacteria per cm^2 of fouled membrane.

Biocide Sensitivity Tests (BST's) have been used to evaluate the performance of selected biocides on sessile microorganisms isolated from membrane foulant and determine optimum conditions for use. A quantitative suspension test is used to determine biocidal efficacy against bacteria and fungal species. Samples of the sessile organisms are obtained by swabbing the foulant from the membrane surface and spot or pour plate counts used to determine the efficacy of each biocide. The biocidal performance is expressed as % kill for a known concentration and contact time. Non-oxidising biocide formulations are preferable due to the limited tolerance of polyamide to oxidising products such as chlorine or peracetic acid.

Table 3 outlines the multi-purpose use of a non-oxidising Biocide A as a periodically shock-dosed biocide, sanitising cleaning agent or for membrane preservation.

Table 3 — *Membrane biocide treatments*

Function	Conditions of use
Intermittent 'shock dosing' on-line	Dose 60 – 80 ppm to feedwater for 4 – 6 hr/day *Non-potable applications only*
Sanitising cleaning agent	Recirculate 0.3% solution for 8–10 hr Precede and follow with alkaline surfactant
Membrane preservative/biostat	Preservation period: up to 7 days: 200 ppm up to 6 months: 500 ppm

MAINTENANCE CLEANING

Maintenance cleaning will ensure optimum membrane lifetime and permeate production. Routine cleaning of membranes should always be carried out at a lower transmembrane pressure (TMP) than that used for water production. It is recommended that an operating pressure of less than 4 bar with minimal permeate flow is maintained for cleaning operations.

Cleaning practices should include periodic soaking of the membrane and the use of warm cleaning solutions up to 30°C. Membrane manufacturers' guidelines should always be followed regarding product compatibility and pH limits.

Cleaning of RO systems typically takes between 4 and 12 hours to perform, depending on the severity of fouling and plant size. Cleaning durations of up to 24 hours incorporating overnight soaking may be necessary if heavy biofouling is suspected. Frequency of cleaning may range from monthly cleaning cycles to an annual maintenance clean. There are many alkaline surfactants, acidic formulations and sanitising agents available in the marketplace. The complexity of the clean and number of products required for optimum cleaning conditions is wholly dependent on the composition and quantity of foulant.

CASE STUDY – EUROPEAN PAPER MILL SITE

Application: Production of boiler feed makeup and process water

Details: The RO plant treats town mains supply to produce 500 m³/d product for industrial use. Polyamide 8" brackish water membranes are installed. Prior to our investigations, pre-treatment included sand filtration, acidification (to pH 5.5), 5-micron cartridge filters, polymer Antiscalant X and dechlorination with sodium bisulphite. The system operates at 75% recovery.

Problem: The plant was suffering from fouling and the membranes required cleaning every 2 weeks to maintain the required treated water volume.

Fouling Investigations: Membrane autopsy revealed an orange/brown foulant covering the membrane leaves and plastic spacer. Chemical composition of the major foulants was determined as 60% organics, 11.4% calcium carbonate and 15% iron oxide.

Microbiology Results: Microbiological enumerations and identifications were performed:

	Bacterial Counts (cfu/cm²)	Fungal Counts (cfu/cm²)
Membrane	3.0×10^7	20
Plastic Spacer	8.8×10^6	2
Product Water Carrier	4.5×10^5	11

The following were identified as predominant in the foulant:

Bacteria: Rod-shaped bacteria, *Arthrobacter*
Fungi: *Trichoderma*

Biocide tests evaluated a fast-acting, non-oxidising Biocide B at 200 ppm and 400 ppm concentration with a 30-minute contact time. A 100% bacterial and fungal kill rate was achieved at the higher concentration.

Cleaning Tests: Crossflow cleaning tests using fouled membrane samples demonstrated that an alkaline clean followed by an acidic clean would successfully remove the organics, biofilm iron and inorganic scale.

Water Analysis and Antiscalant Proposal: The feedwater supply was of good quality, containing negligible quantities of iron. Iron was detected in the feedwater to the RO and the planktonic counts were 1.6×10^6 cfu/ml. Inspection of the pre-treatment plant revealed corrosion of some pipework and the inside of the sand filter vessel. A computerised scaling prediction programme calculated the brine LSI using the non-acidified feedwater at 20°C, pH 7.4 and 75% recovery as +1.79.

Conclusions:

- Corrosion was due to prolonged acid dosing and poor selection of materials.
- The antiscalant in use was not inhibiting scale.
- There was insufficient microbiological control at the site.

Recommendations:

- It was proposed that the polymer Antiscalant X was replaced by a phosphonate Antiscalant A. This product was to be dosed at 2.78 ppm without acid adjustment.
- It was recommended that acid dosing should be ceased to eliminate the risk of further corrosion.
- The following cleaning programme was proposed:
  Step 1: Alkaline Surfactant A — removes organics and conditions biofilm
  Step 2: Biocide B — sanitises membrane
  Step 3: Alkaline Surfactant A — removes biofilm and other organic debris
  Step 4: Weak Acid Cleaner D — removes iron oxide and inorganic scale

Outcome: The site followed all of our recommendations. The plant is now operating well with no indication of severe biofouling, scale or corrosion on the cartridge filters or membranes. Cleaning frequency has been reduced to every 4 months.

CONCLUSIONS

1. The selection of appropriate proprietary chemicals and their use in conjunction with good pre-treatment design will ensure cost-effective operation and optimise product water quality and membrane lifetime.
2. This paper demonstrates how better monitoring and laboratory investigations can identify and anticipate the cause of poor performance and allow recommendations to be made to optimise future operation. This can result in significant cost savings to the operator and end-user.