Desalination and Water Treatment 6 (2009) 80–85
www.deswater.com

Large diameter RO elements: A summary of recent operating experiences

Peter Moss*, Robert Skelton

Koch Membrane Systems, Units 3-6 First Floor, Greyfriars Business Park, Frank Foley Way, Stafford ST16 2ST, England
Tel. +44 1785 272500; Fax +44 1785 223149; email: infoeurope@kochmembrane.com

Received 15 September 2008; accepted 16 March 2009

ABSTRACT

In recent years, the use of large diameter reverse osmosis (RO) elements has gained some considerable momentum as a potential means of lowering the overall cost of desalination by membrane treatment. By the beginning of 2008, a number of systems have been installed so operating experience exists. Along with some design issues, this paper will review some of the currently operating installations and discuss why large diameter elements were selected for specific projects.

The commercial availability of large diameter elements also offers opportunities for alternative system and building layouts. These considerations have implications for cost and space savings. This paper will also review the design approach for large volume systems using the large diameter elements, looking at factors such as the array and rack designs, plant layout and pump sizing.

Keywords: Reverse osmosis (RO); Large diameter RO elements; Water treatment; Membranes

1. Introduction

Worldwide, the use of reverse osmosis (RO) is a standard unit operation for the treatment of water and the recycle of waste water for both potable and industrial users. At the same time there is an obvious need to reduce the cost of RO systems to help reduce the cost of these treatment plants. In some parts of the world, land for new plant construction is at a premium. So as RO plants become larger in capacity it is important to minimize the footprint requirements. Additionally, existing plants where there is little, if any, room for expansion, may need to be retrofitted to help meet the additional demand.

The dimensions of the current industry standard RO element are 8 in. in diameter and 40 in. in length, the so-called 8040 style. In recent years, increasing the diameter of spiral elements has been studied as a method of lowering the cost of membrane treatment. Previously presented technical papers have shown that the installed costs of a RO plant can be reduced by up to 27% using larger diameter elements [1,2]. Large diameter elements provide savings in footprint and building costs, as well as savings in the number of connections, to reduce the installed cost of a RO or nanofiltration (NF) system.

One commercially available large diameter element is 18 in. in diameter and 60 in. long. This product will be discussed further in this paper.

2. Large diameter elements

The first spiral RO element was introduced to the world in 1964. The first commercially available product was a 4 in. in diameter by 40 in. long elements which progressed to 8 in. diameter by 40 in. length in 1975. Fig. 1 shows the evolution of RO elements since those early days.

Clearly then, there is nothing basically new in the concept of large diameter RO elements. The challenges

*Corresponding author

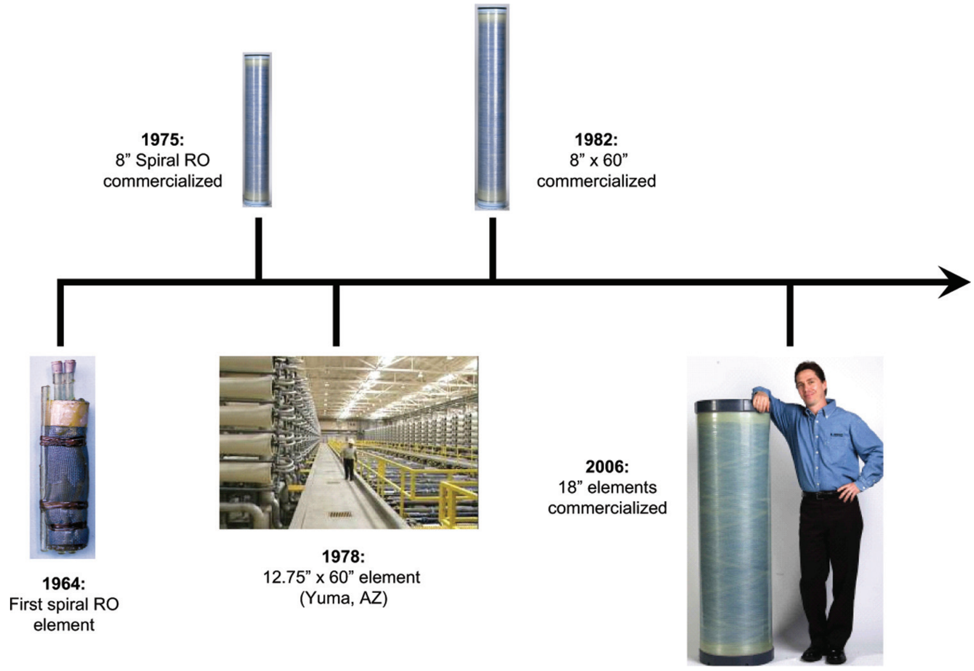

Fig. 1. Evolution of RO elements.

for the manufacturers, of which the author's company is one, were to overcome the element construction and manufacturing issues, make the product scalable from 8 in. and to come up with a simple procedure for loading and unloading.

3. Element construction

The issues around the physical construction of the element have already been described in some detail [3]. However, the selection of the element diameter should be mentioned.

It could be argued that the ''natural'' progression would be 4 in. to 8 in. to 16 in. But since the pressure vessels for this type of element did not exist and needed to be newly developed anyway, clearly the nominal diameter of the element was arbitrary and it made sense to optimise it based manufacturability and vessel design limitations. As a result of this optimisation process the now available commercial product has a diameter of 18 in. This represents a 30% gain in area over the ''natural'' 16 in. for only a 2 in. increase in vessel diameter.

4. Element handling

The membrane area of the 18 in. diameter product is 3050 square feet or 283 square metres. More importantly, the weight of the element is around 150 kg, much more than can be handled by a single workman. At first, weight was perceived to be a problem, but in fact it has been resolved quite easily with just a few simple tools and a hand-operated winch and pulley system. A five elements long vessel can be loaded – under optimum conditions – in 20 min. It can be safely stated, that it will never take longer to load an 18 in. system than to load a – same capacity – 8 in. system, but in most of the cases it will be much faster (Fig. 2).

Using a scissor jack, an element is positioned at the entry point to the vessel where it is connected to a pulley cone via links. It is then pulled into the vessel using the hand-operated winch (1). Skis on the ATD are there to minimize friction. The second element is then lifted into position and connected to the first element (2). This is similarly pulled into the vessel. The process is then repeated until all elements (there could be up to 5 in a vessel) are coupled together. One big advantage of the design of the new large diameter elements is that loading and unloading is carried out from the same end (3).

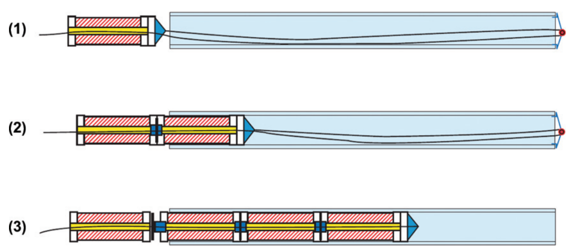

Fig. 2. Loading and unloading of 18-in. elements.

Fig. 3. City of Waupun RO train.

5. Operating installations: potable water

The following is a brief summary of installations where large diameter RO elements have been used in potable water treatment systems. In addition, the reasons why the large diameter elements were selected are mentioned.

6. City of Goodyear, Arizona, USA

This comprises a 2:1 array of large diameter elements in three pressure vessels each of five elements in series. The capacity is around 2000 m^3/day of brackish well water. The system forms part of an overall 8000 m^3/day RO system to allow for population expansion beyond what the City's water infrastructure could other handle. To supply potable water to growing areas, the system has been designed to be easily transportable to a number of well-heads. So it is moved from location to location as necessary.

The design provided the city with additional treatment capacity in a system which has a much smaller footprint and increased flexibility over an 8 in. system.

This was commissioned in May 2007.

7. City of Warpun, Wisconsin, USA

This system treats brackish ground water to produce around 8000 m^3/day of potable water. It comprises two trains, each of six vessels in a 4:2 array, so a total of 60 large diameter elements. The reasons for selection of the large diameter elements – this is a state-of-the-art treatment facility and large diameter elements represented the latest RO technology, and to reduce the installed cost of the plant.

The system was commissioned in December 2007. See Fig. 3.

Table 1
Influent wastewater and MBR permeate

	Influent wastewater		MBR permeate	
	50%ile	90%ile	50%ile	90%ile
BOD (mg/L)	1625	2120	<5	<5
COD (mg/L)	2700	3840	140	162
TSS (mg/L)	145	447	<1	1.4
TDS (mg/L)	2235	2928	1610	1795
TN (mg/L)	42.5	55.3	4	6.6
TP (mg/L)	12.5	23	0.2	0.4
Ph	Range 4.8–6.0		Range 7.8–8.4	
Turbidity	NA	NA	0.35	1.9

8. Tate-Monroe water association, Ohio, USA

This system will be used to produce potable water from ground water using a softening membrane at a capacity of 8000 m^3/day. The system configuration is two trains, each of six vessels in a 4:2 array so 60 element in total. The reason for selecting the large diameter element was simply to reduce the total installed cost of the treatment plant.

System commissioning is scheduled for Q3, 2008.

9. Operating installations: industrial water

Now two recent examples of where and how the large diameter elements have been used as part of an industrial water treatment solution.

10. Joe White Maltings, Australia

This is the earliest installed industrial application for large diameter elements. The issue was to reduce the volume of incoming fresh water for their process by recycling the wastewater produced from the process [4]. Firstly they installed a biological system to treat the wastewater from the process by reducing the COD and providing a barrier to suspended solids. MBR technology was selected for this process as it was able to provide treatment to a quality suitable for use as feed to a RO system.

The wastewater recycling plant consists of four stages – mechanical pretreatment, the biological process, the MBR process and finally the large diameter RO system. Commissioning was in April 2006. The capacity is 2000 m^3/day, which is 75% recovery of the MBR effluent and which is of a standard suitable for reuse in the process. Table 1 shows the influent and MBR effluent (permeate) qualities.

Table 2 summarises the RO permeate quality which is equal to, or better than, the local potable water supply.

The RO rack is shown in Fig. 4.

Table 2
RO permeate quality

	RO permeate
TDS (mg/L)	256
COD (mg/L)	<10
True color	2.5
Total coliform (cfu/100 mL)	<1
TN (mg/L)	<1
TP (mg/L)	<0.1

11. Bundamba AWT Plant, Queensland, Australia

Due to the increasing water shortage in Australia, a need for advanced systems of wastewater treatment and water recycling was identified. Clearly this challenged the wastewater treatment industry to develop technology and processes for municipal and industrial wastewater treatment to meet the drinking water standards for reuse. One of a number of plants to meet this challenge is the Bundamba AWTP in Queensland. A lot has already been written about Bundamba, but since it is the largest installation of its kind in the world, it is worth repeating some pertinent facts [5] (Fig. 5).

The AWTP treats existing biologically treated municipal effluent using microfiltration, RO and Advanced Oxidation. The recycled water will be used initially for supply to two power stations nearby, freeing up an equivalent amount of water for potable use. Phase 1A if the plant was commissioned in August 2007 and produces 30,000 m^3/d. This phase comprises four equal trains of 12 vessels in a 7:4:2 array. Phase 1B has since been commissioned, this comprises another five identical trains to produce a further 36,000 m^3/d. Fig. 6 shows a 1A skid being loaded into position.

Fig. 4. MegaMagnum® reverse osmosis system at Joe White Maltings in Australia.

Fig. 7 shows the four Phase 1A in position with the hollow fibre ultrafiltration racks in the foreground.

Table 3 shows the average feed and permeate qualities from this installation.

12. System design and layout

Taking 2:1 array described earlier as an example, it has a nominal capacity of 2000–2500 m^3/d at modest fluxes. This compares with 10:6 array using 8 in. elements. See Fig. 8.

This comparison can be analysed for the number of parts used. See Table 4.

There are significantly fewer parts in the 18 in. system, this in itself gives savings on costs, installation time and failures. Others [6] have studied the failure rate of O-rings on a large system. At Ashkelon they calculated for their 8960 elements there were 17,920

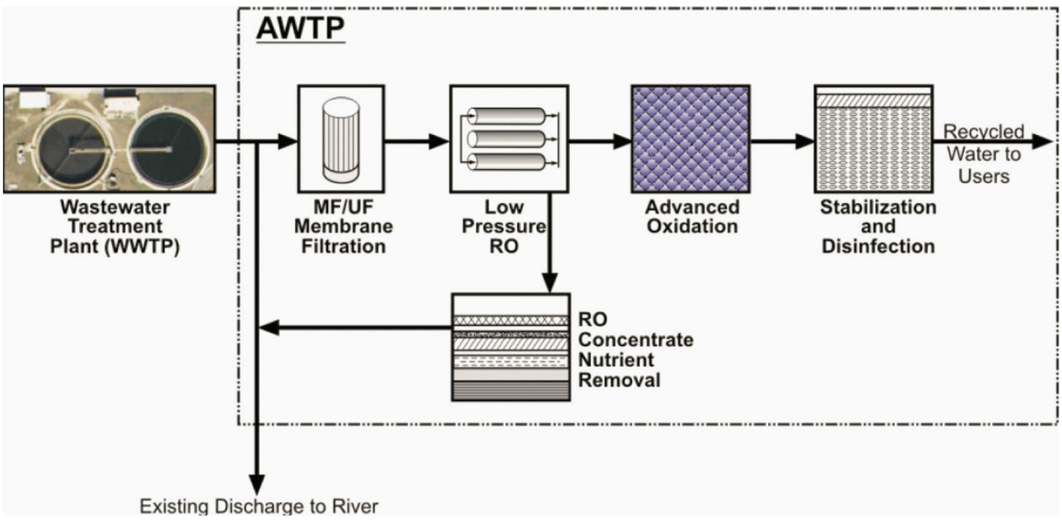

Fig. 5. Principle process flow diagram of the Bundamba AWTP.

Fig. 6. Installation of RO rack at Bundamba AWTP.

O-rings and a failure rate of 2.39 O-rings per day was expected, each involving 3 h stoppage for repair. This would be reduced by a factor of 7 for the 18 in. system (comparing one 18 × 60 is equivalent to seven 8 × 40 in. elements), reducing stoppage time from 2617 h per year to 374 h. A similar exercise can be done for any size of plant.

The large diameter element gives a system footprint saving over the conventional 8 in. element and allows large capacity multiple trains to be considered. This is ideal where the Three-Centre Design is used and is well described elsewhere [7]. The large diameter would allow compact multiple trains feeding from the high pressure headers, which in turn allows optimisation of pump size to feed the header.

Table 3
Bundamba feed and permeate

Constituent	Avg. feed	Avg. permeate
Calcium (mg/L Ca^{2+})	35	<0.2
Magnesium (mg/L Mg^{2+})	21	<0.2
Sodium (mg/L Na^{+})	182	6.0
Potassium (mg/L K^{+})	24	0.9
Strontium (mg/L Sr^{2+})	0.17	<0.005
Barium (mg/L Ba^{2+})	0.007	<0.005
Iron (mg/L Fe^{2+}) (soluble)	0.035	0.003
Manganese (mg/L Mn^{2+})	0.041	<0.001
Bicarbonate (CO_3^-) (mg/L as $CaCO_3$)	141	11
Sulfate (mg/L SO_4^-)	188	<1
Chloride (mg/L Cl^-)	177	4.3
Nitrate (NO_3^-) max (mg/L as N)	2.0	0.19
Fluoride (mg/L F^-)	0.17	<0.05
Silica (mg/L SiO_2)	6.7	0.2
Phosphorous (mg/L as P)	3.2	<0.01
Sum of ions (mg/L)	782	23
TDS (180°C) (mg/L)	697	23
pH feed	6.8	5.8
SDI_{15}	1.3	NA
Turbidity (NTU)	<0.1	NA
TOC (mg/L)	11.1	<0.5
Conductivity (μS/cm)	1162	35
Feed chloramine (mg/L)	3.9	NA

The savings in capital costs using large diameter elements have been shown to be shown [1,2] to be up to 27% for large systems.

Taking 5 MGD (19,000 m^3/d) brackish water unit as a typical building block and the array assumes approximately 27 lmh design flux. The 8 in. and 18 in. trains can be compared using the schematic diagrams in Fig. 9.

The footprint saving is given in Table 5.

Fig. 7. Bundamba AWTP.

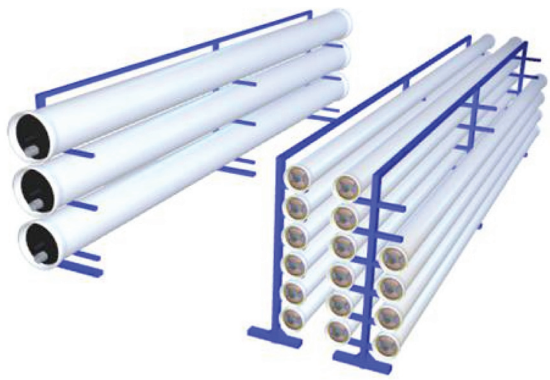

Fig. 8. Schematic of 2:1 18 in. array vs. 10:6 8 in. array.

Table 4
Comparison of parts required

	18 in.	8 in.
Number vessels	3	16
Number elements	15	112
Number piping connections	9	48
Number O-rings	36	256

Table 5
Comparison of footprint and volumetric space capacity

	8 in.	18 in.
Number vessels	114	21
Number elements	798	105
Footprint (m)	6.7 × 7.7	4.4 × 9.5
Volumetric space capacity ($m^3/d/m^3$)	85.7 $m^3/d/m^3$	103.5

There is a significant saving in footprint which if considered in terms of permeate capacity per volume of space needed for this design is equivalent to 85.7 $m^3/d/m^3$ for the 8 in. and 103.5 $m^3/d/m^3$ for the 18 in., the 18 in. giving more than 20% permeate for a similar volume of space, again confirming the potential savings in construction costs.

13. Conclusion

Large diameter RO elements have come a long way in the last 5 years or so. The practical considerations, such as loading/unloading, vessel availability, etc, have been overcome. Full-scale plants, upto 30 bar operating pressure, are now in use for water and waste water treatment applications.

The examples show the advantages in system design and layout of large diameter elements both for smaller package plants and larger arrays, offering more compact and competitive designs.

Questions now deal more with commercial rather than technical issues indicating that large diameter elements are fully accepted and here to stay. The initial challenges have been met, so we can look forward to full commercialisation of the sea water version in the coming years.

References

[1] T.I. Yun, C.J. Gabelich, M.R. Cox, A.A. Mofidi and R.K. Lesan, Reducing costs for large-scale desalting plants using large-diameter RO membranes, AMTA Membrane Conference, 2002.
[2] C. Bartels, R. Bergman, M. Hallan, L. Henthorne, P. Knappe, J. Lozier, P. Metcalfe, M. Peery and I. Shelby, Membrane consortium analysis of large RO/NF element diameters, AWWA Membrane Technology Conference, 2005.
[3] B. Antrim, R. Lesan and A. von Gottberg, World's largest spiral element – history and development, Desalination, 178 (2005) 313-324.
[4] B.M. Gibbs and M.C. Newland, An integrated MBR-RO system for water recycling – an insight into Australia's future, Int. Conf. Water and Wastewater Treatment, Harrogate, UK, 2007.
[5] A. Day, A. von Gottberg, R. Lesan, P. Lambert and J. Bates, Large Diameter Elements – Case Studies, Enviro 08, Melbourne, Australia.
[6] M. Faigon and B. Liberman, Pressure centre and boron removal in Ashkelon desalination plant, IDA Conference, Bahamas, 2003.
[7] N. Voutchkov, Advances in RO membrane technology promise future breakthroughs, World Water and Environmental Engineering, vol. 30, no. 6, November/December 2007.

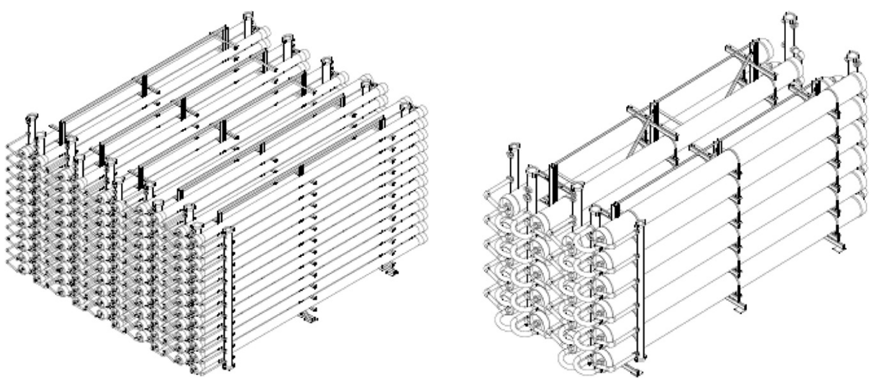

Fig. 9. Schematic of 5 MGD train using 8 in. vs. 18 in. elements.