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Upgrading and capacity extension of old brackish water desalination plants

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ABSTRACT

In some cases upgrading and extension of old BWRO plants is far more economic in comparison with the development of new plants. This is especially true at sites where expenses related to the infrastructure are high and increase the cost of new installations.

Another aspect is technological – usually the operation in the old systems requires excessive energy due to the old generation membranes that are installed that should anyhow be upgraded to reduce the energy cost.

The concept will be demonstrated by describing the upgrading and extension of a 17-year old 10,000 m^3/day BWRO system operating in Eilat. The system desalts a source of 6,000 ppm brackish water with high content of calcium-sulphate at 63% product recovery. The redesign of this plant comprises replacement of the 12-year old RO membranes by a set of new high permeability membranes and addition of a second desalination stage. As a result, the capacity increased to 18,000 m^3/day at 80% recovery and the specific energy consumption has been reduced from 1.0 kWh to about 0.80 kWh at full capacity operation, and to less than 0.65 kWh, when operating at a partial load of 12,000 m^3/day.

Due to the existing infrastructure and the increase of the recovery, the required investment in the extension and the old membranes replacement has been relatively low and the pay back time is of less than 4 years.

Keywords: BWRO; Specific energy; Redesign of old systems

1. Introduction

The Eilat Desalination Center supply more than 90% of the town's water demand, currently about 50,000 m^3/day. The center consists three desalination plants, two brackish water reverse osmosis plants and one seawater reverse osmosis plant.

The first plant Sabha A started operating in 1978, extended from one small unit of 700 m^3/day to four units with combined capacity of about 35,000 m^3/day [1,2].

The second BWRO plant – Sabha B, having a capacity of 10,000 m^3/day started operation in 1993.

The third plant Sabha C is a unique seawater reverse osmosis plant for a capacity of 10,000 m^3/day. The plant is fed with a mixture of 80% Red Sea water and 20% of reject brine of the adjacent BWRO plants [3].

Recently, an upgrading of the old BWRO units was started, mainly to reduce energy consumption by replacing the old RO membranes by new generation of low energy requirement. One, 10,000 m^3/day unit was replaced with Filmtec LE-400 membranes, and a second 10,000 m^3/day unit with Hydranautics ESPA2$^+$ membranes.

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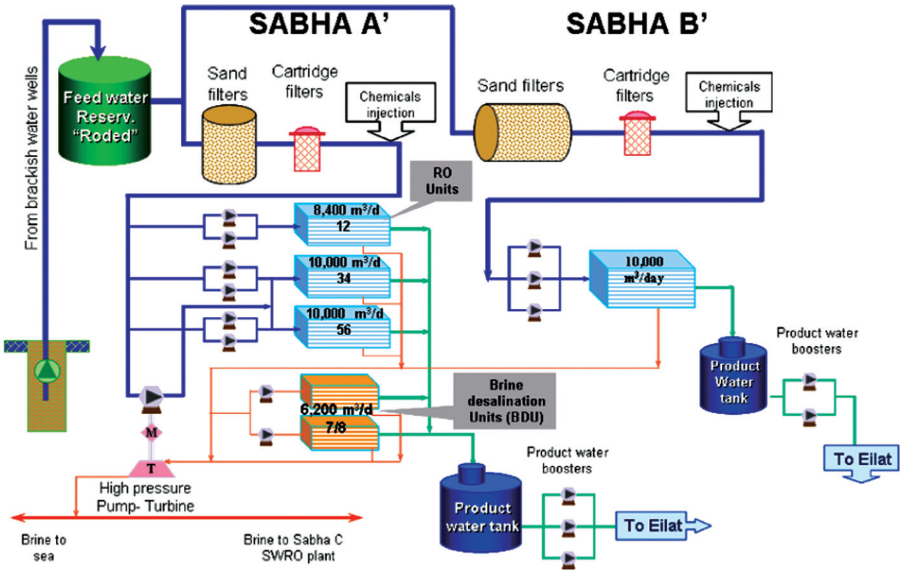

Fig. 1. Principle flow diagram of Sabha A and Sabha B brackish water reverse osmosis plants at Eilat.

As can be seen in Fig. 1, three BWRO units in Sabha A and a forth unit in Sabha B use a common second stage, called a Brine Desalination Unit (BDU) to increase the overall permeate recovery from about 65% to about 78–80%. Due to recent extension of the total BWRO capacity the existing BDU cannot receive the brine from the four regular units because of its limited capacity of about 6,000 m^3/day. Therefore it was decided to redesign the BWRO to a independent two stage unit operating at a 78–80% permeate recovery, instead the existing single-stage unit operating at a 65% recovery. In this context the Sabha B unit will be extended from a 10,000 m^3/day capacity to a 18,000 m^3/day capacity.

2. Redesign of Sabha B BWRO plant

A simplified flow diagram of Sabha B is shown in Fig. 2. The unit consists of 72 pressure vessels containing 7 RO membranes, each. The existing old RO membranes are 4 out of 7 Hydranautics CPA2 and the other 3 are Hydranautics CPA3. The pumping

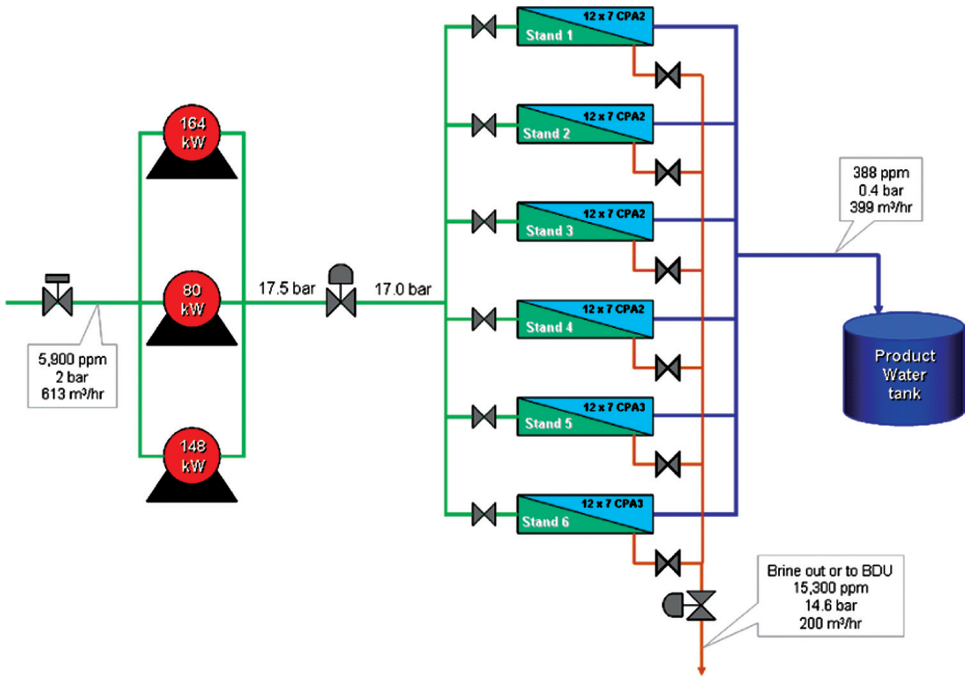

Fig. 2. Simplified flow diagram of an existing 10,000 m^3/day BWRO plant.

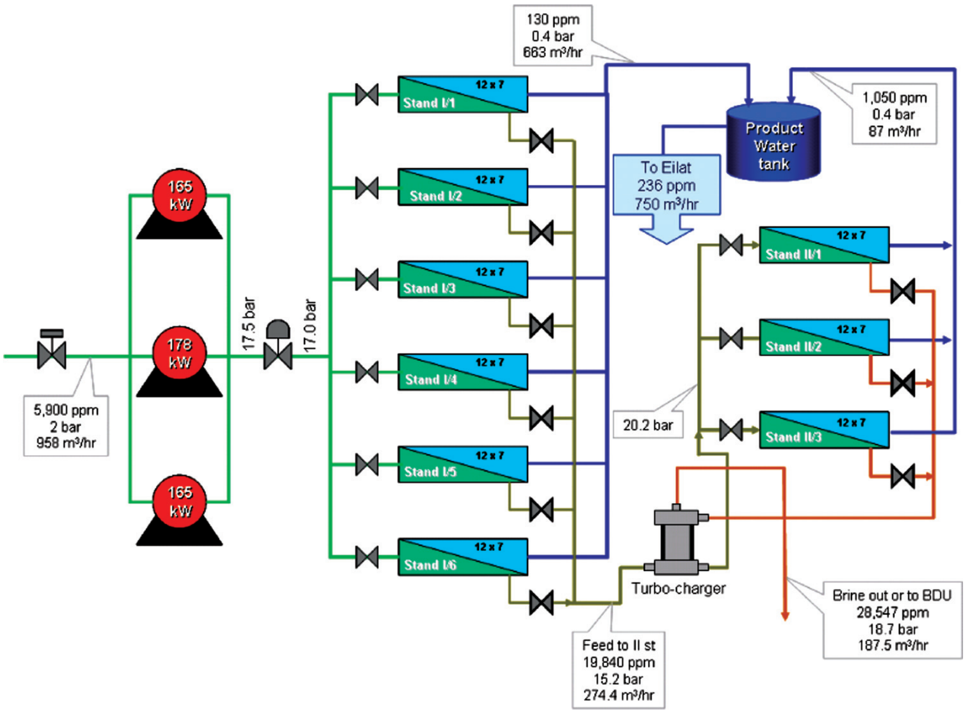

Fig. 3. Simplified flow diagram of the redesigned BWRO plant, 12,000/18,000 m^3/day capacity.

pressure supplied by 3 centrifugal pumps is currently about 18 bar, and the specific energy consumption is about 1.0 kWh/m^3.

The new design (see Fig. 3) will include a second stage consisting of 36 pressure vessels having 7 membranes, each a new set of low energy membranes, replacement of one or two high pressure pumps, an additional cartridge filter and an inter-stage booster pump powered by a turbo-charger.

3. Operating modes of the new Sabha B BWRO plant

The new unit will have two operating options:

- a full capacity operating option producing 18,000 m^3/day;
- an energy saving operating option producing 12,000 m^3/day.

At full capacity the average flux rate will be 24.3 lmh, the operating pressure about 17 bar and the specific energy consumption – about 0.8 kWh/m^3.

At the energy saving operating mode the average flux rate will be 16.2 lmh, the operating pressure about 13.7 bar, and the specific energy consumption about 0.65 kWh/m^3.

4. Economic evaluation

1. Cost of incremental water production

- The incremental water production of the full capacity operating option is: (18,000–10,000) × 250 equivalent day/year = 2,000,000 m^3/year.
- The estimated additional investment is approximately 1.1 million US$.
- The annual fixed charges and operating cost are presented in Table 1.

According to Table 1 the incremental annual cost sums up to approximately 365,850 $/year and the incremental water production cost to about 0.18 US$/m^3, excluding feed water supply.

The incremental feed water supply amounts to

$$\frac{4,500,00\,\frac{m^3}{year}}{80\%} - \frac{2,500,000\,\frac{m^3}{year}}{65\%} = 1,780,000\,\frac{m^3}{year}$$

At an estimated cost of 0.3 US$/m^3, the yearly incremental feed water supply cost amounts to 1,780,000 × 0.3–534,000 US$/year adding about 0.27 US$/m^3 of desalted water production.

The total incremental water production sums up to 0.45 US$/m^3.

Table 1
Incremental cost of extending the existing 10,000 m^3/day plant to a two stage 18,000 m^3/day plant

Description	Unit	Value
Incremental investment	Million US$	1.1
Capital cost @ 7.5% interest rate and 20 years depreciation = 9.81%	US$/year	107,900
Incremental fixed operating costs	US$/year	
Maintenance (@ 1.5% of investment)		16,500
Membrane replacement (@ 14.3%)		18,000
Operational overhead (@ 10%)		3,400
Subtotal		37,950
Incremental variable costs	US$/year	
Energy cost (@ 0.8 kWh/m^3, 10 ¢/kWh, 2 M m^3/year)		160,000
Chemicals (@ 2 ¢/m^3 × 2 M m^3/year)		40,000
Operational overhead (@ 10%)		20,000
Subtotal		220,000
Total incremental cost for production of 2 M m^3/year	US$/year	365,850
Incremental unit water cost (excluding feed water supply)	US$/$m^3$	0.183
Incremental feed water supply cost (4.5 × 10^6/0.65–2.0 × 10^6/0.8)	US$/year	534,000
	US$/$m^3$ product	0.267
Total incremental unit water cost	US$/$m^3$	0.45

The unit water cost of an independent 8,000 m^3/day plant supplying 2 M m^3/year (250 operating days at full capacity) is estimated to cost 0.728 US$/$m^3$ (see Table 2).

The extension of the existing 10,000 m^3/day plant yields therefore a cost saving of

$$\frac{0.728 - 0450}{0.728} = 38\%$$

2. Energy saving option

In case where the additional capacity is not needed the additional investment for the second stage is fully justified by using the energy saving option. By operating at low membrane flux and higher permeate recovery the following savings are achieved:

- Energy saving of 0.15 kWh/m^3 and feed water saving of $\frac{1}{0.65} - \frac{1}{0.80} = 0.288$ m^3feed water per m^3 product.

Table 2
Investment, operating and unit water cost of an independent 8,000 m^3/day BWRO plant

Description	Unit	Value
Investment cost (@ $500/$m^3$ day)	Million US$	4.0
Capital cost @ 7.5% interest rate and 20 years depreciation = 9.81%	US$/year	392,400
Annual fixed operating costs	US$/year	
Maintenance (@ 1.5% of investment		60,000
Membrane replacement (@ 14.3%)		25,000
Operational overhead (@ 10%)		8,500
Subtotal		93,500
Annual variable costs	US$/year	
Energy cost (@ 0.8 kWh/m^3, 10 ¢/kWh, 2 M m^3/year)		160,000
Chemicals (@ 2 ¢/m^3 × 2 M m^3/year)		40,000
Operational overhead (@ 10%)		20,000
Subtotal SGUA		220,000
Total annual cost for production of 2 M m^3/year	US$/year	705,900
Unit water cost (excluding feed water supply)	US$/$m^3$	0.353
Feed water supply cost	US$/$m^3$	0.375
Total unit water cost	US$/$m^3$	0.728

- For the production of 3 (12,000 × 250) M m^3/year of product water the annual saving amounts to:

$$3 \times 10^6 \times \left[0.15\frac{kWh}{m^3} \times 0.1\frac{US\$}{kWh} + 0.288m^3 \times 0.3\frac{US\$}{m^3}\right] = 304,200\frac{US\$}{year}$$

- The payback of the 1.1 MUS$ investment by assuming a 7.5% discount rate is approximately 4 years.

5. Summary and conclusions

- Upgrading and/or extension of old RO desalination plants are in many cases a competitive option of building a new plant.
- Replacing old generation RO membranes by new generation energy saving membranes along with increased permeate recovery yield very significant cost saving, especially at high energy prices, and high feed water supply cost.
- In cases where existing infrastructure can be utilized, the required investment cost of upgrading the old plants have a relative low pay-back, and are therefore the more competitive option.

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