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Effect of recent technological developments on SWRO incorporated in the Red–Dead project

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ABSTRACT

Since the last relatively detailed study of the large SWRO incorporated in the Red–Dead project (Harza 1996), several important technological developments were made. The most relevant are large-diameter RO membranes, large and high-efficiency pressure pumps and Pelton turbines, and the isobaric energy recovery device. All have a significant effect on the sizing and economics of this large desalination project. Moreover, the new energy recovery device (ERD), aimed to reduce energy consumption, imposes a revision of the conceptual design regarding location of the pretreatment and combined production of electric power and desalination. The new concept of using an isobaric ERD or the former concept using more efficient RO membranes and more efficient pressure pumps and a Pelton-type ERD, may eventually significantly reduce investment and energy consumption; the number of RO membranes could be reduced by a factor of 4; and total energy consumption, excluding product delivery, could be reduced from about 0.9 kWh/m^3 to about 0.6 kWh/m^3 or less.

Keywords: Red–Dead Sea project; Large-diameter membranes; Isobaric energy recovery devices

1. Introduction

Since the mid-1970s when the Inter-Sea Project was first conceived by Israel and Jordan, the main focus was on the production of electricity. Israel investigated various tentative alignments from the Mediterranean, and Jordan considered a route from the Red Sea. In the early 1980s, in light of the rapid development of RO technology, Mekorot, Israel's national water company, was the first to propose use of hydrostatic pressure to produce desalinated seawater [1].

In the early 1990s, the change in the political atmosphere, along with the severe regional water problem, have created a new interest in the Dead Sea Hydro Project (DSHP) via a canal from either the Mediterranean or the Red Sea. Thus, the Ministry of Energy and Infrastructure of Israel (IL-MOE) initiated an economic reassessment of DSHP schemes, based on a new concept of integrated production of desalinated water and hydro power.

A team nominated by the Minister of Energy and Infrastructure investigated three DSHP schemes (Fig. 1):

- a Med–Dead Sea route via Qatif (the Qatif alignment)
- a Med–Dead Sea route starting near Haifa or Hadera (the Amakim alignment)
- a Red–Dead Sea route starting near Eilat or Aqaba (the Arava alignment).

Hydrostatic-powered desalination plants were designed in addition to electric power production for each scheme and their cost was estimated. At this stage, in

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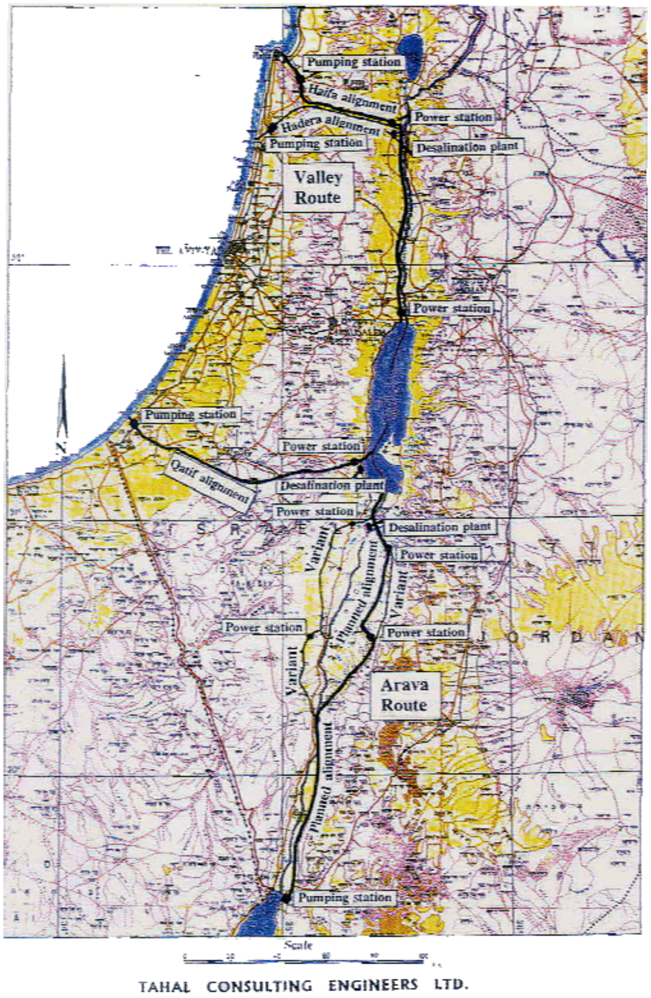


Fig. 1. Map showing alternate alignments.

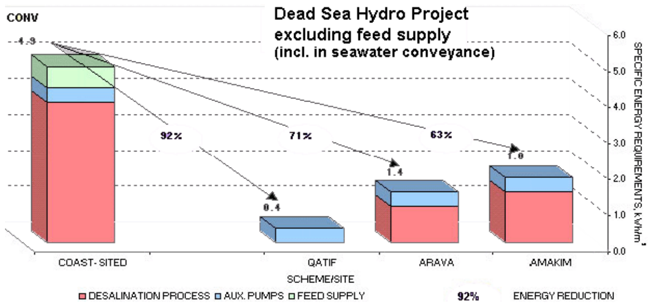


Fig. 2. Comparative specific energy requirements of the desalination plants investigated.

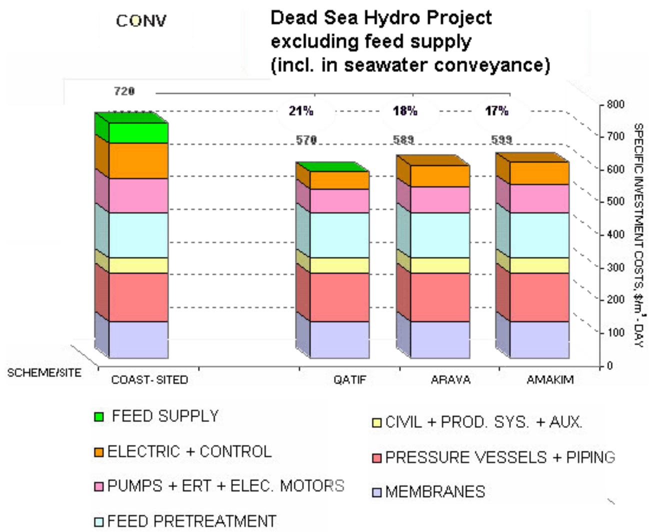


Fig. 3. Comparative specific investment costs of the desalination plants investigated.

accordance with conservative projections of the Dead Sea water balance, an overall final potable production of 800 Mm^3/y (MCMY) was assumed to be installed according to projected time schedule of desalinated water demand.

The required seawater supply capacity to produce 800 MCMY was about 2,000 MCMY. However, the design considered a 2,700 MCMY capacity to enable the Dead Sea level to reach its target in about 15 years and to make the most effective use of the available hydrostatic energy.

Specific energy consumption (kWh/m^3) and specific investment cost ($/m^3-d) of the desalination plants at the investigated schemes, in comparison with specific energy and investment cost of a conventional seashore SWRO system, are shown in Figs. 2 and 3, respectively.

The economic criterion to evaluate the different DSHP schemes was the net present value (NPV) at the assumed prices of desalinated water and electricity produced by the project on the basis of the alternative production costs of supplying these products.

The preliminary findings of this study, also reported at the JRV Development Symposium held in April 1995 in Amman Jordan [2], indicated possible economic viability of all DSHP schemes, providing that the projected market for desalinated water will prevail and a financing package based on a 3% discount rate could be realized. It was however emphasized that the results regarding the cost/benefit of producing desalinated water and electricity did not take into account neither possible benefits derived from regional development consisting of a variety of ancillary projects on the one hand nor hazardous effects on the other hand.

The ancillary projects include tourism, marine agriculture, solar energy and cooling of inland power stations. Hazardous effects may include, among other things, risks to groundwater resulting from seismic activities and potential damage to the Dead Sea Works in Israel and in Jordan.

A comparison with other reported assessments of the Dead Sea hydro projects showed similar findings in some cases to one of the investigated schemes while others showed contradictory results. However, none of them was prepared with all the outlined aspects essential for comprehensive economic comparison as is indicated below:

- Comparative assessment of all feasible options
- Identical and consistent assumptions and methodology
- Updated design and cost data
- Integrated production of power and desalinated water

In 1996, the Harza JRV Group presented a draft prefeasibility report of the Red Sea–Dead Sea Canal Project [3] to the JRV Steering Committee of the Trilateral Economic Committee (Jordan, Israel, US). According to this report, the project will produce 840 Mm^3/y of fresh water intended for the neighbouring countries: two-thirds of the water will be delivered to Jordan and one-third to Israel and the PA (see Fig. 4).

The economic viability of this project was analyzed vs. other possible desalination alternatives for Jordan and Israel. The Israeli reviewers of the Harza report did not agree to the findings of the report regarding the assumed high alternative cost of seashore SWRO systems. This reservation was fully verified by the actual cost of a relatively small SWRO plant operating since 1997 in Eilat [4].

Bechtel proposed to consider multiple pipelines instead of a tunnel, while previous studies in Israel [5] considered desalination development in several phases, using the excess seawater conveyed by the canal to produce peak-load electricity. Only after reaching full demand of potential water production 800–1,000 Mm^3 or more, all conveyed seawater will be used for desalination and the hydroelectric plant will be used as a pumped storage facility for peak-load electricity supply.

Both the Harza and Bechtel reports indicate expected future cost reductions due to technological developments. Some reduction was indeed realized in the last several years and further reduction is expected in the course of more developments and improvements accomplished [6].

2. Potential cost reduction

The early 1990s study made by the IL-MOE estimated a cost of about 0.57$/ m^3 of desalted water produced in conjunction with the Red–Dead project. This estimate was based on a 5% discount rate and supplied seawater cost of about 0.2 $\$/m^3$. The cost does not include delivery of the product. However, since the early 1990s, significant cost reductions have been observed due to dramatic technological improvements such as:

- improved RO membranes regarding production, salt rejection, boron rejection and performance stability;
- new large SWRO projects (Singapore, Ashkelon);
- improved cost-effective membrane pretreatment (MF and UF);
- large high-pressure pumps and Pelton turbines;
- larger pressure exchange devices;
- various cost-effective boron reduction design options;
- dramatic cost reduction in large BOT projects.

Therefore, an approximate reassessment of the desalination component of the RSDSC indicates a substantial cost reduction due to a sharp cost reduction of the seawater supply evaluated on the basis of the expected very comfortable financing condition of the "Peace Conduit", and the above-mentioned technological improvements.

3. Preliminary evaluation of recently developed technologies of SWRO cost

3.1. Specific energy consumption

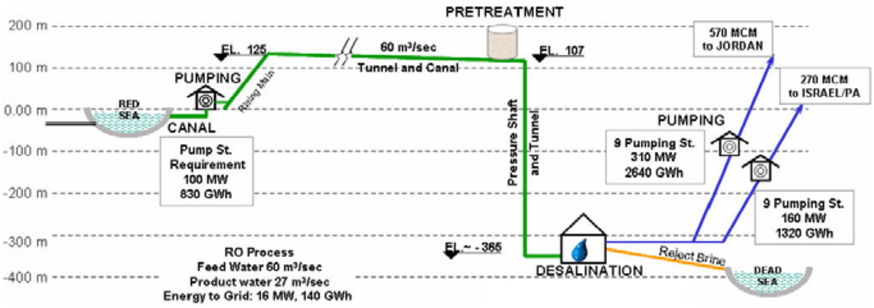
Referring to the Harza study, specific power consumption (Fig. 4) was calculated to be 0.86 kWh/m^3. This figure was obtained for the chosen RSDSC alignment for a 27 m^3/s SWRO plant operating with a 45% recovery using 5,000 gpd membranes and Pelton-type energy recovery turbines. For the same alignment using more efficient, regarding production rate and salt and boron rejection membranes and isobaric pressure exchange (PX) energy recovery devices (ERD), the net specific energy consumption (including seawater pumping) was reduced to 0.53 kWh/m^3 (Fig. 5).

In order to use the more efficient isobaric ERD, the general plant layout has to be revised by splitting the pretreatment section into two parts: the product recovery part (45% for the current example) at the upper level and the rest (55% for the current example) at the lower level (Fig. 5), adjacent to the RO section of SWRO plant. This would result in a reduced footprint at the upper level (where space is limited), but would need a second pressure shaft and a hydraulic turbo-generator.

The investment for the second pressure shaft and the turbo generator is partially off-set by reducing the diameter of the single shaft concept and the much smaller size high-pressure pump and Pelton turbines plus a generator to utilize the excess power from the desalination process. However, by using for the former design concept of more current, more efficient RO membranes and large and more efficient high-pressure pumps and Pelton turbines, the resulting net specific energy consumption (see note, Fig. 4) is also reduced from about 0.86 kWh/m^3 to about 0.57 kWh/m^3—almost the same as for the isobaric ERD concept. For a more accurate estimate, a detailed design has to be made, which is out of scope of the present preliminary study.

3.2. Comparative cost estimate

The early 1990s study made by the IL-MOE estimated a cost of 0.57 $\$/m^3$ of desalted water produced by a



Net specific power for desalination:

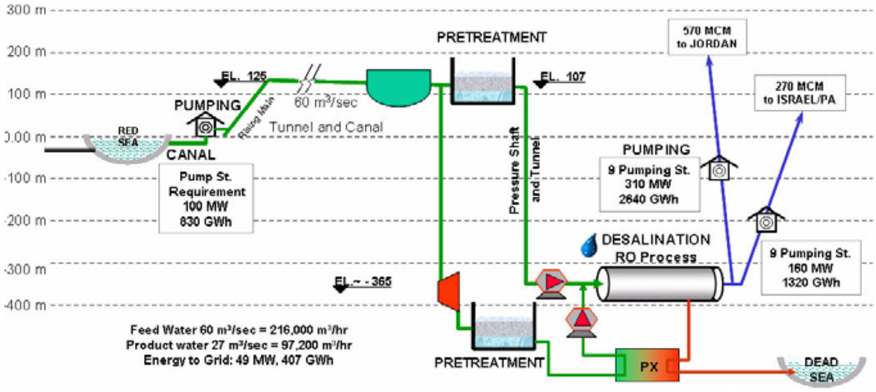
1995 technology:

$$\frac{830\text{GWh}-140\text{ GWh}}{800\text{ Mm}^3}=0.86\text{ kWh/m}^3$$

2008 technology:

$$\frac{830\text{ GWh}-376\text{ GWh}}{800\text{ Mm}^3}=0.57\text{ kWh/m}^3$$

Fig. 4. Schematics of Harza Jordan Rift Valley integrated development study, Red Sea– Dead Sea Canal Project.



Net specific power for desalination:

$$\frac{830\text{GWh}-407\text{ GWh}}{800\text{ Mm}^3}=0.53\text{ kWh/m}^3$$

Fig. 5. Design change on the Harza SWRO schematic layout to include an isobaric ERD.

Table 1
Comparative cost estimate

	1995 technology	2008 technology	
Specific investment cost[a], $\$/m^3$-d	900	720	
Sp. energy consumption[b], kWh/m^3	0.86	Isobaric ERD 0.53	Pelton ERD 0.57
Unit water cost, $\$/m^3$:			
Capital cost @ 10% capital recovery[c]	0.270	0.216	
Fixed operating costs:			
Staff	0.013	0.013	
Maintenance, @1.5% of investment	0.041	0.033	
Membrane replacement	0.048	0.020	
Operating overhead, @ 10%	0.010	0.007	
Subtotal	0.112	0.073	
Variable operating costs:			
Energy cost[b] @ 0.10 \$/kWh	0.086	0.053	0.059
Chemicals	0.070	0.060	0.060
Operating overhead, @ 10%	0.016	0.011	0.012
Subtotal	0.172	0.124	0.129
Total	0.554	0.413	0.420

[a]Excl. feed water supply; [b]Incl. feed water supply.
[c]5% interest rate, 30% equity at 15% interest rate + 0.5% insurance.

Table 2
Relative effect of 2008 technology on cost reduction

	1995 technology	2008 technology	Cost reduction, %
Capital cost, $\$/m^3$-d	900	720	20
Sp. energy consumption, kWh/m^3	0.86	0.53–0.57	34–38
Unit water cost, $\$/m^3$	0.554	0.413–0.420	24–25
Unit water cost, incl. boron reduction cost, $\$/m^3$	0.624[a]	0.413–0.420	33–34

[a]Boron reduction cost by ion exchange = 0.07 $\$/m^3$.

800 Mm^3/y SWRO in conjunction with the Red–Dead project estimated for a 5% discount rate and supplied seawater cost of about 0.2 $\$/m^3$. The estimate was made for an SWRO investment cost of about 589 $\$/m^3$-d (Fig. 2, Arava alignment).

Since the early 1990s the CPI due to inflation has increased by about 50%. Thus, based on early 1990s technology, the current cost would amount to about 900 $\$/m^3$d. However, recent technological developments, especially larger and more efficient membranes, pumps and ERDs, along with more efficient pretreatment methods, result in a significant cost reduction [6] of about 20%. Based on this very preliminary estimate and observed cost reduction in membrane replacement and use of more efficient antiscalants, a cost comparison for the two concepts using early 1990 technology vs. current technology is made and summarized in Tables 1 and 2.

4. Conclusions

In the last 15 years since publishing the IL-MOE and the Harza studies, negative and positive developments have affected the costing of seashore-sited desalination plants and also expected cost of desalination in conjunction with the Red–Dead project. Both inflation and the increase in the cost of energy have a negative effect on desalination. However, dramatic technological developments have a very positive effect and the cost increase is partially and sometimes fully offset.

Two basic design concepts are analyzed for the initially considered 800 Mm^3/y SWRO in conjunction with the Red–Dead project. A concept is shown in Fig. 4 using the Pelton turbine ERD, and another concept is shown in Fig. 5 using the isobaric ERD. While for seashore-sited SWRO the isobaric ERD has significant energy-saving benefits for the SWRO in conjunction with the Red–Dead project, the energy-saving benefit is strongly reduced because of the large hydraulic head reducing the required pressure of the SWRO process pumps. Both concepts should therefore be considered in the general and detailed design of the project.

The current very rough estimate of about 0.4 $\$/m^3$ for a 800 Mm^3/y SWRO plant, excluding investment cost for seawater supply, is significantly lower in comparison to large 100–200 Mm^3/y seashore-site SWRO plants, even by taking into account about 0.2 $\$/m^3$ for investment in the seawater supply system.

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