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2.9 Seawater desalination in the Arabian Gulf countries

Owing to the rapid increase in demand for water in the Arabian Gulf countriesSaudi Arabia' Kuwait, the United Arab Emirates, Qatar, Bahrain, and Omanwhere conventional water resources such as fresh surface water and renewable groundwater are extremely limited, other alternatives such as wastewater reclamation and desalination have been adopted since the 1960s. Countries such as Saudi Arabia, Kuwait, Qatar, and Bahrain all use nonrenewable groundwater resources in large quantity, causing depletion of these valuable resources and deterioration in the quality of water. Although conventional water resources such as renewable groundwater and surface runoff are available in countries like Oman, the United Arab Emirates, and Saudi Arabia, these resources still need to be properly developed in an integrated water-resources planning context.

In some of the more arid parts of the Middle East, in particular the Gulf states, where good quality water is not available or is extremely limited, desalination of seawater has been commonly used to solve the problems of water supply for municipal and industrial uses.

Kuwait was the first state to adopt seawater desalination, linking electricity generation to desalination. The co-generation station, as it is called, re-uses low pressure steam from the generator to provide energy for the desalination process. As a result, both energy and costs are minimized. Kuwait began desalinated water production in 1957, when 3.1 million m^3 were produced per year. By 1987 this figure had risen to 184 million m^3 per year.

In Qatar, too, an intensive programme of desalinated water production has been started, which should be supplying about 150 million m^3 of water per year by the year 2000. This is believed to be about threequarters of the total water demand, with the rest to be supplied from groundwater sources, which are mostly brackish. About half of the country's demand will be generated in the urban/industrial centres.

Saudi Arabia entered the desalinated water field much later than Kuwait. The first plant was commissioned in 1970. It has, however, gone in for an ambitious programme of desalination plant construction on both the Red Sea and Gulf coasts. The Saline Water Conversion Corporation had installed 30 desalination plant projects by the end of the 1980s. The total production of desalinated water is estimated to be 2.16 million m^3 (572 million [US] gal.) per day including a facility at Al-Jubail producing 1 million m^3 per day, which is currently the world's largest distillation plant.

In spite of the high cost of seawater desalination, with unit water costs five to ten times as high as those of conventional water-resources development, a vast quantity has been produced to meet the increasing demand for domestic water in the Arabian Gulf countries. As in Kuwait, however, there is increasing government concern about the production cost of desalinated water, and every effort is being made to ensure that water use is as efficient as possible.

2.9.1 Installed capacity of desalination plants

There are about 1,483 desalination units operating in the Arabian Gulf countries, which account for 57.9% of the worldwide desalting plant capacity. The dominant plant type is multi-stage flash (MSF) which accounts for 86.7% of the desalting capacity, while the reverse osmosis accounts for only 10.7%. The installed capacity of desalination plants in the Arabian Gulf countries is estimated at 5.76 million m^3 per day in total, including 2.98 million m^3 in Saudi Arabia, which is approximately half of the total desalination capacity of the Gulf countries (Al-Mutaz 1989). The installed capacity with shares of each process are shown in table 2.10.

MSF desalting has proved to be the simplest, most reliable, and most commonly used seawater system in large capacities. It has reached maturity with very little improvement in sight. This maturity is expressed in reliable designs of large units up to 38,000 m³ (10 million gal.) per day, long operation experience with high on-line stream factors (up to 95%), confidence in material selection, and very satisfactory water pre-treatment. However, there has been a recent trend towards the use of reverse osmosis in seawater desalination, both for new plants and in connection with the present MSF plants, taking into account the possible reduction in energy requirements and the lower operation and maintenance cost for RO.

Table 2.10 Installed capacity of desalting plants and share by process type in the Arabian Gulf countries

	No. of units	**Capacity (1,000 m³/day)**	**Share by process type (%)**				
			MSF	**RO**	**ED**	**VC**	**MED**
Saudi Arabia	874	2,980	80.7	16.2	2.6	0.5	
Kuwait	279	1,090	95.5	1.8	0.55	1.6	0.25
U.A.E.	99	1,020	98.3	0.9	0.5	-	-
Qatar	47	310	9 7.9	-	-	0.7	0.9
Bahrain	143	260	56.7	37.2	4.9	0.8	0.4
Oman	41	100	91.1	1.9	0.9	1.7	
TOTAL	1,483	5,760	86.7	10.7	1.8	0.65	0.15

Source: Akkad 1990.
MSF = multi-stage flash. RO = reverse osmosis. ED = electrodialysis. VC = vapour compression. MED = multi-effect distillation.

2.9.2 The world's largest seawater desalination with high-pressure pipeline system

To meet the water demands of the increasing population and water short regions in Saudi Arabia, the Saline Water Conversion Office (SWCO) under the Ministry of Agriculture and Water was made responsible for providing fresh water by desalination of seawater in 1965. The first seawater desalination plant was commissioned in 1970. With its increasing responsibilities to provide fresh water, the SWCO was changed in 1974 into an independent corporation, the Saline Water Conversion Corporation (SWCC), which then developed an elaborate plan to construct dual-purpose plants on both the east and west coasts of the kingdom.

The SWCC had constructed 24 plants by 1985, including 17 plants on the western coast along the Red Sea, from Haql on the Gulf of Aqaba in the north to the tiny Farasan island in the south, and 7 plants on the east coast along the Arabian Gulf from Al-Khafji to Al-Khobar (fig. 2.48). These plants were producing 1.82 million m³ (481 million gal.) of fresh water per day and 3,631 MW of electric power. By the end of the 1980s the total production of fresh water was estimated to have been increased to 2.17 million m³ (572 million gal.) of fresh water per day and 4,079 MW of electric power by the addition of six cogeneration plants (SWCC 1988).

Fig. 2.48 Desalinsation plants and water supply in Saudi Arabia

In addition to desalination and power plants, the SWCC provides water to inland regions by means of pipelines. The Al-Jubail-Riyadh pipeline is one of the world's largest water pipeline systems with seawater desalination plants. The pipeline has a diameter of 1.5 m (60 inches), a length of 466 km, a differential head of 690 m, and a pumping capacity of 830,000 m³ per day (SWCC 1988).

2.9.3 Cost constraints of seawater desalination

The MSF process has served very well during the past ten years, especially in the Middle East. During this period, operating experience has been developed that should result in substantial extensions to what was heretofore considered a reasonable operating life. Certainly this favourable experience will be a factor in the selection of future plants.

However, the lower capital and operating costs for the RO process should receive increasing attention in the selection of a desalination process in coming years. There are still opportunities for further lowering of costs through improved membrane technology, notably in increasing membrane life. Another new development with good potential for reducing costs for the RO process are membranes for operating at high pressures up to 1,500 psi (105 kg/cm^2) and 50% conversion when operating on seawater with 45,000 mg of TDS per litre.

Another alternative process will be low-temperature multi-effect horizontaltube evaporators. If aluminium tubes and tube sheets can be shown to have a reasonable life in Middle East seawater, the capital cost can be reduced, or a higher performance ratio can be achieved.

Another factor which will favour reverse osmosis in coming years is that it is the most energy-efficient of all of the processes. This will be of increasing importance if in fact fuel-oil prices rise further as expected and environmental considerations increase in importance. The cost of energy consumption is also the largest single item in the cost of desalted water. It is significant that, for either a single-purpose or a dual-purpose plant, RO appears to be the most cost-effective. On the basis of world fuel costs in 1989, the RO process would save over 10% compared with multi-effect distillation and 32% compared with MSF (Leitner 1989).

2.9.4 Hybrid RO/MSF seawater desalination to compromise quality-cost constraints

It seems that the race for the second generation of seawater desalters has been settled, with RO and low-temperature multi-effect horizontal tube evaporators as front runners. Both systems are characterized by their low energy requirements compared with the MSF system. As shown in fig. 2.49, which gives the worldwide market shares of various desalination processes, RO accounted for 65% of market share in 1987 (Wangnick and IDA 1988). Beside these two options, there are combination possibilities of different desalting plant types. In the hybrid MSF/RO desalination-power process, a seawater RO plant is combined with either a new or existing dualpurpose MSF plant with the following advantages:

Fig. 2.49 World market share of various desalination processes (Source: Wangnick and IDA 1988)

>> The capital cost of the combined RO/MSF plant can be reduced.

>> A common seawater intake is used.

>> Product waters from the RO and MSF plants are blended to obtain suitable product-water quality. Taking advantage of the fact that the MSF product (25 mg of TDS per litre) typically exceeds potable water specifications (WHO standard: 500-1,000 mg/l the product water specification in the RO system can thereby be reduced.

>> A single-stage RO process can be used and the RO membrane life can be extended because of the reduced product-water specification. (The life of the RO membrane can be extended from three to five years, or the annual membrane replacement cost can be reduced by nearly 40%.)

>> Electric power production from the MSF plant can be efficiently utilized in the RO plant, thereby reducing net export power production. In addition, the electric power requirement to drive the high-pressure pumps of the RO system, which is a major factor of energy consumption, can be reduced by 30% by adding an energy recovery unit to the brine discharge in the RO system. (Power consumption for a single-stage seawater RO plant at 30% of recovery/conversion is estimated to be 9.24 kWh/m^3 without or 6.38 kWh/m^3 with energy recovery on brine discharge [Awerbuch et al. 1989].)

>> Blending with RO product water reduces the temperature of the MSF product water. A problem common in areas in the Middle East is the high temperature of the product water. RO for high pressure brine when no energy recovery is used can be used to cool the MSF product water with an eductor.

JEDDAH RO/MSF HYBRID PROJECT. The first large-scale MSF/RO hybrid project, the Jeddah I rehabilitation project in Saudi Arabia, is now in operation by the Saline Water Conversion Corporation. This 15 million gal. (56,800 m^3) per day RO plant, the world's largest facility for seawater conversion, has demonstrated the attractiveness of the hybrid concept. The Jeddah I MSF desalination plant was completed in 1970, with an installed capacity of 5 million gal. (18,925 m^3) per day. It was one of the world's largest plants in the early 1970s and therefore has a significant place in history. The installed capacity of the Jeddah desalting complex was expanded by steps to a nominal capacity of 85 million gal. (321,725 m^3) per day, all by MSF.

In 1985 the operation and maintenance of the Jeddah I MSF plant had become increasingly costly. To keep pace with the increasing water demand, the 5 million gal. per day Jeddah I MSF plant was replaced by a 15 million gal. per day RO plant (phase I) in 1986-1989, which is incorporated in a hybrid RO/MSF desalination system. The RO unit has the following design criteria (Muhurji et al. 1989):

- feed-water quality: TDS = 43,300 mg/l chloride as Cl^- = 22,400 mall, pH = 8.2, water temperature 24.5-32.5°C;
- operating pressure at 60 kg/cm^2 (maximum design pressure: 70 kg/ cm);
- a single-stage design, including 10 RO trains, with each train including 148 RO modules;
- hollow fine fibre (Toyobo Hollosep made of cellulose triacetate) RO module with 10 inch diameter;
- recovery ratio of 35% of product water;
- product-water salinity as specified at 625 mg of chloride per litre (= 1,250 mg of TDS per litre).

Since MSF product water has a salinity as low as 25-50 mg of TDS per litre, the salinity of the permeate from the Jeddah I RO plant (phase I) was specified as 625 mg of chloride (1,250 mg of TDS) per litre, which is a major factor in minimizing the cost of the RO. In a cost analysis done by Bechtel (Muhurji et al. 1989), it was shown that the product water cost from the RO system in a hybrid MSF/RO plant can be reduced by 15% compared with a stand-alone RO plant.

2.10 Groundwater-hydro development in Chile and Libya

Groundwater-hydro has been studied in two development projects in the arid regions of north-west Chile and the Sahara desert in Libya. The Chilean plan will involve constructing a high-pressure pipeline to exploit the height difference between the wellfield in the Andes and the coastal terrain. The Libyan plan will involve installing a mini-hydro station at the end of the Great Man-Made River pipeline to exploit the height difference of 200 m.

2.10.1 Groundwater-hydro in multi-purpose Salar del Huasco scheme in Chile

The coastal plains in the northern part of Chile may be classified as arid to extremely arid (fig. 2.50). The extremely arid Iquique region is located in the northern corner of Chile, where rainfall is only 10 mm or less per year. No water resources are available in these arid coastal regions except for a very limited amount of groundwater, whose quality is likely to be saline or brackish. By contrast, huge renewable groundwater resources with excellent quality can be tapped in the Andes mountain ranges. The hydro-potential of the Andes mountain ranges in South America is one of the world's largest, and includes both surface water and groundwater.

The Salar del Huasco project is being planned to develop groundwater for water supply, irrigation, and hydroelectric power. The groundwater-hydro scheme would use the substantial head difference between the wellfield on the mountain range (3,750 m) and the irrigation area on the coastal terrain (1,400 m). The water will be supplied from a wellfield 76 km away by a pipeline that will cross the mountains using pumping stations. The project will assure adequate drinking water supplies to Iquique until the middle of the next century and will increase the local availability of irrigation water by 50%. This will suffice for the cultivation of 4,800 ha of land on the extremely arid terrain. The hydro units will have a combined capacity of 50 MW (WPDC 1988).

Fig. 2.50 Salar del Huasco groundwater development scheme and wafer pipeline system in Chile

Fig. 2.51 Schematic profile of the Salar del Huasco groundwater-hydro scheme

The scheme will comprise the extraction of 2.4 m^3 of groundwater per second from 54 wells in the area of Lake Huasco, which is at an elevation of 3,785 m. The water will be piped through a central collector to Iquique and Pica, and the available head will be used to generate electricity. The first or upper station will be built between the wellfield and Pica, at an elevation of 3,000 m, and the second or the lower station will be built in Pica, at an elevation of 1,400 m (fig. 2.51). The theoretical hydro-power is estimated to be 50 MW in total, 16 MW at the first power station and 34 MW at the second. The installed capacities of the power stations are preliminarily estimated to be 42 MW in total, consisting of 13 MW at the first station and 29 MW at the second.

2.10.2 Groundwater-hydro in the Great Man-Made River project, Libya

A hydroelectric power station will be installed in part of the massive Great Man-Made River project, which will carry an eventual 6 million m^3 of water per day from beneath the southern Sahara desert for agricultural, industrial, and domestic use in the heavily populated coastal regions in Libya (see section 2.7.3 above). This groundwater-hydro plant will be the first of its kind.

The second phase of the project, begun in 1986, includes an option for an 18 MW hydroelectric station to be built adjacent to a terminal reservoir with a planned capacity of 28 million m^3 (WPDC 1986). The station would use a differential head of water of some 200 m, and power output would compensate for the energy used to pump the water to the coast.

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