WATER DESALINATION IN SAUDI ARABIA

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الخلاصــة :

تعتبر المملكة العربية السعودية بلداً صحراوياً جافاً لا تتخلله أنهار أو مياه عذبة أو بحيرات إلا أنه قطر يتمتع بكميات وفيرة من المياة الجوفية ومياة البحر . ويتعين تحلية هذه المياة بطريقة ما حتى تكون صالحة الشرب . والطرق المستخدمة عادة لمثل هذا الغرض هي :

التبخير الومضي المتعدد المراحل والتناضح العكسي والديلزة (الفرز الغشائي) بالكهرباء .

وبفضل التصنيع والتطور السريع الذي تشهده المملكة فإن الطلب على المياه في تزايد مستمر . واستهدافاً لتحقيق هذا المطلب قامت المملكة بوضع أكثر البرامج طموحاً لتحلية المياه . وقد بلغ إجمالي الطاقة الإنتاجية للمياه المحلاة بالمملكة حوالي ٢ × $١٠^{٦}$ متر مكعب في اليوم . أي حوالي ٢٥٪ من إجمالي الطاقة الإنتاجية للمياه المحلاة في العالم . ومن المتوقع أن تبلغ الطاقة الإنتاجية في نهاية عام ١٩٨٥ ٤×$١٠^{٦}$ متراً مكعباً في اليوم .

يتضمن هذا البحث وصفاً موجزاً للمياه الجوفية ومياه البحار والخواص التي عليها تلك المياه وأهم مراكز التحلية بالمملكة والتعليق على الدور الذي تلعبه تلك المراكز ومدى كفاءتها .

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ABSTRACT

Saudi Arabia is an arid desert country without rivers or fresh water lakes. However, it does have large amounts of groundwater and seawater. These waters must be desalted by some means in order to make them potable. The methods most frequently used for that purpose are multistage flash (MSF) evaporation, reverse osmosis (RO), and electrodialysis.

Because of rapid industrialization of the country, the demand for fresh water has been growing steadily. To satisfy that demand, the Kingdom has embarked on the most ambitious water desalination program ever undertaken. At present, the total production capacity of Saudi Arabia is about $2.0 \times 10^6\ m^3/day$ (25% of world's total); by the end of 1985 it is expected to reach the figure of $4.0 \times 10^6\ m^3/day$.

This paper gives a brief discussion of ground and seawaters and their characteristics, an inventory of major desalination plants in the Kingdom, and some comments on their performance.

WATER DESALINATION IN SAUDI ARABIA

INTRODUCTION

Saudi Arabia is an arid desert country deprived of fresh water supplies such as rivers and lakes. Its topography has been created by regional tilting and uplift of the western and southern regions of the peninsula. The mountain ranges of Hejaz and Asir spread along the coast of the Red Sea. From there eastwards, the land declines gradually toward the Arabian Gulf.

Weather conditions vary almost as much as the terrain. In the mountains, annual rainfall is about 50 cm while the Rub Al-Khali region may receive no rain for years. Over the country as a whole, the mean precipitation is estimated to be about 5 cm. This low precipitation and intense heat during the months May through October are the obvious reasons why there are no perennial rivers or lakes in Saudi Arabia. Surface runoffs, however, frequently occur during the rainy season in the western part of the country when flash floods develop as a result of intense rainfall. Part of such surface waters is absorbed underground, enriching aquifers, part is used for irrigation, and the rest is lost through evaporation or to the sea. To prevent such losses, 173 dams have been built; more are under construction and in the planning stage.

Since the watershed between the Red Sea and Arabian Gulf drainage basins is only some 100–150 km from the Red Sea coast, the larger floods to the west of the divide often reach the Red Sea while the runoff from the highland eastwards has no chance of ever reaching the Gulf.

Because of the lack of reliable surface water resources, the Kingdom must depend on its groundwaters and seawaters. Saudi Arabia is fortunate to have large amounts of both.

WATER QUALITY STANDARDS

According to the recommendations of the U.S. Public Health Service, potable water should not contain more than 500 ppm TDS (parts per million of total dissolved solids). This organization also sets 1000 ppm as the maximum allowable level. The World Health Organization sets that maximum at 1500 ppm [1].

While the total amount of dissolved solids is a commonly accepted indicator of water quality, it is not an accurate index. Some of the components are more harmful than others, either from the health point of view or in terms of problems they may create during the operation of a desalination plant.

All waters may be considered as solutions of salts (solids) of various compositions and concentrations. Since the salts are almost completely disassociated in water, the water analyses are given in terms of concentrations of individual ions. In most waters the concentration of sodium and chloride ions are the largest. While the high sodium concentration in drinking water may present a health problem, high concentration of chlorides in desalination plant feedwater may lead to corrosion problems. However, these are not the most troublesome components in operating a desalination plant. Calcium, magnesium, bicarbonate, and sulfate ions present a much bigger problem. If the concentrations of these ions exceed certain limits, they form insoluble deposits (scales) which impair operation of the desalting plants. Other elements which even in minute amounts create problems are metal oxides, colloids, micro-organisms, and other organic matter. These should be removed by a proper water pretreatment method before the actual desalination process.

GROUNDWATERS AND AQUIFERS

Groundwaters of Saudi Arabia, unlike those in many other countries, are not, for the most part, the product of the ongoing hydrological cycle (i.e. derived from recent precipitation); they are fossil waters trapped in sedimentary rocks such as limestone and sandstone. Geological formations, in which these waters are stored, are called aquifers.

Runoff waters help to recharge the aquifers; however, it seems that most of the water entered there 16 000 to 35 000 years ago during the wetter conditions in the Quaternary [2, 3]. Hence, essentially they should be considered as a nonrenewable resource. This situation would be extremely disturbing if it were not for the magnitude of groundwater reserves. However, in view of the ever-increasing demand for water, they cannot be considered as inexhaustible. Recent excessive exploitations of such waters in some instances have already led to significant drops in water levels. [4, 5].

There are 12 major aquifers in the Kingdom: Neogen, Alat, Khobar, Umm er Radhuma, Wasia, Biyadh, Dhurma, Minjur, Wajid, Jawf, Tabuk, and Suq [6]. The first four are exploited mainly in the Eastern Province. Waters from the Wasia and Biyadh aquifers are used in the Eastern Province and also in the Riyadh area. Water from the Minjur basin is used in the regions of Riyadh, Sudyar, Al-Washm, and Al-Kharj. The Wajid water is used in the Dawasir region and the western part of Rub Al-Khali. The Jawf aquifer serves the Al-Jawf area, while the Tabuk and Suq aquifers serve the Tabuk and Tayma regions. The most prolific aquifers are: Umm er Radhuma, Wasia, Minjur, Wajid, and Suq. More information on this subject is available in additional cited literature [7, 8].

Although groundwaters of Saudi Arabia are in ample quantity, their quality varies from place to place and only in few areas it is of what may be called drinking quality. In most cases its salinity varies from 1000 to 10 000 ppm and more. Waters with such amounts of salt fall in the category of brackish waters. They can be used for irrigation of some crops, but are not suitable for human consumption. In order to make them potable, most of their salts must be removed by some means.

In general, groundwaters in the vicinity of outcrop areas have lower salt content. The content increases as the aquifers approach the Gulf coast. This is well illustrated by Table 1 listing ionic compositions and other characteristics of waters from selected ARAMCO wells, all from the same aquifer, Umm er Radhuma (UER). As can be seen, salinity of these waters ranges from just above 1000 ppm in the Haradh area (near outcrop) to over 20 000 ppm in Khursaniyah on the Gulf coast.

Another important characteristic of groundwater is its temperature. For example. waters from deep wells (up to 2000 m) around Riyadh (Minjur aquifer) have temperatures as high as 75°C. This necessitates cooling of such waters in order to make them less corrosive and suitable for some desalination processes such as reverse osmosis.

The Ministry of Agriculture and Water in Riyadh is in the process of compiling data on all wells in Saudi Arabia. At present, data on over 17 000 wells have been compiled and are available in form of a computer printout [9].

SEAWATERS

Seawaters that are available to Saudi Arabia come either from the Red Sea on the west coast, or from the Arabian Gulf on the east coast. Their salinities are considerably higher than that of the oceans which is considered to be about 35 000 ppm TDS. The salinity of the Red Sea is about 40 000 ppm and is, more or less, constant. The salinity of the Arabian Gulf varies widely, from 40 000 to 60 000 ppm, depending on location, currents, time of the year, etc. This makes desalination of such waters not only more costly, but also too difficult for some methods.

Table 2 gives the ionic compositions of seawaters taken from various places on the east and west coasts of the Kingdom. These are typical values; significant variations take place, especially in waters from the Gulf. Table 3 shows variation in salinity of the Gulf water as a function of location along a 150 km stretch of coastline from Jubail southward to Half Moon Bay [10]. The current along that coastline is from north to south.

Table 1. ARAMCO Well Waters (UER Aquifer)

Well #	Location	Depth (m)	Temp. (°C)	Ionic composition							TDS	pH
				Na	Ca	Mg	SO_4	Cl	HCO_3	SiO_2		
823	Haradh	—	—	139	128	52	240	312	177	—	1,048	7.2
966	Uthmaniyah	350	38	235	137	43	328	380	186	—	1,309	7.4
754	Uthmaniyah	325	46	237	134	49	338	376	207	—	1,341	7.2
894	Shedgum	415	36	307	179	69	463	511	238	27	1,794	7.4
904	Shedgum	—	—	341	274	77	920	454	177	—	2,143	7.7
831	Dhahran	200	37	591	236	80	450	1,118	192	24	2,691	7.3
839	Dhahran	190	36	616	226	79	430	1,140	210	—	2,701	7.1
829	Dhahran	200	37	611	256	90	425	1,214	223	—	2,819	7.1
890	Abqaiq	310	31	1,973	472	180	530	3,905	183	—	7.243	7.1
846	Berri	—	37	2,381	716	212	888	4,793	186	18.5	9.176	7.1
805	Khursaniyah	320	—	2,951	824	290	1,050	5,964	198	—	11,277	7.5
2	Khursaniyah	425	36	6,133	1,616	507	1,701	12,425	195	—	22,577	6.8

Table 2. Seawaters of Saudi Arabia

Location	Ionic composition							TDS	pH	Temperature (°C)	
	Na	Ca	Mg	SO_4	Cl	HCO_3	SiO_2			Min.	Max.
Al-Khobar, Gulf	15,478	780	1,667	4,134	28,026	148	2.0	50,272	8.1	15	35
Al-Jubail, Gulf	12,998	517	1,594	3,282	23,588	141	2.5	42,528	8.2	15	35
Al-Khafji, Gulf	13,460	500	1,665	3,100	23,100	135	5.0	42,000	8.3	15	33
Jeddah, Red Sea	14,235	520	1,464	3,078	22,219	146	0.4	41,680	8.0	23	31
Yanbu, Red Sea	14,130	460	1,489	2,960	22,000	145	0.5	41,200	8.0	22	30

Table 3. Salinity of Arabian Gulf

Location	TDS, ppm
Jubail	41,200
Dammam	46,500
Dammam port	45,500
Al-Khobar (north)	46,500
Al-Khobar (south)	52,000
Aziziah Beach	58,000
Half Moon Bay	66,500

It is interesting to note that waters from onshore wells often have salinities considerably higher than that of the sea itself. For example, the Polymetrics RO plant for desalination of seawater in Yanbu, on the Red Sea, takes water from wells located about 1 km from the sea. The first wells were about 30 m deep. The objective of using the well water was to obtain better filtration. This objective was met, but the salinity of that water turned out to be 58 000 ppm, and in a relatively short time increased to 61 000 ppm, a value some 45% higher than that of the sea. This high salinity was believed to be due to high evaporation rate of subsurface water. However, new and shallower (15 m deep) wells dug on the same site yielded water of considerably lower salinity, 51 000 ppm [11]. This would contradict the evaporation theory. The unusually high and unexpected salinity of the feedwater had an extremely adverse effect on the plant performance. This experience shows that before designing any desalination plant, a thorough analysis of local water should be performed.

WATER DESALINATION METHODS

Basically, there are four types of desalination processes. These are:

(1) distillation,
(2) crystallization,
(3) membrane,
(4) chemical.

The first two types require change of phase; the others do not.

The distillation processes include multistage flash evaporation, vertical-tube distillation, multieffect–multistage distillation, vapor-compression distillation, and solar humidification. Of these, the multistage flash (MSF) process is by far the most widely used.

The crystallization or freezing methods have still not found any wider application.

There are four membrane processes: reverse osmosis, electrodialysis, transport depletion, and piezodialysis. Of these, only reverse osmosis (RO) and electrodialysis (ED) have commercial significance.

The only chemical method that is used for desalination of water is the ion-exchange process.

The MSF process makes use of the fact that water boils at progressively lower temperatures as it is subjected to progressively lower pressures. In that process, heated seawater (up to 120°C) passes through a number of chambers (stages) with successively lower pressures. In each chamber part of the water boils instantly or flashes into steam which, then, passes through a demister and condenses on feedwater carrying tubes.

The MSF process, although not the most economical in terms of energy requirements, even amongst the distillation methods, is the most widely used desalination process for a number of reasons. In comparison with other distillation methods, it proved to be more successful because it operates at lower temperatures; hence, its scaling and corrosion problems are less severe. Further, its simplicity allows the design of simple and large (hence more economical) plants. In comparison with the membrane processes, it also proved to be more economical and dependable in desalination of seawaters. These, and the fact that most of the desalted water, 75% worldwide [12], comes from the sea, explain why the

MSF process has, so far, been so successful commercially.

In the reverse osmosis process, a flow of water takes place across a membrane from concentrated to dilute solution, as the result of applied pressure. In practice, this applied pressure varies from 24 to 28 bars for most brackish waters, and from 55 to 70 bars for seawaters.

In terms of their design, there are essentially two types of commercially available membranes, spiral-wound and hollow-fine fiber. In the first design, the water permeates through membranes in sheet form, in the second case, through very small tubes of about 0.1 mm outside diameter and 0.5 mm inside diameter.

The material most frequently used for membranes are cellulose acetates (CA) and polyamides (PA). The CA membranes are used mainly for brackish waters while the PA membranes are used for seawater applications as well.

The membrane performance is characterized by its water flux and salt rejection. The brackish water membranes have relatively high water flux and a low salt rejection of about 90%; hence, they do not require high pumping energy (2–3 kWh/m^3 of product water). The seawater membranes have low water flux and high salt rejection, 98% or better; they require much more pumping energy, 8–10 kWh/m^3 of product water. Still, this compares favorably with energy requirements in the MSF process which are in the 16–20 kWh/m^3 range.

The saline water entering a membrane unit is called the feedwater; water that permeates the membranes is called the product water; the concentrated feedwater that leaves the unit is called the brine. If in an RO system, brine from one membrane unit is used as feedwater for another unit, and the process is repeated a number of times, then such a system is called a multistage system. On the other hand, when the product water is processed in a similar manner, then it is called a multipass system.

The objective of a multistage system is to get as much of product water out of feedwater as possible. The ratio of product water rate to feedwater rate is called water recovery; it is one of the most important indices of performance in an RO plant.

The objective of a multipass system is to obtain higher purity water. Actually no more than two passes are used. A two-pass system is used, for example, in seawater desalination in order to obtain product water of potable quality (less than 500 ppm TDS); it is also used in brackish water application to obtain product water of 10 ppm quality for industrial applications.

A multistage system does not require additional pumping energy because the pressure drops in feedwater streams in individual membrane units are relatively small. In the case of a multipass system there is a completely different situation. Since the pressure of product water in any RO system can be assumed as equal to atmospheric pressure, processing such water again requires additional pumping energy and, of course, additional capital expenditure. This is the main reason why the reverse osmosis process, while performing very well in brackish water applications, still has a hard time competing with the MSF process in seawater applications, at least in Saudi Arabia.

In the electrodialysis process water flows between alternately placed cation-permeable and anion-permeable membranes. A d.c. current provides the motive force for the ion migration through the membranes. Hundreds of alternating cation and anion membranes, separated by cut-out spacers, are assembled into membrane stacks. The spacers contain and form water streams. As the result of ion migration, the feedwater is depleted of salts in half of these streams and becomes the product water; in the other half of the streams, the feedwater is enriched in salts and becomes the brine.

The power consumption in this process is proportional to the amount of salts removed. Hence, the process is very suitable for mildly brackish waters, but not very suitable for seawater conversion. Its power consumption, in the case of desalination of seawater of 35 000 ppm TDS, is about 16 kWh/m^3. In addition, little merit is associated with increasing the size of the plant. Therefore, really large (and hence more economical) ED units are seldom built. Furthermore, the electrodialysis process is more labor intensive than, for example, the RO process.

The ion-exchange process is widely used in industrial applications to obtain water of very high purity (1–2 ppm TDS). It is often used as a 'polishing' process in conjunction with any other desalination method discussed here.

The MSF process accounts for about two-thirds of production of potable water in Saudi Arabia. It is used exclusively for conversion of seawaters.

The reverse-osmosis and electrodialysis processes are used for desalination of brackish waters, with reverse osmosis being a strong leader and accounting for 80% of conversion of such waters. In recent years, a number of RO plants have been built in the Kingdom for desalination of seawaters as well. Their commercial success in this application has still to be demonstrated.

WATER DESALINATION PROGRAMS

The organization that is responsible for most of Saudi Arabia's desalination programs is the Saline Water Conversion Corporation (SWCC). It was created in 1965 as the Saline Office within the Ministry of Agriculture and Water. Today, it is an independent government organization with over 30 billion Saudi Riyals (current exchange: 1SR = 0.29 U.S. $) of projects either completed or under construction. However, SWCC is not the only organization that is active in this field. The Ministry of Agriculture and Water has its own plants and programs, and so does the Royal Commission for Jubail and Yanbu. ARAMCO also has a good number of desalting plants to provide sweet water for its communities and industrial applications. SWCC just does it on a scale far larger than anyone else. Further, SWCC is chiefly responsible

Table 4. MSF Plants in Operation

Location	Production capacity		Supplier	Start-up date	Contracting agency
	Water (m^3/day)	Electricity (MW)			
Wajh I	230		Aquachem	1969	SWCC
Duba I	230		Aquachem	1969	SWCC
Jeddah I	18,900	50	AEG, Contin. Eng., IHI, Aquachem	1970	SWCC
Khobar I	28,400		Aquachem	1973	SWCC
Khafji I	450		Sasakura	1974	SWCC
Khafji	1,250		Krupp	1978	SWCC
Umm Lejj I	450		Krupp	1975	SWCC
Jeddah II	38,000	80	Brown Boveri, C. Itoh, Sasakura	1978	SWCC
Jeddah III	75,700	200	Kraftwerke Union, Deutsche Babcock, Weir Westgarth	1979	SWCC
Farasan	500	0.77	Krupp	1979	SWCC
Haql I	450		Hitachi-Zosen	1979	SWCC
Wajh II	450		Weiritam, Sowit	1979	SWCC
Duba II	450		Weiritam, Sowit	1979	SWCC
Khafji	1,900		Sasakura	1966	Arabian Oil Co.
Khafji	2,300		Sasakura	1971	Arabian Oil Co.
Khafji	2,300		Sasakura	1975	Arabian Oil Co.
Dammam	1,300		Sasakura	1973	SAFCO
Ras Tanura	2,750		Sasakura	1973	ARAMCO
Ras Tanura	1,600		Sasakura	1975	ARAMCO
Yanbu (barge plant)	2,000		Sasakura	1978	Royal Commission for Jubail & Yanbu
Jubail (barge plant)	18,900		Hitachi	1980	Royal Commission for Jubail & Yanbu
Jeddah Refinery	6,000		Weir Westgarth	1976	PETROMIN
Yanbu Refinery	3,800		Weir Westgarth	1979	PETROMIN
Jeddah Airport	20,800		Sumitomo, Weir Westgarth	1980	International Airport
Yanbu/Medina I	95,000	250	Mitsubishi, Sasakura	1981	SWCC
Jubail I	136,000	350	Sasakura, GIE, Breda, Franco Tosi, Bin-laden, Safarco	1982	SWCC
Rabegh	900		Ital-Impianti	1982	SWCC
Yanbu (barge plant)	18,900		Hitachi	1982	Royal Commission for Jubail and Yanbu

for nearly all seawater desalination programs; it is not involved in desalination of brackish waters.

The SWCC desalination program started in the late 1960s with a very modest 230 m^3/day MSF unit in Al-Wejh in northern Hejaz. Then, it expanded rapidly at a drastically increasing rate. Today the SWCC plants account for 95% (or 1.25×10^6 m^3/day) of the seawater conversion in the Kingdom.

Table 4 lists all major MSF plants in Saudi Arabia that are in operation, as well as their production capacities, supplier, start-up date, and contracting agencies. Table 5 lists major MSF plants under construction, while Table 6 lists the MSF plants under study by SWCC.

Table 7 lists all major RO plants, their capacities, designs, types of feedwater and product water, contracting agencies, contractors, costs, and completion dates.

The electrodialysis plants are of smaller sizes, usually of less than 1000 m^3/day production capacity. The only large ED plant, of 5000 m^3/day capacity, is the ARAMCO plant at the Uthmaniya Gas Gathering Center. It was completed in 1981 and it is used, in conjunction with an ion-exchange unit, for production of boiler water.

Table 5. MSF Plants under Construction or in Testing Stage

Location	Production capacity		Supplier	Expected start-up date	Contracting agency
	Water (m^3/day)	Electricity (MW)			
Jeddah IV	189,000	500	Sogex, Envirogenics, Franco Tosi	1983	SWCC
Khobar II	189,000	500	Kraftwerke Union, Sidem, Babcock and Wilcox, Hyundai	1983	SWCC
Jubail II	945,000	1,300	Sasakura, IHI, Hitachi Westinghouse, Stein, GIE, Rolaco, Mitsubishi, Technip	1984	SWCC
Haql II	5,700	15		1983	SWCC
Umm Lejj II	3,800	10		1983	SWCC
Mecca/Taif	150,000	400	Mitsubishi Heavy Industries	1985	SWCC
Asir I	95,000	N.D.	Mitsubishi Heavy Industries	1987	SWCC

Table 6. MSF Plants in Planning Stage

Location	Production capacity		Expected start-up date
	Water (m^3/day)	Electricity (MW)	
Yanbu/Medina II	150,000	400	1985
Qunfudhah	3,800	10	1984
Khobar III	150,000	400	1984
Wajh III	5,700	15	1986
Khafji II	22,700	50	1984
Jeddah V	95,000	N.D.	1987
Duba III	3,800	10	1984
Thool	1,900	—	1984
Mastoura	1,900	—	1984
Tabuk	150,000	N.D.	1987

Table 7. Major RO Plants

Location	Capacity (m^3/day)	Design	Feedwater	Product water	Contracting agency*	Contractor	Cost (SR.10^6)	Completion date
Jeddah	12,000	SW	Seawater	Potable	SWCC	U.O.P.	138	1979
Yanbu	5,000	HF	Seawater	Potable	R.C.J.Y.	Polymetrics	42	1980/1981
Manfouha I	27,300	HF	Brackish	Potable	M.O.A.W.	Degrémont		1980
Manfouha II	36,400	HF	Brackish	Potable	M.O.A.W.	Degrémont		1980
Malez	18,200	HF	Brackish	Potable	M.O.A.W.	Degrémont		1980
Shemessy	27,300	HF	Brackish	Potable	M.O.A.W.	Degrémont		1980
Salbukh	38,400	HF	Brackish	Potable	M.O.A.W.	Degrémont	310	1979
Buwayb	45,000	SW	Brackish	Potable	M.O.A.W.	Ames Crosta	378	1980
Jubail	15,000	SW	Brackish	Potable	R.C.J.Y.	Hydranautics	10	1979/1980
Shedgum	5,300	HF	Brackish	Boiler	ARAMCO	Sasakura	8	1979
Dhahran	3,500	HF	Brackish	Potable	ARAMCO	Sasakura	10	1982
Berri	6,800	HF	Brackish	Boiler	ARAMCO	Polymetrics	4	1975/1977
Riyadh	4,500	SW	Brackish	Potable	M.O.D.A.	Hydranautics	3.5	1979
Majmaah	3,800	SW	Brackish	Potable	M.O.A.W.	Hydranautics	2.8	1978
Riyadh Ref.	17,000	HF	Brackish	Boiler	Petromin	Permutit		1980
Al-Birk	2,300	HF	Seawater	Potable	SWCC	Al-Kawther	75	1982
Jeddah	2,300	HF	Seawater	Potable	M.O.D.A.	Al-Kawther	75	1983
Meccah	15,000	HF	Brackish	Potable	M.O.U.A.	Al-Kawther	27.5	1983
Ras Tanajib	13,600	HF	Seawater	Potable	ARAMCO	Al-Kawther		1984

*R.C.J.Y. = Royal Commission for Jubail and Yanbu
M.O.A.W. = Ministry of Agriculture and Water
M.O.D.A. = Ministry of Defense and Aviation
M.O.U.A. = Ministry of Urban Affairs

Locations of most of the plants listed in Tables 4–7 are shown on the map of Saudi Arabia in Figure 1.

Figure 2 shows the growth of the desalination industry in the Kingdom in terms of production capacity of units installed each year. There are four graphs here, three for the individual processes, MSF, RO, and ED, the fourth represents their total.

Figure 3 shows the production capacity of units in operation. Again, there are four graphs here, three for the individual processes, the fourth represents the total for all plants and processes.

From these two figures, it is quite clear that the MSF process is the strong leader and its dominance will continue for years to come. This is not surprising, since it is the policy of the Kingdom to depend on desalination of seawaters and, thus, preserve the groundwater resources. Further, the MSF process is at present the most dependable and economic process for seawater conversion on large scale, especially when it is used in conjunction with power generation as is done in dual-purpose plants.

Figure 1. Map of Saudi Arabia

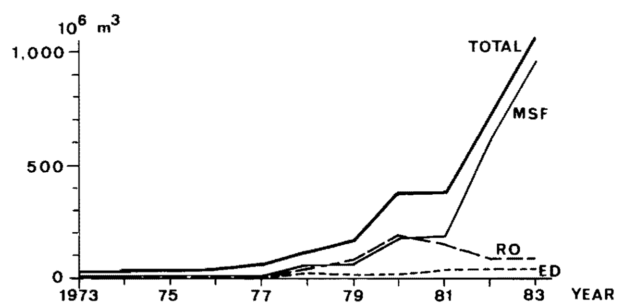

Figure 2. Capacity of Units Installed

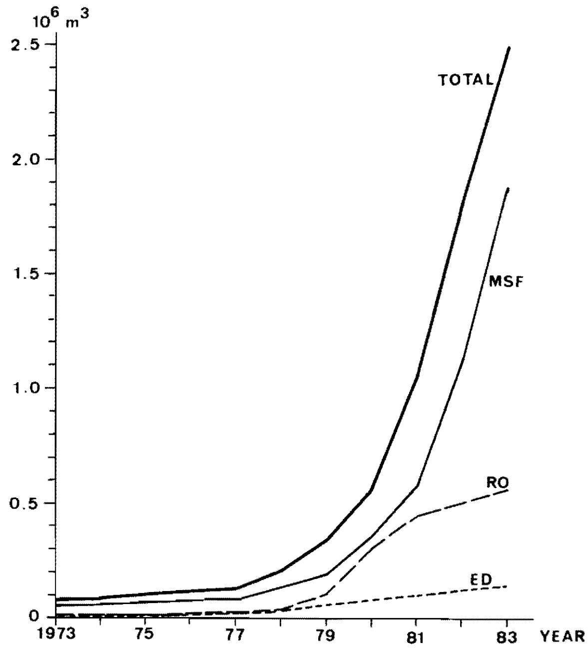

Figure 3. Capacity of Units in Production

While the growth of the desalination industry is very impressive, production of potable water still lags behind the demand. This is well illustrated in Figure 4. Here, the 'demand' curve was derived from data contained in the Saudi Arabian Third Five-Year Plan [13]. The 'supply' curve is based on data collected for the study [4] on which this paper is based. Intersection of the two curves represents the event of supply catching up with the demand; this is expected to occur in 1985.

From inspection of Figure 1 and the preceding discussion, it is clear that most of the desalination plants and water produced are on the seacoasts. However, most of Saudi Arabia's population lives inland. Till now, all inland communities have had to depend on groundwaters, in most cases desalted either by reverse osmosis or electrodialysis. Pursuing the policy of conservation of groundwater resources, the Kingdom has embarked on still another spectacular program of bringing the distilled seawaters to inland communities by means of water transmission lines, where they are then blended with local well waters. Four such transmission lines will be in operation shortly. They are the Riyadh, Yanbu/Medina I, Mecca/Taif, and Asir lines.

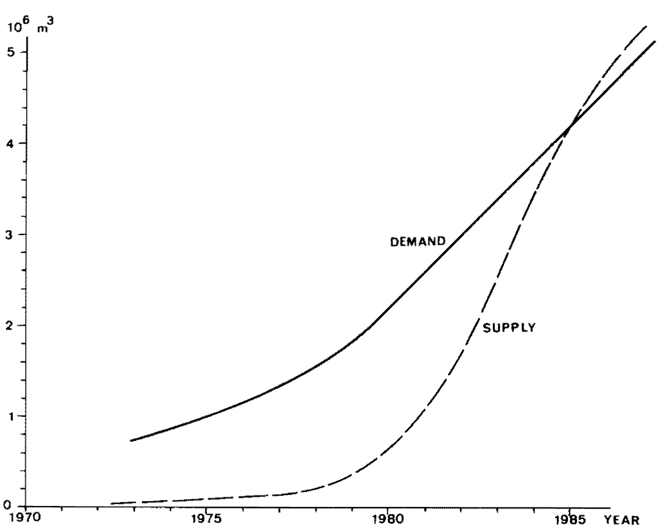

Figure 4. Potable Water Demand and Supply

Water for Riyadh will be produced in the Jubail II MSF plant, the largest desalting plant ever built. Out of its total daily production of 0.95×10^6 m^3, 0.83×10^6 m^3 will be pumped to Wasia, east of Riyadh. There, the distillate will be blended with well waters from the aquifer bearing the same name.

The water from Jubail will be carried by two 60 in. pipes and will pass through six pumping stations in Jubail, Dhahran, Shedgum, Hofuf, Khurais, and Wasia [5]. The installed pumping capacity of all stations is 430 MW. The total length of the pipeline is 466 km; the difference in elevation of both ends is 670 m.

The total cost of the whole project is 5.5 billion SR, about the same as that of the Jubail II plant. The expected completion data is July 1983.

The Yanbu/Medina I desalination complex consists of a 95 000 m^3/day, 250 MW, dual-purpose MSF plant and the water transmission lines joining the plant with the cities of Yanbu and Medina. Yanbu receives 19 000 m^3/day of distilled water and Medina 76 000 m^3/day. The line to Yanbu is 48 km long, the line to Medina is 176 km long and it rises 1000 m over the mountains *en route*. The total cost of the plant is 1.33 billion SR; the cost of the pipelines is 403 million SR. Two more pipelines to Medina will be built for the water from the Yanbu/Medina II plant which is expected to be completed by 1985.

The Asir complex will consist of a dual-purpose MSF plant and a 300 km pipeline. The plant will be located at Shuqaiq on the Red Sea coast in Tihama. Its production capacity will be 95 000 m^3/day and it will cost 1.5 billion SR. The pipeline will pass through the mountains region of Asir carrying water to Abha, Khamis Mushayt, and down to Jizan on the coast. The cost of pipeline will be 1.5 billion SR. The expected completion year is 1987.

COMMENTS ON PERFORMANCE OF DESALINATION PLANTS

The operating experience on desalination plants in Saudi Arabia has, in general, been good. In any new venture, mistakes are bound to be made; development of the desalination industry in the Kingdom has been no exception. Most of the problems encountered were related to the rather harsh conditions in which these plants had to operate, lack of trained operators, inadequate planning, poor design (or designs that did not take into consideration the above factors), lack of preventive maintenance, etc.

In the case of the MSF plants, major problems seem to be related to scale control, corrosion, design of seawater intake, and lack of preventive maintenance.

To illustrate these difficulties let us consider the Jeddah I and Khobar I plants. The Khobar I plant was designed for seawater of salinity below 50 000 ppm TDS, the actual salinity turned out to be 57 000–63 000 ppm. Both plants were designed to operate at top brine temperature of 121°C and acid injection for control of alkaline scale. Right from the start, the plants were beset with a number of scale, corrosion, and operational problems due to tight design specifications and poor choice of construction materials. To make matters worse, the critical shortage of water in 1970s necessitated round-the-clock operation without shutdowns for necessary preventive maintenance. These problems caused rapid deterioration of the plants. Water production of the Jeddah I plant was about 62% of the rated value; the on-stream factor was 79%, and the performance ratio was 8.3 compared with the design value of 9.5. Now, after about ten years of operation, the plant is shut down completely. It will be replaced by another MSF plant.

The Al-Khobar I plant is still operating and after initial problems its present performance may be termed as satisfactory. Its top brine temperature has been reduced to 112°C. Because of this, and loss of some heat transfer area due to corrosion problems encountered in the early stage of operation, the current plant output is only about 70% of the rated capacity.

The Jeddah II and Jeddah III plants represent the second generation of MSF plants in the Kingdom. Their designs are more realistic and selection of materials more appropriate, thanks to experience gained from operation and maintenance of the Jeddah I and Al-Khobar I plants. Consequently, Jeddah II and Jeddah III have exhibited good performance. During the two year period of study [4], these two plants logged high on-stream records, produced better than the design distillate output, and consistently maintained better than the design performance ratio.

Performance of RO plants in brackish water applications has been, in general, very good. The RO systems are simple, easy to operate, and can be installed in a matter of months. Smaller plants usually suffer from inadequate pretreatment of water which leads to shortening of the life of membranes. To prevent this, a common practice is to reduce the operating pressure and water recovery. This means that more water in the form of brine is discarded, a rather wasteful practice that should be discouraged.

In seawater applications the RO process, so far, has not been a commercial success mainly because of the very high salinity (for the RO process) of feedwaters which leads to corrosion, deterioration of membrane performance, and many maintenance problems.

The cost of the product is one of the most important indices of plant performance and of suitability of the desalination method used. Table 8 gives that cost for various plants considered in the study [4]. From an inspection of this table we see that the lowest cost is for brackish waters desalted by means of reverse osmosis. In the seawater applications the MSF process produces water more economically. Further, the MSF product is pure distillate which for drinking purposes is always blended with well water (to 500 ppm level). The cost of such a blend should be 25–30% lower than that of the distillate.

Table 8. Cost of Water

Plant	Process	Type of feedwater	Cost of water (SR/m³)
Jeddah II	MSF	Seawater	6.22
Jeddah III	MSF	Seawater	5.84
Salbukh	RO	Brackish	3.52
Buwayb	RO	Brackish	4.15
Jubail	RO	Brackish	2.09
Jeddah	RO	Seawater	8.87

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