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RECENT TREND TO RVERSE OSMOSIS FOR DESALINATION IN SAUDI ARABIA

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Saudi Arabia experiences a large need for water supplies to provide continued growth, development and industrialization all over the country. It is aimed to have desalting water replace natural water resources, which are quite few and diminishing, for municipal and industrial use. By the recent advances in membrane technology, desalination of sea water by reverse osmosis is a practical and economical method of providing fresh water in Saudi Arabia. Reverse osmosis was only used to provide potable water to small dispersed communities as well as individuals.

This paper reviews the latest technological development in the field of water desalting by reverse osmosis which are presently use or planned to be established in Saudi Arabia.

INTRODUCTION

Saudi Arabia is a large country without a single river. It is an arid country. The average annual rain fall is less than 101.6 mm (4 in). Table 1 shows the annual rain fall in different parts of the country(1). The best choice for obtaining fresh water in the country is to efficiently utilize the ground and sea water resources. Unfortunately, these sources are highly saline and can not be used directly without treatment of desalination.

It is planned to supply fresh water in Saudi Arabia from sea water desalination with the ground waters as back up. Ground waters resourcees are limited and need to be desalted too. As shown in table 2, nearly 50% of desalination plants that are in operation worldwide are located in Saudi Arabia(2). Large numbers of multistage flash evaporation (MSF) plants are used for sea water desalination in Saudi Arabia. Some reverse osmosis (RO) plants and electrodialysis (ED) plants are used mainly for brackish water treatment. A recent trend is for the application of RO in the desalting of sea water in Saudi Arabia due to the high energy consumption of MSF, country economics, and recent developments in membrane technology. The following are some highlights on this recent application of RO in sea water desalination in Saudi Arabia.

WATER DEMAND

The need for treated water in Saudi Arabia is increasing due to the high growth rate of urban population, improvements in living standards, and rapid industrial and agricultural developments. The natural water balance presented in the Third Development Plan(3) is the most recent and comprehensive study to evaluate available ground and surface water resources in Saudi Arabia. Table 3 shows this water balance in the country. Table 4 lists the average daily consumption in five major cities(4).

As can be seen on Table 3, desalination is the most feasible water supply source. Reclaimed water from urban waste will contribute only 15% of the country resources. Ukali and Husain(5) developed a simple water demand model using the water utilization data. This demand model is based on the following equation

$$Dt = a \exp(b\ t)$$

where, Dt is the demand in million cubic meter/year at time t

t is the time in years [t=0 at year 1399AH (1978)]

a & b are regression coefficients given in Table 5. The coefficient a indicates the initial demand and b the growth rate.

WATER DESALINATION PROGRAM

As mentioned early, Saudi Arabia has developed a sea water desalination program to satisfy the growing demands of fresh water. By the end of 1985, the total production capacity of all desalination plants in Saudi Arabia was 3.0 x 10E06 m^3/day (793 mgd). MSF plants account for 1.8 x 10E06 m^3/day (480 mgs), while RO plants account for 1.0 x 10E06 m^3/day (264 mgd) and the rest are produced by ED plants.

MSF was first introduced commercially in late 1950. The largest plant is in Al-Jubail II in Saudi Arabia with a capacity of 912,000 m^3/day (240 mgd). For the use of RO in sea water desalting, high pressure is required. RO was first used for this purpose since 1970. The first large municipal RO desalting plant of 570 m^3/day (150,000 gpd) capacity was in Greenfield, Iowa, USA and was built in 1971. The largest sea water RO plant is in Malta with a capacity of 20,000 m^3/day (5.3 mgd). A plant of twice this capacity is being built in Bahrain.

Sea water desalination of MSF is still the predominant method. However, in recent years, RO has become a competitor to

MSF. This competition is because of the increased energy prices and the lower energy consumption of RO. At the end of 1971, there were only 94 membrane desalting plants (RO and ED) of 95 m^3/day (25,000 gpd) or larger with a combined capacity of 87 m^3/day (23 mgd) in operation(6). According to the latest survey shown in Table 2, RO plants accounts for 23% of the world capacity of desalted water. The total RO plant capacity is 2.3 x 10E06 m^3/day (603 mgd). The rate of improvements and innovations in RO desalintion processes is remarkably high with respect to other desalination processes.

RO PLANTS AND RO PROCESS DESCRIPTION

There are many RO plants in Saudi Arabia used for desalination of brackish water. Most of these plants are small 500 m^3/day (0.13 mgd) or less. They are used mostly in private sectors and small communities. According to the new desalination trend in the country, large RO plants will be built for sea water desalting. Table 6 shows the major RO plants in Saudi Arabia.

RO is one of the membrane processes that are used in commercial practice for producing fresh water from saline water. The other process is Ed. Both RO and ED processes are based on the use of special membranes to achieved salt water separation.

In ED, demineralization of saline solution takes place by the passage of salt through the membrane. An electric current acts as the driving force. In the case of RO, the driving force is the hydraulic pressure which cause fresh water to diffuse through the membrane leaving the salt behind.

Osmosis refers to the transport of a solvent from a low concentration solution to a high concentration if these two solutions are brought together and separated by a semipermeable membrane. The driving force for this transport is called the osmotic pressure. As the salt concentration increases, the osmotic pressure increases too (7), as indicated in Table 7. Sea water with salt concentration of 3.5 wt % has an osmotic pressure of 24 Kg/cm^2 (350 psi). For a rejected brine of 5.2 wt % salt concentration, the osmotic pressure is 37 Kg/cm^2 (550 psi).

The application of a pressure higher than the osmotic pressure on the high concentration solution will result in a transfer of water from this solution through the membrane. Since this is opposite of what happens naturally by osmosis, it is called reverse osmosis. The applied pressure for brackish water ranges from 17 Kg/cm^2 (250 psi) to 48 Kg/cm^2 (700 psi) depending on the feed water salinity levels. But for sea water, the applied pressures are in the range 55 to 70 Kg/cm^2 (800-1000 psi), since the sea water osmotic pressure is 35 to 42 Kg/cm^2 (515-618 psi). The quantity of water flowing through the membrane is given by (8)

$$Qw = K A(Dp - Ds) / t$$

where, Qw is water flux through the membrane
K is the membrane constant
A is the membrane area
Dp is the differential pressure across the membrane
Ds is the differential osmotic pressure
t is the membrane thickness

The rate of water permeation through the membrane increases as the feed water temperature increases since the viscosity of the solution is reduced(9). High temperature raw water problems are often encountered in Saudi Arabia. The temperature correction factor, TCF, which is equal to the ratio of water flux at any temperature, t1, to that flux at temperature t2, is given by (9)

$$TCF = a^{(t1-t2)}$$

where, a is constant.

RO process consists of three main steps; (a) pretreatment, (b) membrane passage, and (c) posttreatment. In the posttreatment step, product water passes through a decarbonation system, a pH adjustment syustem, a chlorine injection to comply with the required quality and use of the product water.

The purpose of the pretreatment step is to avoid any risk of clogging, fouling or scaling the membrane. Pre-treatment is an important aspect of RO system. All RO devices required pretreatment to remove the suspended solids, scalants, foulants, and colloidal matters. The important scalant encountered in sea water is calcium carbonate. Its effects can be eliminated by pH adjustment to 6.0-7.0. Various processes are used in this step according to the conditions of the feed water. In general, the following pretreatment schemes are employed;

1- Surface water
(Chlorination, Coagulation, Sedimentation, Sand Filtration)

2- High Hardness Water
(Lime or Lime-soda Softening, Sand Filtration)

3- Low Hardness Water
(Sand and Manganese-Zeolite Filtration)

4- Activated Carbon Filtration: for excess organics Concentration

5- pH Adjustment

6- Scale Prevention

A softening process is used as pretreatment for recovery levels of 40% or higher to remove calcium sulfate and silica. While at low recovery levels acidification is enough to delay

bicarbonate precipitation on the membrane.

Recovery in RO is defined as the ratio of the product water flow rate to the feed water flow rate. It is usually varied from 45% to 55% for brackish water RO plants, and 20 to 35% for sea water. For high recovery, multiple staging is normally used.

There are many factors influence the design of RO plants. These factors can be summarized in two groups (10).

1- Independent (Site-specific) factors:
(energy cost, finance charges, feed water salinity, feed water temperature, operation and maintenance cost).

2- Dependent (Design) Factors:
(membrane performance, array configuration, feed pressure, system waste recovery, equipment choices, pH of the feed water, pretreatment).

MEMBRANE CHARACTERISTICS

The characteristics of an effective membrane can be summarized by the following :

1- withstands high pressure

2- permits a large flow of water relative to the occupied volume.

3- rejects dissolved solids.

4- remains physically and chemically stable for a long time.

High recovery RO can be achieved by high pressure operation which is made possible by the high pressure capabilities of aramid hollow fine fiber (HFF) membranes. This membrane, reduces the effect of concentration polarization significatnly, since they have relatively low fluxes(11).

Polyamide and cellulose acetate are widely used in the production of membranes for the RO industry. Aramid polymers are replacing cellulose acetate polymers in membrane manufacturing because they resist mechanical changes, as well as chemical and biological attack(12). Since cellulose acetate membranes are susceptible to chemical attack, they must be used within a narrow pH range to prevent hydrolysis. Permasep B-10 permeators (Dupont Corp., Modol, etc.) operating at 55 to 70 Kg/cm^2 (800-1000 psig) pressures in sea water applications have performed longer than four years without replacement.

Several types of RO membranes are commercially available. These are prepared either as flat sheets or as hollow fibers from cellulose acetate ester or aromatic polyamides. There are dif-

ferent ways of packing RO membranes. Of these, three configurations have been produced commercially; spiral wound, tubular and hollow fine fiber.

The common membrane problems are

1- membrane fouling by particulate matter present in the raw water.

2- scale formation due to the precipitation of iron, manganese, magnesium, and calcium salts.

3- deposition of organics of the membrane.

4- membrane hydrolysis and decomposition.

THE FUTURE

RO desalination process appears to offer the best promise for conversion of saline water resources in Saudi Arabia. The major advantages of the RO desalting process are

1- ambient temperature operation.

2- requires one-third to one-half the energy when compared to MSF.

3- no need for expensive metallic components.

4- no thermal pollution

5- amenable for operation with any source of energy; electricity, solar, wind, etc.

6- flexibility to obtain the desired quality of water.

7- no restriction on plant siting

8- spare parts can be manufactured and assembled locally

9- plant capital costs are low compared to MSF.

10- Plants are easy to install, maintain, and operate.

These advantages have made RO a practical and economical desalting method, besides the rapid improvements and developments in membrane technology.

The most important advantage of RO plants is the low energy requirement. Table 9 shows an economic comparison between some desalination processes. About 1.9-3.2 kwh/m^3 (7-12 kwh/1000 gal) is required in all RO plant for the desalting of brackish

water, and 7.9-10.6 kwh/m^3 (30-40 kwh/1000 gal) for sea water based on 30% recovery at standard conditions(12,13).

The economy for RO as shown in Table 8 ranges from 4.6-21.7 kwh/m^3, without power recovery. With power recovery, economy can be as high as 31 kwh/m^3, since the rejected brine can be used to provide pumping power via an energy recovery turbine. New techniques have been developed for cheaper brine disposal and water recovery from the brine(14). These processes are based on vapor compression distillation and will be built in Qasium, Saudi Arabia by the end of 1986. The replacement of one of the MSF plants in Jeddah, Saudi Arabia with RO plant of 5.68 x 10E06 m^3/day (15 mgd) indicates the preference of RO plants in Saudi Arabia.

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Table 1. Annual rainfall in Saudi Arabia in mm in 1974

Northern region	80 - 120
North-east region	50 - 70
Central region	85 - 100
Red Sea cost (west)	250
Mountain (south)	400

Table 2. World Desalting Market in 1985

Total number of plants	4600
Total capacity	9.92 Mm^3/day (2621 mgd)
% MSF capacity	67.6
% RO capacity	23.0
Geographical Distribution	
Arabian Peninsula	60.0%
	(Saudi Arabia 50% of world capacity)
USA	17.0
Lybia	5.4
Iran	3.1
USSR	2.5
Plant size < 0.01 mgd: MSF	44.0
RO	43.0
< 1.0 mgd: MSF	84.5
RO	11.2

Table 3. National water balance, million m^3/year

Water resources	1979	1984	1989
non-renewable	3450	3450	3450
renewable	1145	1145	1145
desalination	63	605	794
urban waste	-	140	335

Water Utilization	1979	1984	1989
urban & industry	502	828	1211
rural & livestock	27	28	31
irrigated agriculture	1832	1873	3220
surplus (deficit)	2247	2137	986

Total resources :	4658	5340	6523
Total utilization:	4658	5340	6523

Table 4. Average daily water consumption in Saudi Arabia 1977.

City	m^3/day	gal/day
Jeddah	4.81	1271
Riyad	1.21	320
Mecca	1.52	402
Yanbu	0.73	193
Medinah	0.65	173

Table 5. Water demand forecasting model for Saudi Arabia (model constants; Dt = a exp(b t))

	a	b
urban & industrial	500.0	0.0744
rural & livestock	25.8	0.0177
agriculture	1683.3	0.0300
surplus (deficit)	2916.4	-0.0453
total	4715.9	0.0162

"The coefficient a indicates the initial demand and b the growth rate. The negative values of b in surplus forecasting model means that the surplus water is decreasing with time which shows an improvement towards better water resources management" ref.(5).

Table 6. Major RO plants in Saudi Arabia producing potable water.

Plant	Plant Type	Feed water	Capacity (m^3/day)
Jeddah	spiral wound	sea water	12,000
Yanbu	hollow fiber	sea water	5,000
Manfouha I	" "	brackish water	27,300
Manfouha II	" "	" "	36,400
Malez	" "	" "	18,200
Shemessy	" "	" "	27,300
Salbukh	" "	" "	38,400
Buwayb	spiral wound	" "	45,000
Jubail	" "	" "	15,000
Dhahran	" "	" "	3,500
Riyad	spiral would	" "	4,500
Majmaah	" "	" "	3,800
Al-Berik	hollow fiber	sea water	2,300
Jeddah	" "	sea water	2,300
Mecca	" "	brackish water	15,000
Umlujj II	" "	sea water	3,800*
Hagl II	" "	brackish water	6,600*
Duba III	" "	" "	3,800*

* under construction

Table 7. Osmotic pressures of sea salt solution, in atm

Temperature C	wt % salt 1.0	2.0	3.45	5.0	7.5	10	15
25	7.1	14.3	25.1	37.5	59.3	84	145
40	7.4	14.9	26.3	39.3	62.4	89	153
60	7.8	15.7	27.7	41.5	65.9	94	162
80	8.1	16.4	28.9	43.3	68.8	98	168
100	8.4	16.9	29.9	44.7	71.1	101	173

Table 8. Economy comparison for desalting processes

Process	Economy kwh/m^3	Primary energy	Top Operating temp. °F
RO	4.6-31	Electricity	32-100
mech vapor compression	2.6-5.1	Electricity or high energy steam	170-215
multiple eff evaporation	1.5-2.3	Low pressure steam or hot water	185-240
MSF	0.46-1.9	low pressure steam or hot water	170-250
Thermocompression	0.46-1.5	high pressure steam	120-170