WATER DESALINATION INDUSTRY IN EGYPT

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ABSTRACT

This paper presents the Egyptian experience in water desalination and introduces environmental, technological and economical aspects of water desalination industry in Egypt, and sheds the light on the kind of consumers for this product in Egypt. Desalting technologies have witnessed great deal of development in the last two decades. Thermal systems and membrane schemes are now operating successfully for commercial production of desalted water. Non-conventional systems are existing in numerous locations in Egypt, but only for small-scale applications. Economic evaluation of water desalination is given by analysis several input indicators (seawater, brackish groundwater and agriculture wastewater) based on Egyptian experience in technology, field characteristics, energy and materials. Considerable effort has been directed to assess what may be termed the Egyptian desalination experience. The prime target was to explore key issue areas hindering wider utilization of desalination technology in Egypt. A second immediate target was to explore the expected environmental impacts under conservative scenarios. The analysis of Egyptian desalting experience revealed numerous constraints related to institutional, technical, economic, human resource status, and the environmental aspects. Future planning requires identification of current financial trends pertinent to the utilization of the desalting technology. The proposed milestones of the national desalination policy have been summarized. Egyptian future of desalination industry is presented.

INTRODUCTION

The need for high-quality water significantly increased during the second half of the last century. While heading towards the third millennium, an important problem is about to be solved at a near-affordable cost. The need for water is rapidly increasing, and current freshwater resources will not be able to meet all requirements. Water cannot be considered now as a natural, self-renewable, low-cost resource, easily accessible to all. Many years of drought at various locations, followed by desertification and movement of the population towards this essential resource calls for different considerations in terms of economic and social effects.

Desalination of seawater has been practiced regularly for over 50 years and is a well-established means of water supply. Two main directions survived the crucial evolution of desalination technology, evaporation and membrane techniques. Thermal and membrane schemes are operating successfully for commercial production of desalted water. Thermal systems are applied for seawater while membrane systems are for brackish water desalination. Non-conventional systems are existing in numerous locations in Egypt, but only for small-scale applications. It is now feasible, technically and economically, to produce large quantities of water of excellent quality from desalination processes. The cost of desalinated seawater is decreasing. Desalination of brackish water is even cheaper. Many countries are now considering desalination as an important source of water supply. Challenges, however, still exist to produce desalinated water for relatively large communities, development, and health, and for modern efficient agriculture, at affordable costs. This paper explores current status of desalting industry in Egypt with emphasis on environmental, technical and economic indicators.

EGYPTIAN EXPERIENCE IN DESALINATION INDUSTRY

Considerable effort has been directed to assess what may be termed the Egyptian desalination experience. The analysis of Egyptian desalting experience revealed numerous constraints related to current institutional setting, inadequate technical support, and lack of economic incentives, human resource status, funding limitations and the limited role of the local industrial sector. The current total production capacity amounts to 170,000m^3/day. The anticipated minimum effective demands approach 280,000m^3/day in the year 2007. These estimates are highly conservative and would escalate significantly with emerging national development programs mandating higher reliance on upgrading drainage water and brackish water sources.

The selection of desalting techniques depends upon many factors such as capacity, salinity, power and operational characteristics taking into consideration conditions of the site. The following prevailing desalination systems in Egypt could be concluded Ion Exchange (IE), Thermal Systems, Electro dialysis Reversal (EDR) and Reverse Osmosis (RO).

The IE system is mainly used in petroleum sector and pharmaceutical industries are used in water treatment to treat Nile water or municipal water in the range from 50 to 500 m^3/day. Thermal schemes for water desalination are rarely used because of the high thermal energy requirements and the attack of saline water on construction materials. Multistage flash distillation, vapor compression, multiple effect evaporator, etc are used for large scale seawater desalination for providing some potable water to remote cities on Red Sea coast and some companies and communities in petroleum sector. Most of thermal systems will be replaced by RO systems. EDR desalination systems are mainly applied to brackish water. These systems are the most effective processes for desalting water with mineral content in the range from 1000 to 5000 ppm total dissolved solids. Special considerations relative to raw water, pretreatment, maintenance, water chemistry and waste concentration can extend this range. EDR are distributed mainly in remote areas where the water source is brackish water from wells. Petroleum sector in Ras-Shokair, Abu-Redeis, Ras-Ghareb, West Desert and other locations utilize EDR for water desalination. North and South Sinai and Matrouh

Governorates depend mainly on EDR desalting technologies to provide potable water to small communities. Desalination systems by RO are widely used in Egypt in different sectors. The rapid development in the technology especially in membrane manufacture led to marked decrease in cost and operating pressure which enabled RO to compete with other systems.

Different production sectors and enterprises in Egypt are using water treatment and desalination for seawater, brackish well water and Nile water. The main sectors utilizing such technologies are tourism, petroleum, urban communities & services, industry and hospitals sectors. Water desalination systems are widely used in tourism sector "present desalted water consumption is around 30,000 m^3/day" to provide local communities with potable water. The technologies used are mainly RO system. Petroleum companies depend mainly on desalination systems to provide potable water in remote areas in addition to some industrial and agricultural applications. Petroleum production sector uses RO, EDR, thermal stations and IE for treatment and desalination of sea and brackish well water. Urban communities represent high consumers in water treatment and desalting technologies. The northern coast villages consume about 18,000 m^3/day, agricultural drainage water desalted by RO and mixed with municipal water from Alexandria network. North Sinai water consumption by RO desalination is estimated to be about 5,000 m^3/day. Electricity sector's water consumption is around 1,000 m^3/day and uses different desalting technologies to produce the water needed for boilers. The treated water in pharmaceutical industry is used in boilers, production processes and pharmaceutical solutions products. Most of recent pharmaceutical factories tend to generalize RO systems for water treatment. The present desalted water consumption is about 120 to 200 m^3/day. Textiles and fertilizers industry use RO and EDR systems to provide desalted water for different production processes. The capacities range from 2,000 to 5,000 m^3/day. The hospitals use high quality treated water to artificial kidney units. RO systems with capacities ranging from 20 to 60 m^3/day are widely used.

The contribution of RO systems is around 50% of the total desalination systems needed. The plan was to cover part of the shortage in potable water by directing part of irrigation water to drinking water, desalting the agricultural drainage water, brackish and seawater, use of treated water in irrigation. Table 1 summarizes the trend, present and predicted desalination consumption in Egypt till year 2007.

Table 1. RO Desalted Water Consumption in Egypt (m^3/day)

Sector	**Year 1997**	**Year 2002**	**Year 2007**
Tourism	18500	43600	69900
Urban communities	5500	35500	52000
Petroleum	30000	30000	30000
Industry	24000	65500	82000
Electricity	1000	16000	48000
Total	**79000**	**190600**	**281900**

Agricultural Drainage Water Desalination

Agriculture Drainage Water ADW is, in general, characterized by high salt content, organic, and bacteriological contamination. Table 2 shows the quantities and salt concentration of ADW discharging to the Mediterranean sea and connected lakes. The quantities and salinity are depicted in Table 3 which reveals that about 9 billion m^3/year ADW discharges to the Mediterranean due to its high salinity which prohibits its reuse. About 4 billion m^3/year are considered low salinity brackish water (1500-2000ppm). Medium salinity brackish water (2000-5000 ppm) amounts to about 1.4 billion m^3/year. High salinity brackish (>3000 ppm) amounts to about 3.5 billion m^3/year. Organic and bacteriological contamination of ADW is typically demonstrated in Table 4 which indicates organic contamination of ADW as depicted from the high value of BOD and COD. Bacteriological qualities indicate the contamination of ADW with domestic sewage. Further, the contamination of ADW with pesticides is typically depicted in Table 5.

Table 2. Characteristic of ADW Discharging to the Mediterranean Sea

Area	Quantity (10^9 m^3/year)	Salt Conc. (ppm)
East Delta	3.182	1127
Middle Delta	4.361	2430
West Delta	4.437	3387
Total	**11.980**	**-**

Table 3. Quantities and Salt content of ADW in Delta*

Salt content PPM	Quantity (10^6 m^3/year)			
	East Delta	**Middle Delta**	**West Delta**	**Total**
1500-2000	923	1832	1291	**4046**
2000-3000	309	275	803	**1387**
>3000	433	1191	1912	**3536**
Total	**1665**	**3298**	**4006**	**8969**

* *Not including ADW of salinity less than 1500 ppm*

Table 4. ADW Organic and Bacteriological Quantity "Bahr El-Bakar Drain (1995)"

Biological Oxygen Demand (BOD)	90 ppm
Chemical Oxygen Demand (COD)	88 ppm
Total suspended solids	143 ppm
Total fixed suspended solids	59 ppm
Bacteriological quality MPN-index /100 ml	
Total coliform	2.4×10^4
Faecal coliform	2.4×10^4
Faecal Streptococci	9×10^4

Table 5. Typical Pesticides Content of ADW

Pesticide	Lanette	Demilin	Dorsban	Cetrolene	Hostathion	Curacron	Garadona	Gesapex
Conc. ppm	21-80	5-15	1-42	14-90	18-75	5-80	16-63	5-70

ADW in Egypt could be considered as an important water supply if desalting is considered. The ADW with high salinity (1500-3000 ppm and more) amounts to 9 billion m^3/year. The cost items for ADW treatment for potable purposes shown in Table 6 (for TDS = 1500 and 3000 ppm).

Table 6. Cost items for ADW treatment

ITEM	% of Total Cost	
	TDS = 1500 PPM	TDS = 3000 PPM
Depreciation	16	16.7
Electricity	23.3	28.2
Chemicals	27.7	24.8
Membrane replacement	11.2	11.5
Cost (LE/m^3)	**2.05**	**2.36**

Sewage Treatment

Membranes penetrate into wastewater treatment. Many projects at a pilot stage use membranes to treat the water. In some cases membranes are directly used on strained wastewater to remove suspended particles that are too large for the gap between two membranes. The treated water is transferred directly to RO membranes to remove salts. Permeate is usually allowed to pass across active coal in order to remove remaining dissolved organic materials. In other cases RO membranes are used to treat effluent after secondary treatment, just to remove most of the remaining dissolved solids.

Desalination Techniques

The development of membrane modules gave a boost to the use of membranes in water purification and treatment. Nano-filtration membranes are used for the removal of hardness from drinking water. They can also be used to remove some other unwanted dissolved species, even partial removal of nitrates from groundwater. Ultra-filtration and micro-filtration can be back-washed occasionally to remove accumulated solids from the membranes. While MF can be used to remove micron size and upper suspended particles, namely bacteria, algae, etc., UF membranes can also be used to remove most of the viruses found in surface water. In fact the solid layer, the "cake" that adheres to the membranes in the last two techniques, acts like a dynamic membrane and removes smaller particles even at a level of colloids and viruses. The use of MF membranes might be cheaper than sand filtration in the treatment of surface water. The use of membranes penetrates into the process industry, where better water quality is needed. Power stations and petrochemical and high-tech production plants seek better quality water and use different types of membranes to meet their needs.

Desalination by New and Renewable Energy

Egypt is undertaking numerous projects for promotion of new and renewable energy (NRE) utilization. Desalting schemes based on NRE are currently under field assessment. The techno economic indicators obtained through these projects will enable sound decisions to be taken regarding large scale application. The wide application of NRE-powered desalting systems requires availing appropriate funding for targeted Research and Development (R&D) programs regarding solar or wind systems, establishing international networking among developers, manufacturers and users to share information, and developing appropriate economic incentives for local manufacturers, investors and users to promote increasing utilization of NRE sources. Problems related to this technology include high capital cost, large area requirements and vulnerability to weather-related changes.

Water Quality

Water produced by the different techniques mentioned varies significantly in quality. Thermal processes may produce water containing 5 to 50 ppm of TDS, similar in composition to the feed seawater. The RO product may contain 300 to 500 ppm of TDS, basically NaCl and a smaller portion of other salts. Some minor constituents as boric acid, hydrogen sulfide, and CO_2, can also be present in the product, depending on the composition of the feed water, but may be removed by adequate post-treatment. It is important to mention that feed water containing dissolved volatile organic compounds will generate water contaminated with the same components, unless special care is taken. This is true for RO and evaporation techniques. The product water is aggressive, tends to corrode iron pipes, and dissolves protective layers containing calcium and other salts on the inner sides of the mains. The water needs, therefore, post-treatment that usually includes an increase in the pH level, addition of Ca (to the level of about 100 ppm as $CaCO_3$) and alkalinity, namely HCO_3, (also to a level of about 100 ppm as $CaCO_3$), according to local water regulations.

Preliminary Economic Indicators

Desalination cost, is highly variable and is affected significantly by many factors, including water quality, technology, energy cost, plant capacity and plant availability. The updated cost shows marked variation of cost estimates for desalination. The cost of energy affects greatly the cost of desalination. Electricity and/or fuel consumption represent the major cost item, especially for high salt content. Type and concentration of pollutants affect greatly the cost of pre-treatment and post-treatment. The cost is significantly sensitive to capital costs, membrane replacement and electricity costs. Numerous economic incentives mechanism should be explored and assessed. Tax reduction, availing low cost infrastructure, encouraging water pricing systems for BOT projects are examples of economic incentives to be assessed. Special revolving fund may be arranged to support private sector initiatives. The interest may be reduced or provided by the government.

Techno-Economic Indicators

Future planning requires identification of current financial trends pertinent to the utilization of the desalting technology. Cost of desalted water revealed considerable variability to site characteristics, type of technology, level of sophistication, system design and configuration,...etc. The cost of desalination, under Egyptian conditions for an average level of RO technology is estimated in Red Sea and Mediterranean locations. The cost of desalination for high salinity seawater (TDS 50,000 ppm) in Red Sea locations amounts to LE 6.72/m^3, while it amounts to LE 5.59/m^3 for normal seawater desalination system in Mediterranean locations (TDS 35000 ppm). The cost for desalting of brackish ground water (TDS 5000 ppm) amounts to LE 2.67/m^3. Suitable techno-economic indicators pertinent to Egyptian situation due to the influence of national and site constraints are shown in Table 7.

Table 7. Techno-Economic Indicators by RO Technology

Water Source	Production Capacity m^3/day	Feed Water Salinity PPM	Capital Cost LE. Million	O&M Cost LE. Million	Cost / m^3 LE. Million
ADW	3000	1500	4.2	1.7	2
	3000	3000	5.0	1.9	2.4
Brackish	3000	5000	6.0	2.2	2.6
Mediterranean	3000	35,000	20.0	4.1	5.6
Red Sea	5000	45,000	40.0	8.2	2.8

In view of the outlined techno-economic indicators and the anticipated national needs, Egypt has been automated institutional development as high crucial for planning, follow up, technical support and coordinating the involvement of different stakeholders. The role of private investment is catalyzed via appropriate mechanisms.

Desalination Industry Restriction

Analysis of current Egyptian desalting experience reveals the institutional, technical, financial and other issues:

Institutional issues are related to lack of institutional core within the structure of governmental entities, insufficiency of technical support, need of integrated human resource programs, needed encourage private participation and shortage of desalination database.

Technical issues lead to frequent shutdown, short system life, high operation and maintenance costs, lack of confidence regarding reliability, more reliance on traditional finite supplies (water pumping), high capital risk, and environmental quality deviation. Technical issues are related to inappropriate design of the desalting facility and improper choice of desalting technology, unsuitable characterization of feed water, inadequate design review, insufficient operation and maintenance, lack of after sale services, ineffective supply procedures, improper disposal facilities and insufficiency of environmental management.

Financial issues are related mainly to the high capital needed to install large scale desalting systems, need to relatively high operating capital to guarantee operating and maintenance, frequent component failure and shutdowns causing low availability and high unit cost, undeveloped banking support and need of economic incentives.

Other issues are related mainly to insufficient studies regarding of feed water supply "incomplete assessment of groundwater supply may lead to full system shutdown", insufficiency of contribution given by local manufacturing, limited funding for targeted desalination research and development, and inadequate utilization of available chains through international operation.

ENVIRONMENTAL ASPECTS IN DESALINATION INDUSTRY

Desalination processes may be characterized by their effluent to the environment, the air, the nearby land, and to the seas. Desalination is dependent on energy and usually uses fossil energy. All types of air pollution associated with energy production, namely emission of NO_X, SO_2, volatile compounds, particulate, CO_2, and water exist here as well, either by using electricity produced by a conventional power station or by using a dedicated power station.

Effluents of desalination plants contain relatively highly concentrated water, which depends on the water recovery from the feed brine. In the case of seawater desalination, rejected brine is concentrated close to twice the original sea water solution. The concentrate also contains chemicals used in the pretreatment of the feed water. The latter may contain low concentrations of anti-scalants, surfactants, and acid. To this may be added occasional washing solutions or rejected backwash slurries from feed water. In small operation scales, the problem is mild and no serious damage may affect the marine life. In large scales of water production, the problem is a little more severe; however, dilution and spreading of effluents may solve the problem. Natural chemicals that do not harm the environment will probably replace the added chemicals in the future.

The more serious problems are those concentrates produced inland, in cases of brackish water desalination. The concentrate composition in these is not similar to seawater composition. In most cases the solution contains more calcium and magnesium, and sometimes other components are involved, depending on the composition at the source. The problem is less severe when the solutions are purged into the open sea. Where no access to the sea is possible, the concentrate may increase groundwater salinity if allowed to penetrate the earth. A possible solution to that problem includes zero discharge treatment, namely evaporative separation between solids and water, so solids may be stored properly inland. This solution may be performed by solar ponds or by forced evaporation using available heat sources. The process is expensive, but the basis for comparison is the cost of brine transportation to the nearest possible authorized area, taking into account the influence of this treatment on the product cost.

Under normal operating conditions the following environmental impacts of different desalting systems “thermal, reverse osmosis and electrodialysis” may be detected.

Thermal desalting scheme: Rejected brine at high temperature can lead to oxygen depletion in the surrounding area, thus affecting aquatic life. Chemicals used in the pretreatment for scale & corrosion inhibition and biocides can be a source of minor pollution. Mitigation measures include proper design of rejected brine, the use of low temperature schemes, and adequate selection of chemicals types & doses.

Reverse Osmosis: For Brackish water systems, the rejected brine could be a source of pollution, if it is not disposed of in an environmental safe way. Mitigation measures include proper conditioning and discharge of rejected brine.

Electrodialysis: Rejected brine could be a source of pollution. Vented gases include chlorine. Mitigation measures include proper brine, conditioning and adequate ventilation.

EGYPTIAN POLICY

Egypt should continue developing appropriate water conservation measures. Technical support and economic incentives should be the basis for potential conservation plan. Utilization of current groundwater sources should receive immediate priority. Appropriate protection and utilization measures should be developed. The governmental agencies should encourage development and utilization of Best Available Technology to realize efficient water use and source protection. Current programs to reuse ADW, and wastewater should be developed and vitalized. Identification of technology options required to upgrade wastewater to cope with intended or potential uses. Water desalination should be considered as significant potential component within notional water supply system. Due to relatively high cost of water desalination (compared to other available options), priorities should be given to the desalination of brackish water with salinity exceeding 1000–1500 PPM, desalination of seawater remote coastal and desert regions. A comparative cost analysis is needed to identify the distance from the nearest conventional water supply beyond which desalting option should be considered more cost effective if compared to water pumping. Desalination systems should be implemented in strategic locations as a backup for interruptible conventional supply systems. A long-term policy is adopted to develop current water desalination systems. This policy acknowledges the current data which indicates the possible reduction of desalting cost by about 30-50% for large desalting schemes. Due to uncertainty regarding future energy costs, numerous new and renewable energy options should be incorporated within the national program. Development of integrated national action plan for promoting non-conventional is supplied with emphasis to water desalination. Undertaking necessary actions and programs for human resources development to ensure availability of adequate national expertise demanded by water treatment and desalination projects.

DESALINATION INDUSTRY FUTURE

There is no doubt that desalination techniques even now being matured to produce water on a commercial basis are still climbing on the learning curve. Each new development reduces the cost and takes a further step. It is important to continue the investment efforts in (R&D) programs in order to reduce the cost of water production. The key is to invest in new plants, increase the free competitions between producers, and cooperate with research institutes. A few possible directions for future R&D are listed below.

The mechanism of water transfer and salt rejection in RO membranes is not clearly understood. Better understanding at the molecular level will lead to new membranes that may show higher fluxes and better salt rejection.

It is evident that the most expensive steps in membrane operations are independent of water recovery. Increasing water recovery is therefore a key for reducing water production costs. Operation of systems with untrained, inexperienced workers increases the need for expensive safety factors, like extra pre-treatments. Better-trained operators and more sophisticated automation and control may result in lower cost of water production.

The VC and MED techniques produce better water quality than the RO process. The two techniques need further development, to improve heat transfer surfaces, reduce equipment size, and improve energy efficiency. Again, more research work is needed.

The energy question is very important, not only for desalination but also for future general energy needs, and in terms of environmental problems. It is necessary, therefore, to continue with international efforts toward revolutionary new renewable sources of energy, which in due time will also be used for desalination.

The implementation of water desalination in existing water systems is a complicated issue that needs strong, intelligent policies. It is easier to introduce desalinated water into developed cities where people pay almost threefold or more than the cost of desalination for their water uses. Usually those locations do not suffer from water scarcity. Water is needed in locations where agriculture is still the basis for life, and simple agriculture cannot afford the costs described here.

In the meantime, to summarize and induce a general framework for possible research directions in different desalination directions, a methodical evaluation of R&D needs for achieving meaningful desalinated water cost reductions is presented as reduction of desalination energy requirements, improvement is in current thermal technologies, improvements in current membrane technologies, integration of desalination into the overall water system and reduction of environmental problems associated with brine disposal.

CONCLUSION

It is clear that the water desalination industry is currently at an important stage, where the need for water availability and quality is increased in many places. The production cost is declining due to healthy competition, while performance is improving along with production efficiency. No arguments are needed with respect to the quality of the water the main struggle is still the cost of the production. It is clear, however, that the cost of water is steadily declining so that more people can afford desalination. A small barrier must still be broken in order to facilitate the use of desalinated water in modern agriculture. This too is close to being achieved in the near future.

In order to achieve these targets, significant international research and development efforts are needed. A few international organizations exist that are devoted to these tasks; however, more effort is needed, especially along production lines, for building operating plants, water factories, producing freshwater, and further reducing the cost of water. Future developments do not need to concentrate only on technical aspects. Looking at the global picture, it is important to pay attention to the *environment*, namely to produce fresh and clear water without causing harm to the surroundings. Therefore, new developments in renewable energies are needed, independently with current and near-future desalinated water production. New techniques are needed to overcome the current pollution-causing aspect of the processes. Desalination techniques will also serve as important tools in the reduction of pollution from waste industrial solutions.

Finally, it is time for an international act to achieve direction and means to benefit from all new developments. Together with acts that have already started in relation to energy use and environmental issues to ease the implementation of new sources of water, including desalination, for improving life on earth and reducing fights and wars.

REFERENCES

1. Awerbuch, L. 1997a. "Dual Purpose Power Desalination/Hybrid Systems/Energy and Economics." IDA Desalination Seminar, Cairo, Egypt, September.
2. Awerbuch, L. 1997b. "Current Status of Seawater Desalination Technologies." IDA Desalination Seminar, Cairo, Egypt. September.
3. Bergman, R.A. 1995. "Florida -A Cost Comparison Update, Membrane Softening Vs Lime Softening." International Desalination and Water Reuse 5, No. 3: 35 43.
4. Baudin. I., M.R. Chevalier, C. Anselme, S. Cornu, and J.M. Laine. 1997. "L. Apie and Vigneux Case Studies: First Months of Operation." Desalination 113: 273-275.
5. Dean, D., R.P. Hammond, D.M. Eissenberg, D.K. Emmermann, J.E. Jones, H.H. Sephton, F.C. Standiford, R.E. Scott, and W.J. Rider. I 995a. "Seawater Desalination Plant for Southern California: Part 1." International Desalination and Water Reuse 5, No. 1: 10-16.
6. Dean. D., R.P. I Hammond, D.M. Eissenberg, D.K. Emmermann, J. E. Jones, H.H. Sephton, F.C. Standiford, R.E. Scott, and W.J. Rider. 1995b. "Seawater Desalination Plant for Southern California: Part 2." International Desalination and Water Reuse 5, No. 2:19-24.
7. El-Nashar, A.M. 1997. "Energy and Economic Aspects of Co-generation Plants for Power and Fresh Water Production." IDA Desalination Seminar, Cairo, Egypt, September.
8. FaIler, K.A. 1999. "Reverse Osmosis and Nanofiltration." AWWA Manual of Water Supply Practice, M46.
9. Furukawa, D.H. 1997. "A Review of Seawater Reverse Osmosis." 1IDA Desalination Seminar, Cairo, Egypt, September.
10. Gagliardo, P., S. Adham, R. Trussel, and A. Olivieri. 1998. "Water Purification via Reverse Osmosis." Desalination 117:73-78.
11. Hassan, A.M., M. AK. Al-Sofi, A. Al-Amoudi, T.M. Jamaluddin, A.G.I. Dalvi, N.M. Kitner, G.M. Mustafa, and L.A. AI-Tisan. 1998a. "A New Approach) to Membranes and I.A A1-Tisan. 1998a. "A New Approach to Membranes and Thermal Seawater Desalination Processes Using Nanofiltration Membranes: Part 1". International Desalination and Water Reuse 8, No. 1: 53-59.
12. Hassan, AM., M. AK. AI-Sofi, A. Al-Amoudi, T.M. Jamaluddin, A.G.I. Dalvi, N.M. Kitner, G.M. Mustafa, and L.A. Al-Tisan. 1998b. "A New Approach to Membranes and Thermal Seawater Desalination Processes Using Nanofiltration Membranes: Part 2." International Desalination and Water Reuse 8, No. 2: 39-45.
13. Johnson, W.T., R.W. Phelps, P.J. Beatsor. 1997. "Wastewater Reuse Using Membranes." IDA World Congress on Desalination and Water Science, Madrid, October.
14. Leitner, G. 1999. "Developer Selected for 25MGD (94,625 m^3/d) Florida West Coast Seawater Desalting Plant." Desalination and Water Reuse 9, No. 1: 11-16.
15. Leitner, G.E. 1998a. "Updates on the Tampa Bay Projects." International Desalination and Water Reuse 7, No. 5: 14-20.

16. Leitner, G.F. l998b. "Updates on the Tampa Bay Projects." International Desalination and Water Reuse 8, No 2: 58-60.
17. Leitner, G.E. l998c. "Updates on the Tampa Bay Projects." International Desalination and Water Reuse 8, NO) 3: I 2-13.
18. Leitner, G. F. 1998d. "Vibrant, Prosperous, Singapore, Time for Seawater Desalination?" International Desalination and Water Reuse 7, No. 4: 10-21.
19. Leitner, G.E. 1995. "Water Cost Analysis... We Need To Do Better." International Desalination and Water Reuse 5, No 1:24-27.
20. Ophir, A. and J. Weinberg. 1997. "MED (Multi-Effect Distillation) Desalination Plants: A Solution to the Water Problem in the Middle East." IDA World Congress on Desalination and Water Science. Madrid.
21. Pepp, F., L. Weinberg, D. Lee, A. Ophir, and C. Holtyn. 1997."The Vertical MWD-MED (Multi-Effect Distillation) Process." IDA World Congress on Desalination and Water Sciences, Madrid, October.
22. Thampy, S.K., R. Rangarajan, and V.K. Indusekhar. 1999. "25 Years of Eletrodialysis Experience at Central Salt and Marine Chemicals Research Institute Bhavnagar, India." International Desalination and Water Reuse 9, No. 2: 45-49.
23. Wangnick, K. 1996. "1996 IDA Worldwide Desalting Plants Inventory Report" No. 14. Privately published.
24. Wangnick, K. 1998. "New IDA Worldwide Desalting Plants Inventory Report No. 15-55% Higher Sales arid Dramatic Changes in Market." International Desalination amid Water Reuse 8, No. 2: 11-12.
25. Weinberg, J. and A. Ophir. 1997. "Ashdod Experience and Other Dual Purpose Desalination Plants Based on Multi-Effect Desalination with Aluminum Tubes." Symposium of Desalination of Seawater with Nuclear Energy, Taejon, Korea, May.
26. Wilbert M.C., F. Leitz, E. Abart, B. Boegli, and K. Linton. 1998. "The Desalting and Water Treatment Membrane Manual: A Guide to Membranes for Municipal Water Treatment." 2nd Edition. Water Treatment Technology Program Report No. 29. Bureau of Reclamation, United States Department of Interior.