European Water 58: 103-109, 2017.

Desalination and alternative water resources

N.X. Tsiourtis
Water and Desalination Consultant, Cyprus
* *e-mail: tsiourti@gmail.com*

Abstract: With water demand increasing due to population growth, life style change, more water for irrigation to feed the increasing population and increasing environmental needs, and water availability remaining the same or reducing due to pollution or droughts and in some parts of the world decreasing because of climate change, the need for additional water in many countries is increasing. With almost all the conventional water resources developed and exploited, the desalination seems to be an alternative water supply. Desalination is now becoming relatively cheaper when compared to the increased cost of developing conventional water resources. This report examines the subject of Desalination, as an Alternative water supply, outlining in general the basic principles that a water entity and engineer must be aware when embarking on the subject. It also outlines the step that a water entity must make for establishing a desalination plant.

Key words: Desalination, membranes processes, thermal processes, seawater, brackish water, environment, marine works, on land works, product water quality.

1. INTRODUCTION

Water, a limited finite resource, vital for the very existence of life on earth and a necessity for economic and social development and for the environmental sustainability, is becoming a scarce commodity, caused by the population growth, the change of life style, water pollution caused by the human intervention, the inefficient use of water, droughts that are more frequently occurring and the climatic change. Where the water availability cannot be increased by using conventional resources or by recycling or cannot be made safeguarded by water demand management and integrated water resources management methods, the desalination of sea or brackish water offers an alternative solution. The desalination of water has been practiced since ancient times but was not widely used due to technological limitations, the prohibitive high capital cost, the high-energy consumption and finally very high unit cost when compared to conventional water. New technological advances, in the last fifty years, reduced tremendously the capital cost and the energy consumption so that desalination projects can be considered economically affordable as alternative solutions to water development. Today many countries in the Mediterranean basin, the Gulf Area, Australia, Asia, and Western USA and all over the world, use desalinated water for domestic water supply, for industry to satisfy their increasing or special quality needs and even for irrigation. However, desalination projects are still not very cheap to be easily accommodated by the economies of many countries, energy consumption is still comparatively high, and acceptance of such projects is questioned by environmentalist, politicians, engineers and other groups of the population on economic, social and environmental issues. The present paper shall highlight the desalination technologies, the growth of desalination, the energy requirements, the advantages and disadvantages, the desalination projects capital cost and desalinated water unit cost, the options for financing of desalination projects and the environmental impacts and considerations. The paper also outlines the steps that are necessary to establish a desalination project.

2. DESALINATION TECHNOLOGIES

Desalination was first used by Greek sailors in the 4^{th} century BC to evaporate seawater and create drinking water. The same method was used later by Caesar in his invasion of Egypt to secure potable water for his soldiers. Today there are two commercially available desalination technologies used extensively for desalinating water, the membranes technology (Reverse Osmosis and Electrodialysis) and the thermal process desalination (MED, MVC and MSF) (Burros, 2000).

2.1 Membrane processes

This technology uses membranes which have the ability to differentiate and selectively separate salts and water. There are two important commercially available membrane desalting processes, depending on the form of the driving force, the Reverse Osmosis and the Electrodialysis, as follow:

a) *Reverse Osmosis:* This was initially developed in the late 1950s, with successful commercialization occurring in 1970 after efficient effective membranes development, which now is the leading desalination technology globally, offering the most cost effective process to desalinate seawater. In this process, saline water is pressurized to go through the membranes, which have the ability to separate the solutes from the water. The energy required to pressurize the feed water is needed by the high pressure pumps, which provide enough pressure to overcome the osmotic pressure of the saline water. The salty water is pumped against the membranes, with a portion passing through the membranes after desalination, where the rejected salt becoming brine is discharged back to the sea or to special rejection points. Depending on the quality of the product water, the reverse osmosis process may have one or two passes through the membranes. A Reverse Osmosis plant is basically made from the following systems (a) Intake system, (b) Pre-treatment system, (c), High Pressure pumps, (d) Energy recovery system (f) Pass 1 and Pass 2 membranes systems (g) Post treatment, (h) Brine discharge system and (i) Effluent Treatment Plant (Wilf, 2007).
b) *Electrodialysis:* This was commercially introduced in the early 1960's and provided a cost effective way to desalinate brackish water. This technology uses, membranes which permit selective passage of anion or cation ions, and electrons connected to an outside source. Anions and Cations selective membranes and positive and negative electrodes are placed in a container of saline water and when electrical current is carried through the solution the ions migrate to the electrode with the opposite charge, thus desalting the saline water. By this arrangement and operation, concentrated and diluted solutions are created in the spaces between the alternating membranes (Burros, 2000).

2.2 Thermal processes

In this process saline water is heated, producing water vapor that in turn is condensed to form fresh water. Most applied methods are the Multi-Stage Flash Distillation process, the Multi-Effect Distillation process and the Vapor Compression Distillation. Thermal desalination uses heat, often waste heat from power plants or refineries, to evaporate and condense water to purify it. In the most advanced desalination plants, water is pretreated in order to improve the efficiency of the plants.

3. GROWTH OF DESALINATION

Desalination of brackish and seawater is expanding rapidly, primarily to support urban and industrial developments in arid and semi-arid areas and in remote areas where, water is not available or it is too costly to transfer or develop. The market is driven by the water scarcity created by the limited water supply, the population growth, the improvement of the life style, which increases water demand, the climatic changes and droughts and human intervention that reduce water availability. The market is driven also by the falling costs of the desalination, which are due to the technological advances in the desalination process, in the membranes efficiencies, in the energy recovery systems etc.

Figure 1 shows the Global Yearly contracted desalination capacity and the Cumulative Contracted and the Commissioned Quantities (IDA, 2009-2016). From the Graph the following is observed.

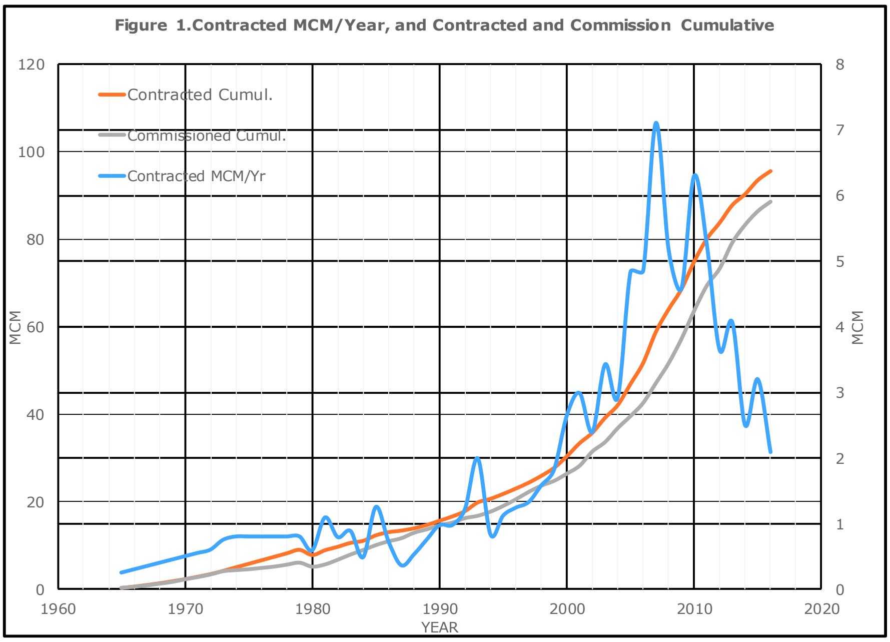

Figure 1. Contracted MCM/Year, and Contracted and Commission Cumulative.

- The Global cumulative desalination capacity contracted is 95.6 MCM/day.
- The Global annual contracted desalination capacity has reached a maximum of 7 MCM/day in 2007 and since then is reduced to 2.1 MCM/day in 2016.

Table 1 shows the evolution of Membranes versus Thermal Technology, Globally, in the MENA region and the GCC (IDA, 2009-2016).

Table 1. Evolution of membranes vs thermal technologies

YEAR	**GLOBAL**		**MENA**		**GCC**	
	Membranes	Thermal	Membranes	Thermal	Membranes	Thermal
2000-2009	75%	25%	55%	45%	40%	60%
2010-2014	88%	12%	76%	24%	61%	39%
2015-2016	93%	7%	86%	14%	82%	18%

There are so far 18,486 desalination Plants in more than 150 countries serving around 300 million people and many industries.

Since 2006 the additional desalination capacity commissioned is 48.4 MCM out of which 60.1% are for potable water and the rests 39.9% for industry.

4. WATER AND POWER EQUIREMENTS AND SUPPLY

The desalination process requires raw water and energy. The water for desalination may be abstracted from underground brackish water or from wastes and/or from the sea, depending on the selected site. It also requires a brine discharge point which is better served by the sea. For better and efficient brine discharge and enough raw water quantities the large scale desalination plants are located next to sea. For the desalination process, depending on the technology, energy in the form of electricity from oil or natural gas, or from renewable resources (hydraulic, solar, wind etc.) is requited for membranes technology and steam for thermal technology, taken preferable from power stations (Burros, 2000). For the reverse osmosis process the energy required ranges from 2.5-3.0 Kwh/m^3 of desalinated water, plus 0.5-1.0 KWH/m^3 for the pumping of water other than the desalination process. The energy for the membranes systems may come from the national Grid, from an Independent Power Production Plant, or solar energy or wind energy. The solar energy and wind energy for desalinations is at present confined to small plants. Today's thermal MED/TVC plants use about 1 KWH/m^3 of energy in addition to the steam input required, which ranges from 8-15 GOR (Gained Output Ratio), approaching equivalent to 5-8 KWh/m^3 and these are best suited to take advantage of co-production of energy and water. GOR is defined as follows. How many kilograms of distilled water are produced per kilogram of steam consumed and it varies from 1 to 15 Kg/Kg (IDA, 2011). For Renewable Energy Desalination Projects the readers are referred to World Bank publication "MENA Development Report Renewable Energy Desalination" (The World Bank, 2012).

5. ADVANTAGES AND DISADVANTAGES OF DESALINATION WATER SUPPLY PROJECTS

Advantages:

- It is an alternative water supply not dependent on the rainfall
- It provides the design production rate with a relatively high security, compared to lower reliability of the conventional water supply systems
- The water quality may be designed to meet the consumers' requirements (potable or industrial)
- It can be installed in remote areas where conventional water supply is not available
- The time required for its development is comparatively small compared to other alternatives.

Disadvantages:

- High capital cost and high energy demand.
- High production costs because of high energy consumption.
- It may cause Environmental problems on the marine, land, underground and air environment including noise pollution.
- It may face the rejection by the owners of the project land and of the neighboring land because the plants look like industrial building reducing the price of the neighboring land.

6. CAPITAL COST OF PROJECTS AND UNIT COST OF DESALINATED WATER

6.1 Capital cost of desalination projects

The capital cost depends mainly on the plant location, the quality of the raw water, the quality of the product water, the site environmental sensitivity, the intake and brine discharge systems, the intake pumping system, the on land raw and brine discharge systems, the Pre-treatment system, the High pressure Pump and energy recovery systems, the desalination process system (SWRO and/or BWRO, or the thermal desalination unit, the Post Treatment, the Pretreatment Effluent Plant, the Power supply system (Grid or IPP or else) and the energy supply and the energy unit cost. Also added are the insurances and guarantees during the construction phase.

6.2 Production unit Cost

The Unit cost of desalinated water depends on the Capital cost, the financing costs, the years of depreciation of the Plant (10, 15, 20 or 25 years), the energy consumption, the energy price, the chemicals costs, the operation and maintenance team costs, the plant size, the insurances and guarantees during operation and the plant's daily production (Tsiourtis, 2004).

7. FINANCING OF DESALINATION PROJECTS

With the desalination projects having a very high cost, big utility projects may be financed by one of the following methods.

a) *Turn Key Method*: By the Government issuing a Turn Key Project tender for the execution of the proposed desalination project, undertaking to construct and commission a project all in accordance with the tender specification and either operate the project by itself or by hiring a special entity to operate the project. This method is not preferred by most of the Governments because it creates a financial problem to the Governments who do not want to have deficits in their budgets.
b) *Public Private Partnership method*: By issuing a Tender by the Government for a Build, Operate and transfer (BOT) project or other forms, under which the successful Tenderer will undertake to design, build, commission and operate the specified project with the undertaking by the Government that it will buy the conforming quantities of water for a fixed period of time with an agreed price updated to compensate for fiscal changes. By this method the Government will not have to pay for the capital cost. The cost of the water (capital and variable) are directly transferred to the water consumers.

In all cases the Projects must be economically viable (Tsiourtis, 2011, 2016; Latterman and Hopner, 2003; Sommariva, 2004).

8. ENVIRONMENTAL AND OTHER IMPACTS

In all cases, the environmental and economic impacts of the project on the site and in the lands lying in the vicinity of the site must be carefully considered. An environmental study must be carried out to evaluate the projects impact and mitigation measures must be proposed to reduce or minimize the impacts during construction and during operation of the project Just to summarize the possible impacts, which are mostly mitigated with a proper project design and execution and during the construction and operation phases are the following (Tsiourtis, 2001a).

- Impacts by the intake and brine discharge systems on the marine environment. The adverse impact may affect the marine life in the vicinity of the intake heads and at the brine discharge points during the operation and during the construction phase (Tsiourtis, 2001a; Latterman and Hopner, 2003; Tsiourtis, 2008a).
- Impacts on the on-shore area, near the Intake pumping Station on the onshore land corridors and the plant area and underground aquifers, during construction and during the operation phase due to seawater and or brine spillage (Tsiourtis, 2001a).
- Noise impact during construction and operation because of big pumps and machinery.
- Air pollution during construction and gas emissions during the operation of the plant for the production of the energy.

All the above impacts are manageable by adopting the required designs which shall secure the environment. Concerning the emissions to the atmosphere for the energy production the following can be said. With a specific energy consumption for the production of one cubic meter around 3 KWh, the energy required for the production of 200 liters per day for the daily needs of one person, is only 0.6 KWh. It is the responsibility of all of us to make a saving of 0.6 KWh/day for securing the water quantity necessary to satisfy our daily demand. This is a very small quantity of energy, compared to the average daily consumption of around 10KWh/day per person in a household and compared to our car consumption estimated at 1 KWh per kilometer.

9. EXPERIENCE IN VARIOUS COUNTRIES IN THE MEDITERRANEAN

Desalination is now in use in many countries of the world. I shall concentrate on the experience of countries in the Mediterranean. Such countries are Cyprus (Tsiourtis, 2001b), Israel, Malta, Spain, Algeria, Morocco, Egypt and Greece. Israel has developed desalination in the last 15 years and it has now five plants of reverse osmosis with an annual production of 575 MCM and Cyprus has four plants of reverse osmosis with an annual capacity of 70 MCM, Malta has three plants of reverse osmosis, with an annual capacity around 30 MCM. Algeria and Spain have embarked on a large scale desalination in the last decade. The rest of the countries have less desalination capacity except the Gulf countries which have very big hybrid plants (thermal and SWRO Plant).

10. STEPS TO ESTABLISH A DESALINATION PROJECT

For the establishment of the Desalination Project the water authority must organize a team consisting of various disciplines to carry out the various steps as follow.

Step 1: Carry out a diagnostic study to establish the real extra needs of water quantities, for short and long term and if a desalination project is justified (Tsiourtis, 2008b).

Step 2: If Step 1 shows that there is a need for more water resources, and desalination is justified decide on the technology of desalination, the power supply and raw water supply etc.

Step 3: Locate 2-3 potential sites and carry out preliminary environmental studies for each of them and select the most suitable site (Tsiourtis, 2008a,b).

Step 4: For the selected site prepare the possible draft P&I diagrams and the layout for all the systems and draft the technical specifications.

Step 5: Prepare the Contract conditions (including risk allocation) and the material specification which shall constitute the Tender Documents, for a Turnkey or a Public Private Partnership (PPP) project (Tsiourtis, 2016). The specifications and the Contract documents shall provide for a Bankable project.

Step 6: Issue Tenders and accept offers from qualified Contractors.

Step 7: Evaluate the Tenders received and award the Contract to a qualified Contractor who shall meet the tender requirements criteria.

Step 8: After signature of the Contract in the event of a PPP project carry out the Due Diligence Study for securing the project's financing.

Step 9: Proceed with the construction of the project in accordance with the approved Time Schedule.

Step 10: Upon Construction Completion carry out the machinery and the systems complete test to secure that the Plant attains the guaranteed performance criteria and the Permit to Operate and start the Commercial Operation Phase.

11. CONCLUSIONS

With the water demand increasing because of population increase, life style change, etc. while the conventional water resources shall not be able to close the gap between supply and demand, many countries will face water shortages. Some countries, possibly will be able to close the gap between supply and demand with better management of their conventional resources where others have to secure additional non-conventional water coming from further treatment of wastewater, seawater or brackish water. Under such conditions the desalination may be an alternative water supply source. The desalination project must prove to be bankable so that the incomes secure the capital cost (studies, machinery installation. Construction, erection, completion tests etc.) the production costs during commercial operation phase, the management costs, the loan repayment installments with the interest any overflow costs and secure a logical profit for the project owners.

REFERENCES

Buros O. K. 2000. The ABCs of Desalting. Published by the International Desalination Association, Topsfield, Massachusetts, USA.

IDA 2009-2016. Desalination Yearbooks

IDA, 2011. Desalination at a glance

Latterman, S. and Hopner, T., 2003. Sea water desalination Impacts of Brine and Chemical Discharge on the Marine Environment.

Sommariva, C. 2004. Desalination Management and Economics. Sponsored by Mott MacDonald. Published by Faversham House Group.

The World Bank, 2012. MENA Development Report Renewable Energy Desalination. The World Bank Washington D.C.2012.

Tsiourtis, N. X., 2001a. Desalination and the Environment. Keynote Speech. Contribution to the European Desalination Society European Conference on Desalination. Limassol Cyprus, May.

Tsiourtis, N. X., 2001b. Sea water desalination Projects. The Cyprus Experience. Desalination; 139: 139-147.

Tsiourtis, N. X., 2004. Desalination Water Costing the Financiers View: Conference organized in Lemesos by the Middle East Desalination Research Centre, December.

Tsiourtis, N. X., 2008a. Criteria and Procedure for selecting a site for a desalination project. Desalination; 221: 115-125.

Tsiourtis, N. X., 2008b. Diagnostic of the Situation. Published in the Options Mediterrannennes Series B, No 58, Technical Annex of the Drought Management Guidelines.

Tsiourtis, N. X., 2011. Bankability of Desalination Projects. 12th Annual Conference of Israel Desalination Society, Technion Haifa 14-15 Dec 2011.

Tsiourtis, N. X., 2016. Specifying and Keeping bankable desalination projects. EDS Conference on Desalination and the Environment, Clean Water and Energy, 22-26 May, Rome.

Wilf, M., 2007. The Guidebook to Membrane Desalination Technology. Balaban Desalination Publications.