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Desalination and energy consumption. What can we expect in the near future?

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ABSTRACT

Desalination technologies have become necessary tools for hydrological planning, along with conventional water resources.

One of the main barriers to extend desalination is higher water costs, which are seriously influenced by energy consumption (represents > 50–60% of total costs).

This paper takes into account relevant energy and desalination aspects and different available technologies.

This work focuses mainly on reverse osmosis, which is the most widely used technology. It also considers aspects like major consumers and their contribution to overall. The configuration of HP pumps, membranes and ERDs is explored, as is what we can expect in the future, while we bear in mind that we are currently very close to reaching the thermodynamic limits for energy consumption.

Special dedication will be taken to renewable energies and how they can be combined with desalination to produce more efficient systems, though not necessarily directly coupled to desalination plants.

How to choose the most adequate energy rates and the production plus storage combination is another important consideration to optimize energy costs. An adequate production management strategy can significantly reduce the cost of water.

To conclude, emerging technologies are analyzed, by looking at all the possible improvements and potential generated uses.

1. Introduction

Desalination has become one of the world's most important unconventional water resources in recent years, and it is particularly relevant in places where water is scarce.

Together with the huge desalination benefits (increasing water resources and improving water quality), there are still ample research and improvement opportunities, especially in those aspects related to reducing energy consumption (EC).

According to IDA (International Desalination Association), desalination cumulative contracted capacity is estimated at 99.8 millions of m^3/day worldwide (considering the installations built since 1965), while the capacity of operative plants is 92.5 millions of m^3/day [1].

Among the different existing desalination technologies, there are two main process groups; processes based on evaporation and processes based on membranes. Evaporation processes can operate by heat supply, as in Multistage Flash (MSF) and Multi Effect Distillation (MED), or through the supply of electric energy by mechanical compression (Vapor Compression – VC).

Regarding membrane technologies, except for a few emerging technologies (e.g., membrane evaporation or pervaporation), they all operate by supplying electrical energy, but in different ways; by membrane pressurization (Reverse Osmosis (RO) and Nanofiltration (NF)) or by passing a direct current between electrodes to separate ions by ionic membranes (Electrodyalisis Reversal (EDR)).

Other processes that can be used for salt removal, such as ion exchange, precipitation or freezing, are not used for desalination on a large scale.

As evaporation technologies use much energy, RO is currently the most prevalent technology, with approximately 65% of the installed capacity [2], and with the majority of new facilities. For this reason, the present paper focuses mainly on this desalination technology.

An analysis by Acuamed [3] (the Spanish public company in charge of large desalination projects) with over 12 large SWRO (seawater RO) plants in Spain and a global capacity of 409 hm^3/year, determined by energy costs, represents around 60% of water production costs, with variable plant production (60% for 100% water production and 30% for 20% water production).

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Table 1
Specific energy consumption in different large desalination plants (design).
Source: Valoriza Agua.

Plant	Capacity (m^3/day)	Contract year	SEC (kW-h/m^3)
Skikda (Algeria)	100,000	2004	3.65
Honaine (Algeria)	200,000	2005	3.5
Aguilas (Spain)	200,000	2008	3.3 (5.4, including product water pumping)
Southern Seawater desalination plant (Australia)	305,000	2012	3.1 (3.7, including product water pumping)

Specific energy consumption (SEC) in large SWRO plants is currently in values of 2.5–4 kW-h/m^3, as shown in some examples presented in Table 1.

2. Energy consumption in desalination

The minimum energy required for desalination is the equivalent to the energy produced when salts are dissolved in pure water.

Energy produced = $R\ T\ \ln a_W$

where

R = constant and
T = absolute temperature
a_W = activity of Water

Considering seawater with 35,000 ppm of TDS (total dissolved solids), at 25 °C the minimum required separation energy is 13.6 cal/mol, which is the approximate equivalent to 0.9 kW-h/m^3. Real consumption is higher and also depends on other factors, such as operating conditions, temperature, recovery, etc.

This means that we are currently close to the thermodynamic limit (considering that it is not an ideal system), and it is becoming increasingly difficult to reduce energy consumption in desalination technologies below current values. However, the evolution of energy consumption in recent years has been significant (see Table 2), which represents the historical evolution in desalination plants in Spain, published in 2009 by AEDyR (Spanish Desalination and Reuse Association) [4]. The data table also shows the historical reduction of SWRO energy consumption due to the inclusion of the new incoming ERDs (Energy recovery devices, such as Francis turbine, Pelton turbine, hyperbaric recovery devices, etc.).

Table 2
Evolution of average SEC in Spanish seawater desalination plants.
(AEDyR, 2009) [4].

Year	Technology	kW-h/m^3
1970	MSF	22
1980	MSF	18
1985	VC	15
1988	VC	13
1990	RO	8.5
1994	RO	6.2
1996	RO	5.3
1998	RO	4,8
1999	RO	4,5
2000	RO	4,0
2001	RO	3,7
2002	RO	3,5
2005	RO	3
2009	RO	< 3

Table 3
The EC breakdown at the Southern Seawater Desalination Plant (SSDP), Binningup, Western Australia (SWRO, 306,000 m^3/day).
Source: Valoriza Agua.

Process	SEC (kW-h/m^3)	Percentage (%)
Intake-pumping station	0.33	8.9
Pretreatment (Ultrafiltration, UF)	0.05	1.3
RO 1st pass	2.3 (2.2 real operating value)	62
RO 2nd pass	0.35	9.4
Ancillary equipment	0.01	0.3
Post-treatment	0.01	0.3
Product water pumping station	0.58	15.6
Effluent treatment plant	0.02	0.5
Ancillary equipment and others	0.06	1.6
TOTAL	3.71	
TOTAL with no product pumping station	3.13	

3. Sources of energy consumption in RO desalination plants

There are different sources of energy consumption in RO plants, where it is possible to act to optimize or reduce energy use. A real example of an energy use breakdown in a SWRO plant is found in Table 3. Of course, high pressure systems for RO stage form the majority of uses, and are some processes that are strongly influenced by local conditions, such as product water pumping intake.

The most relevant aspects of the different processes from an energy use point of view are commented on below.

3.1. Intake and product water pumping stations

The location of desalination plants and the delivery point are often predetermined by the promoter. Then there is not much left to do to reduce energy use, except for pump selection (efficiency), motor selection (induction motors, permanent magnetic motors, etc.) and reducing pressure losses in the pipe layout and installation of VFDs (Variable Frequency Drives) to adapt the working point of pumps to real needs at any given time.

Intake or product water pumping entails different casuistries, based on differences in heights and distances, ranging from 0.1–0.2 kW-h/m^3 to much higher values.

In some cases, product water pumping can use even more energy than the desalination process itself. By way of an example, the SWRO plant called Mantoverde, installed on the coast of Chile for the mining industry, feeds water to the industry located at a height of 700 m and a distance of 35 km, which uses 2.5 kW-h/m^3 in desalination and 2.5 kW-h/m^3 in product water pumping (data from Valoriza Agua).

Height differences in brine discharge (discharge height-seawater level) can also be taken advantage of, and it is possible to use a turbine to produce energy, which is the case of the SWRO plant in Adelaide (Australia). In this plant (300,000 m3/day production) taking advantage of 40 m height difference, 685 kW are produced at 100% capacity (using Francis turbine), representing 3% of the energy consumption [5]. Valdelentisco SWRO plant in Murcia (Spain) also produces 133 kW at 100% capacity (140,000 m3/day) [6]. The main problem with this kind of turbines is the reduction of efficiency for lower flows and foam generation. Other option for smaller plants can be the installation of microturbines.

3.2. Pretreatment

Although pretreatment is not the major energy user in RO plants, some design aspects can determine the most efficient process; it is possible to choose between conventional or membrane treatments, work by gravity or pressurized in different stages, and intermediate