DESALINATION

Desalination 221 (2008) 143–150

www.elsevier.com/locate/desal

Desalination and energy consumption in Canary Islands

J. Jaime Sadhwani*, Jose M. Veza

University of Las Palmas de Gran Canaria, Department of Process Engineering, Campus de Tafira Baja, E-35017, Las Palmas de Gran Canaria, Spain
Fax +34 928458975; email: jsadhwani@dip.ulpgc.es

Received 24 January 2007; accepted 4 February 2007

Abstract

The Canary Islands represent an almost perfect model of reference in the field of the water desalination. Starting from the 1960s, many desalination plants have been built to provide fresh water from non-conventional sources; making it necessary to search from other sources of supply, like seawater or brackish groundwater.

Desalination in the Canary Islands has contributed to the progress and development of the islands, considering that its main economic activity is the tourism. In addition, water desalination has improved the population life quality, allowing a safe and continuous supply of water for domestic and agricultural consumption. Nevertheless, the desalination systems show a high power demand with a strong dependency on the non-renewable energies, basically of oil products.

The desalination technologies that require electricity have gradually reduced their energy consumption, lowering the water supply bill. The reduction has been made possible thanks to the development and consolidation of efficient methods or through improvements in the equipment of desalination itself.

In the present paper, we analyse with a retrospective vision the evolution experienced by the consumption of energy in the existing desalination plants in the Canary Islands, as well as the outlook in the long term. We will try to answer questions that we are considering nowadays, as it is for example whether the industry has arrived at the bottom line in energy consumption, what is the optimal size of a plant and its energy consumption of energy, etc.

In our discussion we will consider the conditions of design and operation, as well as the different technological changes that have occurred during the life time of the installations. This exposition will allow us to learn in depth the existing deviations in the energy consumption and therefore, to include or understand the solutions adopted.

The final objective is to contribute by explaining the state-of-the-art on the existing relationship between the energy consumption and the water desalination, by means of the knowledge of the improvements and decisions taken at each moment in a part of the world, where the water desalination accumulates more than forty years of experience.

Keywords: Energy consumption; Pump; Energy recovery

*Corresponding author.

Presented at the conference on Desalination and the Environment. Sponsored by the European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort, Halkidiki, Greece, April 22–25, 2007.

doi:10.1016/j.desal.0000.00.000

1. Introduction

The Canary Archipelago is situated in the north-east of the African continent, between, the latitudes 27° 37′ and 29° 25′ North (subtropical situation) and the longitudes 13° 20′and 18° 10′ West of the Greenwich Meridian.

The Northwest winds (alisio), combined with the orography of the islands, are responsible for the stable climatic situation, with moderate temperatures and scarce rainfall. This is fundamentally concentrated between November and March, when the Azores Anticyclone goes to the south and gives way to squalls from the north and west [1].

The scarce hydraulic resources due to low rainfall, the excessive aquifer exploitation, the demographic increase and the tourist development have driven the search for new alternatives and technologies that would guarantee the availability of this so much valued resource.

The technical evolution that has occurred in seawater desalination since 1965 up to now is perfectly represented in Spain, especially in the Canaries. From these early times until 1980, the scene of desalination is dominated by the distillation processes. The constructed plants are dual, producing water and electricity. The plants of Fuerteventura, Lanzarote, Las Palmas I, Ceuta and Las Palmas II correspond to this model [2].

Also it is in Lanzarote, where the first seawater desalination plant with reverse osmosis membranes is installed, with a production (although small) of 500 m^3/day but which meant a revolutionary technological change in the water sector. Therefore, the first significant plant with this system corresponds to Lanzarote II in 1984 and it consisted of 3 production lines of 2500 m^3/day.

With this process, seawater desalination opened the doors to the progress and to the development of dry and arid regions, as it was the case of the rest of the eastern islands (Fuerteventura and Gran Canaria) and later even the western islands (El Hierro and Tenerife).

2. Desalination development in Canary Islands

Desalination in Canary Islands has had several development steps, all of them mentioned in the different regional desalination schemes. In all of them, the most used system for seawater desalination is reverse osmosis.

The production capacities of the desalination plants with reverse osmosis membranes were not higher than 20,000 m^3/day, except in the case of the plant Las Palmas III-IV (36,000 m^3/day) or the multiple effect plant Las Palmas-Telde with 35,000 m^3/day.

In the following Table 1, the number of constructed desalination plants and the selected process is indicated.

The first desalination scheme began in 1988, with the construction of ten plants and a production capacity of 74,500 m^3/day. In that action

Table 1
Number of desalination plants by process built in the Canary Islands

	First regional desalination scheme	Second regional desalination scheme	Third regional desalination scheme
Number of plants	9 RO 1 VC	7 RO 1 ME 1 VC	14 RO 1 ED

RO: Reverse Osmosis, VC: Vapour Compression, ME: Multi Effect distillation, ED: Electrodialysis.

programme the plants of Gáldar-Agaete, Las Palmas III-IV, Lanzarote III, Puerto del Rosario III, Sureste de Gran Canaria, etc. were included [3].

The second scheme included nine new actions on the subject of desalination, by means of the construction of new plants or expansions, with a total capacity of 92,500 m^3/day, where some of the western islands are incorporated. This is the case of Tenerife, with the construction of two plants, the first one in Santa Cruz (20,000 m^3/day) and the second one (10,000 m^3/day) in Adeje-Arona, etc. [4].

With the third scheme agreed in 1997 and expanding until 2004, again 16 actions were planned through the enlargement or construction of new desalination plants, with an approximate production capacity of 185,800 m^3/day such as San Nicolás de Tolentino, Telde, Guía, Gáldar, and others [5].

During the last decades, most actions carried out on the subject of water desalination have been concentrated on the construction of seawater desalination plants of low or medium production capacities, as well as on their enlargements. The average capacity of desalinated fresh water production per plant is quite lower than the actual production capacities of the new plants that are being built in the mainland nowadays.

In the following Fig. 1, the number of desalination plants installed in the Canaries can be observed, where production capacities lower than 10,000 m^3/day predominate [6].

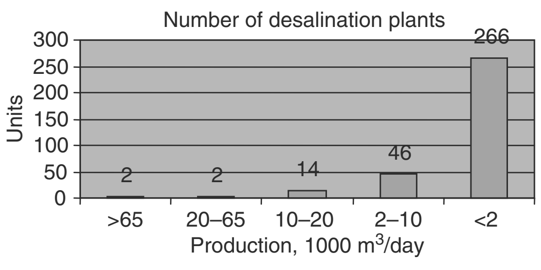

Fig. 1. Production capacities and number of installed plants. *Source*: (Courtesy of Centro Canario del Agua)

Until the mid 90s, the seawater desalination in Spain was mainly located in the Canary Islands, but with the strong drought experienced in the mainland many and important actions on the subject of seawater desalination have been developed. So the focus of desalination has moved from the Atlantic Ocean to the Mediterranean Sea, being localized in the east coast and in the Balearic Islands desalination plants of large production capacities [2].

3. Singular cases of seawater desalination plants

We will take as examples, two of the most relevant seawater desalination plants in the isle of Gran Canaria.

The first one is justified for being one of the pioneer plants regarding its production capacity as well as for the high values of SDI (silt density index) because of its surface intake (open sea).

The second one represents a plant with a production capacity by modules, with production units of 5000 m^3/day, an amount that was very common in the plant design for many years.

3.1. Las Palmas III-IV desalination plant

The seawater desalination plant "Las Palmas III-IV" started producing desalinated fresh water in October 1989. At that time, it was the largest plant installed in Spain which used the reverse osmosis membranes technology. Its nominal production was 36,000 m^3/day and the conversion ratio was 45% in a double stage [7].

During its first operating phase, the design conditions relative to the energy consumption, production and seawater quality were not easily achieved. Hence, new actions were planned in 1996 to improve the operation and optimize the plant design; all of them directed to increase its production, to improve the product water quality and to reduce the energy consumption of the plant.

To increase the production capacity of the plant, initially it was decided to replace the existing membranes for ones of the latest generation, and to reduce the energy consumption, the energy recovery system (Francis turbine) was replaced with another one of a higher efficiency (Pelton turbine).

To enlarge furthermore the production capacity of the plant, a booster pump between stages is incorporated in the six production lines, to increase pressure into the second stage. Finally, a seventh production line of 8000 m^3/day is added to reach the production capacity of roughly 52,000 m^3/day. Furthermore, all these actions have resulted in lower energy consumption, which reduced from 6.16 to 5.2 kWh/m^3 [8].

To enlarge the production capacity plant, were installed recently three new production lines reached the actual production capacity of 80,300 m^3/day. The major technical characteristics of the plant are indicated in Table 2, where the existing differences in two situations, the design and the current one, are reflected.

3.2. Sureste desalination plant

This plant was commissioned in 1993, taking the seawater through coastal wells, with a design conversion of 43%. Its nominal production was 10,000 m^3/day using two production lines, where each one had 528 RO modules accommodated in six-element pressure vessels. The membranes were made of polyamide and spiral wound configuration. The energy recovery was performed with Francis turbines and the design specific energy consumption was 5.75 kWh/m^3, where the energy consumption due to the water pumping for its distribution to the elevation +200 m was included.

Regarding the energy consumption evolution experienced by the plant with respect to the design conditions, in the period between September 1993 and December 1994 this has been lower than the limit value, that is to say, 5.39 kWh/m^3 as an average value [8].

The plant has had several expansions. The first one took place in 1998, increasing its production capacity by another 15,000 m^3/day making

Table 2
Principal actions carried out in the desalination plant Las Palmas III-IV

Technical characteristics	Initial state, 1989	Current state, 2006
Nominal production, m^3/day	36,000	80,300
Number of production lines	6	10
Conversion factor, %	45	52
TDS seawater, mg/L	38,300	38,300
TDS fresh water, mg/L	400–500	400–500
Number of reverse osmosis membranes	4608	8904
Number of elements per pressure vessel	6	6
Specific energy consumption, kWh/m^3 [a]	6.16	4.40
Energy recovery systems	Francis	Pelton
Number stages in the RO membranes	2	2
Booster pumps (units)	No	10
Physical pretreatment (units)		
Sand filtration	6	12
Cartridge filtration	7	11

[a]Including energy consumption by pumping water desalted to 180 meters altitude.

a total capacity of 25,000 m^3/day. The enlargement consisted in incorporating two new production lines of 7500 m^3/day each. The energy consumption improved significantly by means of the new adopted energy recovery system, Pelton turbines instead of Francis.

Four years later, in 2002, a second enlargement was realized reaching a total 33,000 m^3/day. So the additional 8000 m^3/day were obtained by upgrading the design of the four existing production lines. A brine concentrator was added in the second stage by means of a booster pump, achieving an increase of the conversion factor to 55%. Other changes planned in the optimization and improvement of the plant's energy consumption, were to incorporate the latest generation reverse osmosis membranes as well as increasing its number changing the six-element pressure vessels for the seven-element pressure vessels.

The specific consumption including pumping to the elevation +200 m, has reduced from 5.75 to 4.4 kWh/m^3, that is to say it has experienced a considerably reduction of 30.68% [9].

To summarise, the major actions carried out in the improvement and reduction of the plant's energy consumption are indicated in Table 3.

4. Energy consumption in water desalination in the Canaries. Perspectives and future approaches

The evolution in the last thirty years experienced by the energy consumption of the large seawater desalination plants can be observed in Fig. 2.

Until the year 2000, the technological improvements planned to reduce the energy consumption have been very beneficial. A first goal of 5 kWh/m^3 has been reached due to the use of some new hydraulic designs (with higher efficiencies both in pumps and turbines).

From 2000 on, a second challenge was proposed: to reach a further reduction in the energy consumption to values closer to 3.5 kWh/m^3. In this case, the solution has been to incorporate new energy recovery systems and adapt them or not, together with the traditional ones. Another important factor that has made the achievement of this objective possible, has been to calculate the optimal size of the plant; in other words, the average production capacities have increased to figures higher than 50,000 m^3/day.

For example, in other countries of the world such as Australia, only the energy recovery system

Table 3
Characteristics of Sureste desalination plant

Technical characteristics	Initial state, 1993	Current state, 2006
Nominal production, m^3/day	10,000	33,000
Number of production lines	2	4
Conversion factor, %	40	55
TDS seawater, mg/L	37,500	37,500
TDS fresh water, mg/L	500	400
Number of reverse osmosis membranes	1056	3108
Number of elements per pressure vessel	6	7
Specific energy consumption, kWh/m^3	5.75	4.40
Energy recovery system	Francis	Pelton
Number of stages in the RO membranes	1	2
Booster pumps (units)	–	4
Physical pretreatment (units)		
Sand filtration	3	5
Cartridge filtration	5	6

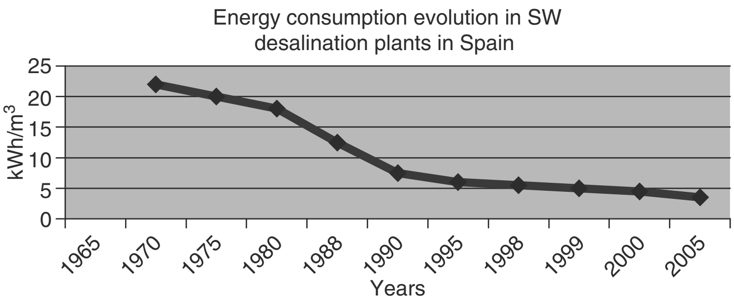

Fig. 2. Energy consumption evolution in the seawater desalination plants. *Source*: Desalination and Reutilization Spanish Association (AEDyR) [10].

with isobaric chamber (ERI) has been used for the seawater desalination plant of Perth with 144,000 m^3/day, so that 12.1 MW out of the 13.2 MW installed in the engines are recovered [11].

But, what happens with the energy consumption in the large desalination plants in the Canaries? To answer this question it is necessary to indicate several decisive aspects in the state-of-the-art of the desalination in Canary Islands: (1) The number of desalination plants is very high, being the density ratio 22.73 km^2/plant. (2) The production capacity most used in the design of the plants is lower than 2000 m^3/day. (3) The enlargements and new constructions of plants are planned to duplicate their production capacities.

Therefore, on the subject of energy efficiency in the large seawater desalination plants, the first action carried out in the Canaries has been to replace the energy recovery system traditionally used till the end of the 90s, where the solution planned in the first plant designs was to install a reversed pump which operates with the brine pressure and flow. Afterwards with the appearance of the "Pelton" turbine which had a higher efficiency in energy recovery, the reduction in energy consumption in the desalination plants has been spectacular and notable [14].

However, there are new energy recovery systems, denominated as pressure exchange chambers, based on displacements (as in the case of the patents of Aqualing, RO Kinetics, Siemag, among others) as well as the rotaries (ERI). Both systems present high efficiencies and allow even further reduction in the energy consumption in the desalination plants with reverse osmosis membranes. Moreover, these have gradually been incorporated into the plants with small production capacities, obtaining values even lower than 3.0 kWh/m^3; this is the case of Club Lanzarote Plant in Playa Blanca with 500 m^3/day [12].

Thus, in the medium and long term, one might think that to obtain an even higher reduction in the energy consumption, the Canaries designers must decide whether to integrate or not the new energy recovery devices (ERD) with the traditional ones. Moreover, these ERD must be able to adapt to the varied and wide production capacity of the plants. The energy saving obtained using either Pelton turbines or the pressure exchange ones depends on the plant conversion; the higher its operating conversion the lower its difference [13].

Finally, a parallel evolution in the latest technological advances carried out in the design of the reverse osmosis membranes is observed in the Canaries, although somehow delayed in time. The new designs plan to work with higher conversions and to incorporate booster pumps to feed between stages, as well as the replacement of the RO membranes for others of higher productivity.

5. Conclusions

For many years, the Canary Islands had been a world reference in seawater desalination, both because of its high number of desalination plants and because of the use of different technologies.

The desalination technology mostly used was, and still is, the reverse osmosis membranes. Their production capacities are very different, being plentiful especially the ones with 2000 m^3 day. On the other hand, there are no plants with large capacities as in the case of the mainland; they only have use of a plant of more than 50,000 m^3/day, which is the case of the desalination Plant Las Palmas III-IV.

Regarding the energy consumption in the large SWRO desalination plants, the Canaries have not reached the top in the energy consumption reduction yet. So far, the main actions have been focused on substituting the traditional energy recovery system "reversed pump" by another of higher efficiency, as in the case of the "Pelton" turbine; still pending the incorporation of the new and efficient systems based on pressure exchanges in chambers. A conversion factor in the plant, which will produce the highest energy saving with the adequate energy recovery system, should be considered for study.

However, in the Canaries, new designs are being developed to improve the production of the membranes with production capacities equal to or higher than 5000 m^3/day; such as incorporating a booster pump for feeding the second stage to obtain higher flow and operate with a higher conversion, and to use the latest membranes generation, which are able to support higher pressures than in the previous stage.

Acknowledgement

The authors are grateful to all those individuals and companies that have contributed with information for this work particularly to J.J. Rodríguez (Engineer, Las Palmas City Water Company — EMALSA) and to Tracy Cabrera for his cooperation.

References

[1] Canary Islands Portal www.canarias.org.
[2] M. Torres, Desalación y planificación hidrológica hoy, Ingeniería y Territorio, 72 (2005) 8–13.
[3] J.M. Veza, Desalination in the Canary Islands: an update, Desalination, 133 (2001) 259–270.
[4] Cooperation Agreement of 21 July 1992, Official Journal of Canary Islands, 2 December 1992.
[5] Cooperation Agreement of 21 December 1997, Official Journal of Canary Islands, 4 March 1997.
[6] Manuel González, Desalination in Canary Islands, General Overview, Centro Canario del Agua, Personal communication, May 2005.
[7] J. Jaime Sadhwani Alonso, Operation of the desalination plant Las Palmas III and IV, Proceedings Symposium on Desalination Plants Operation, EDA-CANAGUA, Las Palmas, 1990.
[8] J. Jaime Sadhwani Alonso, Criterios de Explotación en Planta Desaladora de Agua de Mar por Ósmosis Inversa, CANAGUA, Symposium Internacional de Desalación y Reuso del Agua, November 1995.
[9] Rafael Sánchez Ramírez, et al., Etapas de concentrador de salmuera de la planta desaladora del Sureste de Gran Canaria: primer año de funcionamiento, Proceedings IV National Congress AEDyR, Desalación y Reutilización "Mirando al Futuro", Noviembre 2003.
[10] Asociación Española de Desalación y Reutilización. www.aedyr.com.
[11] G.G. Piqué, Osmosis Inversa para Desalación de Agua de Mar, utilizando baja energía desde Jeddah I (1980) hasta California (2006), VI Congreso Nacional AEDyR. Noviembre 2006.
[12] D. Ponce, Desalination plants in Canary Island: set new low energy record, Personal Communication, DPG, Desalinizadoras Osmosis Inversa.

[13] J.M. Sanchez y R. Sanchez, Representación y comparación entre las curvas de operación de un modelo de planta desaladora que utiliza un sistema de recuperación de energía SIP y Turbinas Pelton, VI Congreso Nacional AEDyR, Noviembre 2006.

[14] M. Fariñas Iglesias, Pelton turbines compared to counter pressure turbines in the recuperation of energy in desalination plants, Proceeding IDA World Congress on Desalination and Water Reuse, San Diego, 1999.