Membrane Desalination Technology in Algeria: Reverse Osmosis for Coastal Areas

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1 Introduction

Seawater desalination is necessary in a number of countries that witness water shortage, as an option for securing the supply of drinking water to the population, given the rapid increase in water demand in the sectors of agriculture and industry. The biggest constraints of the desalination system are its energy consumption per cubic meters product and environmental impacts due to discharges of brine in the natural environment. Despite these constraints, desalination plants grow around the world, including desalination processes to deal with the increasing water demands. Resources are limited in quality and quantity, resulting in the establishment of treatment solutions of brackish water and seawater.

Currently, on the industrial scale more than 15,000 desalination plants have been installed worldwide with a production capacity of about 56 million m^3/day with 64% seawater while the global capacity of drinking water production is about 500 million m^3/day. In the Mediterranean, the production of desalination plants is 10 million m^3/day. The total production capacity is estimated to be more than 8.5 billion gallons/day (Quteishat and Abu-Arabi 2006).

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In remote regions, particularly in the Middle East and North African countries MENA, freshwater scarcity is a huge problem. The exploitation of groundwater aquifers and surface water has contributed to the decrease in quantity and quality of existing natural water resources (Mohamed et al. 2008).

Availability of electricity networks in these regions is frequently limited; technologies that are able to remove pathogens and dissolved contaminants require large amounts of energy (Eltawil et al. 2009; Schafer et al. 2007). Different economic constraints encouraged the spread of desalination technologies in the Arab countries where potable water is an essential resource as electricity (Al-Karaghouli et al. 2009). The total population is around 325 million with a very high growth rate of 2.7%; the per capita share of the total annual renewable water resources (TARWR) has dropped well below the UN threshold for water poverty (1000 m^3/year) with most of the Gulf Arab countries reaching per capita TARWR below 200 m^3/year (El-Nashar et al. 2007).

One of the most common membrane desalination methods is reverse osmosis; it has emerged as the dominating technology to produce freshwater from seawater for many industrial and domestic applications (Greenlee et al 2009). Several technologies allow the production of freshwater from seawater and brackish water. In general, desalination technologies can be classified into two different processes of separation, namely, thermal and membrane-based desalination. Among the known thermal processes, multiple effect distillation (MED), multistage flash (MSF), and vapor compression distillation (VCD) can be cited while the membrane processes include reverse osmosis (RO), electrodialysis (ED), and nanofiltration (NF).

Processes based on separations' membranes know in this context a great interest. They seem to be very powerful tools for desalination, purification, and recycling of fluids for a "zero waste" goal.

The reverse osmosis technique is the most commonly used technology for desalination where it comprises up to 45% of the total world desalination capacity. The development of desalination applications and positioning of membrane processes compared to thermal processes can boost technological and process innovations in this field. The changes aim to reduce energy consumption, investment, and operating costs.

Furthermore, the reverse osmosis facilities are mainly concentrated in the regions situated around the Mediterranean Sea where energy consumption is lower compared to the other water desalination technologies. The energy consumption of seawater reverse osmosis plants decreased in time from 20 kWh/m^3 in the 1970s to 3.5 kWh/m^3 in the 1990s due to energy recovery, pumping systems, and the development of efficient membranes destined and characterized for seawater (MacHarg and Truby 2004).

However, the costs of water desalination are very high for its intensive use of energy. As seawater has a higher osmotic pressure than brackish water, the energy requirement to desalinate brackish water was estimated below 1.5 kWh/m^3, and it remains lower than that for seawater (Kehal 1991). As the cost to desalinate brackish water is less than other existing alternatives, desalination in many arid and semiarid regions can be the best way to obtain clean and freshwater.

More recently, membrane technology has witnessed an enhancement, resulting in a significant increase in water production with high quality and cost saving.

More improvements of membrane desalination efficiency, namely, the development of new fouling resistant membranes, use of appropriate pretreatment, optimization of reverse osmosis operating factors, brine management, as well as renewable energy coupling to desalination technologies, can contribute to reducing water production cost. Due to rising environmental concerns, renewable energy technologies are most interesting for powering water desalination facilities.

For well over a decade, there have been a large number of experimental and theoretical works on characters that have been carried out in order to make changes and improve the performance of this type of desalination plant. However, in some cases, for example in small rural sites or during disasters where potable water is not available, small RO systems operating using photovoltaic (PV) systems could also be used to obtain drinking water, to help people survive.

Many attempts and experiments have been conducted to find appropriate coupling processes between the RO desalination processes and PV systems as renewable energy resources. This area has continued to attract the interest of many researchers. Several studies focused on this type of configuration by carrying out experimental small plants. With support from the Canadian government, Keefer et al. (1985) developed two small reverse osmosis systems powered by photovoltaic energy in Vancouver, British Columbia, to demonstrate the use and optimization of solar energy consumed with storage batteries (panels have a power of 480 W). To produce demineralized water 0.5–1 m^3/day, they examined the differences between the direct connections of PV reverse osmosis system, the maximum power tracking, and included storage battery. Using a positive displacement pump with variable speed, with energy recovery of the rejected brine, they claim to be able to reduce life cycle costs by 50% compared to conventional systems OI/PV. Other investigations illustrated that power consumption can be reduced to 0.89 kWh/m^3 (Maurel 1991; Kehal 1991), and an attempt was made to model this type of coupling without using batteries as given by Thomson (Fritzmann et al. 2007).

Hanafi (1994) studied the different desalination technologies associated with renewable energy, mainly solar, wind, tidal, and geothermal. He presented some control limits for the use of energy sources including wind, which are more recommended than RO/PV. A systematic approach to renewable energy-powered desalination considering all the alternatives was presented by Rodriguez et al. (1996). Of all the combinations studied, they concluded that RO powered by PV is interesting in very specific cases, such as in sunny remote sites.

A small reverse osmosis system (RO) powered by photovoltaic (PV) systems has been installed and tested at the island of Gran Canada by Herold et al. (1998). A feasibility study of this small PV system RO of 1 m^3/day was presented. The pilot plant, with an average production capacity of 3.2 m^3/day of freshwater, is coupled to a stand-alone PV system and storage batteries. The rated power consumption is 2.35 kW. They described in detail the technical characteristics of the installation (RO) as regards its operating constraints and energy consumption.

Antho Joyce et al. (2001) described a small pilot reverse osmosis unit powered by a PV system that was implemented in the Department of Renewable Energy, INETI. This small compact unit with a daily production of 100–500 L operating at low pressure (<5 bar) with a PV module 3 × 50Wp can produce drinking water from brackish water containing salt concentrations of about 5000 ppm. They presented the preliminary results of laboratory tests carried out in the summer of 2000 in Lisbon. A spiral membrane-type MP-TA50 with a filtration mode coupled with the low pressure operation (<5 bar) enables low power consumption, around 100 kJ/kg impregnation. However, these results related to daily production have been confirmed by other operating conditions by comparing the quality of impregnation and the energy consumed according to pressure. Nevertheless, they may conclude that the energy consumption of the small pilot of reverse osmosis system decreases as the feed water recovery and supply pressure increase. The results of these experiments are used to validate a mathematical model of a system based on the I-V characteristics of PV modules. This model predicts the annual production of drinking water of this unit and the cost of the water produced by this type of system.

In Algeria, Sadi and Kehal (2002) and Kehal (2003) conducted experiments on a reverse osmosis desalination plant installed in Hassi Khebi (south-eastern Algeria) with a capacity of 0.85/h driven by a photovoltaic generator. This unit was acquired as part of the collaboration between the research center CDER (Algeria) and the Commissariat à l'Energie Atomique (CEA France). They presented the evolution of power and pressure versus time; the results were encouraging during the experimentation period, giving a conversion rate of 40.7%. Subsequently, the rate dropped to 24% due to neglect and lack of skilled technicians. Unfortunately, the membranes were clogged, causing a loss of production. They also presented the perspectives and desalination opportunities along the Algerian coast with 1200 km and within the country where several aquifers are characterized by high salinity, 2–5 g/l salts dissolved.

Badreddine et al. (2004) were able to build a prototype of a reverse osmosis desalination unit with 100 L/h at the laboratory scale powered by a photovoltaic energy source (550 W–4.2 A). This innovative concept was installed at AAST in Egypt in the framework of a cooperation project with PROAUT UASZ and supported by SwissContact. The plant is intended for educational and research purposes. This preliminary operation experience shows that skilled personnel is required for operating and maintaining these kinds of desalination systems. They briefly discussed some of the issues of research that can be studied at laboratory scale, by modeling the system to optimize energy consumption, system availability, and production of water under variable weather conditions.

In Jordan S. Abdallah et al. (2005) have presented an experimental study which aims to investigate the potential for water desalination development using a solar-powered system. The results have shown that the reverse osmosis system powered by photovoltaic energy can be easily applied. They may conclude that a gain of 25 and 15% of electrical energy and the flow of desalinated water, respectively, is possible using the tracking system on east-west axis with flat fixed plate. The results are presented in curve form, namely, the electric current, voltage, electric power, and the production rate for a fixed surface and a tracking PV system versus time. Furthermore, the production rate for a fixed surface and a tracking PV system according to electric current was introduced. They reported that more experimental work must be done to study the continuous performance of the system, and further investigation should be directed to the membrane fouling and system recovery.

Different possibilities of coupling RO with the most appropriate sources of renewable energy as hybrid systems (photovoltaic and wind) are presented by Bourouni et al. (2011) using a new model based on the genetic algorithms to minimize the total water cost. Village of Ksar Ghilène located in the south of Tunisia was chosen for this study that presents the case study of PV/RO unit installed since 2007. A comparative analysis with reference software (ROSA for the RO unit and HOMER for the PV modules) was validated.

Numerical simulations on a small-scale, stand-alone, solar-PV-powered (RO) system, with or without battery storage, were reported by Daniel et al. (2013). They note that the system scalability influences the sensitivity of simulations and the type of I-V characteristics used. The results confirm that including batteries to store excess renewable energy has a significant impact on the performance of smaller systems compared to larger ones. Various alternative systems can be used for desalination technology integrating the RO desalination process. Ibarra et al. (2014) analyzed the performance of a specific solar desalination organic Rankine cycle (ORC) system at part load operation. They tried to understand its behavior from a thermodynamic perspective and were able to predict the total water production with changing operation conditions. It is seen that the water production is stable during day and night through the thermal storage where the rate flow was around 1.2 m^3/h.

Current desalination technologies were described by Youssef et al. (2014) by comparing their performance in terms of input and output water quality, amount of energy required, and environmental impact. They suggest that adsorption desalination technology is a suitable technology for seawater desalination with its low running cost and low environmental impact as it uses waste energy resources.

To meet the demand for potable water in areas where reserves are insufficient, the recourse to desalination remains the best solution.

The Algerian government has launched several large-scale programs to eradicate the problem of drinking and irrigation water shortage. Among them are the construction of new dams, water transfer, the implementation of desalination plants, and the development of new treatment plants and wastewater treatment. The aim of this chapter is to review the water shortage problem in Algeria and to present several plants of desalination that can be implemented on the Algerian Mediterranean coastal areas using reverse osmosis technology which are very effective for solving water scarcity problem from economic and environmental viewpoints. As the Algerian population is growing, the need for drinking water is increasing; water desalination is a promising means for producing clean water from saline water abundant in sea and also in the large Saharan region. We choose a case study: Fouka seawater desalination plant by providing its monthly rate production and energy consumption for 1 year.

Water and energy are two main topics for any country's development plan. A small reverse osmosis equipment coupled with a solar energy system such as PV, wind, and CSP (Concentrating Solar Power) could be useful to produce electricity which is able to generate the energy required by membrane desalination reverse osmosis applications. It seems that according to bibliographic research, photovoltaic energy system is an alternative to provide electricity and clean water. The most promising PV energy conversion technologies are available for remote and arid areas. This technology is in development in many regions where various technologies used to desalinate saline water have different performance and characteristics. We conclude that this type of technology is destined to remote areas where the access to electricity and water is a challenge.

2 Problematic and Hydric Resource in Algeria

Algeria is an important Mediterranean country; it faces increasing water shortages due to climate change (low rainfall, desertification, etc.). It stretches from east to west on a long coastline of 1200 km in length. The continual population growth, of which 80% is concentrated in the coastal cities, and business growth in socioeconomic sectors such as agriculture, industry, and tourism have led to increased consumption of water. Desalination and wastewater reuse solutions are imperative for Algeria to overcome water shortage.

Algeria still faces drinking water supply problem; first, mechanisms must be employed to reduce wastage and water leaks, as water remains insufficient in semiarid and arid regions. One solution is the production of freshwater from brackish water and/or seawater. With its ideal location, Algeria has the largest solar resource in the Mediterranean basin. The average duration of the Algerian territory sunshine exceeds 2000 h annually, reaching nearly 3500 h of sunshine in the Sahara desert. The total received power is estimated at 169,400 TWh/year, that is to say 5000 times the annual electricity consumption of the country. Algeria has limited water resources that are unevenly distributed in time and space, and the imbalance between supply and demand of water becomes a major constraint.

Algeria has very limited water resources, largely insufficient to cover domestic, agricultural, and industrial needs. A population of 90% is concentrated in the coastal strip where all economic activities of the country are concentrated, and it requires a considerable water supply. Its climate is diverse according to its geographical diversity and interannual rainfall variability. A variability in rainfall between West (350 mm average rainfall), East (1000 mm) and high relief (2000 mm), which becomes almost absent from the Sahara (average below 100 mm) and a concentration of precipitation over time, is noticed. The evolution of rainfall during 1922–2005 is presented in Fig. 1 for three regions, namely, Algiers, Constantine, and Oran. The figures show strong decrease in rainfall, especially in the Oran region. This situation causes drought cycles. Practically,

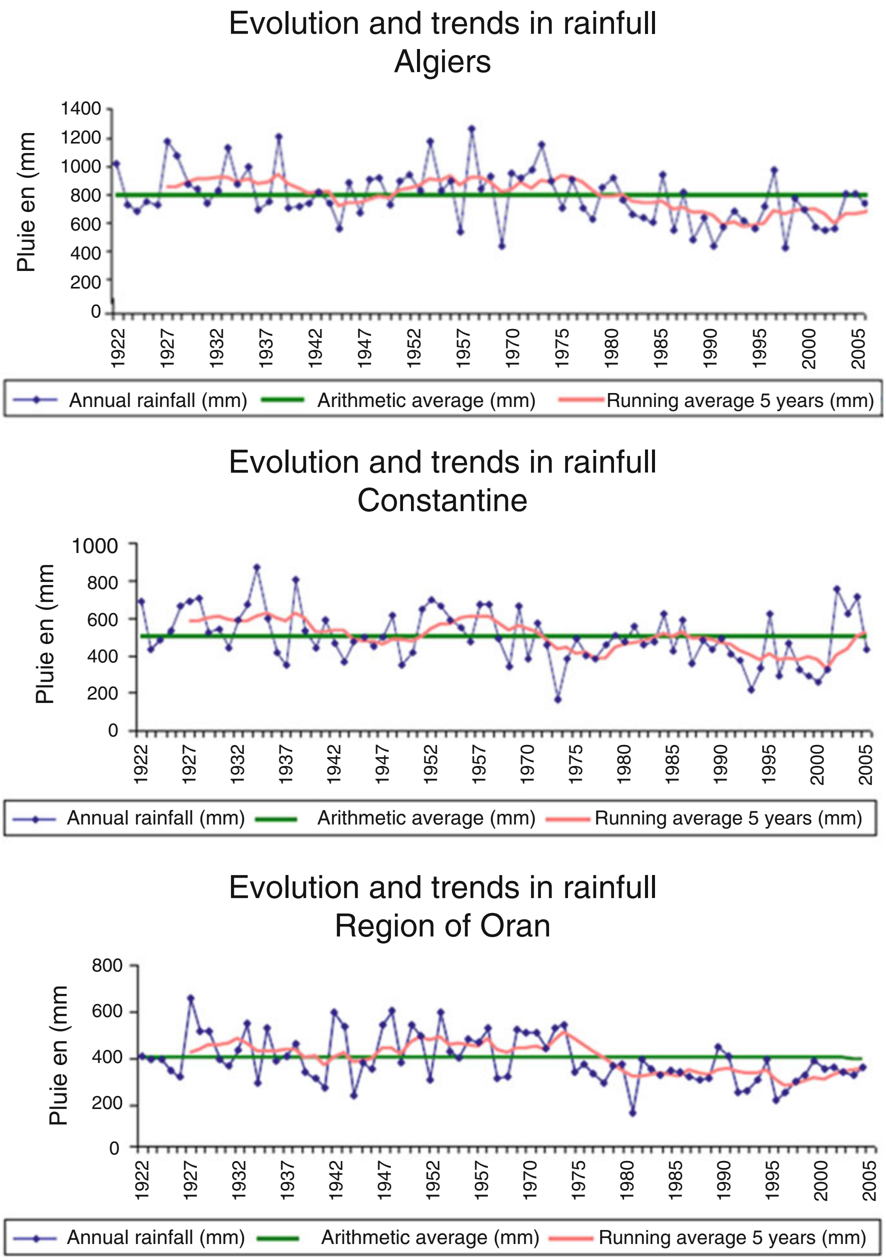

Fig. 1 Evolution of rainfall in three regions (Algiers, Constantine, and Oran) in 1922–2005 (Services de l'eau en Algerie Faire 2011)

Table 1 Total actual renewable water resources in the North African countries in 2005 according to AQUASTAT, FAO

Country	Population (1000 s)	Precip rate (mm/year)	TARWR volume (km^3/year)	TARWR per capita (m^3/year)	TARWR per capita (m^3/year)
Algeria	32,339	100	14	478	440
Tunisia	9937	300	4.6	482	460
Egypt	73,390	100	58	859	790
Morocco	31,064	300	29	971	930
Mauritania	2980	100	11	4278	3830
Libya	5659	100	1	113	106
Sudan	34,333	400	65	2074	1880

the North African countries have a low precipitation rate as shown in Table 1 that depicts water availability in the North African countries in 2005 according to FAO.

The hydrological context of Algeria is summarized within exorheic watersheds whose wadis have the outflow to the Mediterranean Sea, and the endorheic watersheds are formed of the chotts and sebkhas (saline lakes). The Sahara regions have an important subsoil rich in water and oil slicks (fossil fuel) according to Remini (2010).

Among the main technical problems encountered in the dams that affect the quantity and quality of water resources in the north of the country are the evaporation of dam lakes, the leaks in dams, the eutrophication of dam reservoirs, and the intrusion of seawater into coastal aquifers.

The country has five hydrography networks, by grouping 17 watersheds as shown in Fig. 2. Water resources are not equally distributed, in terms of either their geographical distribution, quantity, or nature (surface or groundwater). Water potential is estimated at 19.4 billion m^3/year among them; 12.5 billion m^3/year is distributed in the northern regions (superficial and underground resources) and 5.5 billion m^3/year in the Saharan regions (Problématique du secteur de l'eau 2009).

The country currently has 66 dams with a storage capacity of nearly 7 billion m^3. This number is expected to increase as 19 dams are under construction at present to allow regularize half of the total contribution of the wadis, or 5 billion m^3/year for an installed capacity of around 10 billion, and 20 new dams are planned for 2015. It is estimated that 1.6 billion is their average annual volume. Figure 3 represents the total surface water and groundwater resources and their distribution. In 1962, the annual water availability per capita was recorded about 1500 m^3.

This value was rapidly lowered over time; it recorded 720 m^3, 680 m^3, and 630 m^3 in 1990, 1995, and 1998, respectively. Today, owing to population pressure the annual water availability per capita is 500 m^3; this availability will be only 430 m^3 per capita by 2020. In terms of water potential, Algeria is below the theoretical scarcity threshold set by the World Bank (1000 m^3 per capita per year). Table 2 shows the water availability per capita in Algeria by 2020 (Problématique du secteur de l'eau 2009).

According to the Ministry of Water Resources, Algeria has 50 dams in operation, 11 are under construction, and 50 other dams are being studied; they should be

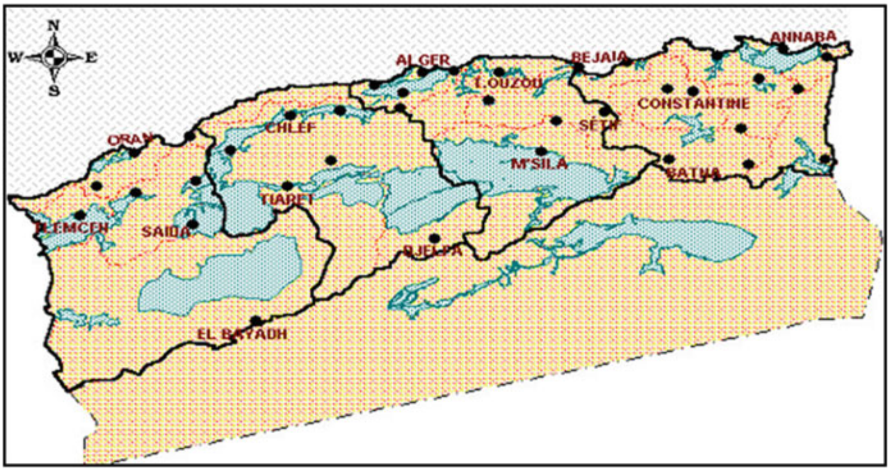

Fig. 2 Map of five geographic planning areas (Problématique du secteur de l'eau 2009)

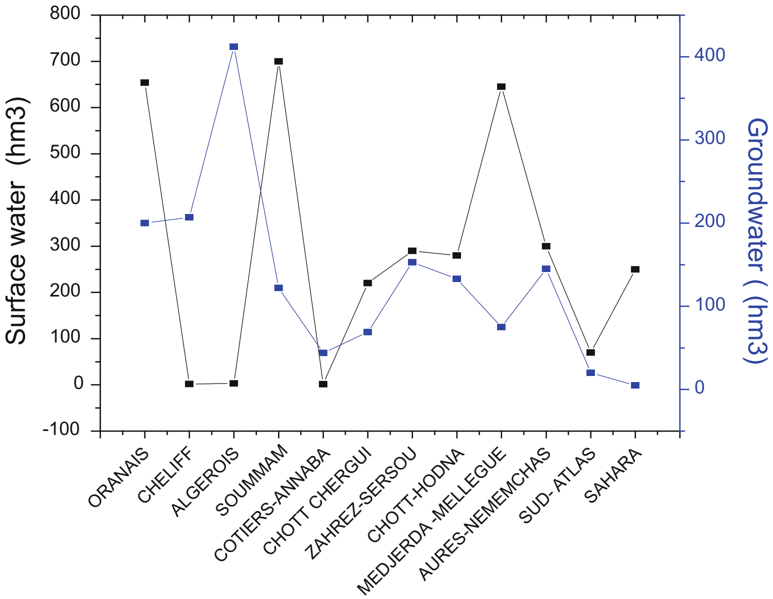

Fig. 3 Potential distribution per basin

completed before 2020 in order to catch up a delay found because of water losses estimated at 50%. Despite the construction of new dams and the use of desalination, Algeria will record a water deficit of 1 billion m^3 by 2025. The lack of resources is compounded by the poor spatial and temporal distribution of these resources, the soil erosion and siltation of dams, and the losses due to the obsolescence of

Table 2 Water availability per capita in Algeria by 2020 (Problématique du secteur de l'eau 2009)

Basin hydrographic	Resources (hm)	Population (106 capita)	Availability (m^3/capita)
Oranie chott Chergui	1400	6.3	220
Chélifer	2072	7.0	300
Algérois Soumma-Hadna	5125	15.8	320
Const-mejd Mellegue	5048	10.0	500
Sud	5436	4.9	1120
Total	64,518	44.0	430

distribution networks and insufficient management. In particular, the desalination of seawater and brackish water is one of the promising techniques for some regions of the country. It responds primarily to drinking water supply and irrigation of agricultural land. For this purpose, desalination is encouraged by the state whose government has installed several desalination plants in Algeria. Several major centers, such as Arzew which provides 90,000 m^3 or center of Beni Saf, have solved the problem of water scarcity in some cities.

3 Seawater Desalination Technology in Algeria

Water and energy are two main topics for any country's development plan. Algeria is the second largest country in Africa and the Arab world after Sudan in terms of surface area, and the largest around the Mediterranean whose southern areas include a significant part of the Sahara (80%). To meet the demand for freshwater in areas where reserves are insufficient, several countries have called on water desalination. The Algerian government has launched several national large-scale programs to eradicate the problem of drinking and irrigation water shortage. Among them are the construction of new dams, water transfer, the implementation of desalination plants, and the development of new treatment plants and wastewater treatment.

Desalination is a process that removes salts from water so that it may be used in municipal and industrial applications. With advanced techniques, desalination processes are becoming cost competitive with other methods of producing freshwater. Two main categories of technologies used for desalination can be classified as thermal and membrane. These technologies need energy to operate and produce clean water. Desalination processes using different techniques are determined by category as shown in Fig. 4.

Due to a severe continuous drought, the Algerian government has adopted a huge desalination program to overcome the water deficit. Thirteen seawater

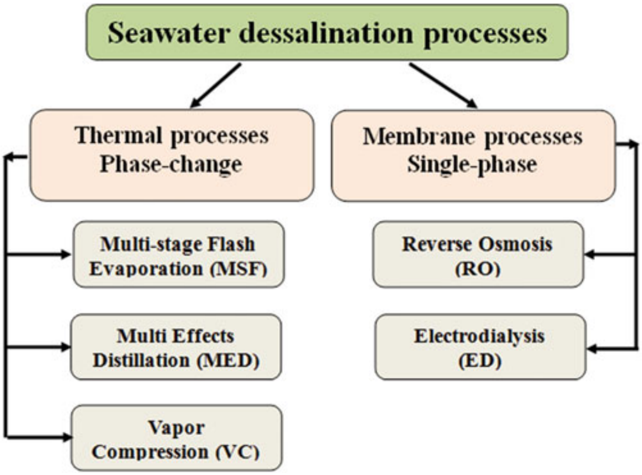

Fig. 4 The main desalination technologies and processes

desalination projects are operational with a total capacity of 2260 million cubic meters, that is, 2.26 billion liters per day. A determined program launched by the government in the last decade aims to deal with the lack of conventional drinking water resources and meet the domestic needs of more than 20 million Algerians. Moreover, 75 dams in construction will bring the overall volume of 6 billion m^3; they will be operational by 2025. Seawater desalination capacity in Algeria increased from 152,500 m^3/day in 2006 to 1. 2 Mm^3/day in 2011. At the end of 2012, the production capacity was 1.3 Mm^3/day, and the total capacity in 2014 reached 2.1 Mm^3/day. In Algeria, reverse osmosis technology is the most used for desalination that represents more than 95% as reported by Fig. 5. The general location and distribution of water desalination plants in Algeria is provided in Fig. 6.

Desalination of seawater in Algeria is an ambitious program; it is implemented through the installation of large seawater desalination plants as El-Magtaâ méga plant near Oran, which is operational since the first semester 2014. It is one of the largest in the world; it uses reverse osmosis process with a capacity of 500,000 m^3/day for the long-term coverage of needs for drinking water of 5 million people. The station of Hamma, called to ensure drinking water supply to Algiers, was inaugurated in February 2008, with a production capacity of 200,000 m^3/day. Figure 6 shows the different desalination plants implemented in Algeria with their capacity in cubic meters per day. We observe that the west region has benefited from a strong desalination capacity in comparison to the center region. The progress of these plants is presented in Fig. 7. This program concerned several regions, namely, Sahara, east, and west cities (Table 3 and Fig. 8).

Now, let us present the evolution of the installed capacity of water desalination in Algeria between 2006 and 2014 as given in Fig. 4 (MacHarg and Truby 2004). It can be seen that the total production capacity of drinking water increases along

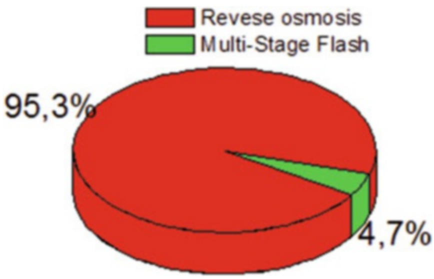

Fig. 5 Energy recovery in reverse osmosis sea water desalination (Ibarra et al. 2014)

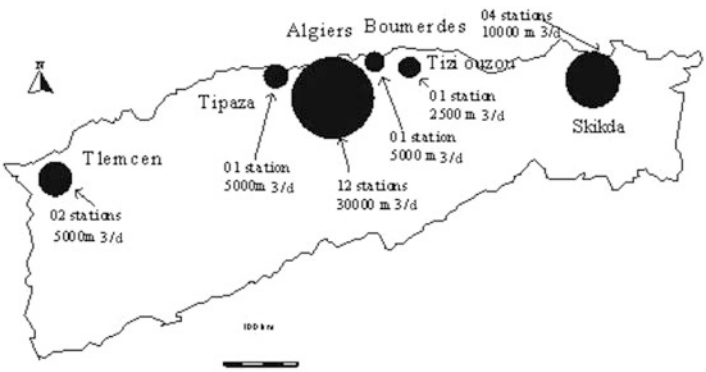

Fig. 6 Distribution of water desalination plants in Algeria (Remini 2010)

time. The following table provides estimates of the capacity that was installed between 2005 and 2010 and which will be installed during 2020–2030. Near-future water needs are estimated according to regions. We note that 16 projects of large units bring the desalted water volume to 942 m^3H for the horizon 2025. The achievement of these 13 seawater desalination plants with a total capacity of about 2260,000 m^3/day made up for the actual need for water despite different technical problems encountered at the station due to electricity cuts (Table 4 and Fig. 9).

In addition to these great stations, the desalination program reveals the presence of some monobloc stations of small capacity (between 2500 and 7000 m^3/day), some of which have been relocated to provide water to the most affected areas (see table 4).

The various stations that exist in Algeria are managed by production companies piloted by the Algerian Energy Company (AEC) which is created by Sonatrach and Sonelgaz groups. The production of freshwater from desalinated water is sold to the Algerienne Des Eaux (ADE) that is a public body of industrial and commercial character. This public body is under the authority of the minister responsible for water resources that was created in April 2001 year by executive Decree No. 01-101. We emphasize that desalinated water prices remained constant for consumers despite the development of desalination plants (Table 5).

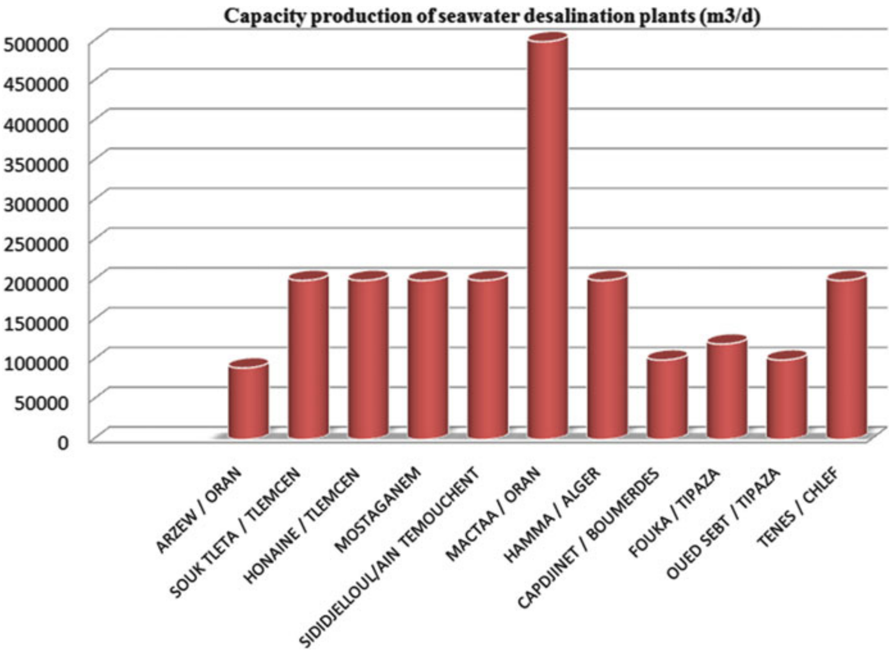

Fig. 7 Capacity of the seawater desalination plants in Algeria

The cost of desalinated water is estimated according to three important elements, namely, financial expenses, energy cost, driving operation and maintenance costs. Over the past decade, the cost of desalination declined by half as the raw materials cost has increased and will continue to increase in the near future. Investment costs are estimated at 900–1000 €/m^3/h for reverse osmosis. The cost of desalinating brackish water is significantly low (0.2–0.3 €/m^3) in comparison to seawater which varies in the range of 0.4–0.6 €/m^3. The desalinated water for large units costs about two times more than conventional water (Ibarra et al. 2014).

4 Case Study: Seawater Desalination Plant of Fouka

The realization of the seawater desalination plant of Fouka is a part of the national program of realization of 13 plants. It is the third station established in the wilaya of Tipaza along with the Bou Ismail station which delivers 5000 m^3/day and Oued Sebt station Gouraya which also delivers 100,000 m^3/day. The seawater desalination plant of Fouka is intended to cover the drinking water needs of the eastern part of the province of Tipaza and part of the western region of Algiers. It is functional since 2011, located in the town of Fouka, Douaouda wilaya of Tipaza and implemented on a surface of 10 ha. This station uses the membrane separation reverse osmosis technique to desalinate seawater; its daily desalination capacity is 120,000 m^3/day.

Table 3 Progress and localization of seawater desalination stations in Algeria (http://www.mre.dz/baoff/fichiers/PROGRAMME_DESSALEMENT.pdf)

Desalination stations of seawater				
Region	Project location	DIM (km) $\ldots < \Phi$ mm $\leq \ldots$	Progress	Investors (SDEM)
West	Ouest Arzew/Oran	37 km $\Phi = 1250$	Operating (August 2005)	Black-Veach (South Africa)
	Souk Tleta/ Tlemcen	157 km $250 < \Phi \leq 1400$	Operating (May 2011)	Hyflux-Malakoff (Singapore)
	Honaine/Tlemcen	160 km $500 < \Phi \leq 1200$	Operating (July 2012	Geida (Spain)
	Mostaganem	117 km $200 < \Phi \leq 1400$	Operating (September 2011)	Inima-Aqualia (Spain)
	Sidi Djelloul/Ain Temouchent	160 km $250 < \Phi \leq 1400$	Operating (December 2009)	Geida (Spain e)
	Mactaa/Oran	21 km $700 < \Phi \leq 1800$	Works in progress	Hyflux-Malakoff (Singapore)
Center	Hamma/Alger	12 km $700 < \Phi \leq 900$	Operating (February 2008)	Ge.Ionix (USA)
	Cap Djinet/ Boumerdes	30 km $900 < \Phi \leq 1000$	Operating (August 2012)	Inima-Aqualia (Spain)
	Fouka/Tipaza	15 km $350 < \Phi \leq 900$	Operating (July 2011)	Snc Lavalin-Predisa (Canada- Spain)
	Oued Sebt/Tipaza	127 km $200 \leq \Phi \leq 1000$	SDEM not launched	Biwater (Angleterre)
	Tenes/Chlef	254 km $200 < \Phi \leq 1400$	Travaux en cours	Befesa Agua (Spain)
East	Echatt/Tarf	20 km $\Phi = 800$	SDEM not launched	–
	Skikda	54 km $400 < \Phi \leq 1000$	Operating (March 2009)	Geida (Spain)
Total	1164 km			

Water produced by the desalination plant will be acquired by Sonatrach, the Algerian waters (ADE) for 25 years. It is equipped with two pumping stations and seven tanks with a capacity of 14,000 m^3 for a total volume of 60,000 m^3 affected for each wilaya. This hydraulic project will cover the needs of 17 municipalities with a total population estimated at 476,372 inhabitants distributed between the two wilayas. The communes supplied with drinking water by this station are Douaouda, Fouka, Bou Ismail, Ain Tagourait, Hattatba, and Chaiba and also the adjoining communes of the province of Tipaza, namely, Zéralda, Mahelma, and Ain Benian Staoueli. This station was carried out by the company "Myah Tipasa" which represents a consortium consisting of AEC (Algerian Electrical Energy) and the Canadian "SNC Lavalin."

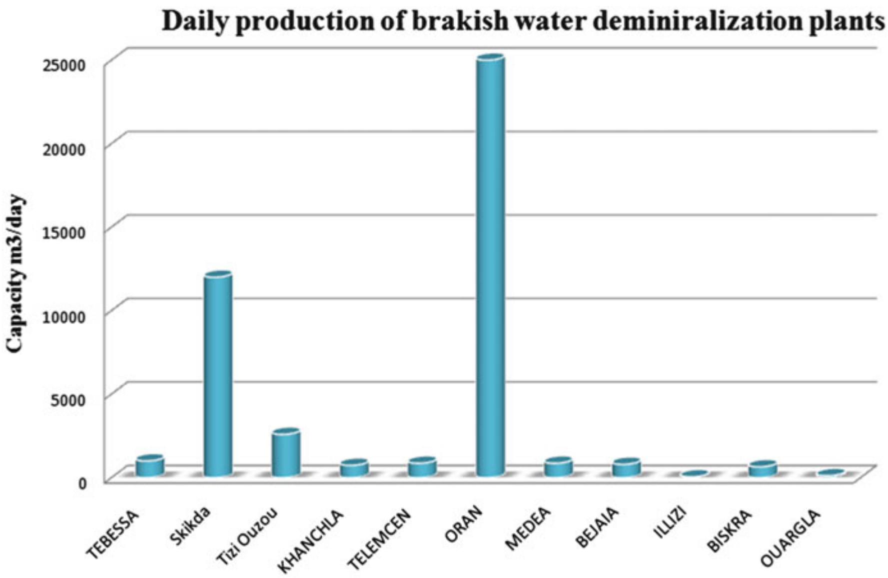

Fig. 8 Capacity of the brackish water demineralization plants in Algeria

Table 4 Seawater desalination program (Services de l'eau en Algerie Faire 2011)

Desalination plants' proposed capacity, m^3/day			
Region	Number of plants	2005–2010	2020–2030
Nord Ouest	6	1,090,000	1,090,000
Nord Center	6	650,000	740,000
Nord Est	4	150,000	380,000
Total program	16	1,890,000	2,210,000
Total desalination program in million m^3/year		690	807

4.1 Basic Diagram of RO

By definition, reverse osmosis is a membrane separation process in which pure water passes from the high pressure seawater side of a semipermeable membrane to the low pressure side of the membrane. It is the most important part of the seawater desalination system. Following the pretreatment (flocculation, chemical treatment, and filtering) and supercharging using the high pressure pump, the seawater enters the membrane and is separated into freshwater that is the permeated water and concentrated brine under the high pressure effect. After further treatment, the clean water is pumped to the terminal users from the storage tanks. The clean water goes to the storage tanks, and after further treatment, water becomes potable. The brine is evacuated into the sea, then further treatment is provided using an energy recovery device (Fig. 10).

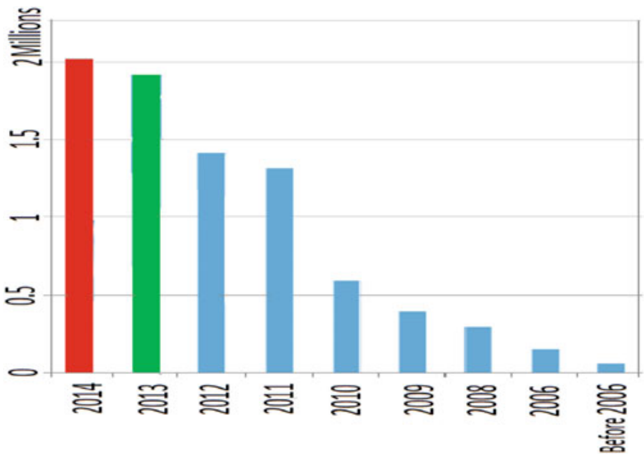

Fig. 9 Evolution of the installed capacity of water desalination in Algeria between 2006 and 2014 (Recuperation D'energie 2014)

Table 5 Monobloc stations of small capacity (Algérienne des eaux. http://www.ade.dz/index.php/projets/dessalement)

Province (Wilaya)	Town	Capacity m^3/day	Population to be served
Alger	Zéralda	5000	33,330
Alger	Staoueli	2500	16,660
Alger	Ain Benian	5000	33,330
Tlemcen	Ghazaouet	5000	33,330
Tipasa	Bou Ismail	5000	33,330
Skikda	L.BenMhidi	7000	47,000
Tizi Ouzou	Tigzirt	2500	16,660
Oran	Bou Sfer	5000	33,330
Oran	Ain Turk	2×2500	33,330
Ain Temouchent	Bou Zdjer	5000	33,330
Ain Temouchent	Bou Zdjer	5000	33,330
Boumerdes	Corso	5000	33,330

4.2 Desalination Production

Now let us present some characteristics and data of Fouka seawater plant that has a capacity of 120,000 m^3/day. It is a private BOO (Build, Own, Operate) contract. The seawater of Fouka is characterized by an electrical conductivity of 56.6 ms/cm and a pH = 8.01 at a temperature $T = 23.3$ °C.

This plant is directly related to the water distribution network of the town. The aim of the Fouka plant is durable supply of freshwater with high quality to several

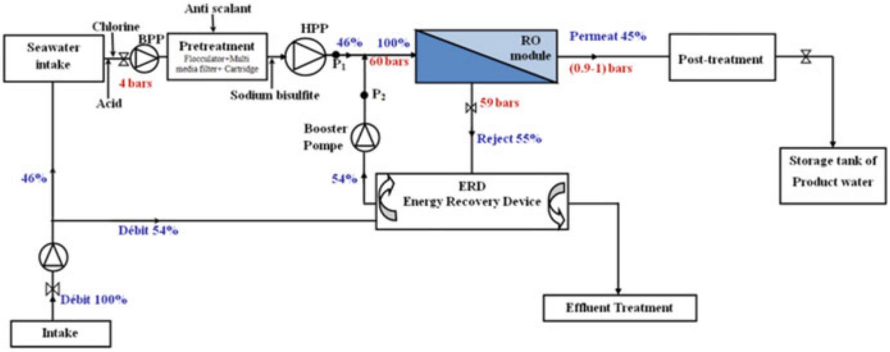

Fig. 10 General diagram of the seawater desalination plant

populations. The table shows the variation of total dissolved solids (TDS) with temperature of the raw water (seawater of Fouka) during 1 year (Table 6).

Figure 11 shows monthly production of freshwater for 2013 and 2014. The monthly production increases when the temperature of water to be desalinated is increased. Indeed, temperature has a significant impact on the production rate. It is seen that the production achieved the optimal range between July and October for the 2 years (2013–2014) when the recorded temperature of the raw water varied in the range 23–24 °C. We note that the minimum production is obtained in December in the case of 2014. As Fouka is a Mediterranean area, the total dissolved solids (TDS) in this region is relatively greater within the range 38–39.5 g/l as illustrated above in Table 6. The variation values of some characteristics such as TDS are very important. From these parameters the quality of freshwater production and the desalination cost can be determined. However, the increase of TDS allows operating the pump for reaching the pressure of 65–70 bar in which this pump HPP (Italian compagny for pumps' manufacturing) consumes more energy. Regarding parameters that can contribute to defining the recovery ratio, seawater has to be analyzed regularly. The evaluation of monthly production of freshwater with energy for 2014 is shown in Fig. 12.

Figure 13 shows the obtained data in which the membrane production of Fouka plant increases and where conversion rate reaches up to a maximum of 46%. The data relates to a plant that is supplied with an average of 38,000 TDS water. We note that, when the conversion rate increases the energy consumption rate increases strongly. It is seen that in the range where the conversion rate of membrane varies between 44.6 and 45.5% the energy consumption does not exceed the value 4 kWh/ m^3, while if the conversion rate exceeds this value a rise of 5% of the energy can be achieved (from 44.6 to 46%); it corresponds to an increase of energy of about 0.215 kWh/m^3. As a result, the reverse osmosis desalination technology requires high rates of energy and generates brackish water discharges.

In fact, the existence of energy recovery systems decreases power consumption, and these are efficient for the production of potable water. Actually, renewable energy can provide a sustainable and alternative solution for reverse osmosis

Table 6 Monthly characteristics of the raw water during 2014

Month 2014	TDS (mg/l) of raw water	T (°C) of raw water
January	38.50	16.00
February	38.90	15.60
March	39.10	15.60
April	39.40	16.40
May	39.50	17.90
June	38.85	21.39
July	38.88	23.99
August	38.68	24.04
September	38.61	24.93
October	38.95	23.20
November	38.38	19.51
December	38.37	17.17

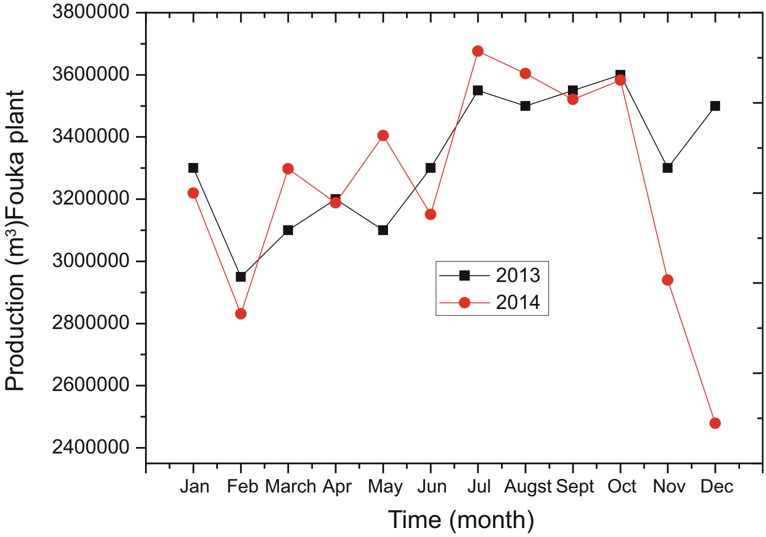

Fig. 11 Monthly production of freshwater for 2013 and 2014

systems that are driven by solar energy. Water desalination technologies operating with renewable energy for the production of drinking water are considered to be a sustainable solution to address the deficit of water in rural areas that have no access to safe drinking water and electrical energy. This principle is currently developed industrially for water purification and seawater desalination (Fig. 14).

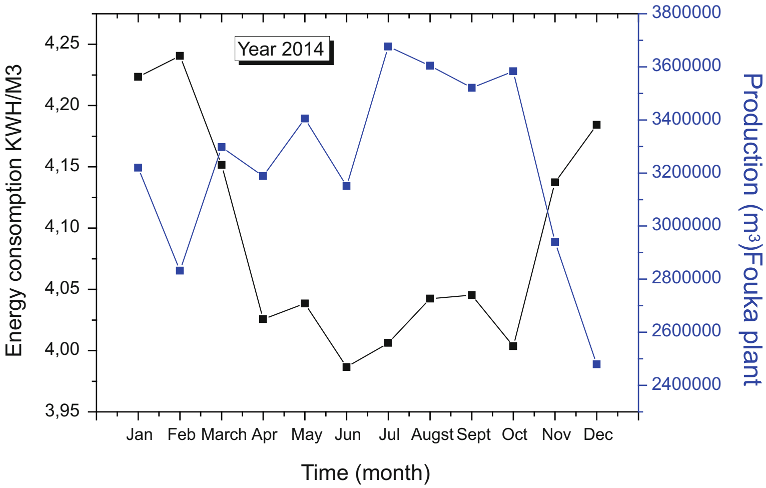

Fig. 12 Variation of monthly production of freshwater with energy consumption versus time for 2014

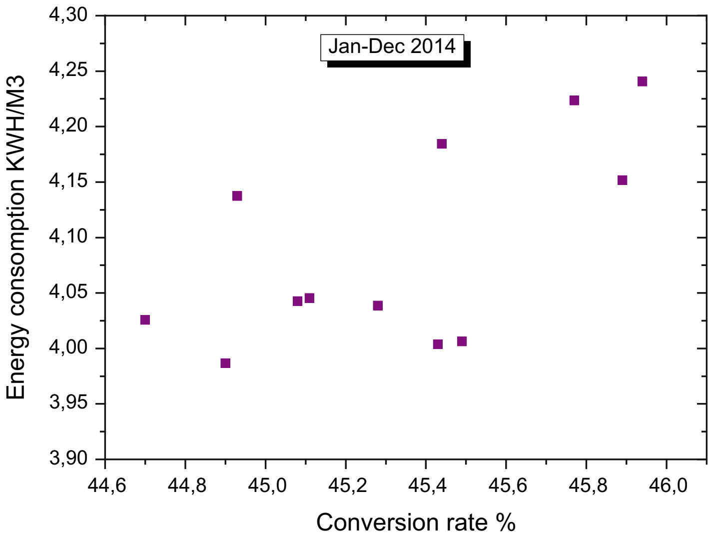

Fig. 13 Plant energy consumption as a function of conversion rate for 2014

5 Conclusions

Seawater desalination technology is used in many regions of North Africa due to population growth, drought, and water scarcity. Different technologies are developed, and they demand high power consumption. Reverse osmosis is the most

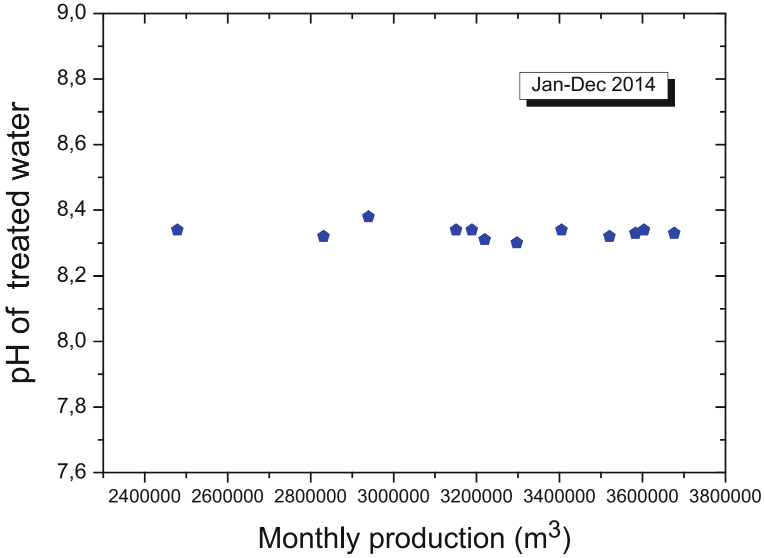

Fig. 14 Variation of treated water pH versus monthly production of freshwater for 2014

suitable process for extracting salt from seawater to meet the increasing water demand.

In this present work, we assessed the currently available seawater desalination plants which are implanted in Algeria. We reviewed the water shortage problem in our country by presenting the main problematic and hydric resources in Algeria. Several plants of desalination located on Algerian Mediterranean coastal areas using reverse osmosis technology and their capacity in cubic meters per day are presented. Case study of seawater desalination plant of Fouka is discussed. Mainly, we show the monthly production of potable water for 2013 and 2014 and their variation of energy consumption with time. Seawater desalination requires much energy and as water demand increases, desalinated water cost increases.

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