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Seawater desalination: Study of three coastal stations in Algiers region ☆

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ABSTRACT

According to recent demographic statistical data, the number of inhabitants in Algeria should double in the next thirty years whereas availability of water resources will not change. The hydrologic situation especially for the coastal areas reflects severe drought conditions that are lasting since two decades. Seawater desalination could be an efficient alternative in order to mitigate the forecasted serious water shortage crisis. In fact, due to rural depopulation a large majority of the people and the economic activities are nowadays concentrated in the coastal cities of the Mediterranean coast along ~1200 km. The good physical and chemical features of Mediterranean seawater (19 °C and medium salinity as compared to that of Persian Gulf which exhibits 30 °C and much higher salinity) make of Mediterranean desalination plants more profitable with less operating costs and better efficiencies.
Reverse osmosis has been chosen as the best desalination process because it has seen many technological improvements especially with regard to better performance and longer membranes lifetimes. The present study focuses on three small desalination plants located not far from the capital city of Algeria (Algiers) namely: Palm-beach sea resort, la Fontaine and Bou-Ismaïl. Our main objective was directed towards the evaluation of the cost of the chemical consumables and the overall cost of the desalinated cubic meter of water. The latter was found lower than 0.5 €, which is quite interesting. All in all, the desalination option seems to be a good alternative to deal with the most urgent matters in terms of ensuring durable water allocation in the climatic context prevailing nowadays.

RÉSUMÉ

Selon les statistiques démographiques, le nombre d'habitants en Algérie va doubler dans les trente années à venir, alors que les ressources hydriques conventionnelles n'auront pas changé. La situation hydrique surtout dans les villes littorales reflète nettement un état de sécheresse, qui dure depuis plus de deux décennies.
Le dessalement se présente comme une solution efficace face au sérieux problème de pénuries d'eau. En effet, par le phénomène de la littoralisation, la plus grande partie de la population et des activités économiques se trouvent le long des 1200 km de côte. Les conditions tout à fait particulières de la mer méditerranée (eau fraîche à 19°c et salinité moyenne, alors que les eaux du golfe sont à 30 °C et très salées) font que les coûts d'exploitation des stations implantées en méditerranée sont plus économiques et les rendements plus élevés. La méthode par osmose inverse a été adoptée pour les stations implantées. Nous sommes intéressés aux stations de : Palm Beach, La Fontaine et Bou-Ismail, qui se situent pas loin de la capitale Alger. L'objectif s'est porté sur l'évaluation du coût des produits chimiques utilisés au niveau de ces stations ainsi que les coûts globaux du mètre cube d'eau potable produit. Le coût global du mètre cube ne dépasse pas 0,5 Euro, ce qui est très intéressant.

1. Introduction

According to demographic forecasts the population of Algeria will double in the next 25 years whereas conventional water resources will not change much since climatic trends are directed towards drier conditions. Seawater desalination option will become thus

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inescapable for a country like Algeria with its 1200 km of Mediterranean seashores.

This choice has been for long left aside due to hesitations motivated by the costly experience of the Arabian Gulf countries. Based on comparative studies specialists have done a lot to make decision makers and high authorities change their mind and become more sensitive to desalination. This is mainly true especially regarding inverse osmosis with its design that is easily adaptable with respect to the water demand.

2. History of desalination in Algeria

The Algerian experience in terms of desalination is closely linked with the development of the petrochemical and steel-making industries. Having recourse to desalination for the unique objective of allocating water to the population has never been thought of seriously and is almost non-existent.

Nevertheless, the only experience that has been tried remains that of the village of Ouled-Djellal located near the city of Biskra (north-eastern part of the Saharan Atlas) where no other choice was available. It was in fact a small groundwater demineralisation plant that was installed in order to decrease the saline load of the local groundwater.

In industry, demineralisation and/or desalination is used to generally provide water for the following parts of the processes:

- boilers,
- cooling cycles
- treatment units.

In 1964 three small desalination units of 8 m^3/h capacity have been installed in the liquid Natural Gas (LNG) plant of Arzew a small industrial port on the western coast of the country. The process that was in use at that time is the “low pressure” immerged tubes. Thereafter in 1969 another unit using the Multi-Stage Flash Evaporation (MSF) technology was then launched with a production capacity of 4560 m^3/day.

Since then numerous other demineralisation or desalination units were put into operation in new built factories and plants. It is the case of high purity water production units installed to fulfil the needs of huge electrical power plant such as that of Cape Djinet (east of Algiers) and the industry of gas liquefaction in both Arzew and Skikda (eastern coast).

Moreover, some smaller units were also used mainly in the Saharan petroleum and gas bases intended to produce quality water for human consumption.

3. Existing and projected units

Some of the units that are present or projected to be built in the country in the near future are listed below:

- Mostaganem — inverse osmosis brackish water desalination unit dedicated to the needs of a paper production plant (52.000 m^3/day — 1994)
- Annaba — inverse osmosis seawater desalination unit of 5.184 m^3/day operated by the fertilizer plant ‘ASMIDAL’ (1996)
- Monobloc units — based on inverse osmosis technology. They were installed in 2002 as a framework of an emergency programme that was intended to face drought conditions in Ghazaouet, Skikda and in the greater Algiers. The total capacity of the former is about 55.000 m^3/day
- Arzew — the construction of a desalination plant that uses the distillation technique (88.000 m^3/day capacity) is still on-going
- Bredea — the building of a brackish water demineralisation unit using the inverse osmosis method (34.000 m^3/day capacity) has also been recently launched
- Hamma (Algiers) — a big seawater desalination plant of 200.000 m^3/day making use of distillation is being built in the immediate vicinity of a brand new electrical power plant
- The electrical power plant of the national electricity and gas company SONELGAZ are provided with small desalination and demineralisation units for the internal use [1].

4. The national emergency desalination programme

The water allocation crisis that was due to severe drought conditions that prevailed during the last decade in numerous regions of the country has a lot to do with the decision of the high authorities to think more seriously about the desalination opportunity. In 2001, the pressure exerted on the public authorities by the population who has suffered harsh water shortage conditions was the catalyser for such a decision as dams and boreholes started to dry up.

The seawater desalination project is part of an emergency programme that was decided in 2002 at a high political and decision making level in order to palliate the lack of natural water resources.

The achievement of such a programme will result in the implementation of 21 small desalination plants with an overall production of a total of 57.500 m^3/day apportioned as follows :

- Algiers province: 12 stations for a daily production volume of 30.000 m^3
- Boumerdes and Tipasa provinces: 01 station each for a daily capacity of 5.000 m^3
- Skikda province: 04 units for a daily production volume of 10.000 m^3
- Tlemcen province: 02 stations for a daily capacity of 5.000 m^3
- Tizi-Ouzou province: 01 unit for a daily capacity of 2.500 m^3

The deal for the project has been concluded and signed between the public company named “Algérienne de Eaux”, for one side and,

1) The national company «Hydro-traitement» since May 11, 2002
2) The German company Linde-KCA since May 11, 2002.

Two main companies own this business monopoly on the Algerian stage in terms of implementing desalination projects. These are namely the ‘Algérienne des Eaux’ (ADE) under guardianship of the Ministry of Water resources and the ‘Algerian Energy Company’. (AEC). The latter company has its equity capital mainly shared by Sonatrach (National Oil and Gas Company) and Sonelgaz (National Company for Electricity and Gas Allocation).

The Ministry of Water Affairs states that all of those plants are operational even though they produce not more than 70% of their total production capacity. Due to technical reasons in relation with the nature of soil where feeding boreholes were drilled, they were inaugurated later on in 2003. As a matter of fact, some boreholes were discarded and replaced by direct intakes from the sea. These problems arise due to lack of sites preparatory studies as projects were launched on an emergency programme. Customers are nowadays using this non conventional water resource and are satisfied with it as long as it flows from their taps and no difference is felt between its features and that of normal water.

The recourse to Water desalination has been decided according to a scheme consisting of implementing small and large plants in order to reach an overall production capacity of the order of 1 Mm^3 per day that is to say the fifth of the country total water requirements as per 2005 (ADE) [1].

5. Desalination cost

It is very difficult to accurately estimate desalination cost without a preliminary survey study taking into consideration local technical and economic conditions. In the early 1980 s, only 20% of desalination plants were using inverse osmosis (IO) [2]. This figure increased to reach 41.9% as compared to the 41.1% making use of the MSF technique (Hydroplus, 2005). That process induces less investment and maintenance costs. The cost of the membranes did not cease to decrease (−50% in ten years). This is the main reason that motivated the Algerian authorities' choice to go for this technique.

For instance, the Hamma desalination plant is the largest MSF plant. The project has been launched early this year 2007 and is composed of two main units designed to produce daily 200.000 m^3 that is to say 30% of the daily required volume for Algiers and its suburbs. It's a 25 years term impact project that will contribute to the drinking water allocation to the capital city. It's a cost shared programme owned at 70% by Ionics, and both AEC and ADE for the rest. The worldwide leader company Ionics is responsible for providing equipment and ensuring operation and maintenance of the plant for 25 years (AEC press release).

5.1. Technical conditions

The technical conditions could be summarised as below:

- Salinity of the water to be treated: seawater or brackish water
- Salinity of the produced water: water for human consumption (according to inhabitants' tolerance) or highly pure industrial water
- Water physical characteristics (turbidity, suspended matter) that can especially in the IO case impose a complex pre-treatment if water is polluted or on the opposite no pre-treatment if water is very clean (case of submarine units in deep seas)
- Chemical composition of water to be treated in the case of brackish water (hardness, sulphates content)
- Automation and control levels
- Source of energy that is available
- Size of the plant [3].

5.2. Economic conditions

Regarding economic conditions one can cite the following:

- Energy coast: negligible for an offshore platform, relatively low in the region of Middle East, and very high for isolated sites
- Cost of chemical variable depending on if they are locally available or being imported and transported over long distances
- Currency fluctuation: this does not allow accurate enough estimations of costs
- Inflation that is variable with respect to country and time
- Funding and financing conditions (interest rates)
- Cost of labour [4].

6. Study of three desalination plants

The present work focuses on the determination and the study of the costs of the reagents that are used for the chemical pre-treatment of seawater before its passage through the membranes.

Three IO desalination plants located on the western coast of Algiers were chosen in order to implement the investigation. Seawater monthly samplings were undertaken during four months of the year 2004 (May, June, July and August) at each plant site in order to analyse for physio-chemical parameters. These analyses were carried out at the ADE Algiers Central Laboratory premises.

6.1. Technical features of the investigated plants

The three studied desalination plants are among the 12 sites chosen in the framework of the governmental emergency programme launched in June 2002 to palliate the water shortage that have happened during the early 2000s for a total capacity of 30.000 m^3/day.

These inverse osmosis plants are located in the provinces of Algiers (02) and Tipasa [1] and are:

- ➢ Palm Beach 2.500 m^3/day
- ➢ La Fontaine 5.000 m^3/day
- ➢ Bou-Ismail 5.000 m^3/day

6.2. The treatment process

The described following steps are identical for the three studied plants:

- ➢ Direct pumping of raw seawater through an intake pipe, except for Zeralda plant where pumping of raw seawater is carried out by means of boreholes pumps
- ➢ Pre-chloration using sodium hypochlorite
- ➢ Filtration on multilayer gravel filter
- ➢ Acid or sodium hexametaphosphate injection
- ➢ Cartridge micro-filtration (5 µm)
- ➢ High pressure pumping
- ➢ Inverse osmosis
- ➢ Re-mineralization
- ➢ pH adjustment
- ➢ Sodium hypochlorite post-chloration
- ➢ Membranes cleaning.

6.3. Operational mode

In addition to the manual and the semi-automatic operation (board of commands) each plant is equipped with a programmable robot (PLC) enabling via software to take control and manage the operation of the plant.

The PLC allows the efficient survey of the exploitation scheme, the balance control, measurements recording, readings survey, counting and launching of the equipments.

6.4. Conception criteria

6.4.1. Raw water data

pH	~7–7.5
Temperature	20 °C
Salt content	~35–39 g/l

6.4.2. Operation requirements

Table 1

Table 1
Operating conditions.

Parameters	2500 m^3/day plant	5000 m^3/day plant
Daily operating time (H/day)	24	24
Annual operating time (days)	~340	~340
Minimum seawater flowrate (m^3/day)	5556	11,111
Filtrate evacuation flowrate (m^3/j)	2500	5000
Concentrate evacuation flowrate (m^3/j)	3056	6111
Conversion rate	45%	45%
Inverse osmosis pressure (bar)	73	73
Operating temperature (°C)	20–25	20–25

6.4.3. Filtrate requirements

- ➢ Daily capacity 2500 (5000) m^3
- ➢ Salt content ~350 mg/l
- ➢ pH value 7–7.5
- ➢ Temperature 20 °C
- ➢ Chloride content ~1–2 mg/l.

Table 2
Filters' technical features.

Capacity (m^3/day)	2500	5000
Number	4	6
Flowrate (m^3/j)	231	462
Diameter (m)	2.8	2.8
Height (m)	3.6	3.6
Filtration area/reservoir (m^2)	~6.15	6.15
Total filtration area (m^2)	~24.6	36.9
Admissible pressure (bar)	6	6
Operating temperature (°C)	20	20
Filtration speed (m/s)	~9.4 (12.5/3 filters in operation)	12.5 (15.0/5 filters in operation)
Counter current cleaning water (m^3/m^2h)	~25	~25
Counter current cleaning air (m^3/m^2h)	68	68
Filtration layers		
Material	Sand	Sand

6.4.4. Offshore intake

The direct offshore seawater intake is ensured by a centrifugal pump which minimum flowrate is estimated to be 231.5 m^3/day via an 800 mm diameter and 4 km length pipe. The pump is submerged at a depth equal to six metres.

6.5. Raw water settler

It is within this intermediate reservoir that the following processes do take place: the pre-chloration, the coagulation/flocculation and the decantation as well. This tank is made of concrete whose dimensions are as follows: 7 m × 3 m × 4 m.

6.6. Chemical injection stations

These are composed in principle of a reservoir where the chemicals to be injected are prepared. They are equipped with level gauges and magnetic injection pumps provided with an aspirator.

6.7. Multilayer filter

The characteristics of the plants' gravel filters are summarised in the following table (Table 2).

6.8. Pressure tubes

Pressure tubes for each plant are illustrated in the table (Table 3).

6.9. Membranes

The membranes that are used in the three investigated IO plants have the technical features as illustrated in the following table (Table 4).

7. Reagents

It can be deduced from the above mentioned information that the chemical and the physical pre-treatments as well as membranes cleaning are of the utmost importance. As the membranes represent a major part of the investment for desalination plant, their lifetime depends much on the efficiency of the previously mentioned treatments. The cost of the chemical treatment comes in third position after energy cost. The overall production cost of the desalinated cubic metre of water as computed by the “Algérienne Des Eaux” was estimated to be 35.2 DZD (DZD = Algerian Dinars, 1 € = 9 DZD) where only 12% are for the cost of chemical reagents.

The following table summarises the reagents' costs at the three selected plants during the four sampling months (May to August) (Table 5).

One can note that the percentages of the costs that are due to reagents are relatively important and variable from a plant to another.

This cost depends on the physio-chemical parameters of the pumped seawater; these features are criteria of the aptitude for seawater to be desalinated.

Table 3
Pressure tubes characteristics.

Capacity (m^3/day)	2500	5000
Pressure tubes number	27 (+1 spare)	54 (+2 spares)
Membranes number per pressure tube	7	7
Number of high pressure pumps	1	2
Material	Super-duplex	Super-duplex
Operating pressure (bar)	73	73

Table 4
Membranes technical features.

Capacity (m^3/day)	2500	5000
Membrane number	196	392
Membrane number per pressure tube	7	7
Manufacturer/model	Hydranautics/SWC3	Hydranautics/SWC3
Membrane nature	Polyamide composite	Polyamide composite
Type	Winded	Winded
Size	0.2m × 1 m	0.2 m × 1 m
Operating pressure	75	75
Max. pressure loss over 7 membranes	4.2	4.2
Operating temperature	~25	~25
Max. cleaning temperature	50	50
Operating pH	2–11	2–11
Cleaning pH	1–12	1–12
Conversion rate	45%	45%
Annual decrease of filtrate flow	~7%	~7%
Annual salt losses	~10%	~10%

8. Conclusion

Inverse osmosis process efficiency depends much on the salinity but also on the turbidity and other physio-chemical of raw seawater. In depth investigations are thus required in order to precisely assess the quality of the pumped seawater. These should aim at finding the best possible chemical pre-treatments and consequently use the adequate reagents concentrations that would lead to desalination process cost optimisation.

Three plants were investigated with a focus on the evaluation of the overall production costs and the percentage that is due to chemical reagents over a period of four months. The overall cost of the cubic metre of desalinated water was found in the range of 35 to 47 DZD with a percentage range of 14 to 18.5% which is due to the reagents cost. This is higher than the average cost of the cubic metre of desalinated water as computed by the ‘ADE’ which was found to be 35.2 DZD where 12% are due to chemical reagents that is to say 4.22 DZD/m^3.

For the sake of optimising costs, a more detailed study on the variation of the chemical reagents cost contribution to the overall production cost for the desalinated water is required.

Table 5
Reagents costs.

Plant	La Fontaine	Palm Beach	Bou-Ismail
Global cost (DZD/m^3)	46.67	28.44	34.67
Cost percentage due to reagents	16.0%	18.5%	14.0%

The major disadvantage of desalination plants is their expensive cost (>200,000,000 DZD). While investment expenses are already very high, it is to be known that the exploitation of such plants requires quite expensive running costs. Presently the citizen pays a relatively small price which is around 4 DZD/m^3. The desalination programme may help to adapt the offer with the demand by associating a global water management policy.

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