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Desalination experience in Morocco

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Abstract

The desalination experience of the National Office of Potable Water (ONEP) is closely related to the water supply in south Moroccan areas which lack fresh water and have limited brackish water resources. The desalination plants built and currently operated in these areas are located in Boujdour (MED MVC 250 m^3/d and SWRO 800 m^3/d), Tarfaya (BWRO 120 m^3/d), and Laayoune (SWRO 7000 m^3/d). The operation of these seawater desalination plants reveals the following: (1) The MED–MVC process is very reliable and has a very high availability. The new version of this process (four to six effects or more) which requires an energy consumption less than 10 kWh/m^3 (against 20 kWh/m^3 for the old version) could compete with RO and needs to be compared to this latter process for small capacities in remote areas. (2) The SWRO process requires skilled manpower and continuous control. The cost of water seems to be more attractive than for thermal processes. In order to complement its desalination experience further, ONEP has carried out the following feasibility studies: (1) design of an MSF plant using solar energy from a solar pond. The pilot project size is 300 m^3/d of potable water; (2) design of a vertical tube multiple effect distillation (VT–MED) plant coupled to a nuclear heating reactor (NHR) insuring 10 MW thermal. The desalination plant was designed to produce 8000 m^3/d of potable water. These studies show that desalination using nuclear energy or heat extracted from a solar pond is relatively expensive for smalls capacities of potable water. Nevertheless, they could be implemented as demonstration plants for future introduction of large-scale desalination units. This paper gives an overview of the operation of the desalination plants and draws conclusions regarding their feasibility.

Keywords: Desalination; Morocco; Solar pond; Heating reactor

1. Introduction

Large quantities of fresh water are required in many parts of the world for agricultural, industrial and domestic uses. Lack of fresh water is a prime factor in inhibiting regional economic development.

The oceans constitute an inexhaustible source of water but are unfit for human consumption due to their salt content, in the range of 3% to 5%. Seawater and sometimes brackish water desalination constitute an important option for satisfying current and future demands for fresh

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water in arid regions. Desalination is now successfully practiced in numerous countries in the Middle East, North Africa, southern and western US, and southern Europe to meet industrial and domestic water requirements. Fresh water produced from seawater desalination plants based on either evaporative or membrane process fully meets drinking water quality standards set by various countries in the world. Desalination is a very safe source of water comparatively to conventional water supply schemes.

ONEP's experience in desalination is in supplying water to Saharan provinces of the kingdom which lack fresh water and have limited brackish water resources. Desalination plants were built as follows:

Year	Process	Capacity, m^3/d	Location
1975	ED (BW)	75	Tarfaya
1977	MED–VC	250	Boujdour
1983	BWRO	120	Tarfaya
1995	SWRO	7000	Laayoune
	SWRO	800	Boujdour

The development of desalination depends on the improvement of the desalination equipment and the reduction of the energy cost by using an appropriate energy source for the desalination plant. ONEP has carried out the following feasibility studies to improve equipment and reduce cost of energy:

- Design of an MSF plant (300 m^3/d) coupled to a solar pond as an energy source.
- Design of a VT–MED plant (8000 m^3/d) coupled to a nuclear heating reactor (NHR) insuring 10 MW thermal.

This paper gives an overview on the operation of these seawater desalination plants (because brackish water desalination plant capacities are limited).

2. ONEP's experience with seawater desalination

2.1. Experience in operation

2.1.1. MED–MVC plant (Boujdour)

This plant was built in 1977 and was in operation till 1995. It had a capacity of 250 m^3/d. Some components of the compressor were replaced in 1991. Its shut-down was due to its limited capacity that could not meet the actual water needs of Boujdour and particularly to its specific energy consumption (around 20 kWh/m^3 of distilled water). The seawater intake was insured through two beachwells, and pretreatment was limited to the injection of an anti-scalant reagent. The desalination process was based on mechanical vapor compression using a single effect operating at a temperature of 36°C.

The required seawater flow rate was 624 m^3/d (TDS = 36,000 ppm, T = 15°C minimum) and the brine recirculating flow rate was 3360 m^3/d). The product water TDS was around 50 ppm.

Through 18 years of operation, it was found that the MED–MVC process has a sufficient availability and is reliable. The new version of this process (four to six effects or more with an energy consumption less than 10 kWh/m^3) could compete with reverse osmosis (RO) and needs to be compared to this latter process for small capacities in remote areas.

2.1.2. Seawater reverse osmosis plants (Laayoune and Boujdour)

In order to choose reliable technology that could be adapted to the relatively large capacities and specifications (energy costs) required to solve water shortage problems in the Saharan provinces, ONEP formed a committee, which at the end of the 1990s visited several countries that had accumulated experience on research and operation of seawater desalination plants producing potable water (Middle East, Canary Islands, Malta, etc.). As a result, desalination using the RO process was adopted and two SWRO plants (Laayoune, 7000 m^3/d and Boujdour, 800 m^3/d) were built in 1995. We briefly present the Laayoune plant, which was conceived on the basis of the same process as Boujdour.

The largest desalination plant currently operating in Morocco is the Laayoune seawater RO plant with a capacity of 7000 m^3/d. The water intake is ensured through beachwells, and pretreatment consists of chlorination, acidification (H_2SO_4) required for adequate coagulation, coagulation using ferric chloride, pressure filtration through sand filters, acidification to reduce calcium carbonate precipitation at the membrane level, injection of an anti-scalant agent (Flocon 260) to reduce sulphate precipitation at the membrane level, microfiltration using 5 μm cartridge filters and dechlorination via sodium metabisulphite (SBS).

The plant uses a brine staging design concept and has four trains, each with a capacity of 1750 m^3/d. The RO section of the plant uses Dupont polyamide hollow-fiber membranes (B10-6845T).

The design specifications were as follows:

- Seawater TDS: 40,000 ppm
- Silt density index: below 2.5
- Maximum pressure: 70 bars
- Recovery ratio: 45%
- Desalinated water TDS: 1000 ppm
- Energy recovery of the brine: Yes

Post-treatment consists of adding caustic soda (for pH adjustment) to minimize corrosion of the product water delivery pipes and the distribution network. Then chlorine is added to disinfect the product water before its distribution for human consumption. The desalted water coming from the RO plant is blended with brackish underground water in the Carrefour reservoir before being pumped to Laayoune city. The RO plant needs a nominal power supply of 2 MW, and the entire plant's process is automated. The plant was commissionned in November 1995 and has been operating ever since at a constant production capacity of 7000 m^3/d.

The main problems encountered during the operation of the plant are described below:

1. Biological contamination and rapid drop in pressure through some trains occurred many times during 7 months of operation without prechlorination dosing. An inspection of the installations was carried out, and a large amount of gelatinous material was found on the bottom and walls of the concrete seawater reservoir. On the basis of these observations, the following actions were taken:

- Complete disinfection from the seawater reservoir to the high-pressure pumps with about 10 ppm of chlorine for 24 h
- Extended flushing of system following disinfection
- Hypochlorite cleaning at high pH (11.8–12)
- Citric acid cleaning at pH 4
- On-line PT-B of the trains
- On-line PT-A of the trains

As a result, system pressure dropped from 4.5 bars to 2.7 bars (across the system), and coliform in the product water was removed.

2. The aggressivity correction facility of the product water, ensured at the present time by caustic soda dosing, is inefficient because it does not allow this water to be brought to its calco-carbonic equilibrium. In fact, the produced water damages the equipment and attacks the transport canalization. This has been confirmed through a pH increase in the product water, which reaches 10 at the level of the Carrefour reservoir (located 9 km from the desalination plant), whereas it was 9 at the outlet of the plant. The only solution for this problem is to remineralize the product water with calcium and bicarbonates. A study has been carried out and has confirmed that filtration with a medium of dolomitic calcium is the most appropriate treatment to ensure remineralization.

Given the results of 5 years of operation, the most suitable pretreatment conditions were found to be:

- Complete disinfection (once a week) from the back-wells to the seawater reservoir, with about 10 ppm of chlorine for 6 h
- Sulfuric acid: 20 ppm
- Flocon 9 ppm
- SBS 3 ppm
- Feed pH 6.5
- Back-wash cycle for sand filter cells 20 days
- Replacement of cartridge microfilters: every 4 months
- Chemical cleaning of RO trains: every 4 months

Under the above conditions, an SDI of less than 1 is consistently maintained in the feed without ferric chloride dosing and continous pre-chlorination.

Key operating features to produce 7000 m^3/d are:

- Operating pressure: 67 bars
- Product salinity: 750 ppm
- Power consumption: 5 kWh/m^3
- Water cost: 2.0 US $/$m^3$

The following conclusions can be made:

- The performance of Laayoune seawater plant exceeds projections both in respect to production and product salinity.
- The correction of the product water aggressivity has to be made on the basis of calcium and bicarbonates.

2.2. Results of feasibility studies

Most of the large plants based on thermal and membrane processes are located near thermal power stations which utilize fossil fuels to supply both steam and electrical power for desalination. The use of fossil fuels to supply current and future water needs has several drawbacks. Combustion of these fuels emits large amounts of greenhouse gases in the environment, which contribute to global warming . These fuels are also non-renewable ressources, and their known reserves are projected to be exhausted (for oil, especially). Because of their versatility as an energy source and hydrocarbon feed stock, there is a keen interest to conserve fossil fuels for other industrial applications, especially in countries having inadequate sources. Nuclear energy and renewable energy sources (solar, thermal, photovoltaic and wind energy) could be considered as alternative energy sources for desalination. In this respect, ONEP has carried out the following feasibility studies.

2.2.1. MSF desalination process coupled to a solar pond

The MSF desalination process coupled to a solar pond was evaluated in 1996. The desalination plant was designed to produce 300 m^3/d of potable water.

Solar pond technology is used on a large scale for energy collection. The water capacity of the pond represents intermediate heat storage and ensures a continuous heat supply for the desalination plant. The solar pond has three zones:

- The top zone is the surface zone which is at atmospheric temperature and has little salt content.
- The bottom zone is very hot (80°C) and salty (TDS = 200 g/l) . It is in this zone that solar energy is collected and stored in the form of heat.
- The intermediate zone is where the salt content increases from the top to the bottom, thereby creating a salinity or density gradient.

The mean conclusions of this study are presented below:

- Required area for the solar pond: 34,000 m^2
- Total investment cost: 43 million US $
- Water cost: 5 US $/$m^3$

2.2.2. Feasibility study of a VT–MED plant coupled to a nuclear heating reactor

Nuclear desalination (ND) has been studied by the International Atomic Energy Agency (IAEA) since 1989 when members states requested the Agency to assign high priority to this topic. With the assistance of experts from member states, the IAEA has been involved in several activities, coming to the conclusion that the use of nuclear energy for desalination is technically feasible and that for medium and large plants, costs are in the same range as conventional energy sources. The IAEA also concluded that ND needs practical demonstrations to build up confidence in its technical and economical viability. The combination of a thermal desalination process (MED) with a heating reactor was identified as a possible option for ND demonstration.

China and Morocco have always supported the IAEA's programs and projects on ND and have contributed to expert meetings and feasibility studies. During the period 1996–1998, China and Morocco participated in a technical cooperation project supervised by the IAEA to carry out a preliminary project study of a nuclear desalination demonstration plant (NDDP) with a 10 MW nuclear heating reactor (NHR 10) from China to be built in Tan Tan (southern Morocco).

The plant was planned with a capacity of 8000 m^3/d of potable water and provides the basis for future large0scale desalination units with 200 MW reactors and a capacity of 160,000 m^3/d.

The conclusion of this preliminary project's study are:

- There are no conditions which could prevent the construction and safe operation of the nuclear desalination plant; the radiological, thermal, and chemical impact on the environment and population is mastered and negligible.
- The NDDP consisting of the 10 MW heating reactor from China coupled to a MED process is technically feasible for the Tan Tan site. The plant will produce 8000 m^3/d of potable water for its growing population, expected to reach 70,000 inhabitants by the year 2010.
- The 10MW heating reactor design is based on the proven technology of the 5 MW NHR located at the Institute of Nuclear Energy Technology of China. This latter has been successfully operated since 1989.
- The NHR 10 design complies with IAEA safety standards.
- The NHR 10 is designed for easy operation and maintenance and achievement of high reliability and availability as required for water production plants. During any outage of the nuclear reactor, a back-up oil-fired boiler ensures continuous production of potable water.
- An advanced MED version with a vertical tube arrangement was selected for this project even if experience with this process is still limited to some countries, but its higher efficiency at a steam temperature of 130°C entering the first effect justifies its selection.
- Desalination water quality will be in compliance with Moroccan standards. Specific design features and continuous accurate monitoring of the produced water before its distribution will ensure that no radiological contamination could occur.
- Water costs are in same range as potable water produced by fossil thermal desalination plants with the same capacity.
- Considerable cost reductions will be achieved for the large desalination plants with 200 MW heating reactor of the same design, producing 160,000 m^3/d. The potable water cost is then estimated at 1.0 US \$/m^3.
- The national share of the construction of the NDDP could reach 40%, which will have a positive impact on training qualified personnel, capabilities of the national industries, and the establishment of a licensing framework.
- The estimated period for the construction of

the 10 MW plant is 36 months, and additional lead time will be needed for implementation of the project.

3. Conclusions

- The MED–MVC process has a sufficient availability and is reliable. The new version of this process (four to six effects or more with an energy consumption less than 10 kWh/m^3) could compete with RO and needs to be compared to it for small-sized capacities, especially in remote areas.
- The results of the two feasibility studies show that desalination using nuclear energy or heat extracted from solar ponds is relatively expensive for small capacities of potable water. Nevertheless, they could be implemented as demonstration plants for the introduction of large-scale desalination units.