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# Autonomous desalination units for fresh water supply in remote rural areas

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**Abstract.** Two autonomous desalination units were installed in two different villages to provide drinking water to the populations. These autonomous desalination units were installed in the framework of the ADIRA project. They both consist of a reverse osmosis unit (production capacity of 1m$^3$/h) which is powered by a photovoltaic plant (3.9 and 4.8 kWp). The systems are described, their water production and energy consumption are presented and their potential as an alternative water supply in remote areas is discussed.

**Keywords.** Desalination – Brackish water – Reverse osmosis – Photovoltaic energy – Autonomous systems – Rural areas.

***Unités autonomes de dessalement pour l'approvisionnement en eau douce des zones rurales éloignées***

***Résumé.*** *Deux unités autonomes de dessalement ont été installées dans deux différents villages afin de fournir l'eau potable aux populations locales. Ces unités autonomes de dessalement ont été mises en place dans le cadre du projet ADIRA. Elles consistent en une unité d'osmose inverse (capacité de production de 1m$^3$/h) qui est alimentée par une installation photovoltaïque (3.9 et 4.8 kWp). Les systèmes sont décrits en présentant la production d'eau et d'énergie et en mettant l'accent sur leur potentiel comme alternative pour l'approvisionnement en eau des régions éloignées.*

***Mots-clés.*** *Dessalement – Eaux saumâtres – Osmose inverse – Énergie photovoltaïque – Systèmes autonomes – Zones rurales.*

## I – Introduction

The supply of drinking water to rural areas is a challenging problem especially when brackish or sea water is the only available resource within reasonable distances. The provision of drinking water is usually carried out by children and women at the expense of schooling and other income generating activities. In addition, in some cases, the available brackish water is used for human consumption which further results in health problems..

On the other hand, fresh water resources in Morocco and other countries are characterized by their large regional variability and increasing scarcity. The situation is worsening in recent years due to climate changes, re-occurring droughts and increasing demand. The exploitation of brackish and seawater resources is therefore becoming increasingly necessary especially in remote rural areas where these are the only available resources. Furthermore, some of these remote rural areas are not /or are weakly electrified. In such cases, desalination systems powered by renewable energies (referred to as autonomous desalination systems, ADS) may offer an attractive alternative to provide drinking water for such villages, especially when electricity grid access is not economically possible (Karagiannis *et al.*, 2007; Outzourhit and Mokhlisse, 2008; Manolakosa *et al.*, 2008; Mohameda Essam *et al.*, 2008)

As a part of its activities in rural areas, Fondation Marrakech 21 (FM21) has recently installed two reverse osmosis (RO) desalination units powered by photovoltaic energy to provide drinking water for the populations of two villages (**Outzourhit and Mokhlisse, 2008**). This task was carried out in the frame work of the ADIRA project (Autonomous Desalination system concepts for seawater and brackish water In Rural Areas with renewable energies- Potentials, Technologies, Field experience, Socio-technical and Socioeconomic impacts), which is co-funded by the European Union Karagiannis *et al.*, 2007. Through the implementation of pilot autonomous desalination units with different technologies and under different boundary conditions, the ADIRA project has intended to demonstrate that this technology may offer an interesting alternative for decentralized drinking water supply in such zones, by using in particular, distillation and membrane techniques powered by renewable energy sources such as solar thermal, photovoltaic and small wind turbines.

In this work, a description of the various parts of the desalination units installed by FM21 is given. Some results obtained from the monitoring the desalination plants are also presented.

## II – Characteristics of the two rural villages

Following a survey of different villages in the Alhouz and Essaouira provinces, and a set of pre-selection criteria, two villages were selected by FM21 for the implementation of the ADIRA project:

– The first, Benssaine village, rural commune Tamaguerte in the Alhaouz province;

– The second, the Msaim village, Had Dra Commune, in the Essaouira province.

The PV-powered reverse osmosis units are designed to provide drinking water for the population of each village using the existing brackish water points. The main characteristics of the two villages are given in table 1.

**Table 1. Main characteristics of the two sites.**

| | Benhssaine | Msaim |
|---|---|---|
| Location | Rural commune Tamguerte, Province of Alhaouez | Rural commune Had Draa, province of Essaouria |
| Water point | Borehole, 160 m | Well, 20 m |
| Salinity (g/l) | 6 | 4.5 |
| Pumping system | Electrical pump/ Diesel Genset (Lombardini, 20 KVA) | Vertical axis Pump* Diesel motor |
| Water reservoir | 25 $m^3$ | 25 $m^3$ |
| Water distribution | Distribution Network | Fountains |
| Number of households | 40 (1 agglomeration) | 60 (6 agglomerations) |

Chemical and bacteriological analysis of the water of both sites was carried out. The results are given in table 2. Given the high salinity of the water of the two sites, we opted for reverse osmosis. In addition, for the two sites, PV-powered RO unit was installed to provide drinking water for each village given the high solar energy potential of the two sites (> 5kWh/$m^2$/day). The chemical analysis revealed also the need for anti-scaling agents for both sites.

**Table 2. Chemical Analysis of the water for the two sites.**

| | Benhssaine | Msaim |
|---|---|---|
| pH | 7,67 | 7,2 |
| Conductivity (mS/cm) | 11,38 | 7,34 |
| Temperature (°C) | 25,5 | 22,8 |
| Dissolved oxygen (mg/l) | 8,2 | 3,7 |
| TDS (g/l) | 6,6 | 4,1 |
| TH (meq/l) (Ca/ Mg) | 24 | 52,8 |
| $Ca^{2+}$ (mg/l) | 204 | 430 |
| $Mg^{2+}$ (mg/l) | 133 | 324 |
| $Na^{+}$ (mg/l) | 2102 | 821 |
| $K^{+}$ (mg/l) | 17 | <0,3 |
| $Ba^{2+}$ (mg/l) | 0,06 | 0,05 |
| $Sr^{2+}$ (mg/l) | 1,9 | 1,8 |
| $Cl^{-}$ (mg/l) | 3684,09 | 2499,43 |
| $SO_4^{2-}$ (mg/l) | 132 | 288 |

# III – Description of the PV-powered Reverse Osmosis Units

## 1. PV plant

A bloc Diagram of the PV plant is shown in figure 1.The main characteristics of the PV plant are summarized in table 2. Two PV panels (150 Wp, 24 V) are mounted in series to provide the nominal DC voltage of 48 volts. The panels are used to charge the batteries (24 flooded 2 V batteries) through two charge regulators. The battery bank is used to power the RO unit and the various equipment through the inverters.

**Table 3. Characteristics of the PV plants of the two sites.**

| | Benhssaine | Msaim |
|---|---|---|
| Installed PV Power (kWp) | 4.8 | 3.9 |
| Battery Capacity (Ah) | 900 | 700 |
| Nominal System DC voltage (V) | 48 | 48 |
| Charge regulators | 2x60 A | 2x40 A |
| Inverters | 3x3 kW | 2x3 kW |

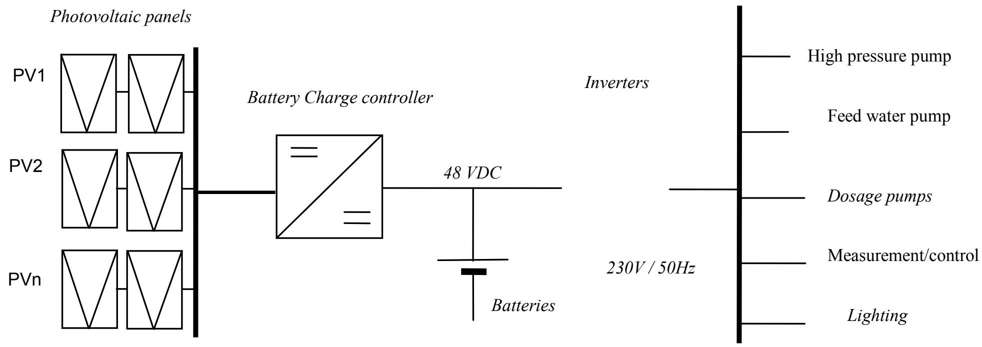


**Figure 1. Schematic diagram of the PV plant.**

## 2. Reverse Osmosis units

A bloc diagram of the RO unit is shown in figure 2 .The feed water from the storage reservoir is filtered by the multimedia filter to remove suspended solid particles. Water is then pre-treated using an anti-scaling agent (HYDREX from Veolia) to prevent fouling of the membrane. The pre-treated water is subsequently filtered by two 5 micron cartridge filters; before, it is forced through the RO modules by the high pressure pump (14 to18 bars). Each RO module contains 3 membranes (BW30 series from Filmtec). The concentrate of the first tube is fed to the second tube (3 spiral-wound membranes BW30LE-4040 for Benhssaine and BW30-4040 for MSAIM). Part of the brine is re-circulated so that only 0.5 m$^3$/h is rejected. The permeate of the two tubes are then mixed using a manual valve which also provides back pressure of 0.8 bars on the first tube.

The permeate fills first the flushing reservoir mounted above the unit. Then the pH of the permeate is adjusted with potash (NaOH) and it is post-treated with hypochlorite using the dosage pumps of the post treatment stage. A check valve prevents post treated water to flow back into the flushing reservoir. The flushing is performed by gravity and direct osmosis. A membrane cleaning system has been designed and tested.

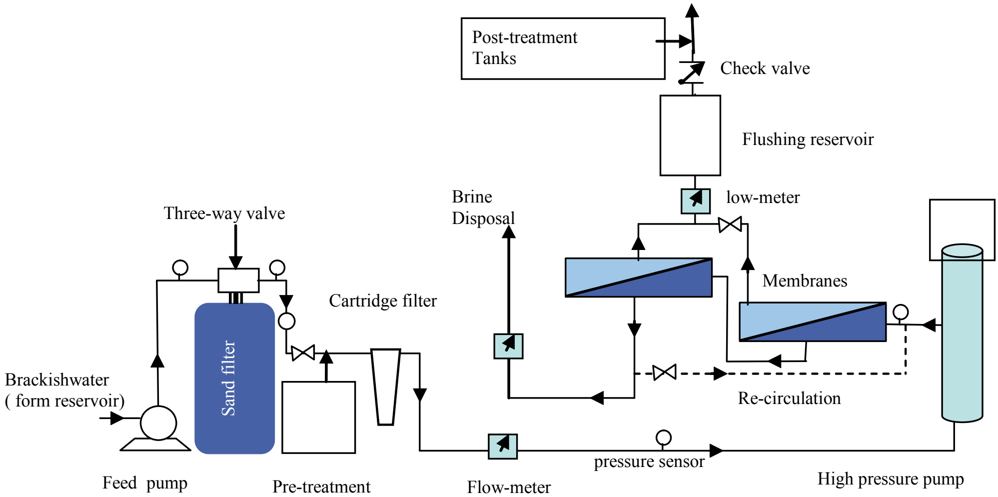


**Figure 2. Schematic diagram of the RO plant.**

**Figure 3. Photographs of the RO unit and the PV panels for the Benhassine site.**

**Table 4. Characteristics of the reverse osmosis units.**

| | Benhsssaine | Msaim |
|---|---|---|
| Production Capacity ($m^3/h$) | 1 | 1 |
| Number of vessels/modules | 2 | 2 |
| Number of membranes /module | 3 | 3 |
| Pre-treatment | Antiscalant metabisulfate | Antiscalant Metabisulfate |
| Post-treatment | Hypochlorite pH adjustment | Hypochlorite pH adjustment |
| HP pump nominal power | 5.5 kW | 2.2 kW |
| Brine disposal | Evaporation ponds | Evaporation ponds |

### 3. Monitoring System

The RO unit is continuously monitored by a Siemens S7-200 family PLC (S7-224) through the different sensors installed in the unit (conductivity, flow rates, pressures, salinity..). The RO unit is automatically stopped when a given parameter is outside specified range and the corresponding alarm is set.

For both sites, the RO units are automatically operated for a preset time fixed by a timer mounted in the control panel. The operation time starts at 12:00 in the winter time and 11 am in the summer time to produce more water. This corresponds to about a 22% depth of discharge of the batteries (when the system is operated only with batteries). This leaves enough time for the batteries to be charged by the PV panels. A remote monitoring system is also installed which enables to remotely monitor the operation of the units and sends alarms by SMS. This way, the source of faults can be known beforehand and the local operator can be guided through the phone to remedy to the fault if its origin is not serious.

## IV – Water production and energy consumption

The operation parameters of the two desalination stations are shown in table 4. The overall recovery rate for the two desalination units was chosen as high as possible (65% to 70%) in order to reduce the quantity of brine rejected. This is done for two reasons: the first is that this will not please to the population as they also pay for this rejected water; the second is to limit the surface needed for the evaporation ponds and to reduce the environmental impacts of the brine. The conductivity of the produced water is on the average equal to 540µS/cm so that it doesn't require any additional re-mineralization. The specific energy consumption is lower for the case of the unit installed in Msaim (about 2 $kWh/m^3$ compared to 3.3 $kWh/m^3$) as a result of the lower salinity and permeate flow rate (0.8 $m^3/h$).

**Table 5. Typical operational parameters recorded for the desalination units.**

| | Benhssaine | Msaim |
|---|---|---|
| Feed water pressure (bar) | 3.5 | 3.4 |
| High pressure (bar) | 18 | 13.5 |
| Brine pressure (bar) | 17.5 | 10,5 |
| Feed water flow rate (l/min) | 26.6 | 22 |
| Permeate flow rate (l/min) | 18 | 14.5 |
| Brine flow rate (l/h) | 500 | 500 |
| Permeate conductivity (µS/cm) | 520 to 534 | 540 to 570 |
| Recovery rate | 70 | 65 |
| Power requirements (kW) | 3.3 | 2.5 |

The evolution of these parameters with time allows to take preventive maintenance actions (membrane chemical washing, filter changes,..).

The unit cost of the desalted water, taking into account the investment and operation and maintenance cost over the life time of the unit (fixed at 20 years), was calculated using the decision support tool (AUDESSY) developed by the ADIRA project and the actual costs of the system. The unit cost of the produced water is estimated to be on the order of 5 Euros/$m^3$ (55 DH/$m^3$). A large part of this cost is due to the renewable energy supply (PV plant) and the associated maintenance and replacement costs (batteries). This high unit cost is, however, compensated by the externalities of providing a safe drinking water supply to the populations such as improving the living conditions and the health of the population by reducing water-borne diseases. In addition, children and women will save time for other activities (schooling, income generating activities..).

In order to promote the sustainability of the units, the following tasks were also carried out:

– Training for basic operation and maintenance of a group of students, local people and technicians from the province;
– Remote monitoring of the units in addition to the regular monitoring carried out by the provider of the equipment;
– Dissemination of the technology and the results of the experience (workshops, conferences, meetings). An after installation workshop was organized on April 26 attended by high level personalities and decision makers, (Ministry in charge of water and environment, the governor of the province), president of rural communes suffering from salinity problems, private sector;
– Awareness raising.

## V – Conclusions

Two PV-powered RO desalination units were installed in two rural villages to provide drinking water for their populations. The units are now operating and are being continuously monitored. The lessons learned from these two experiences are valuable for further promoting these technologies as alternative drinking water supplies in remote areas.

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