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Small reverse osmosis units using PV systems for water purification in rural places

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Abstract

Large-scale reverse osmosis (RO) plants with productions of the order of several cubic meters per day are extensively used throughout the world for water desalination. These systems, using electricity for running the high-pressure pumps, are among the ones with the lowest cost per cubic meter of water produced. Nevertheless, in some cases, for instance small rural sites or during catastrophes where drinkable water is not available, small RO systems running on photovoltaic (PV) systems could also be used to obtain drinkable water for life support. These autonomous systems can be made using commercially available small RO compact units with typical daily productions of the order of 100–500 L and functioning with pressures as low as 5 bar. Running on PV modules from 50–100 Wp, these units can produce drinkable water from brackish waters containing salt concentrations of the order of 5000 ppm. This paper describes a unit of this type that has been assembled at the Renewable Energies Department of INETI and presents the results of the first laboratory tests. These first results are being used for tuning a mathematical model of the system based on the I–V characteristics of the PV modules. The model of the system will be used for predicting the yearly water production of the unit and obtaining a value for the cost of the water produced by this type of system.

Keywords: Reverse osmosis membranes; Seawater desalination; Photovoltaic systems

1. Introduction

Worldwide populations suffer from water scarcity in many arid and desert-like areas. The only source of water available is salty water with conductivity of 1500–5000 μS/cm. Apart from salinity, other important contaminants like, for instance, pathogenic microorganisms, can further affect water quality.

In the case of the Mediterranean basin and the Middle East, there are problems of fresh water

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supply of either a quantitative nature (total absence of water) or a qualitative nature (low water quality). In Latin America there are remote communities in the rural areas of northern Argentina and Chile that show high contamination of salt-arsenic and sodium chloride [1].

Desalination by means of renewable energy sources is a suitable solution for providing fresh water to a number of regions so far apart as the Mediterranean basin, India, Latin America, Africa and world-wide remote areas. This solution becomes more competitive, especially for remote and rural areas where small quantities of water for human consumption are needed.

For some time, a single-effect basin-type solar still has been the cheapest way to produce drinkable water using solar resources. Due mainly to the rejection of the latent heat condensation, daily production small, less than 4–5 L/m^2, with specific energy consumption around 7000 kJ/kg. Solar distillation has been reported in great detail, and many installations have been constructed based on the single-effect basin-type solar still [2,3]. Desalination and water purification using renewable energies was also the subject of a recent project in the framework of the CYTED Ibero-American R&D programme.

At the Renewable Energies Department of INETI (Portugal), special attention was paid to small desalination units of multi-effect solar stills [4] and evaporation type solar stills [5], respectively with consumption of about 1800 and 800 kJ/kg.

Among the desalination technologies available, reverse osmosis (RO) is currently considered as the most attractive process to produce fresh water for both brackish and seawater. With predicted specific consumption from 30 to 50 kJ/kg (with pressure recovery), this well established technology is becoming increasingly popular as a competitive and viable option in several large-scale desalination plants. Several RO plants with production on the order of thousands of cubic meters per day are being extensively used throughout the world for water desalination [6]. These systems, using electricity for running the high-pressure pumps, are among the ones with the low cost per cubic meter of produced water. Nevertheless, in some cases, e.g., small rural sites or during catastrophes where drinkable water is not available, small RO systems running on PV systems could also be used to produce drinkable water for life support. These autonomous systems can be made using commercially available small RO compact units with typical daily productions of the order of 100 to 500 L and functioning with pressures as low as 5 bar. Running on PV modules from 50 to 150 Wp, they can produce drinkable water from brackish waters containing salt concentrations of the order of 5000 ppm.

2. Materials and methods

The process of natural osmosis comprises water flowing out of a pure water compartment and being permeated through a membrane into a concentrated salt solution. In order to reject almost completely all kinds of solutes, the membrane itself must be semi-permeable to suit water passing through it. Until the osmotic pressure is reached, the water continues to flow. At this point the system reaches its osmotic equilibrium. Applying pressure to the salt water compartment higher than the osmotic pressure will force the water to flow in the opposite direction from the salty solution into the pure waterside and desalt the salt water. This modification of flow direction of the osmotic flow process is called reverse osmosis.

In order to evaluate the possibility of using a small RO unit running on PV modules, preliminary experiments were conducted at the Renewable Energies Department (DER) of INETI in Lisbon (Portugal).

The raw water was prepared in laboratory with very low turbidity and neutral pH water, and

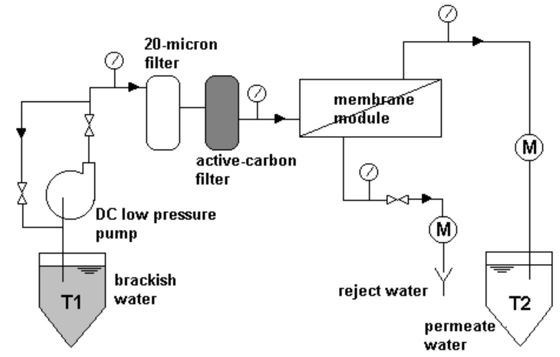

Fig. 1. Schematic configuration of the small RO experimental pilot plant.

Table 1
RO membrane specifications

Parameters	
Material	Cellulosic compound
Type	MP – TA50 – J4
Membrane type	Spiral wound
Membrane length, m	0.3 (12”)
Operation pH	4–11
Max feed flow, Lpm	7.6
Max chloride, mg/L	<0.1
Max temperature, °C	45
Max pressure, bar	17.2

its conductivity varied between 2000 to 5000 µS/cm (at 20°C). A diagram of the pilot system (dead-end filtration) is presented in Fig. 1. The pre-treatment methods in any RO system are dependent upon the composition of feedwater and economics of the overall system. This is especially true when considering a small system based on a compact autonomous PV system used to obtain drinkable water for life support.

The raw water passed first through a prefilter (20 µm), then through a carbon filter (chloride

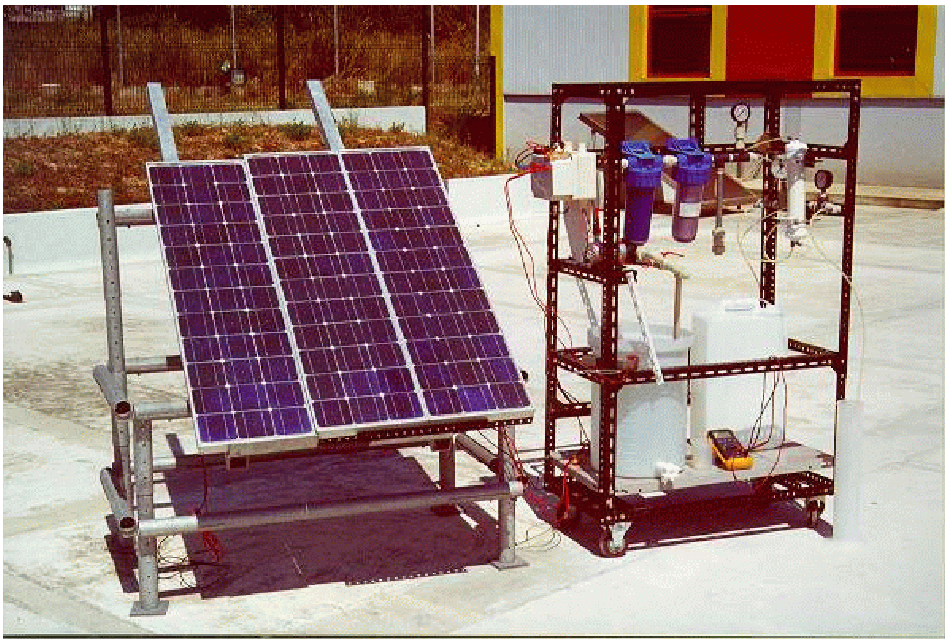

Fig. 2. RO experimental pilot powered by a 3×50 Wp PV system.

Table 2
Operating conditions of RO pilot coupled with a PV system (2 × 50 Wp)

N	Curr., A	Volt. V	Feed			Permeate			System results			
			Flow, l/h	Pressure, bar	Cond., µS/cm	Temp., °C	Flow, l/h	Cond., µS/cm	Temp., °C	Salt rej., %	FWR[a]	Specific energy kJ/kg
1	6.9	8	171.1	3.3	4.00	25.6	1.9	0.52	27.7	87	1.1	103.8
2	6.6	7.6	168.5	3.0	4.23	28.2	1.7	0.8	29.0	81.0	1.0	107.6
3	6.1	7.3	158.4	2.8	4.35	29.5	1.4	0.69	29.4	84	0.9	111.8
4	5.6	6.8	146.8	2.5	4.41	30.0	1.0	0.61	29.2	86	0.7	144.5

[a] Feed water recovery.

Table 3
Operating conditions of RO pilot coupled with a PV system (3 × 50 Wp)

N	Curr., A	Volt. V	Feed			Permeate			System results			
			Flow, l/h	Pressure, bar	Cond., µS/cm	Temp., °C	Flow, l/h	Cond., µS/cm	Temp., °C	Salt rej., %	FWR[a]	Specific energy kJ/kg
5	8.3	13.1	190.1	4.1	4.38	29.9	3.4	0.43	29.5	90	1.8	116.7
6	7.9	10.2	183.4	4.0	4.49	30.1	3.2	0.47	29.8	90	1.7	92.0
7	8.6	13.3	190.4	4.1	2.85	25.6	3.8	0.26	28.0	91	2.0	107.2
8	8.3	14.6	189.4	4.2	3.03	28.7	4.1	0.19	29.4	94	2.2	106.4
9	9.1	14.2	190.3	4.2	3.16	30.7	4.6	0.20	30.8	94	2.4	102.3

removal), and was then introduced to the membrane. The feed water passed through the membrane and the permeate was collected in tank T2. The RO membrane used is spiral wound and is sensitive to chloride concentration. The membrane specifications are presented in Table 1. The run-outs were performed with manual control flow.

The desalination pilot system was first connected to a DC power supply to perform previous testing and then coupled to a stand-alone PV system of 100 Wp and 150 Wp), directly connected to the pump with no batteries. The total cost of the experimental RO plant was US $1000, but a price reduction is expected for commercial systems.

The objective of the experiment is to compare the permeate quality and specific energy consumption vs. membrane working pressure for different feed conductivities. The RO system main characteristic is its production on a daily basis expressed in terms of liters per day (L/d) of drinkable water at a defined temperature.

The operating conditions of the tests performed are presented in Tables 2 and 3 corresponding, respectively, to configurations for the PV power systems with two and three modules of 50 Wp linked in parallel to give the appropriate current to drive a 12 V DC Shurflo pump. Selected run-outs performed during the part of the day with sunshine conditions gave preliminary results of the system performance. Fig. 2 shows the system during the outdoor tests.

3. First results and discussion

During the outdoor tests with PV modules, the flow rate varies between 140–200 L/h, depending on the current delivered by the PV. The initial feeding pressure was 3.3 bar (Table 2) with a flow rate of 171 L/h and a current of 7 A. Other similar results led us to increase the PV system to a nominal power of 150 Wp where we had attained 9 A and a differential pressure of about 4.2 bar (about 0.2 bar for the prefilter system), as shown in Table 3. With this procedure lower conductivity values and better salt rejection (94% sodium chloride) was attained up to a minimum of specific energy consumption of 92 kJ/kg. Even though these are only preliminary results, RO pilot plant can produce about 20 L/d of drinkable water. The RO pilot plant consistently produced drinkable water with a conductivity lower than 500 μS/cm, which satisfies the World Health Organization's sodium chloride parameter for water quality.

The preliminary results performed during August are presented in Figs. 3 and 4. Fig. 3

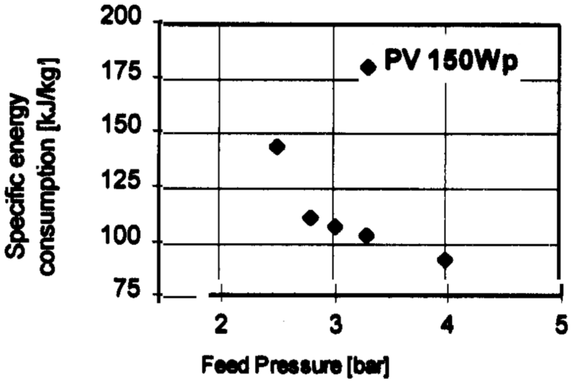

Fig. 3. Specific energy consumption vs. feed pressure.

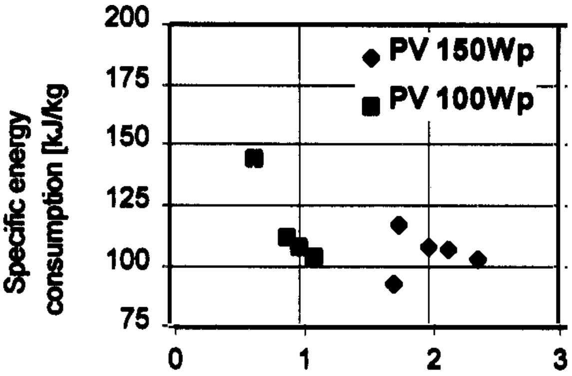

Fig. 4. Specific energy consumption vs. feed water recovery.

shows the decrease of consumption with the increase of feed pressure for the 150 Wp system. Fig. 4 shows the energy consumption vs. feedwater recovery (percentage of permeate over feed water). It can be seen that the 150 Wp system delivered more water with less energy consumption. The general conclusion is that for this sytem the energy consumption decreases as feedwater recovery and feed pressure increase.

4. Conclusions

This paper describes a small RO pilot unit powered by a PV system that has been assembled at the Renewable Energies Department of INETI, and presents the preliminary results of the laboratory and outdoor tests performed during the summer of 2000 in Lisbon.

The commercial membrane type MP–TA50 spiral-wound cellulosic compound with dead-end filtration mode coupled with operation at low pressure (<5 bar) just allow for low power consumption, around 100 kJ/kg of permeate. However, these results must be confirmed by further operating conditions on a daily production basis to compare permeate quality and energy consumption vs. pressure. Other RO membranes will also be tested.

Nevertheless, it can be con-cluded that for the small RO pilot the energy consumption decreases as feed water recovery and feed pressure increase.

The results of these experiments will be used for tuning a mathematical model of the system based on the I–V characteristics of the PV modules. additional information could lead us to predict the yearly water production of the unit and obtain a value for the operation costs of the water produced by this type of system.

Acknowledgements

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