Desalination and Water Treatment
www.deswater.com

7 (2009) 220–235

1944-3994 / 1944-3986

Canary Islands Institute of Technology (ITC) experiences in desalination with renewable energies (1996–2008)

Vicente J. Subiela*, Juan A. de la Fuente, Gonzalo Piernavieja, Baltasar Peñate

Water Department, Research and Technological Development Division, Canary Islands Institute of Technology, Playa de Pozo Izquierdo, s/n. 35119 Santa Lucía, Gran Canaria, Spain
Tel. +34 (928) 72 75 20; Fax +34 (928) 72 75 90; email: vsubiela@itccanarias.org

Received 14 October 2008; accepted in revised form 9 June 2009

ABSTRACT

Fresh water shortage is a raising problem, especially in some parts of the world as North Africa and Middle East areas. Global climate change and progressive increment of population are reducing day by day the availability of per capita drinking water supply; this is becoming a critical question for certain developing countries. Desalination has narrowed the gap of water demand for more than 20 years thanks to a cheap energy supply; but the age of "easy oil" is coming over and the link water–energy is more and more critical. A hopeful option is desalination powered by renewable energies (RE). RE are not only safe but also endless resources, and there are already successful experiences in RE desalination. The Canary Islands Institute of Technology (ITC) has been testing and monitoring RE desalination systems for more than 10 years. Vapour compression, reverse osmosis, electrodialysis, membrane distillation and humidification – dehumidification plants have been connected to wind or solar energy systems in more than ten field projects. This paper summarizes the main outcomes of this long experience, focusing on the more practical questions to be considered in order to implement new RE desalination projects.

Keywords: Reverse osmosis; Photovoltaic energy; RE-powered desalination; Canary Islands; Africa

1. Introduction

Drinkable water is a more and more scarce resource. The increment of population, environmental impacts and climate change are reducing the water availability per person, this is a particularly critical situation in developing countries. United Nations has evaluated in 1,100 millions of persons without a safe access to drinkable water. Additionally, the expected future is even more critical: by 2025, 1,800 million people will be living in countries or regions with absolute water scarcity [1].

The Canary Islands have suffered structural water lack for many decades. Thus, the archipelago was pioneer in Europe in desalination technologies, with the commissioning of the first European desalination plant in the beginning of the sixties. The increment of desalination has meant additional energy consumption; currently desalination represents in the islands approximately 10% of electricity consumption, in some islands this percentage raises up to 25%. Therefore, there has been a progressive interest in reducing the energy costs in desalination and searching new energy resources, like wind power, with very competitive costs.

Moreover, the archipelago has abundant renewable energy resources (particularly wind and solar energy). However most of these resources cannot be converted into electricity due to the reduced size and weakness of the island electric grids.

* Corresponding author.

Presented at EuroMed 2008, Desalination for Clean Water and Energy Cooperation among Mediterranean Countries of Europe and the MENA Region, 9–13 November 2008, King Hussein Bin Talal Convention Center, Dead Sea, Jordan.

Consequently, one of the first strategic lines of the Canary Islands Institute of Technology was the development and testing of renewable energy driven desalination systems, operating in off-grid mode. The facilities of the ITC in Pozo Izquierdo (Gran Canaria Island) are an ideal platform for testing RE desalination systems thanks to the local excellent conditions: direct access to seawater, annual average wind speed of 8 m/s, average daily solar radiation of 6 kWh/m^2. The paper presents a short description of eleven small to medium capacities autonomous desalination units.

On the other hand, Canary Islands are located very close to northwest Africa, wherein millions of people live in isolated villages without access to electricity and good quality water in inland or coastal areas. The technologies developed in the ITC present nowadays a possible solution to the fresh water and electricity supply. The paper includes two cases of autonomous desalination in African countries.

2. Wind powered desalination

The first autonomous desalination concept tested in the Canary Islands was powered by wind energy. Different options were carried out.

2.1. Case 1: Wind–diesel system

The project, located in the municipality of Punta Jandía (Fuerteventura Island), was proposed by the University of Las Palmas de Gran Canaria (ULPGC) with the further collaboration of the Canary Islands Institute of Technology (ITC), and the financial contribution of the European Commission (VALOREN Programme), the municipal Government, the Fuerteventura Island Water Council, and the Regional Industry Ministry. The system consisted of a wind power–diesel system to supply power, water, cooling and ice to the Punta Jandía fishing village (Fig. 1). This project arose from a proposal to the VALOREN programme of the European Union in August 1988. It studied the operational strategies of a wind–diesel system which had been installed in an isolated fishing village community with a permanent population of 60 inhabitants, on the island of Fuerteventura (Canary Islands). The project was implemented with the aim of meeting the complete energy requirements of the community: electricity, desalinated water (Fig. 2), freezer plant, sewage water treatment [2]. Testing period was from 1995 to 2002.

Fig. 2. SWRO desalination plant.

Due to its geographical and climate characteristics (average wind speed of 7.5 m/s), it was proposed as an example of the application of renewable energies for the comprehensive supply of energy to isolated communities based on respect for the environment and maximum independence from external supplies. The location area is classified as a Protected Nature Park and there is no electric grid. According to municipal regulations, in the future the area could house a small residential area for up to 450 inhabitants in the summer and 60 permanent residents, plus occasional visitors; it means a total of about 500 people/d. The main data are summarized in Table 1.

Starting up of the system is carried out from a compressed air tank, which makes the diesel group run. When the nominal frequency is achieved, then stand alone grid is generated, and the system can operate in three different modes:

- Wind power mode: under good wind conditions; all the loads are covered by the wind generator.
- Wind–diesel mode: under low and variable wind; both systems operate to cover the loads.

Fig. 1. View of the project installations in the Punta Jandía fishing village (Fuerteventura).

Table 1
Data of wind– diesel desalination system

Wind turbine	VESTAS V-27
Main characteristics	Diameter 27 m, height of tower 30 m, multiplier gear box, 50 and 225 kW twin spool asynchronous generator
Diesel generating sets	
Main characteristics	2 diesel groups coupled to flywheels and synchronous generators (75 kVA) (Fig. 3)
SWRO desalination plant	
Nominal production capacity, m^3/h	2.3
RO plant operating hours, h/y	800
Cold chamber	
Storage capacity, ton	1.2
Temperature, °C	3

Fig. 3. Diesel generators.

- Diesel mode: when load is small or there is no wind.

2.2. *Case 2: Off-grid wind farm coupled to 3 desalination systems*

The concept of the SDAWES project (Seawater Desalination with an Autonomous Wind Energy System) pursued the use of wind power, to produce a natural scarce resource: water. It consists of the connection of three different desalination systems: reverse osmosis (8×25 m^3/d), vapour compression (50 m^3/d) and electrodialysis reversible (190 m^3/d) to an off-grid wind farm (first in the world connected to a desalination plant) in order to produce fresh water; total nominal water production capacity is 440 m^3/d [3–9].

The main objectives of the project were to identify the best desalination system for connection to a stand-alone wind farm, and to assess the influence of the variations of the wind energy on the operation of the desalination plants and on the quality of the produced water.

This project was co-financed by the European Commission, (Joule III Program); it was co-ordinated by ITC, with the participation of other European partners: ULPGC (Spain), DER-CIEMAT (Spain), ENERCON (Germany), CREST (UK) and NEL (UK). Commissioning and testing period was carried out from 1999 to 2002. The main data of the system are collected in Table 2.

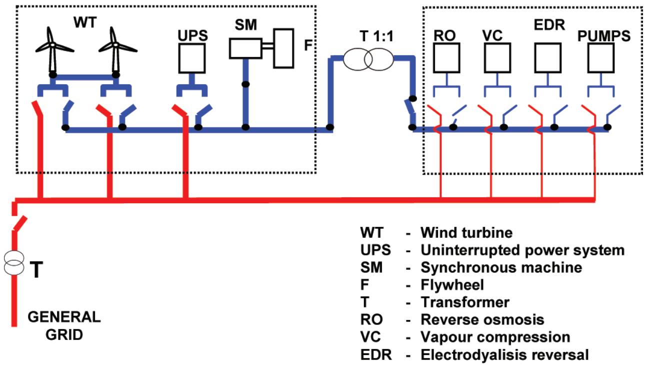
Table 2
General data for the off-grid wind farm coupled to three desalination systems

Energy source	Two wind turbines of 230 kW each
Flywheel, rpm	1,500
Synchronous machine, kVA	100
Uninterrupted power system unit (UPS), kW	7.5
8 RO desalination plants	
Nominal production capacity, m^3/h	1
Conversion rate, %	30
Nominal working pressure, bar	60–70
Specific energy consumption, kWh/m^3	7.2
Vacuum vapour compression plant	
Nominal production capacity, m^3/h	2
Conversion rate, %	50
Nominal working pressure at 62°C, bar	0.2
Specific energy consumption, kWh/m^3	16
Variable compressor speed, rpm	8,000–12,000
Electrodialysis reversal plant (EDR)	
Nominal production capacity, m^3/h	3–7.9
Conversion rate, %	35–75
Nominal working pressure, bar	1
Specific energy consumption, kWh/m^3	3.3
Feed water salinity, μS/cm	2,500–7,500

Every desalination system has a particular way of modifying the power consumption to adapt, in each moment, to the available power variations of the low wind conditions. On the other hand, under strong wind conditions, the wind farm is able to regulate the produced power and to adapt to the connected loads. This double power control makes the system to be very stable.

The system configuration was based on two electric circuits (Fig. 4), supply from the off-grid wind farm (blue line) and supply from the general grid (red line). Visual information about the system is presented in Figs. 5–9.

According to the results of the tests [3–9], one of the main outcomes is that RO technology is the most suitable one for coupling to an off-grid wind farm. Nevertheless, each desalination technology has possibilities to improve the operation with off-grid wind farms by developing specific designs [9,10].



Fig, 4. SDAWES system configuration.

Concerning the case of RO, product water flow and conductivity are slightly affected by the variations in frequency of the electrical grid. The daily average conductivities are practically unaffected as the acceptable decreases in electrical frequency (52–48 Hz) do not produce large increases in the permeate conductivity, approximately 28 μS/cm [8]. However, punctual fluctuations were detected in the short periods with unstable frequency (operation under minimum wind speed) (Fig. 10). On the other hand, simulations results indicate that flow fluctuations created by the variable power supply could be favourable in terms of reducing the concentration polarization in RO, depending on the frequency and amplitude of fluctuations [11].

2.3. Case 3: Small-scale wind autonomous desalination plant

A wind powered SWRO desalination prototype was designed and tested in the Canary Islands Institute of Technology as a technical solution to water shortage in low water demand isolated areas (about 900 inhabitants) where the conventional electric grid does not exist. This experience has served to show the technical and economic feasibility of these systems being able to extrapolate

Fig. 5. 2 × 225 kW off-grid wind farm.

Fig. 6. 100 kVA synchronous machine coupled to flywheel.

Fig. 7. RO desalination plants.

Fig. 8. VVC desalination unit.

Fig. 9. EDR desalination plant.

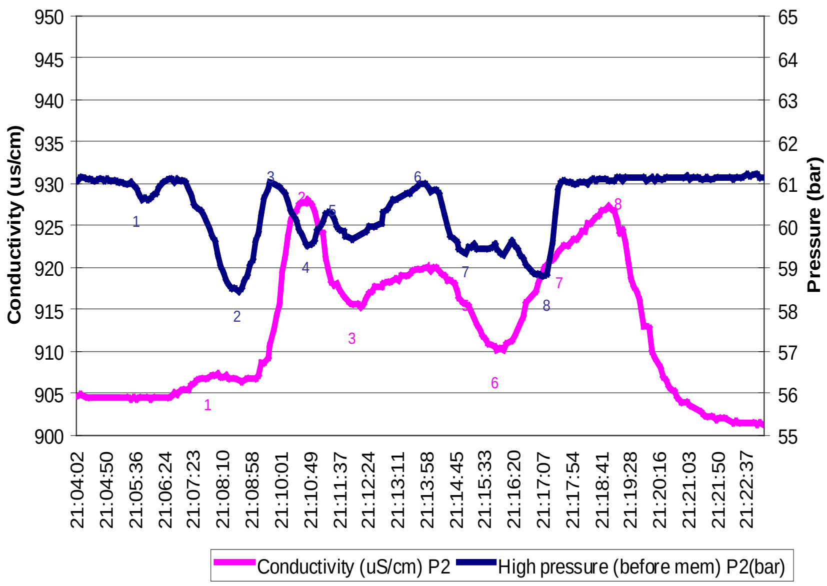


Fig. 10. Fluctuations of drinking water conductivity and feed water pressure.

to greater capacities. Main operation data are given in Table 3.

The configuration of the system is presented in Fig. 11.

The main outcomes extracted from the operation of the system were the following:

Table 3
Data of small wind powered RO unit

Nominal production capacity, l/h	750
Conversion rate, %	24
Nominal working pressure, bar	62
Specific energy consumption, kWh/m^3	8.4
Energy source	Wind turbine of 15 kW (13 m/s)
Average daily operation time, h/d	18
Freshwater conductivity, ppm	360–550

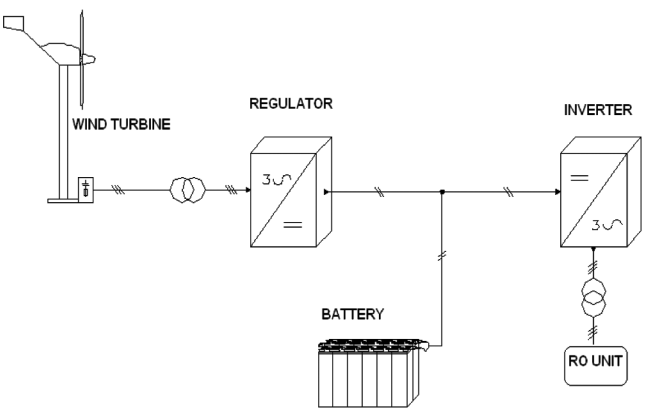


Fig. 11. System configuration of autonomous wind RO system.

- Identification of the most suitable times in startings, shutdowns and membrane cleaning periods.
- Optimization of the water production, considering maintenance and power consumption aspects.
- Incorporation in the system of automatic valves commanded by the control software which allows totally automatic operation.

Visual information about the system is presented in Figs. 12–14. Operating data are represented with graphs in Figs. 15–17. A selection of the operation data is presented in Table 4.

3. Photovoltaic energy driven desalination

The most analysed technical concept of autonomous desalination has been the combination between a photovoltaic field and a reverse osmosis plant with the batteries support. This section presents the most relevant information of the operated and operating units.

Table 4
Operation data in a windy day (20/02/2005) and in a medium wind speed day (19/02/2005)

Parameters	High wind speed	Medium wind speed
Wind speed (average of the day), m/s	9.2	5.8
Pump energy demand, kW	5.6	5.6
Operation hours, h	20.5	7
Daily plant production, m^3	15.3	5.2

Fig. 12. SWRO desalination plant.

Fig. 13. Wind generator.

Fig. 14. Batteries bank.

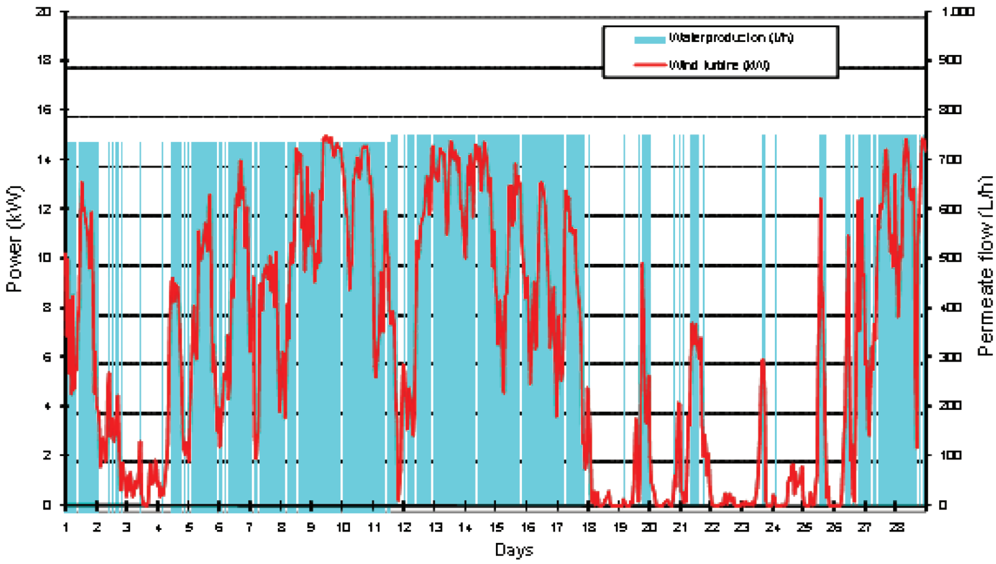


Fig. 15. Wind energy vs. desalinated water produced along a month.

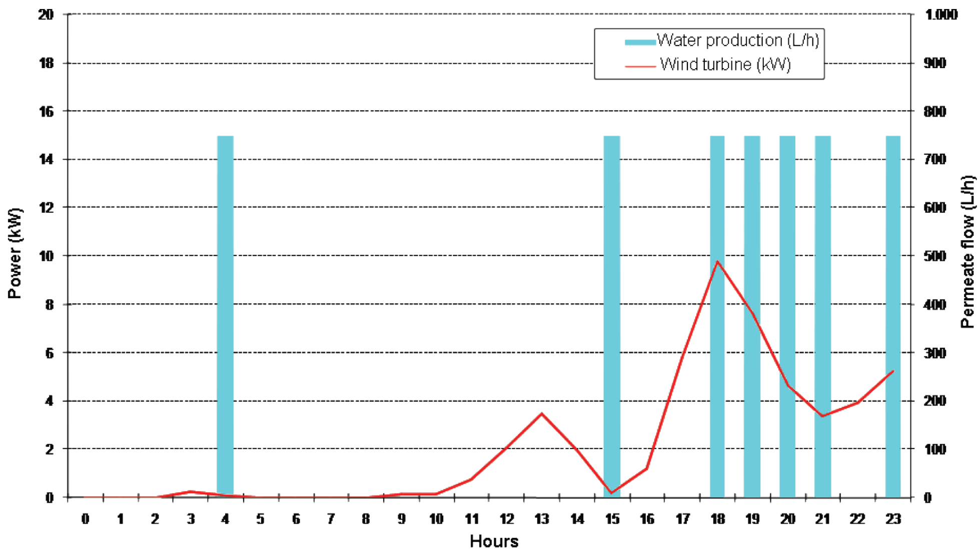


Fig. 16. Wind energy vs. desalinated water produced in a medium wind speed day.

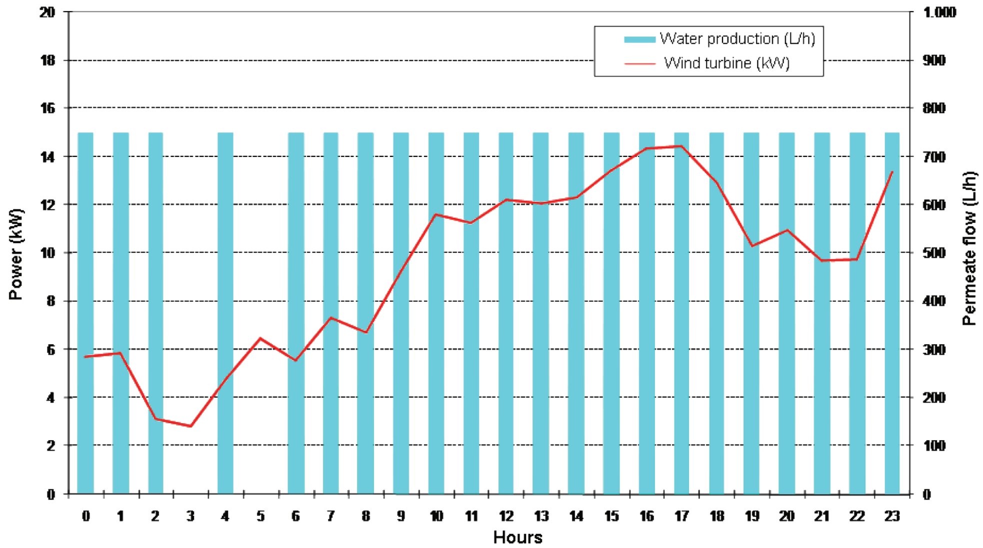


Fig. 17. Wind energy vs. desalinated water produced in a high wind speed day.

3.1. Case 4: Seawater PV desalination unit

The first autonomous photovoltaic-reverse osmosis (PV–RO) system was designed to satisfy a small water demand (for 50–75 inhabitants) isolated from the electric grid and with potable water scarcity [12,13]. An automatic control unit adjusts the plant operation to the changing and discontinuous energy supply from the PV generator. The project was an initial cooperation between ITC and Aachen University of Applied Sciences (Jülich, Germany) and the final development was a high feasibility product patented by the Canary Islands Institute of technology (PCT ES 2004/000568, DESSOL®). It was operative between 2004 and 2007, and functioned more than 5,000 h with a water production over 2,000 m^3 [14]. Even though the project, co-financed by the European Commission under the framework of FEDER programme, finished in 2002, ITC continued testing and optimizing the system until present day. It has been the base for the systems installed in Tunisia (2006) and Morocco (2008) (see section 3.2)

PV–RO systems have been mostly analysed by simulations or designed and tested with a manual mode plant in continuous operation. However, this project is the first one of its kind, on an international scale, that approaches the model from the automation perspective, using control software to manage solar radiation available and optimise the daily operation hours. The main data of the unit tested at the facilities of the ITC in Gran Canaria Island are in Table 5.

The technical concept includes the PV fields, the charge controller, the batteries, the inverter (DC/AC converter) and the RO desalination unit. The diagram is indicated in Fig. 18.

Table 5
Main data of PV powered SWRO system

Nominal production capacity, l/h	400
Conversion rate, %	44
Nominal working pressure, bar	60
Specific energy consumption, kWh/m^3	5.5
Energy source, kWp PV field	4.8
Battery back-up system	19 kWh (385 Ah)
Average daily operation time, h/d	8 (summer), 6 (winter)

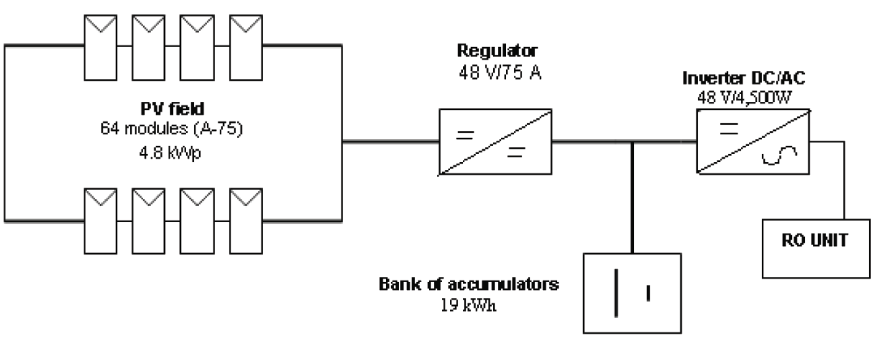


Fig. 18. Basic diagram of PV–RO concept.

Table 6
Summary of the operation on a day with high (10/08/2002) and low solar radiation (06/09/2002)

Parameters	High radiation	Low radiation
Start-up time	8:30 a.m.	10:30 a.m.
Shut-down time	19:30 p.m.	17:00 p.m.
Initial battery capacity, Ah	378	308
Final battery capacity, Ah	367	277
PV field production, kWh	25	12.5
Total plant operating time, h	11	7
Plant production during the day, l	4,165	2,430
Mean conductivity, μS/cm	880	662

A selection of the pictures of the system is shown in Figs. 19–21. The main operational results are summarized in Table 6.

3.2. Case 5: Seawater PV-RO desalination unit with energy recovery system

One of the improvements to the initial PV–RO concept has been the integration of three photovoltaic systems with solar trackers from different manufacturers (Lorentz, Degertracker and Traxle) and an existing SWRO desalination plant including an energy recovery device (ERI® PX). The idea is to know the influence of the energy recovery system and the increment of collected solar energy in the number of daily operation hours and the quality of water. The main operational data are in Table 7.

The elemental layout of the RO unit is in Fig. 22. Some pictures of the system are presented in Figs. 23 and 24.

3.3. Case 6: Autonomous PV–RO unit in Tunisia

After a long path of pilot projects tested in the facilities of ITC, focused on wind driven RO and PV–RO systems, ITC decided to transfer its know-how to nearby African countries, Tunisia and Morocco.

The inland village of Ksar Ghilène (Tunisia) was the first African location of a PV–RO system. The 300 inhabitants of this place do not have access to electricity (closest grid point located at 150 km) or fresh water (original supply was from tank lorries). The project, funded by the International Cooperation Spanish Agency and the Government of the Canary Islands, was commissioned in May 2006. The system, with a nominal capacity of 50 m^3/d (RO plant for brackish water) and a peak PV power of 10.5 kWp, has been operating during more than 2,700 h and producing more than 5,000 m^3 of drinking water. Due to the high temperatures in summer (more than 50°C), the building was built partially underground (Fig. 25). Operating data are represented with graphs in Figs. 26–28.

Table 7
Data of solar PV trackers system coupled to a SWRO with ERD plant

Nominal production capacity, m^3/h	1.25
Conversion rate, %	36
Nominal working pressure, bar	56
Specific energy consumption, kWh/m^3	2.54
Energy recovery device (ERD)	ERI® PX-15
Energy source	3 photovoltaic systems with solar trackers. Degertracker and Lorentz (2 kWp each), Traxle (1.6 kWp). Total power 5.6 kWp.
Battery back-up system	41 kWh (857 Ah)
Average daily operation time, h/d	8

3.4. Case 7: Four autonomous PV–RO units in Morocco

Four PV–RO systems have been installed along this summer in four locations of Morocco (see maps of Fig. 31) as part of the wide set of actions developed within the already finished project called ADIRA (www.adira.info), thanks to the funds from the MEDA-Water Programme of the EC. The main goal of ADIRA was to implement

Fig. 19. SWRO desalination plant.

Fig. 20. Photovoltaic field.

Fig. 21. Bank of batteries.

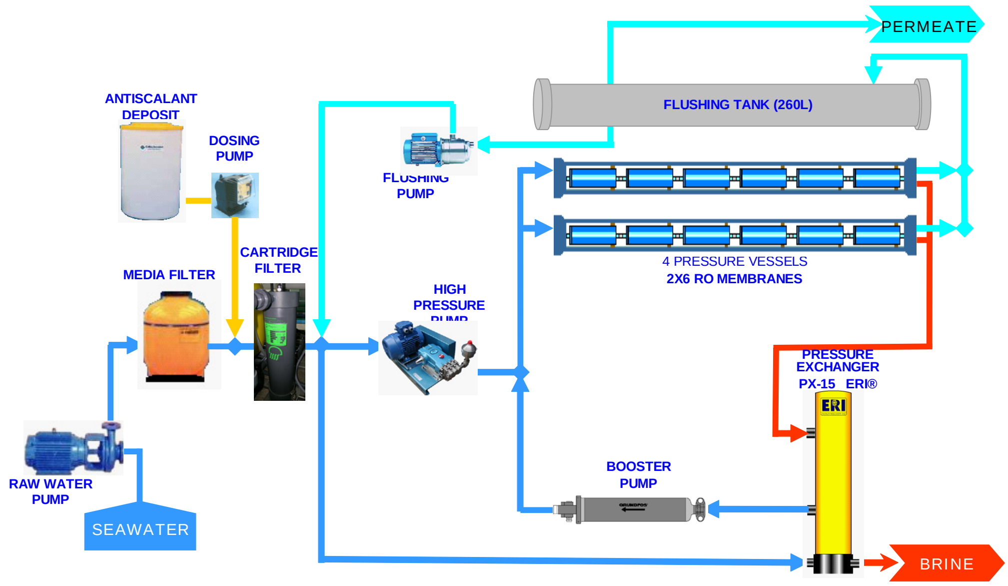


Fig. 22. SWRO desalination plant configuration.

Fig. 23. SWRO desalination plant with ERD (ERI® PX-15).

Fig. 24. View of the PV field with 3 different solar trackers.

Fig. 25. General view of the PV-RO system in the village of Ksar Ghilène (Tunisia)..

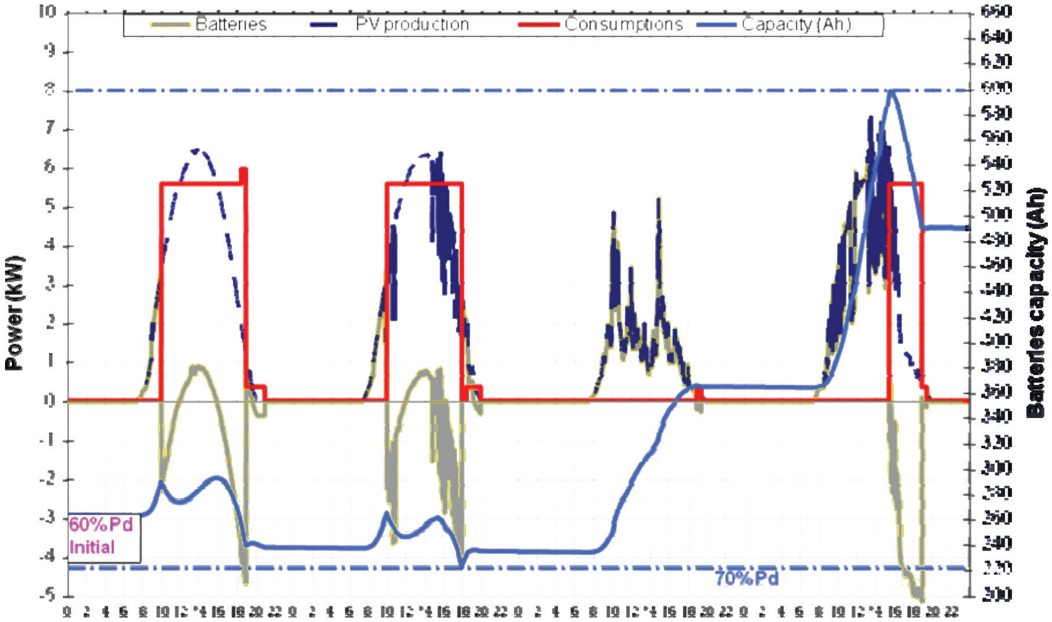


Fig. 26. Ksar Ghilène functioning system, energy balance in summer season.

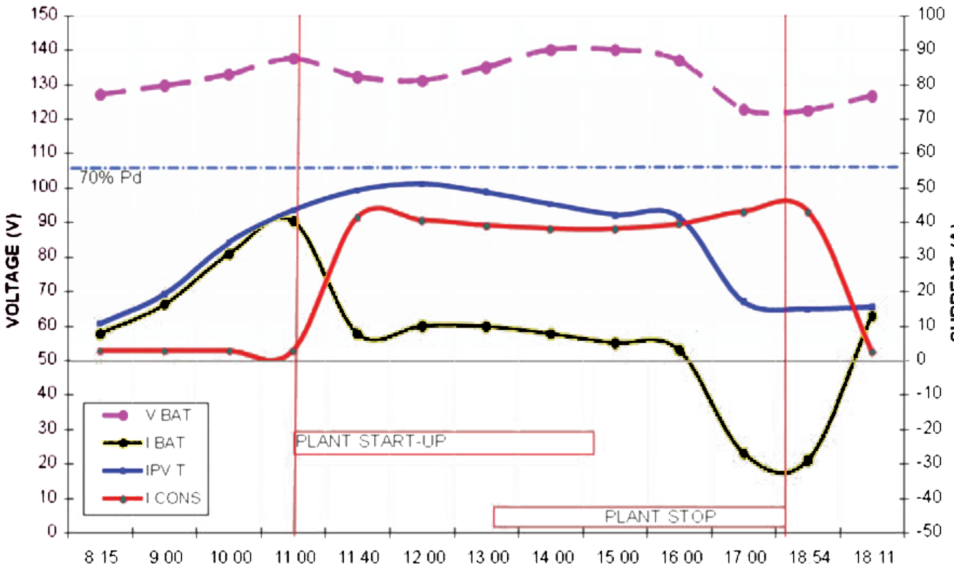


Fig. 27. Ksar Ghilène functioning system, daily energy flow.

autonomous desalination systems in remote areas. Different partners from Germany (WIP, ISE), Greece (AUA, Demokritos), Spain (ITC), Morocco (FM21), Turkey (ITU), Jordan (JUST), and Egypt (EWE) took part in this ambitious project. After a long activity of more than 4 years, ten autonomous systems were successfully installed and operated.

The local rural reality of Morocco is similar to the case of Tunisia: raw water is from inland wells (brackish waters with salinities between 2.5 to 8.7 g/l), small rural areas without direct access to fresh water and located in places without or weak electric grid.

According to the first commissioning tests, the quality of produced water is quite good (under 300 µS/cm for all the cases), and the first receptivity of local people is very positive. Figs. 29 and 30 show the RO unit (1,000 l/h) and the building with the PV field on the roof (4 kWp).

These cases of Morocco and Tunisia are just a small representation of fresh water necessities of African population. The installation of an autonomous desalination system powered by renewable (local) energy sources has made real the self production of fresh water, avoiding the original external dependence.

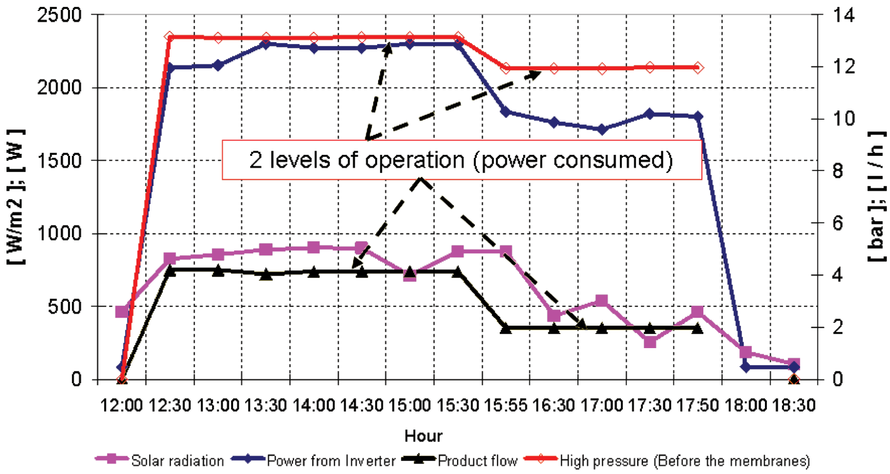


Fig. 28. Ksar Ghilène functioning system, operation case of variable power consumption.

Fig. 29. RO unit installed in Morocco (1,000 l/h)..

Fig. 30. Fresh water tank, building and PV field (4 kWp) in Morocco.

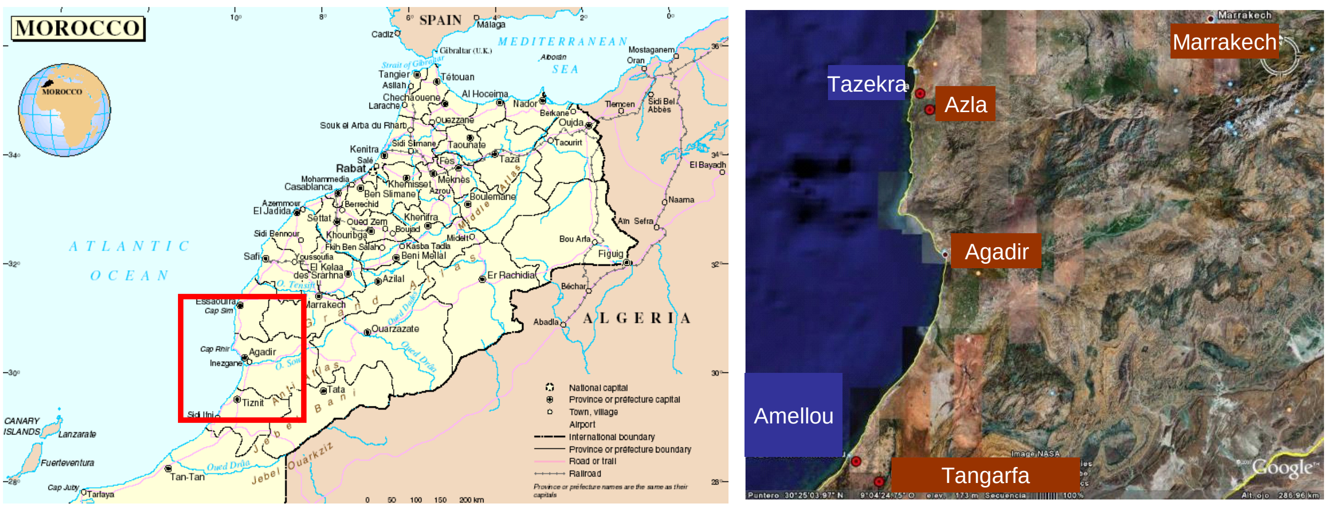


Fig. 31. Maps of Morocco with the location of the four autonomous desalination systems.

4. Thermally driven desalination systems

ITC has also been involved as partner in RE desalination projects of technologies focused on solar distillation. Several institutions have analysed deeply the process and developed the engineering of several thermally driven desalination systems [15–34]. This section presents a short description of the systems that have been tested in the ITC facilities of Pozo Izquierdo (Gran Canaria Island).

4.1. Case 8. Thermal solar humidification–dehumidification unit

The unit was tested within the framework of the SODESA project, co-funded by the European Commission DG XII (JOULE programme) and with the participation of the Institute of Solar Energy (Germany), the Baviera centre of applied research (Germany) the German company TAS and the Agricultural University of Athens (Greece). It was a solar-thermally driven humidification–dehumidification (H/D) desalination system with corrosion-free absorber collector and 24-h/d storage. The pilot plant was installed at the ITC test facilities in May 2000. Main general data are given in Table 8.

Table 8
Data of a thermal solar driven H/D desalination unit

Nominal production capacity, l/h	25
Nominal working pressure, bar	1
Temperature of operation, °C	80–90
Energy source	Solar thermal and photovoltaic energy
Solar collector area, m^2	56 (8 collectors in series)
System special characteristic	Corrosion-free absorber collector and 24 h/d storage

Fig. 32. View of the solar collector field coupled to the H/D desalination system.

A general view of the system (currently dismantled) is in Fig. 32.

4.2. Case 9. Thermal solar driven membrane distillation units

Two units were operated as the main objective of a project co-funded by the EC (MEMDIS project). The partnership of the project was formed by the Institute of Solar Energy (ISE, Germany), the manufacturer of solar collectors ESE (Belgium), the company GEP (Germany) and ITC. The main idea was the development of two stand-alone desalination systems based on the highly innovative membrane distillation technology. The systems integrate solar thermal and PV energy. The desalination energy is supplied entirely by solar thermal collectors. The electrical auxiliary energy is supplied by a PV system. Using membrane distillation technology enables to achieve low-maintenance and durable systems which is extremely important for stand-alone systems entirely powered by solar energy. The MEMDIS project is based on the experience and the lessons learnt from the SODESA project. The project started in April 2003 and finish in March 2006; the main data are presented in Table 9.

Table 9
Data of the solar thermal driven membrane distillation units

	MEMDIS compact system (CS)	MEMDIS large system (LS)
Nominal production capacity, l/h	8	70
Nominal working pressure, bar	1	1
Temperature of operation, °C	60–80	60–80
Specific energy consumption, kWhth/m^3	144	144 (each MD module)
Average daily operation time, h/d	7–10	21
Membrane type	Hydrophobic distillation membrane	Hydrophobic distillation membrane
No. of membranes	1	6 (5 in parallel and 1 as spare unit)
Energy source	Solar thermal and photovoltaic energy	Solar thermal and photovoltaic energy
No. of collectors	3	16
Solar collector area/PV power	6. $m^2$96 / 80 Wp	90 m^2 / 16x130 Wp (2 kWp)
System special characteristic	MD module with high internal heat recovery function	Two loop system with hot water storage tank (4 m^3)

Fig. 33. Small MD unit.

Fig. 34. Large MD unit.

General views of the system can be observed in Figs. 33 and 34.

5. Other autonomous desalination concepts

5.1. Case 10: Wind and PV driven seawater RO unit

The MORENA system (energetically self-sufficient rural module) is a wind/PV/battery hybrid system powering a SWRO desalination unit and a DC load. The energy produced supplies a 552 W RO desalination plant, 120 W of interior lamps simulating the feed pump and 240 W of exterior lamps. This desalination unit may supply the fresh water needs of a village of 185 inhabitants considering the 20 l/d per inhabitant.

The system is mounted in and on a container suited to be shipped all over the world and provides a high level of security, independence and simple operation and maintenance. The container has a working area of 15 m^2 and is divided into three zones: one for the desalination unit (includes an ERD), one dedicated to the battery bank, and one for the electrical data acquisition panels and regulators (PV and wind turbine). The main operation data are given in Table 10.

Table 10
Data of the wind/PV/battery hybrid system powering a SWRO desalination unit

Nominal production capacity, l/h	154
Conversion rate, %	18
Nominal working pressure, bar	40
Specific energy consumption, kWh/m^3	3.74
Wind turbine	890 W (13 m/s)
Photovoltaic array, Wp	600 (8 modules of 75 Wp)
Battery bank at C100, Ah	868

General views of the system can be observed in Figs. 35 and 36.

Fig. 35. View of the MORENA SWRO unit.

Fig. 36. Container that houses the MORENA project.

The MORENA PV/wind/battery bank hybrid system has demonstrated its full ability to provide self-sufficiently the electricity necessary to comply with the case study of supplying 1000 l/d and light for four hours at a really low specific energy consumption of 3.74 kWh/m^3.

5.2. Case 11: Diesel/biodiesel powered compact RO unit

The aim of this project is to supply of potable water and energy small isolated towns (less than 1000 inhabitants), from brackish or seawater. This project consists of a SWRO desalination plant fed by a diesel power generator (2 days autonomy in continuous operation; biodiesel could be used), mounted in a container (15 m^2) of easy transport and installation, with high security and autonomy level and simple operation and maintenance. This system has an international patent PCT in Morocco, Tunisia and the countries of the OAPI.

The current system has two Danfoss equipment in parallel, one working as a pump and the other one as an energy recovery device. The first prototype of this project was installed in Alhucemas (Morocco) in 2004 after an earthquake that devastated the region. The main operation data are given in Table 11.

Table 11
Data of the diesel/biodiesel powered compact RO unit

Operation data	First prototype	Current system
Nominal production capacity, l/h	625	1,875
Conversion rate, %	30	40
Nominal working pressure, bar	70	55
Specific energy consumption, kWh/m^3	—	3.2
Power generator, kW	8	16 (20 kVA)

General views of the system can be observed in Figs. 37–39.

6. Other related activities

ITC activity on desalination by renewable energies has not been only the installation and operation of autonomous systems but also the participation in complementary actions like promotion of this kind of technologies through participation in international consortiums. The main relevant actions are the ADU-RES project, a coordination action (6th FPof the EC) the current project PRODES, both coordinated by the German company WIP[1], the collaboration in scientific books, the consulting assistance, the elaboration of training material and the participation as teachers in different specific advanced courses. At national level, it should be mentioned the project DEREDES, co-funded by the Spanish Industry Ministry, coordinated by the company BEFESA. This finished initiative has made a complete review of the available technologies of renewable desalination and elaborated pre-designs of autonomous desalination systems adapted to three different water demand scenarios[2].

6. Conclusions

This paper summarizes the activities of the ITC during a long period started in mid 90es. After more than 10 years of continuous R&D activity, and more than 10 installed and operated autonomous desalination systems, it is not easy to extract a reduced list of conclusions. Nevertheless, the most relevant outcomes are the following:

- Renewable energy driven desalination is not a novel technology any more. Despite some combinations are under a development step, there are several which have already been tested and operating in systems with proved positive results.

[1] For more details, consult the links www.adu-res.org and www.prodes-project.org
[2] Consult www.befesa-cta.es/deredes for more details.

Fig. 37. SWRO desalination plant.

Fig. 38. Power generator.

Fig. 39. Container housing SWRO unit.

- For those sites with lack of fresh water, presence of solar and/or wind energy resources, and availability of salty raw water, desalination by renewable energy is already an alternative solution to the current supply by trucks. If, as it is probable, oil prices go on rising, autonomous desalination will be more and more competitive.
- For the case of small demand — up to 100 m^3/d — the current more reliable option is PV powered RO system. For medium demands (1,000–5,000 m^3/d), the most interesting system is the combination of an off-grid wind farm and a reverse osmosis plant.
- The main recommendations to be taken into account in a autonomous desalination project are:
  – Design simple and tough, adapted to the local conditions (tailor-made project).
  – Elaboration of a specific control system, programmed for each particular case, addressed to reduce the maintenance activities, maximize the water production and extend the life of equipment.
  – In the case of location in developing countries, it is very important to include the participation of the local entities from the very beginning of the project, in order to establish a coordinated net of actors and to consider all the local aspects, not only the technical elements, but also and mainly the social and economic conditions.

Acknowledgments

The authors wish to thank the constant support from the financing entities: The European Commission, through its wide set of programmes (JOULE III, 6th and 7th FP, MEDA Water), the Spanish Agency of International Cooperation to Development, The Canary Islands Government, and the Spanish Ministry on Industry and Technology. On the other hand, we are also grateful to all those partners and entities from the European Union and Africa, who direct or indirectly, have contributed to the success of the different projects.

References

[1] http://www.un.org/waterforlifedecade/
[2] J.A. Carta, J. González and C. Gómez, Operating results of a wind–diesel system which supplies the full energy needs of an isolated village community in the Canary Islands, Solar Energy, 74 (2003) 53–63.
[3] J.M. Veza, B. Peñate and F. Castellano, Electrodialysis desalination designed for wind energy (on-grid tests), Desalination, 141 (2001) 53–61.
[4] J.M. Veza, B. Peñate and F. Castellano, Electrodialysis desalination designed for off-grid wind energy, Desalination, 160 (2004) 211–221.
[5] L. Arribas, I. Cruz, R. Calero, V. Subiela, J.A. Carta, A. Beekman, D. Infield and M. McCourt, The SDAWES project: A hybrid system?, European Wind Energy Conference, 2000.
[6] R. Calero, V. Subiela, J.A. Carta, A. Beekman, I. Cruz, D. Infield and M. McCourt, SDAWES Project (seawater desalination with an autonomous wind energy system). Mediterranean Conference on Desalination with Renewable Energies, Isla de Santorini, Grecia, 2000.
[7] J.A. Carta, J. González and V. Subiela, The SDAWES Project: An ambitious R&D prototype in wind-powered desalination, Desalination, 161 (2004) 33–47.
[8] J.A. Carta, J. González and V. Subiela, Operational analysis of an innovative wind powered reverse osmosis system installed in the Canary Islands, Solar Energy, 75 (2003) 153.
[9] V. Subiela, J.A. Carta and J. González, The SDAWES project: Lessons learnt from an innovative project, Desalination, 168 (2004) 39–47.
[10] M. Fostmeier, F. Mannerheil, F. D'amato, M. Shah, Y. Liu, M. Baldea and A. Stella, Feasibility study on wind powered desalination, Desalination, 203 (2007) 463–470.
[11] D.G Infield and Z Rahal, Centre for Renewable Energy System Technology (CEST), Loughborough University, Loughborough, Leic., LE11 3TU, UK. Seawater desalination plants connected to an autonomous wind energy system (SDAWES). Progress Report, February 1999 – September 1999.
[12] D. Herold, V. Horstmann, A. Neskakis, J. Plettner-Marliani, G. Piernavieja and R. Calero, Small scale photovoltaic desalination for rural water supply — demonstration plant in Gran Canaria, Renewable Energy, 14 (1998) 293–298.
[13] E. Tzen, K. Perrakis and P. Baltasar, Design of stand alone PV-desalination system for rural areas, Desalination, 119 (1998) 327–324.
[14] T. Espino, B. Peñate, G. Piernavieja, D. Herold and A. Neskakis, Optimised desalination of seawater by a PV powered reverse osmosis plant for a decentralised coastal water supply. Desalination, 156 (2003) 349–350.
[15] H. Müller-Holst M., Engelhardt and W. Schölkopf, Multi effect humidification sea water desalination using solar energy or waste heat — various implementations of a new technology. Proc. Mediterranean Conference on Policies and Strategies for Desalination and Renewable Energies, Santorini Island, Greece, 21–23 June 2000.
[16] H. Müller−Holst, M. Engelhardt and W. Schölkopf, Small scale thermal seawater desalination systems for decentralised use: Optimisation of system design by simulation. Proc. AgEnergy ′99, Athens, Greece, 2−5 June, 1999.
[17] F. Kössinger, D. Jung and R. Sizmann, Autonomous solar desalination plants with internal free convection. Proc. ISES Solar World Conference, Budapest, 4 (1993) 331−336.
[18] F. Kössinger, T. Baumgartner, D. Jung and R. Sizmann, Multi-effect ambient pressure desalination with free circulation of air. Proc. ISES Solar World Conference, Denver, 2 (1991) 2259−2263.
[19] M. Alklaibi and N. Lior, Transport analysis of air-gap membrane distillation, J. Membr. Sci., 255 (2005) 239–253.
[20] M. Alklaibi and N. Lior, Heat and mass transfer resistance analysis of membrane distillation, J. Membr. Sci., 282 (2006) 362–369.
[21] A.M. Alklaibi and N. Lior, Membrane-distillation desalination: status and potencial, Desalination, 171 (2004) 111–131.
[22] B. Li and K.K. Sirkar, Novel membrane and device for vacuum membrane distillation-based desalination process, J. Membr. Sci., 257 (2005) 60–75.
[23] G.L. Liu, C.Zhu, C.S. Cheung and C.W.Leung, Theoretical and experiemntal estudies on air-gap membrane distillation. Heat Mass Transfer, 34 (1998)329–331.
[24] K.W. Lawson and D.R. Lloyds, Membrane distillation. II. Direct contact MD, J. Membr. Sci., 120 (1996) 123–133.
[25] L. Martínez and J.M. Rodríguez-Maroto, Characterization of membrane distilaltion modules and analysys of mass flux enhancement by channel spacers, J. Membr. Sci., 274 (2006) 123–137.
[26] L. Martínez-Díez, M.I. Vázquez-González and F.J. Florido-Díaz, Study of membrane distillation using channel spacers, J. Membr. Sci., 144 (1998) 45–56.
[27] J.M. Rodríguez-Maroto and L. Martínez, Bulk and measured

temperatures in direct contact membrane distillation, J. Membr. Sci., 250 (2005) 141–149.
[28] K.K. Sirkar and B. Li, Novel membrane and device for direct contact membrane distillation based desalination process: Phase II. Desalination and Water Purification Research and Development, Final Report No. 96, 2003.
[29] J. Walton, H. Lu, C. Turner, S. Solis and H. Hein, Solar and wate heat desalination by membrane distillation. Agreement No. 98-FC-81-0048. Desalination and Water Purificaction Research and Development. Program Report No. 81, College of Engineering, University of Texas at El Paso, 2004.
[30] Y. Yun, R. Ma, W. Zhang, A.G. Fane and J. Li, Direct contact membrane distillation mechanism for high concentration NaCl solutions, Desalination, 188 (2006) 251–262.
[31] Z. Ding, R. Ma and A.G. Fane, A new model for mass transfer in direct contact membrane distillation, Desalination, 151 (2002) 217–227.
[32] M. Wieghaus, J. Koschikowski and M. Rommel, Solar membrane distillation ideal for remote areas. Desalination & Water Reuse, 18(3) (2008).
[33] M. Rommel, J. Koschikowski and M. Wieghaus, Solar driven desalination systems based on membrane distillation. NATO Advanced Research Workshop, Tunisia, 2006.
[34] M.l Wieghaus, PV and thermally driven small-scale, stand-alone solar desalination system, Presented at IDA World Congress on Desalination and Water Reuse, Maspalomas, Spain, 2007.