تحت رعاية معالي رئيس مجلس الوزراء المصري المهندس شريف إسماعيل
مؤتمر تحلية المياه الحادي عشر في البلدان العربية
UNDER THE PATRONAGE OF THE EGYPTIAN PRIME MINISTER ENGINEER SHERIF ISMAIL
11TH WATER DISALINATION CONFERENCE IN THE ARAB COUNTRIES
18-19 APRIL 2017 • INTERCONTINENTAL CITY STARS - CAIRO - EGYPT

SOLAR VACUUM MEMBRANE DISTILLATION FOR SEA WATER DESALINATION

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Objective

The main objective is to improve the overall performance of membrane-based water desalination processes by applying innovative technologies to reduce energy consumption by using renewable energy and save energy of condensation.

We design and develop an autonomous solar vacuum membrane distillation for seawater desalination system (PV–thermal collector) for a capacity about 0.5 m^3/day.

Experimental tests were carried to determine the permeate water production.

Introduction

Solar energy

- **Solar energy in Tunisia**
- **Modeling and validation of the meteorological model**
- ***Modeling of solar radiation***

Solar collectors

- **Modeling of the outlet temperature of solar thermal collector**
- ***Choose of orientation and disposition solar collector and field of collectors***

Vaccum membrane distillation

Coupling of solar energy with membrane

EXPERIMENTAL STUDY

- **Experiences**
- ***Determination of production of desalinated water***

Conclusion

Introduction

- Tunisia is located on the southern rim of the Mediterranean basin
- very limited water resources
- A high degree of salinity, a large spatial and temporal disparity between southern and northern parts
- Characterized by an immense wealth of solar energy (350 sunny days per year)

Introduction

Tunisia has good experience in the field of desalination membrane (RO)

Since the 80s, Tunisia has resorted to brackish water desalination via membrane techniques such as reverse osmosis (RO).

The contribution of membrane processes to the production of potable water has become a reality, e.g. the supply of Gabès and Zarzis towns, Kerkennah and Djerba Isles, as well as some tourist unities and oil companies.

The quantity of drinking water produced by membrane techniques represents 1.5% of the total volume distributed by the SONEDE (National Society of Water Exploitation and Distribution).

The desalination by the solar energy coupled with the membrane technique is regarded as an interesting alternative

Modelling of solar radiation

Weather data are a function of:

- site,
- Weather data reconstitution models.

The data weather are measured directly or provided by weather stations.

A big number of models are provided in the literature.

The model of LIU and JORDAN

The model of EUFRAT

Computer code for solar energy

We have designed a computer code for solar energy use and developed an interface which represents a tool of assistance to choice the type of adequate collector.

This interface is formed by two parts:

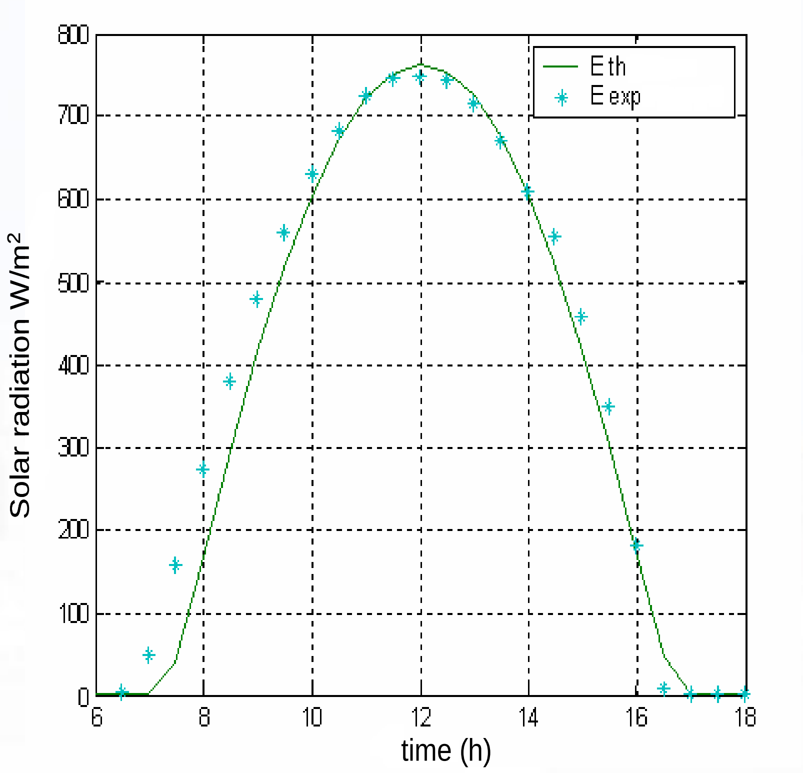
- The first relates to the simulation of solar radiation (direct, diffuse and total) and the ambient temperature and

- The second the exit instantaneous temperature of each solar collector (flat plate, cylindro-parabolic, vacuum).

The program will calculate the sunrise and the sunset in true solar time, the various solar radiations: total, diffuse and direct receipts by a horizontal flat plate and a tilted plan of slope and orientation

Modelling of solar radiation

The comparison of the results of simulations obtained by the EUFRAT Model and the experimental values (taken by means of a weather station installed in ENIG) shows a satisfactory agreement



Modeling of the outlet temperature of solar thermal

The modeling of temperature is based on energy balances on the fluid flowing through the tube of the absorber, the absorber and a heat exchange between the absorber and the fluid between the absorber and glass, and between glazing and the environment.

For calculations of the temperature output of any collector, it must bring the following:

- Wind velocity (m / s).
- The collector characteristics : length of tube (m),
- The number of tubes, the outer and inner diameter (m).
- The collecting area (m^2).
- The coolant flow ($kg.m^2/s$)

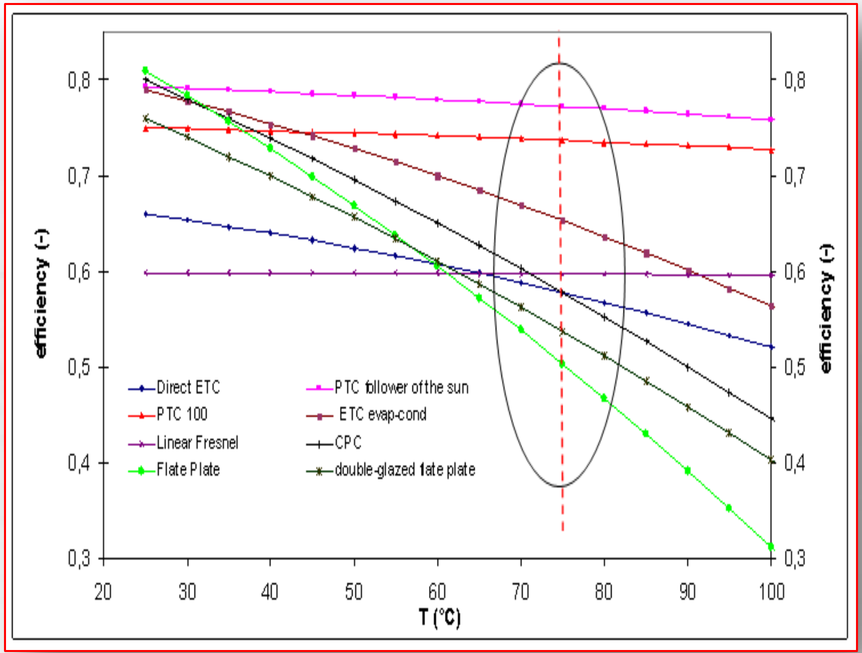
The program will display the temperature of the coolant, absorber and glass.

Choose of solar collector

In the case of a collector, you must choose the glazing type (single, double, etc. ...), selectivity (selective or non selective wall) and type of material of the absorber plate (aluminium, copper, zinc, steel, silver,…).

For a best performance and a temperature of 75°C the choice is made on the collector anti reflexion and double glass. The collector efficiency η can be written as:

$$\eta = 0.76 - 2.66\,\frac{\Delta T}{G} - 0.009\,\frac{\Delta T^2}{G}$$



ΔT is the difference temperature between the temperature of the coolant and the ambient temperature,
G is solar irradiation.

Collector field design

The design of the collector field will depend:

- the **temperature of exit of retentate** that will depend on the membrane characteristics, the crossing through the membrane number,
- **energy recovery** system from the distillate,
- heat exchanger efficiency,
- the **season** choice : summer, winter

Vaccum membrane distillation (VMD)

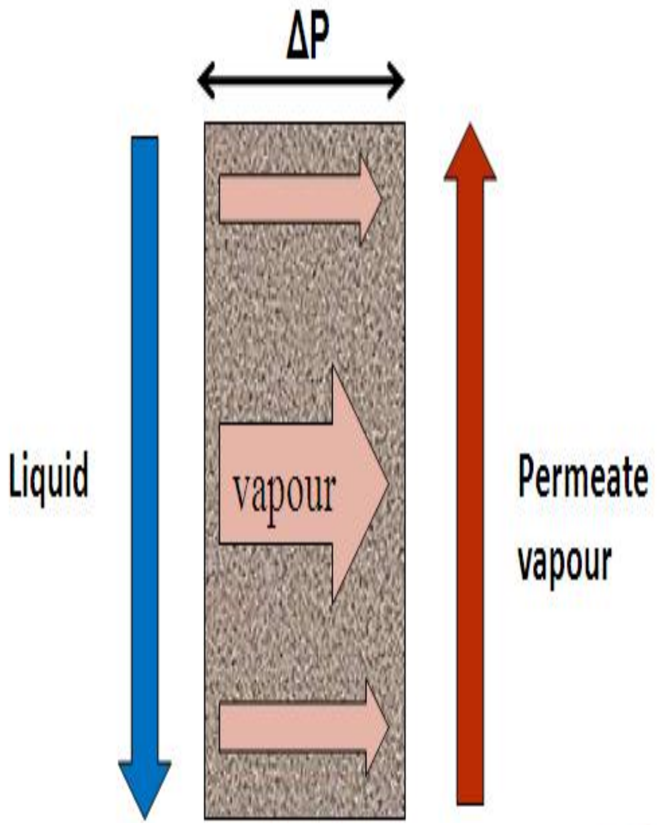
Membrane distillation (MD) is a relatively new process being investigated worldwide as a conventional separation process, such as distillation and reverse osmosis

VMD can be characterized by the following steps:

* vaporization of the more volatile compounds at the liquid/vapor interface

* and diffusion of the vapor through the membrane pores according to a Knudsen mechanism.

* Permeate condensation takes place outside the module, inside a condenser or a trap containing liquid nitrogen



Advantages of Vaccum membrane distillation (VMD)

The MD technique holds important advantages with regard to the implementation of solar driven stand-alone operating desalination systems. The most important advantages are:

- The operating temperature of the MD process is in the range of 60 to 80°C. This is a temperature level at which thermal solar collectors perform well.
- Chemical feed water pre-treatment is not necessary.
- Intermittent operation of the module is possible. Contrary to RO, there is no danger of membrane damage if the membrane falls dry.
- System efficiency and high product water quality are almost independent from the salinity of the feed water.

The choice of the membrane type system depends on a parameters number, such as the costs, the fouling of the membranes, the cleaning frequency, ...

Module of membrane design

The modules are the supports of the membranes, 4 modules types are marketed : tubular modules, hollow fibres modules, plane modules, spirals modules.

The choice of the module of membrane depends on:

- **Physical and chemical membrane characteristics** (natural of material, …)
- **Hydrodynamic :** nature and flow rate,
- **Pass number in the module**,
- **Thermal stress**,
- **The costs,**
- **The fouling of the membranes,**

The cleaning frequency,...

The chosen membrane module is a hollow fiber microfiltration module in PVDF, provided by PALL Company with this characteristics :

Fiber internal diameter (mm)	**$1.4\ 10^{-3}$**
Number of fibers	**806**
Thickness of the membrane (m)	**0,0004**
Module length (m)	**1,129**
Area (m^2)	**4**
Permeability ($s.mol^{1/2}\ K^{1/2}\ kg^{-1/2}\ m^{-1}$)	**$3{,}29\ \ 10^{-5}$**
Porosity	**0,75**
Tortuosity	**2,1**

Coupling of solar energy with membrane

The use of solar energy can be:

• Provided by the heating of sea water by a coolant from the solar collector. The distillation module is separated from the solar system (system not integrated),

* The module **is immersed** in the solar collector,

* The module **is integrated** in the solar collector (integrated system).

In the configuration of the **collector membrane separate** several possibilities are conceivable:

- Sea water flows through the collector and the membrane. This requires a noble material for the collector (e.g titanium).

- Either a heat exchanger between the two.

For the type of solar collector can use a flat plate collectors, a CPC collectors, a solar pond, ...

The choice of membrane is based on the level of desired temperature, collector efficiency, utilizing, cost

Pilot plant DESIGN

The pilot plant was installed in the village of orphaned children (SOS MAHRES).

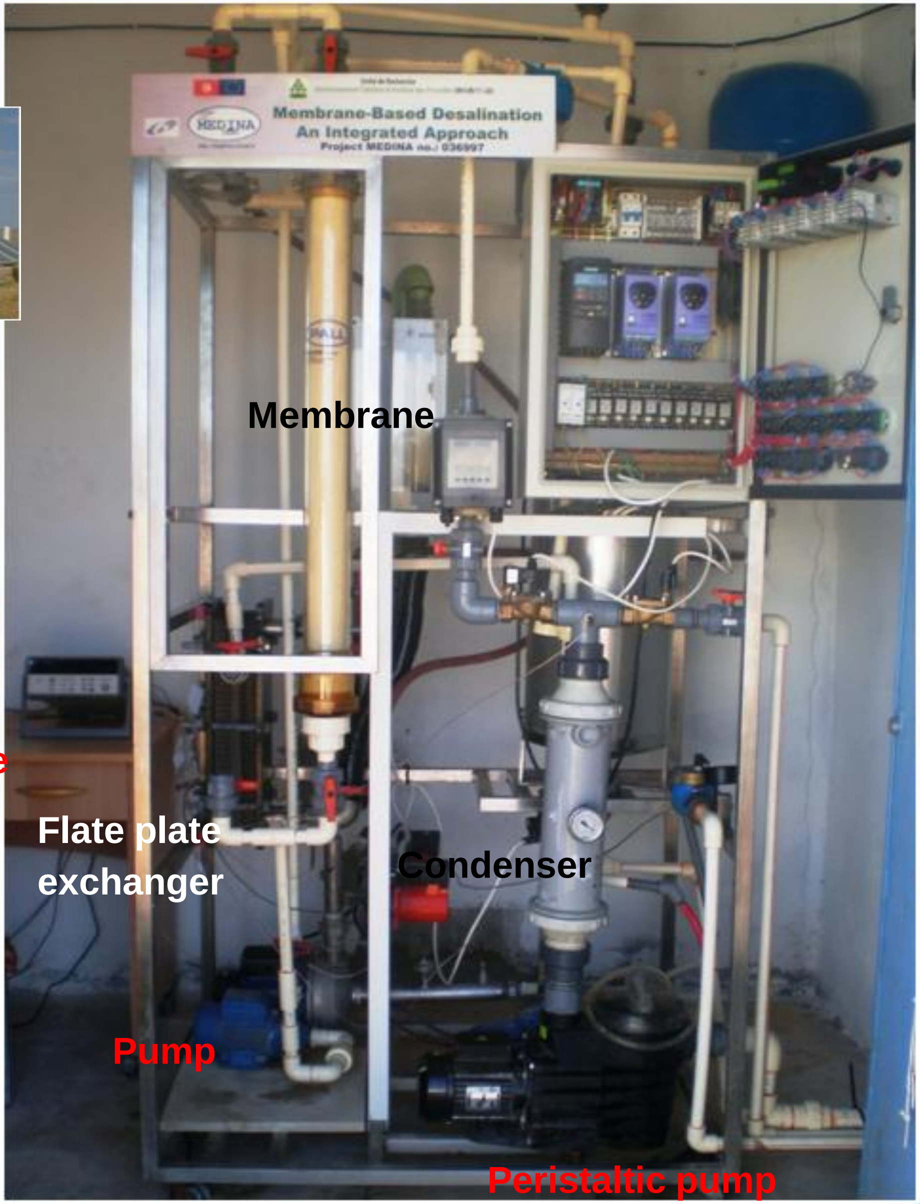
Power supply of the plant with photovoltaic cells to aggregate power of 1.5 kilowatts, with the possibility of storage electrical energy produced.

When the electric charge accumulated in the batteries exceeds the power requirements needed to aliment the pumps, an electrical resistance can heat the contents of the tank.

We have realized a system of data acquisition and control unit.

Photovoltaic collectors

Energy storage




Membrane-Based Desalination
An Integrated Approach
Project MEDINA no.: 036997
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Experiences

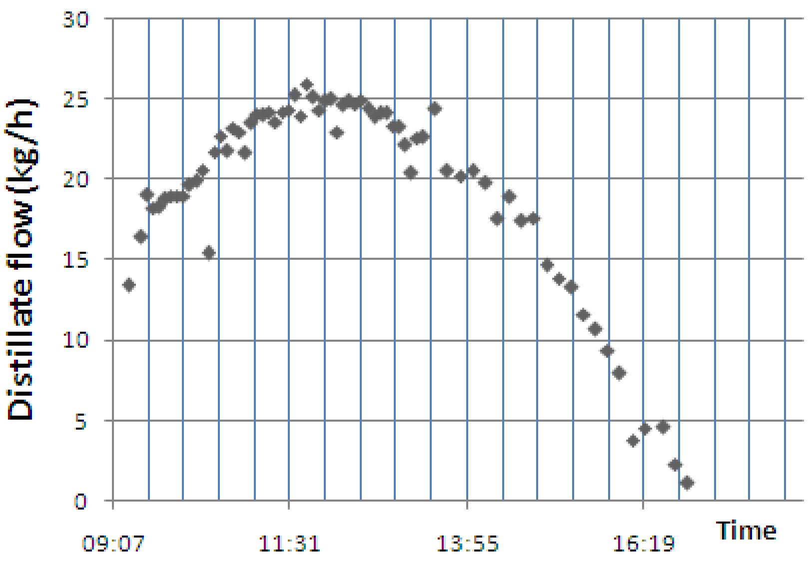
The experimental study involves measuring the following parameters:

- The global solar radiation using a pyranometer,
- The heating and seawater flow using flow-meters,
- The different temperatures using a temperature sensor Pt100.

Determination of production of desalinated water

We present the results collected March 23. This day is characterized by clear skies throughout the day with a maximum ambient temperature of 29 °C.

The evolution of the distillate flow versus time is given in the figure.



The curve increases gradually at the beginning of the day and reached a maximum between 12 and 13h, and then it decreases gradually.

This result is due to the incident solar energy the most parameter affecting the production of a solar desalination unit.

The daily production is about 150 kg.

Figure : Permeate water production versus time shiny day- 23 March 2010- Pressure = 7000 Pa; Feed flow rate = 2130 kg/h, Re <670

Determination of production of desalinated water

Figures show the variations of a solar radiation and distillate flow to a cloudy day. Distillate flows are **low** compared to estimates. This is mainly due to the commercial membrane chosen is not dedicated for membrane distillation.

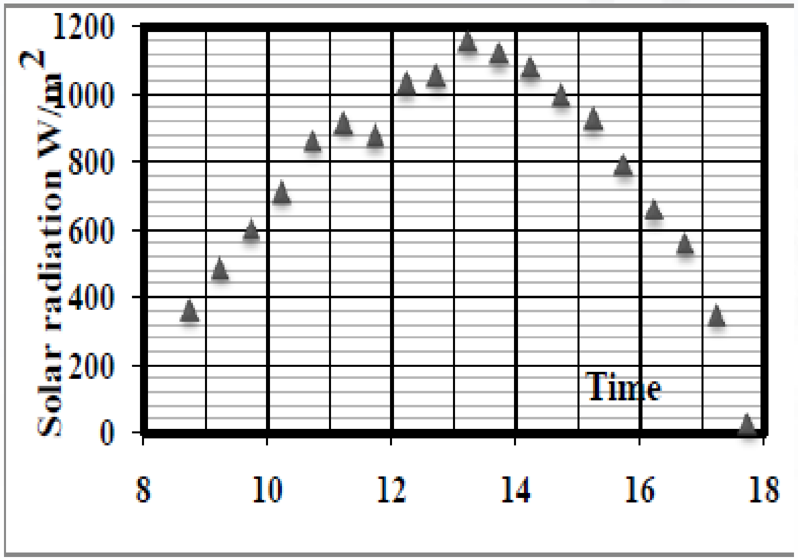


Figure : Variation of solar flux function of time

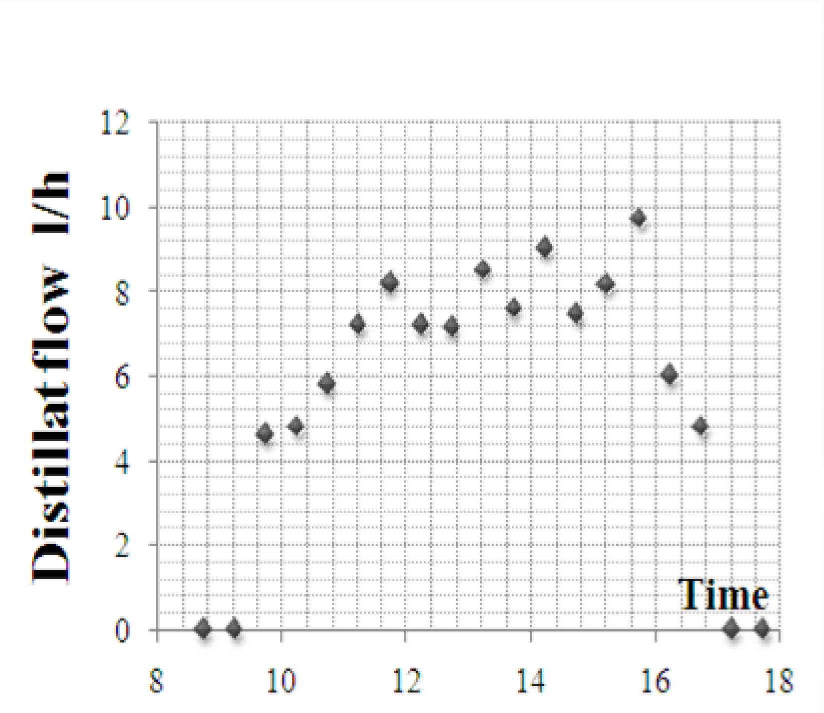


Figure : Permeate water production versus time
Cloudy day- February 24, - Pressure = 7000 Pa;
Feed flow rate = 785 kg/h, Re <250

Parametric study

The parametric study has focused on the effect of:

- **Feed rate of the membrane,**
- **Water temperature supply,**
- **Heating flow,**
- **Heating temperature,**
- **Solar radiation.**

According to tests, it appears that the most sensitive parameter is the feed rate of the membrane.

In the current state, an increase in feed rate of the membrane causes a decrease in exchange area.

We must search a position of the membrane that allows a high flow rate without losing the exchange area.

CONCLUSION

Design calculations of system were performed with Matlab, taking into consideration mass and heat transfer equations in the membrane module, and considering heat power due to the solar collector, along the year.

Based on these calculations, pilot plant will be able to provide average permeate flow ranging from 35 l/ h to 21 December to 70 l / h to 21 June with a temperature not exceeding 75 °C in order to avoid membrane damage.

While the current productivity is lower than desired, but several improvements can be conducted (increasing seawater flow rate, thermal insulation of the membrane and the tank ...).
The objective is essentially to determine the optimal operating conditions and to carry an energetic study of the pilot plant.

Acknowledgment

The authors address the most sincere thanks to the European Commission for its financial support within the framework for the 6th PCRD for the project Membrane-Based Desalination : An Integrated Approach **MEDINA** Project No: 036997

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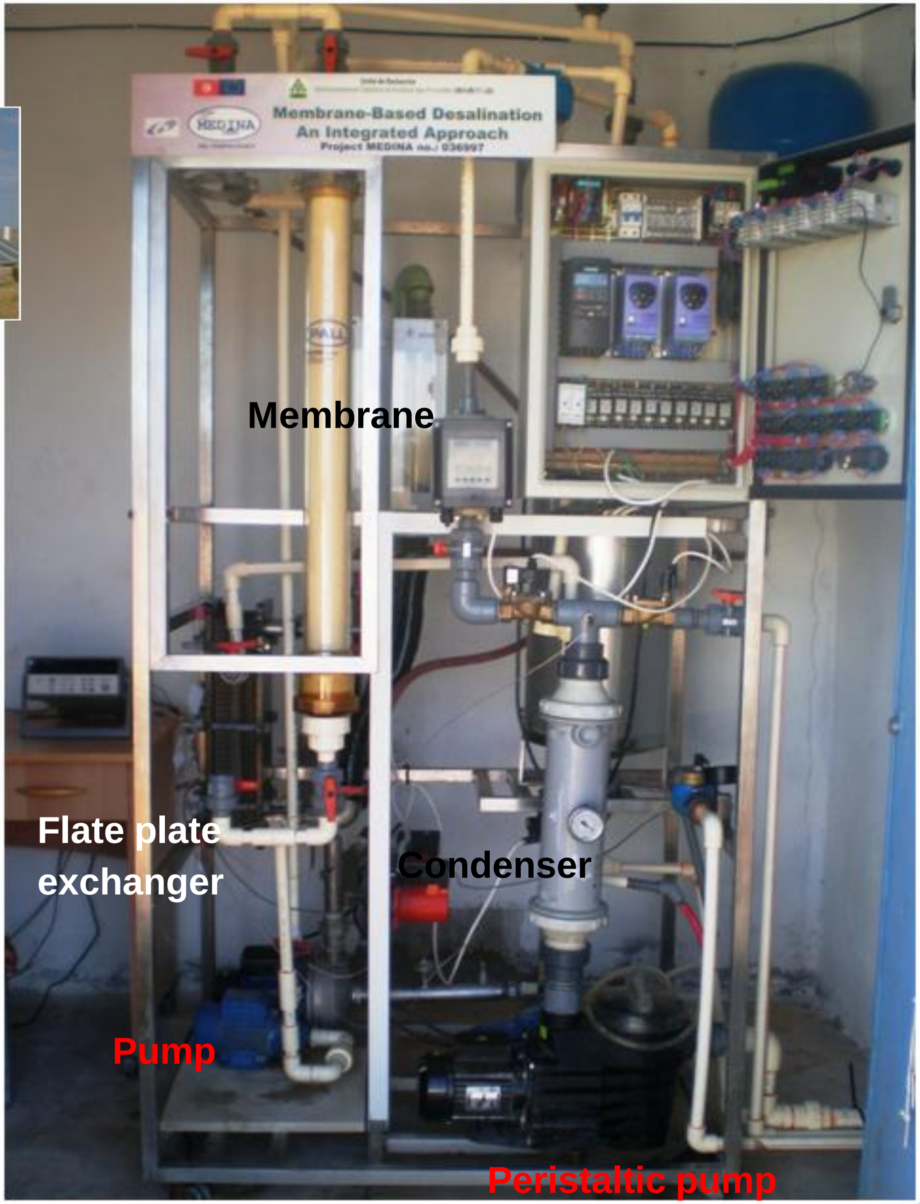
Photovoltaic collectors

Electric control

Energy storage



Membrane

Flate plate exchanger

Condenser

Pump

Peristaltic pump