Potential of Solar Desalination by Vacuum Membrane Distillation

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Context of the study

➢The crisis of drinking water announced for the coming years raise the interest of rapid development of desalination technologies with less energy intensive

➢ Conventional desalination processes require large amounts of energy in the form of thermal energy (MED and MSF) or electrical energy (RO).

➢To deal with these problems, desalination technologies based on renewable energies are highly desirable. Solar energy is one of the most promising renewable energies in the field of water desalination.

➢In this context we have studied the potential of coupling solar energy with vacuum membrane distillation (VMD) coupled with solar energy and examining several possible configurations.

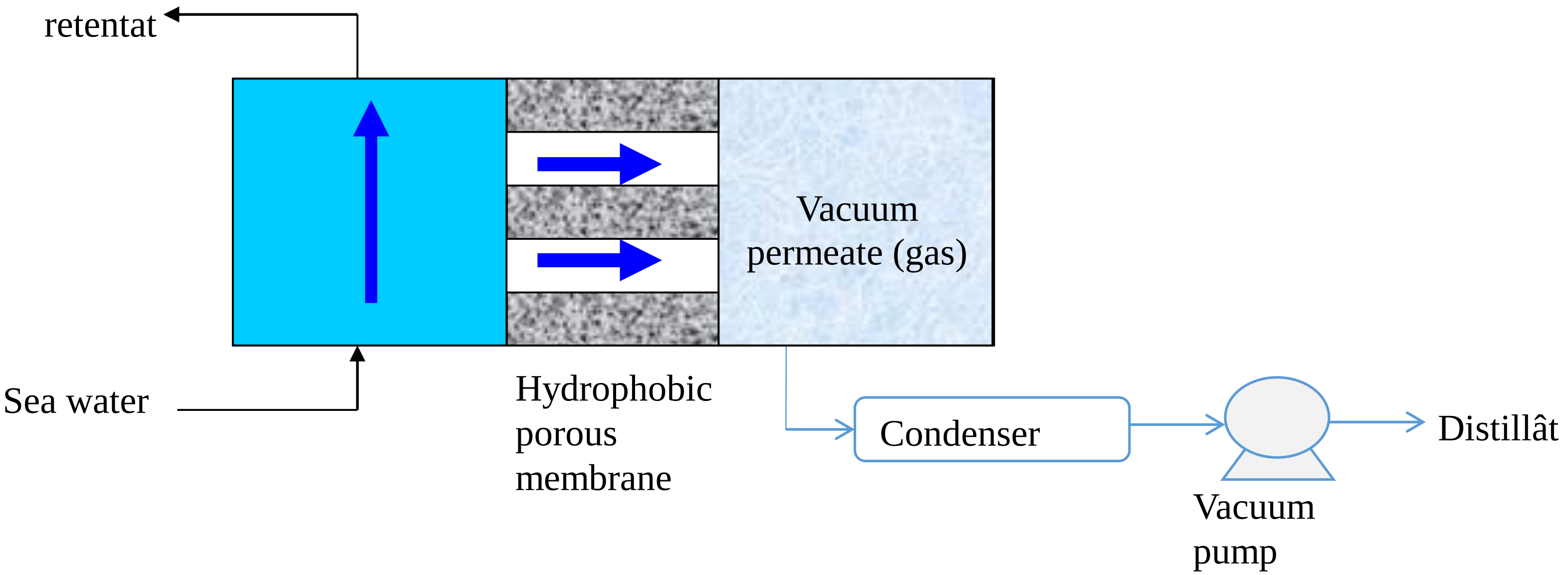
Vacuum membrane distillation

•Membrane distillation (MD) is a thermal membrane separation process which uses hydrophobic porous membranes

• The process driving force is the difference between the vapor pressure between the two sides of the membrane.

• Several membranes can be used (planes, hollow fibers, spiral module and tubular module)

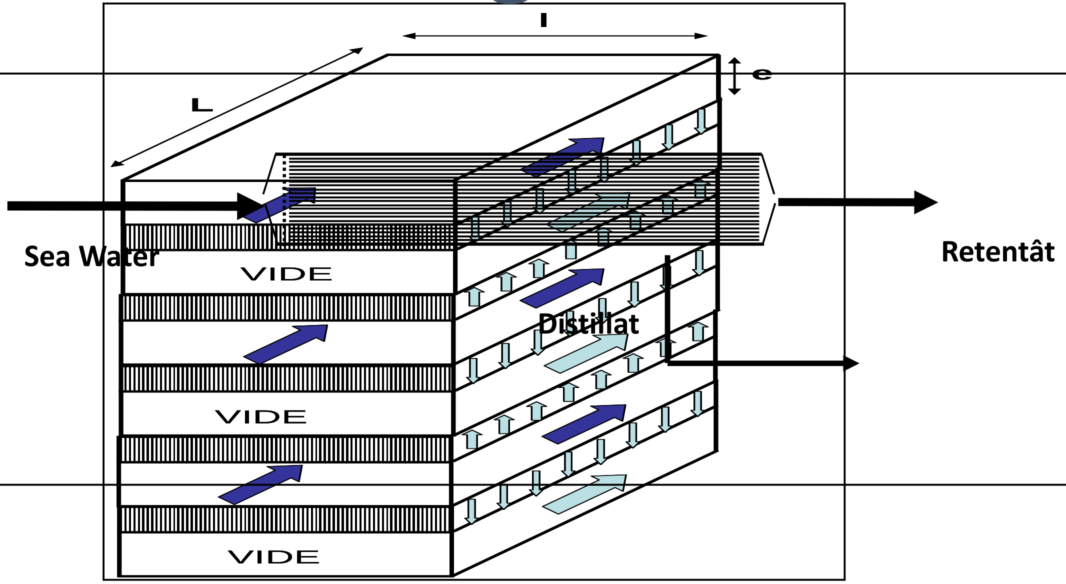
• Desired temperature level: 70-80°C, Using solar energy to heat seawater.



Configurations investigated

Studied membranes

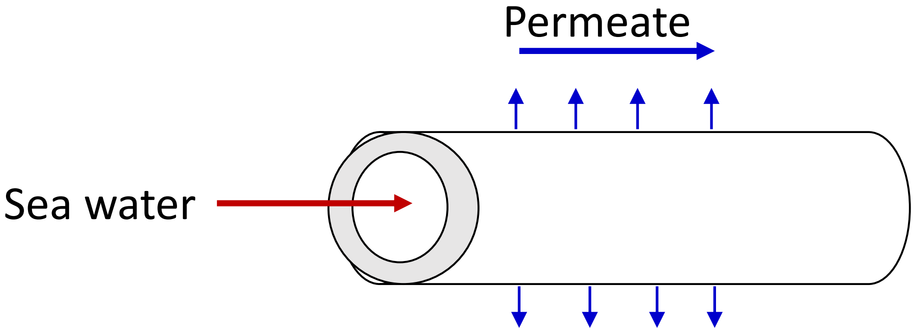
Plane membrane module



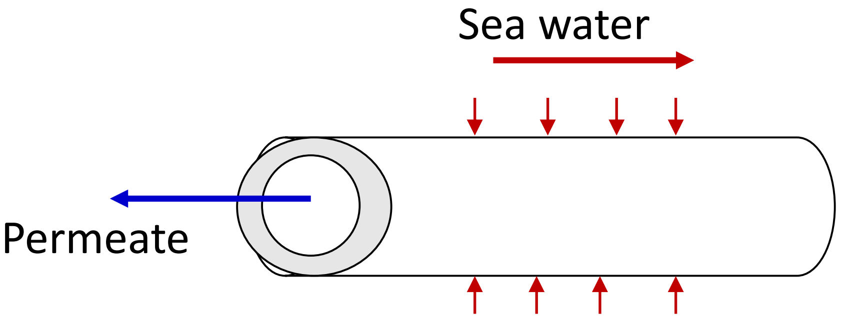
Hollow fiber module

Module configurations

Internal – external



External – Internal



Module arrangement with respect to the solar collector

Separated

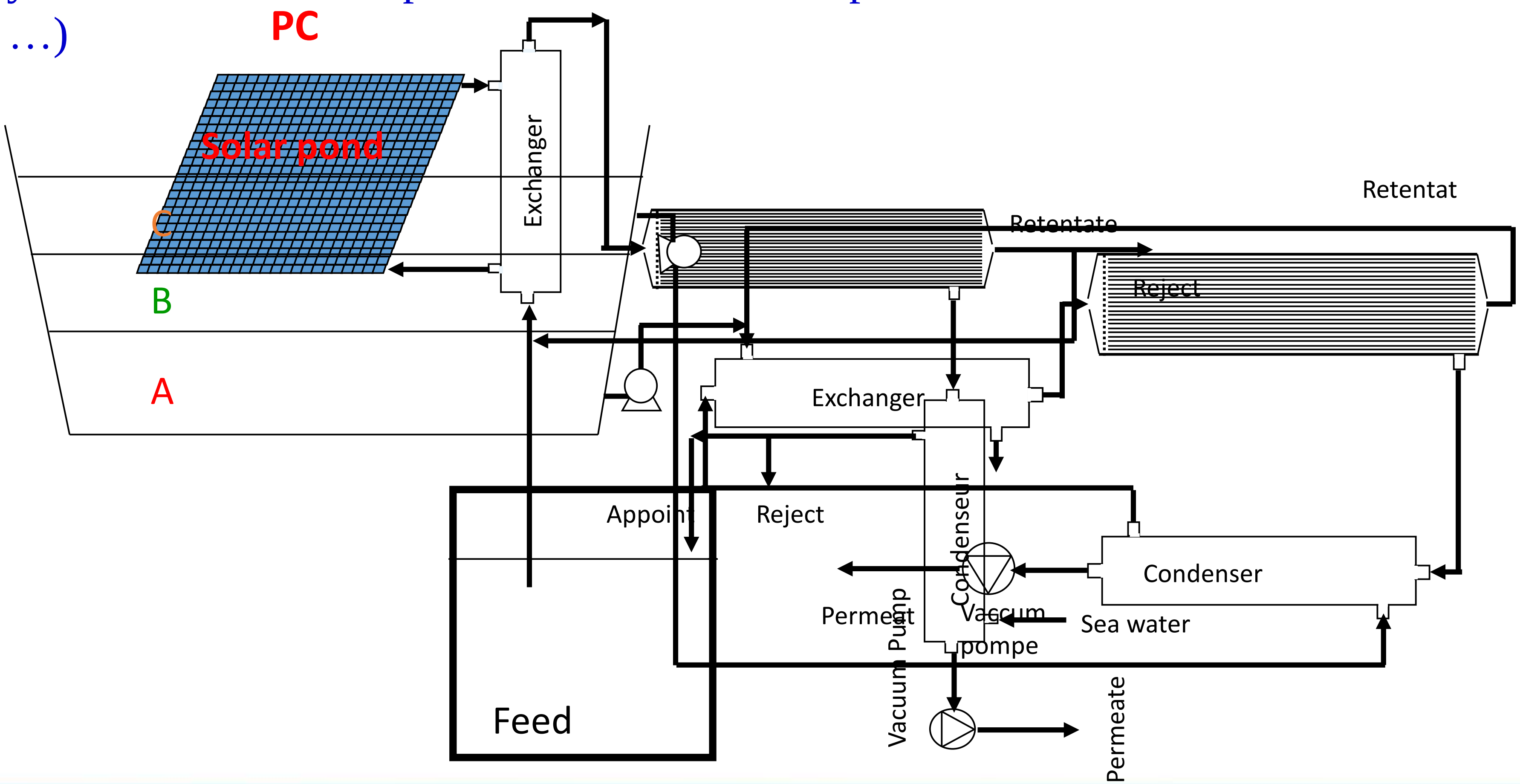
Integrated

Separated system

➢ **Non-submerged system**

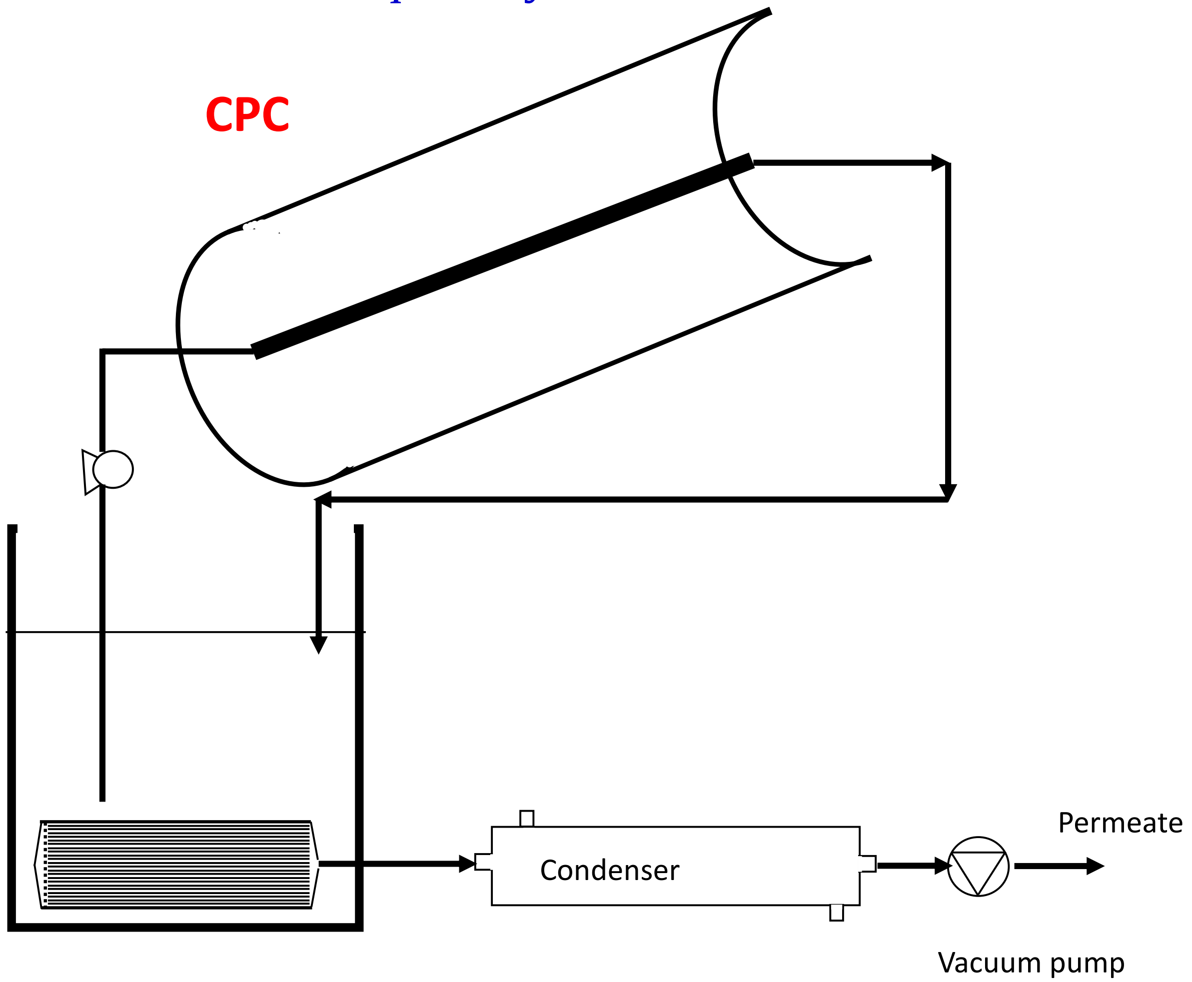
Heating of the seawater by a heat transfer fluid circulating in the solar collector

The majority of solar collectors provide the desired temperature level as this level is moderate.(PC, CPC, Solar pond, …)



➢ Submerged system

The membrane module can be immersed in a tank containing the heated water.
The membrane module must ensure the extraction of a quantity of desalinated water from the solution where it is immersed.

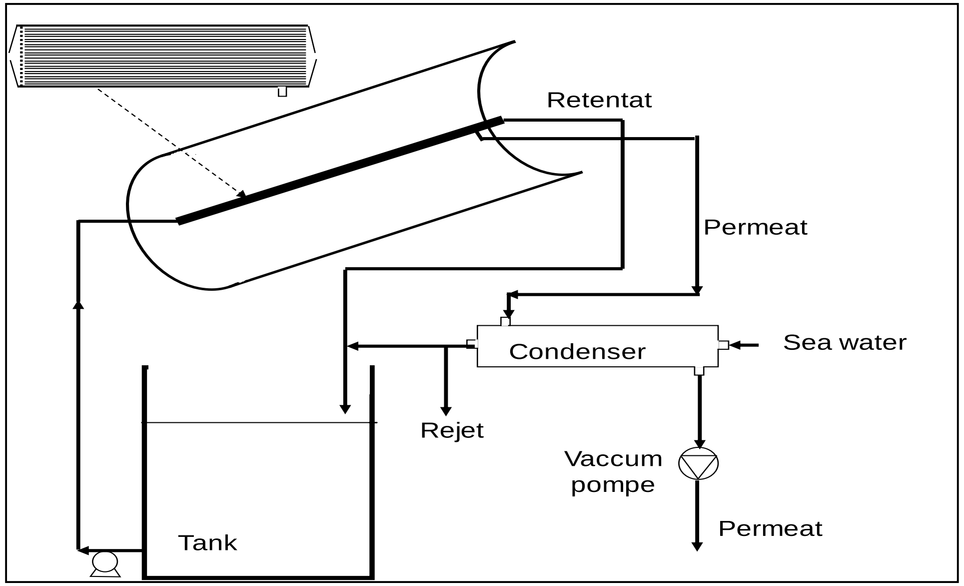


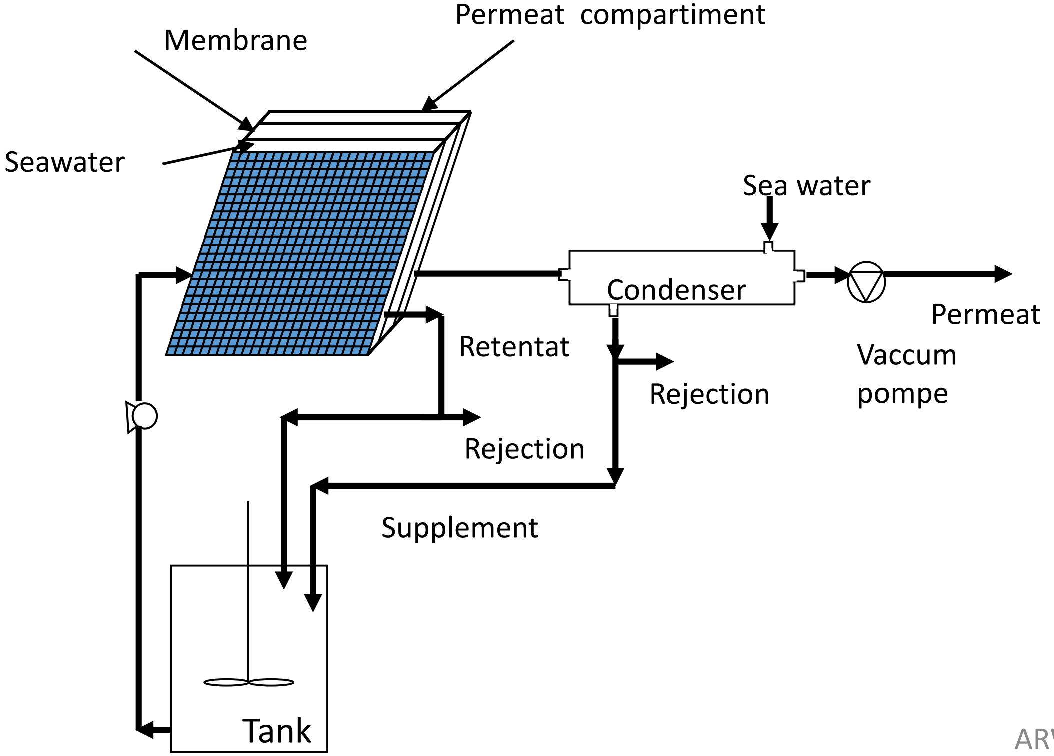
Integrated system

Membrane module integrated in the solar collector.

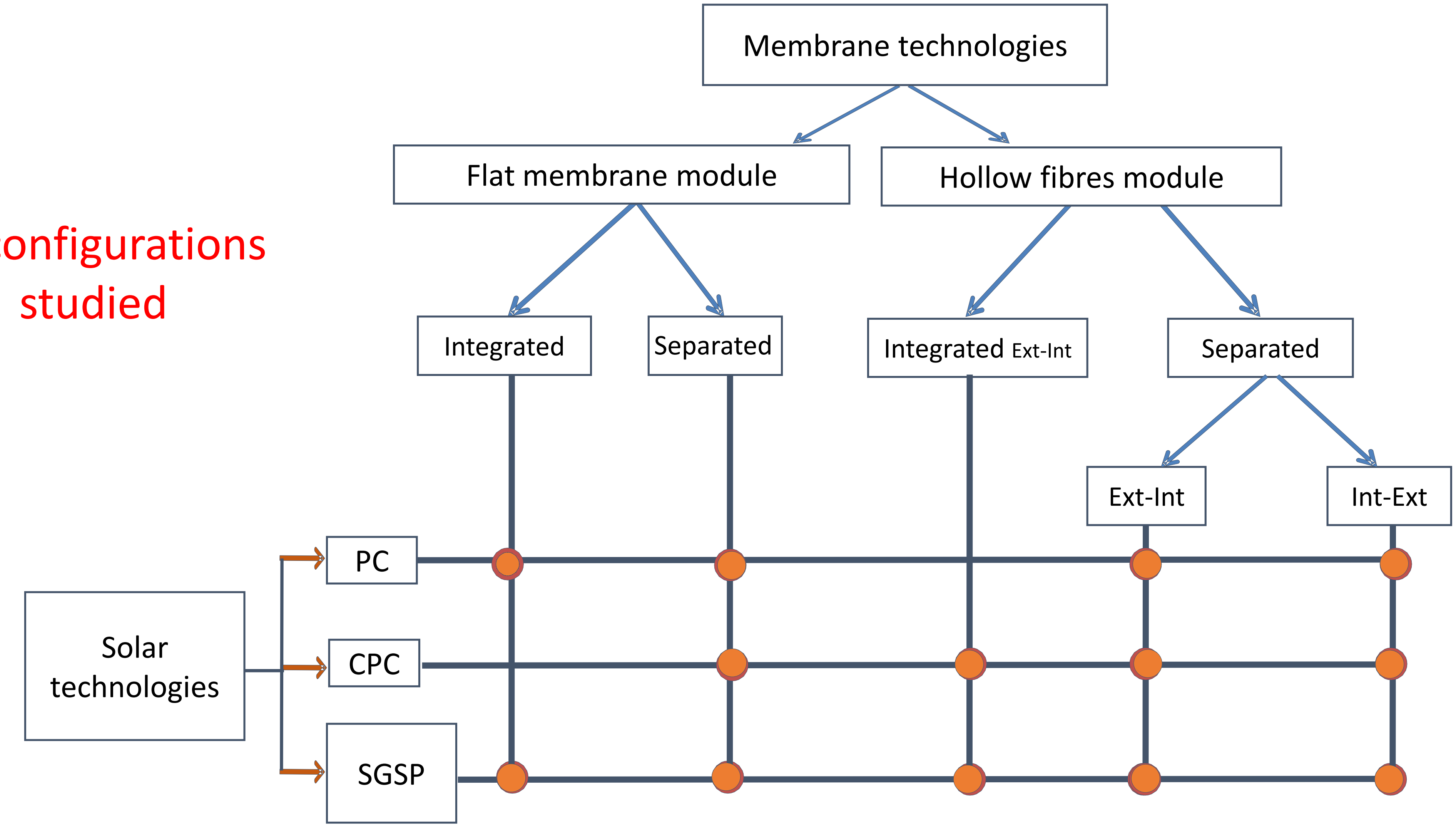
Original configuration:

- Direct heating
- Module carried to a higher T
- Reduction of components
- Reduction of thermal losses.





13 configurations studied



Modeling of solar technologies

Solar flux

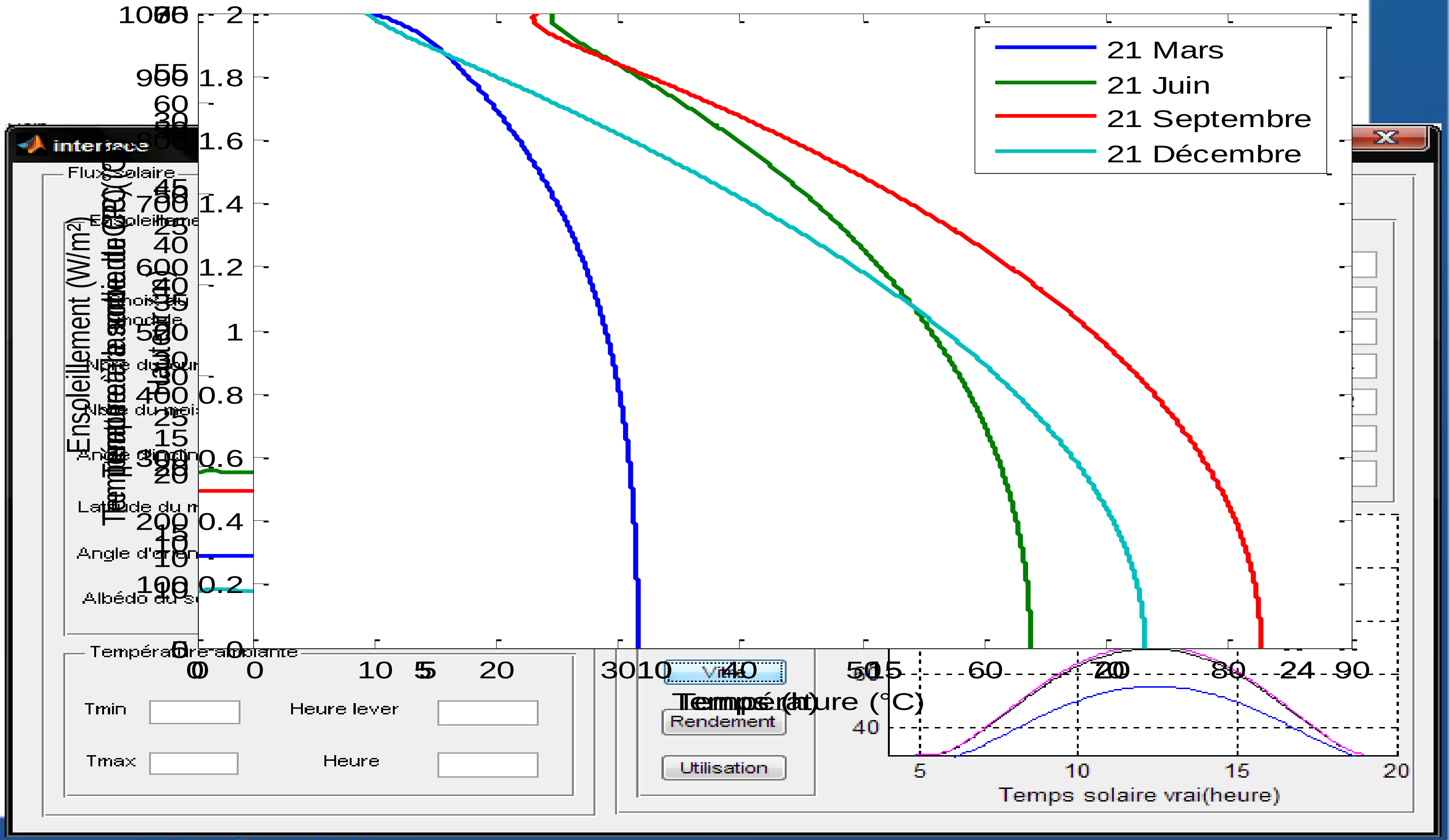
Mathematical models (Eufrat, Liu Jordan, Brichambaut ...)

Ambient temperature

Solar technology

- Plan collector
- Cylindro-parabolic collector (CPC)
- Solar pond (SGSP)

Development of a graphical interface on Matlab software



Dynamic modeling of membrane modules

Objective: Establishment of models allowing the determination of $T_{retentate}$, T_{vapor} and $Q_{permeate}$

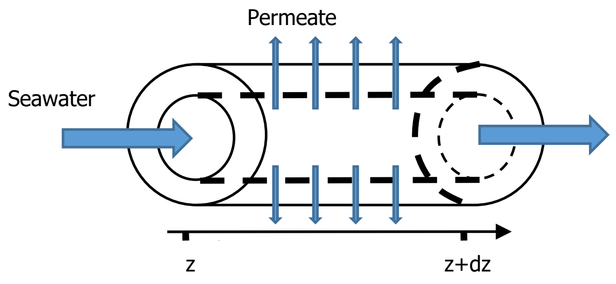
Thermal and material balances

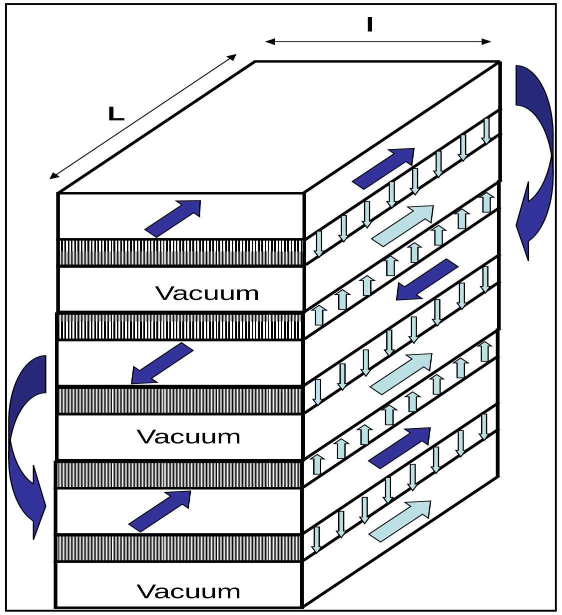
Systems of non-linear partial differential equations.

$$\frac{dT_z}{dt} = -v_z \frac{dT_z}{dz} - \frac{4J_v}{\rho_l\, Cp_l} \frac{S}{V}\left[Cp_l\left(T_{ref} - T_z\right) + L_v\right]$$

$$\frac{d\dot{m}_{dist}}{dz} = Pe\, J_v$$

with $J_v = K\,T_m^{-0,5}\left[\left(1-0.5X_{NaCl} - 10X_{NaCl}^2\right)\left(1-X_{NaCl}\right)\exp\left(A_1 - \frac{A_2}{T_m - A_3}\right) - P_{vide}\right]$

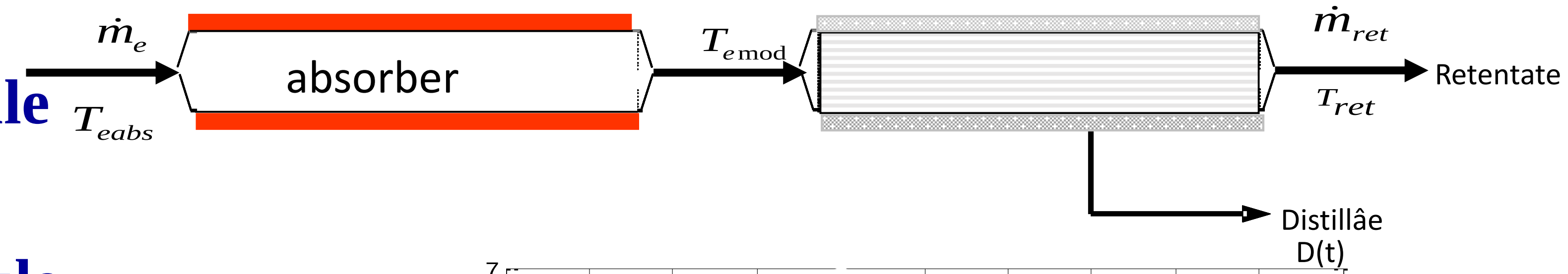




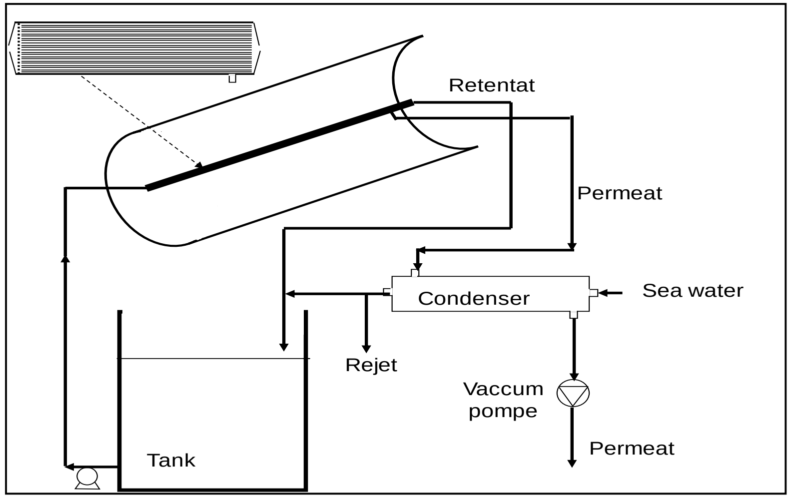
Contribution of integration

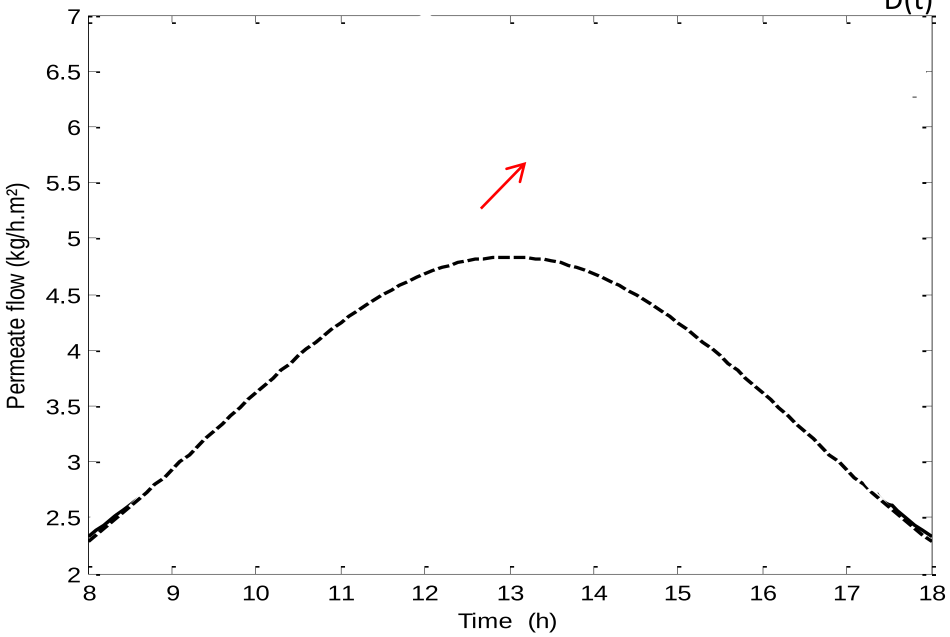
CPC

Separated module



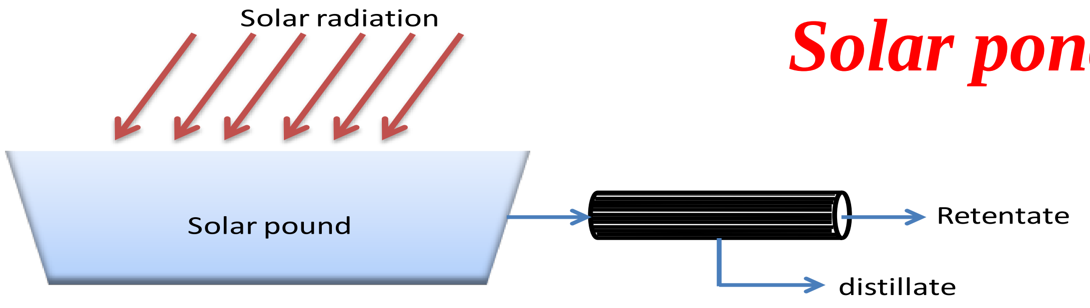
Integrated module



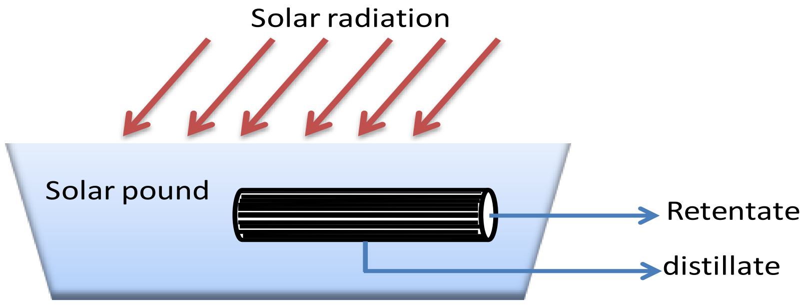


June 21

Contribution of integration

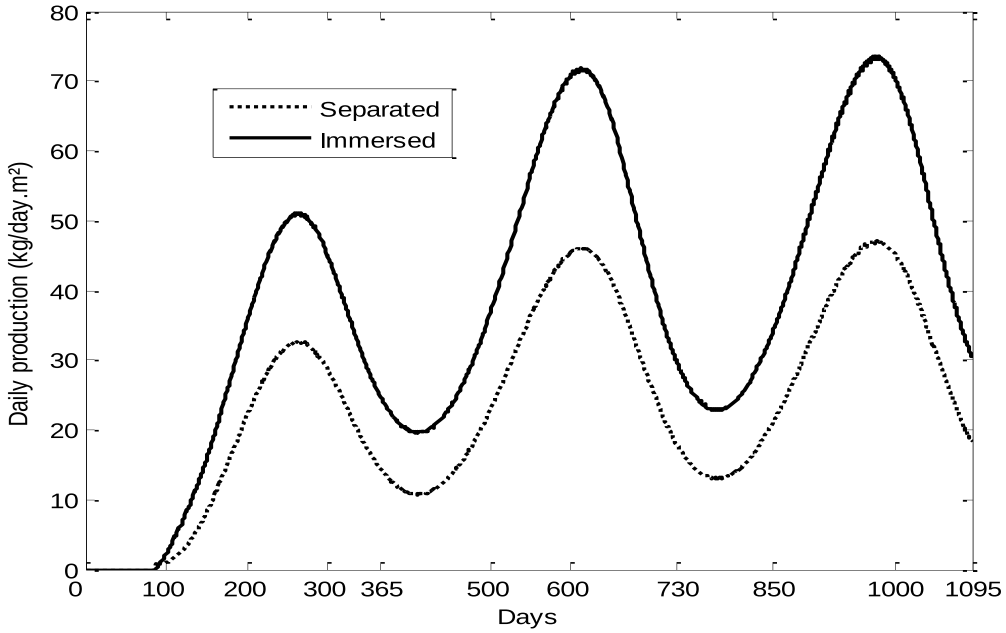


Solar pond



Separated module

Immerged module



The immersion of the module has increased production. For example, the daily production on June 21st of the third year goes from 35 kg/m^2 in the case of a separate module to 54 kg/m^2 in the case of a submerged module..

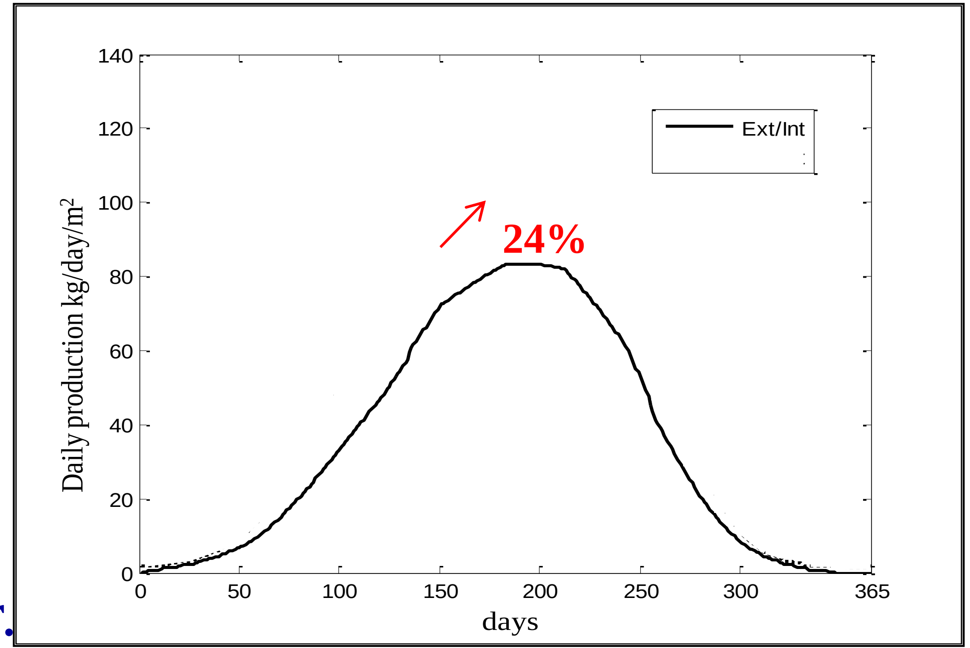
The operating period of the solar pond can last all day, which is not the case for other solar collectors where productivity is closely related to solar flux.

Comparison of internal-external and external-internal arrangements

CPC collector with hollow fiber module

external-internal disposal

December 21st	June 21st
7 kg/m^2	85 kg/m^2



Internal-external configuration presents a better production over the whole of the year.

The productivity of the internal-external arrangement was also better (+ 24%), this is justified by the temperature levels larger output
The increase in productivity with the internal-external arrangement was also observed for the other two collectors studied (solar pond and plan collector).

Potential of different configurations

Hollow fiber module

Annual production m^3/m^2

Configurations du module	Internal-external	External-internal	
	Separeted	Separeted	Integrated
PC	7.1	5.0	-
CPC	19.8	13.7	32.5
Solar pond	13.2	11.4	18.2

- The internal-external disposition leads to higher productivities than those observed with the external-internal disposition.

- The integration alternative makes it possible to improve the production

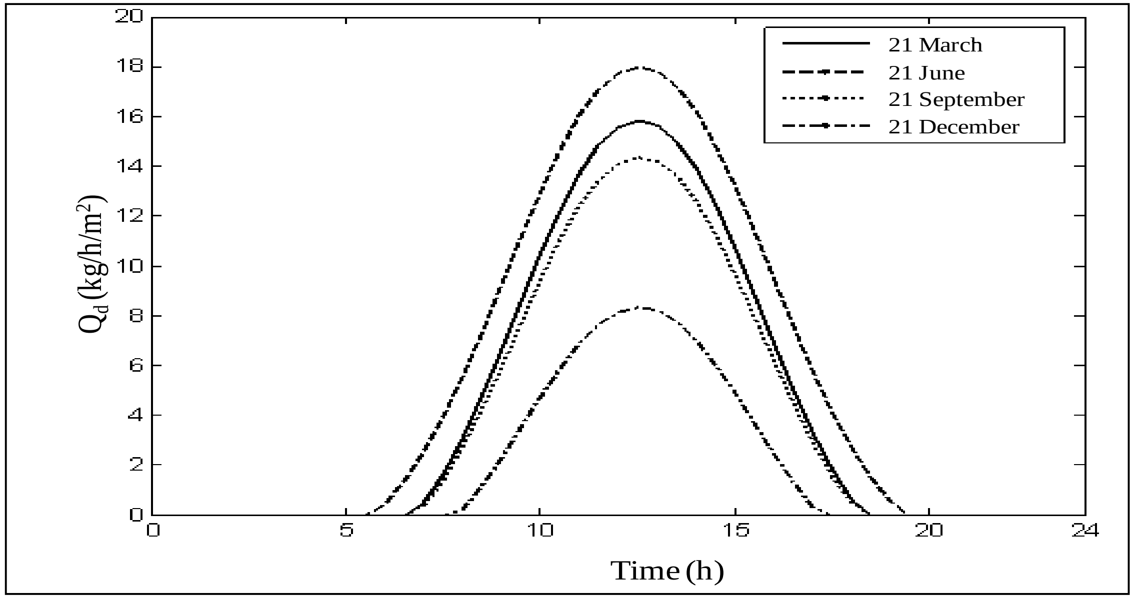
Potential of different configurations

Flat membranes

The same methodology applied in the case of hollow fiber modules has been adopted.

3 types of collectors.

PC
CPC
Solar pond



Plan collector, collecting area of 2 m^2

The productivities per unit area of membranes are close to those obtained with hollow fibers.

Potential of different configurations

Flat membranes

Annual production of a flat membrane module separated from the solar collector

	PC	CPC	Solar pond
Annual production ($m^3.m^{-2}$)	13.3	31.8	13.6

The best configuration is that of the CPC, followed by the Solar pond and finally the PC. This is well justified taking into account the temperature levels obtained at the output of the 3 types of collectors.

Simulation of the distillate production for the configuration of an integrated module shows very low distillate flow rates (less than 14 kg/day/m^2), this is due to the insufficient collecting area compared to that of the membrane.

Taking into account the collecting area, the productivity (per unit area of membrane and per unit area of solar collection) offered by the flat membranes is lower than that relative to the hollow fibers.

Potential of different configurations

This integration has made it possible, in all the cases studied, to improve productivity.
The integration is faced with several technical problems :

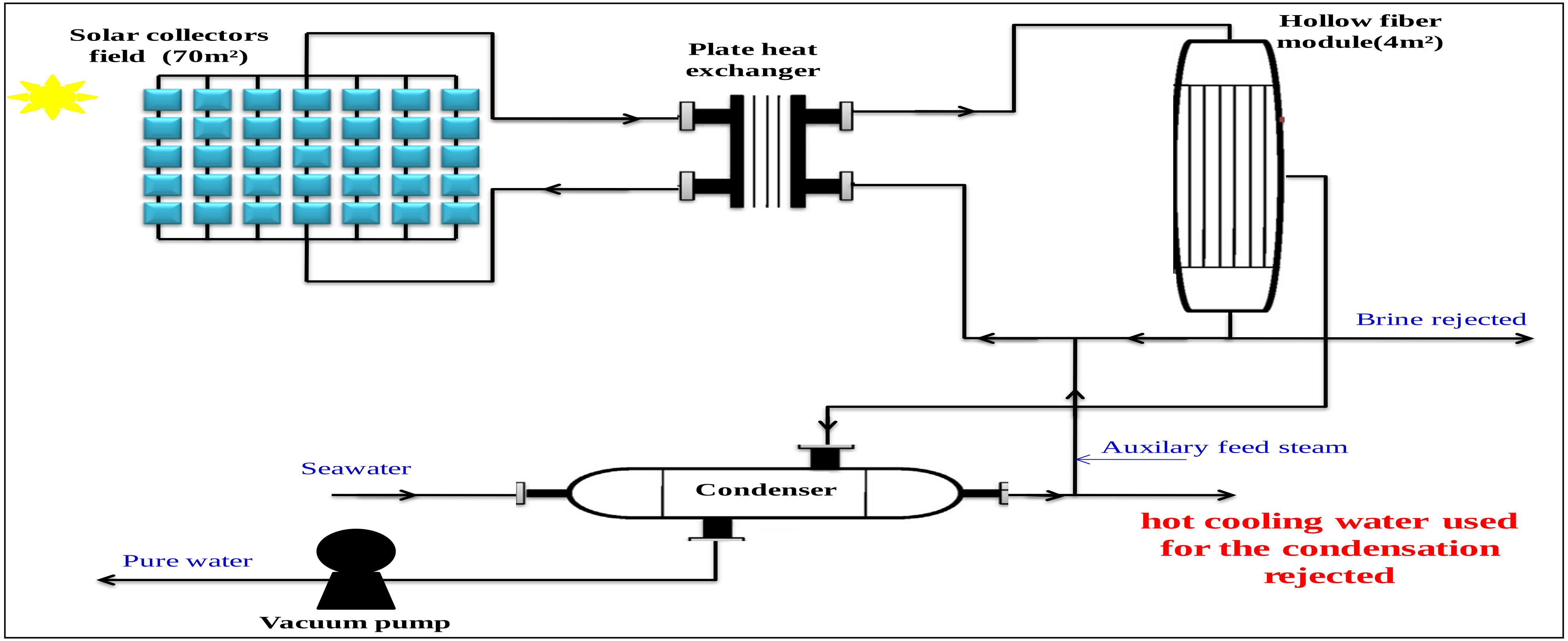
- Corrosion problems.
- Geometric dependence between the membrane surfaces and the capture surfaces

→ Thermal limitation and the membrane operates below these nominal capacities.

The separation of solar collectors from the membrane modules seems like the best solution because we can place the capture surface sufficient to ensure the desired production.

Conception realized

Installation comprising a hollow fiber module and coupled to solar energy.

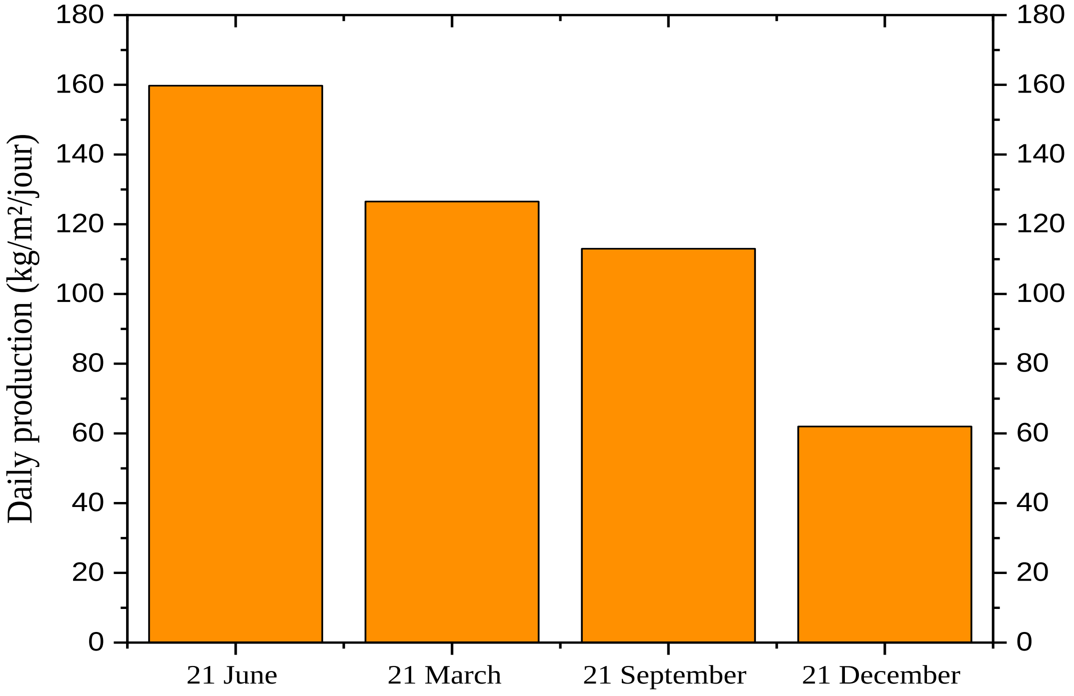


Totally solar installation

- Solar thermal collector field providing water heating (70 m²)
- Photovoltaic cell field providing the necessary electrical energy (16 m2).

Estimated of productivity

The daily productivities corresponding to the four days studied vary from 61 to 160 $kg.m^{-2}$. The annual production of this installation will be around 39.4 m^3/m^2, the membrane surface installed is 4 m^2, so it is estimated an average daily production of 432 L .



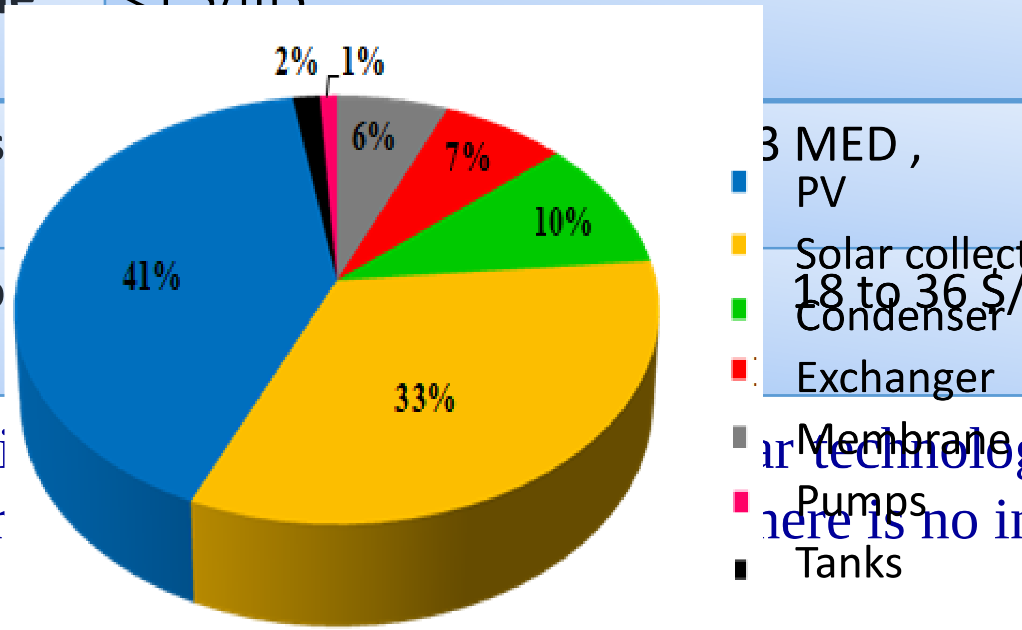
Variation of distillate flow for different days of the year.

P_{vacuum} = 5000 Pa, = 1200 kg/h

Estimated of unit cost

The cost of desalination is usually a function of: plant capacity, energy cost, and investments. The estimated unit cost for the water produced by our facility cost is 11.7 $/m3.

non-solar systems with large scale production	<1 $/m3	Pugsley , 2016
totally solar desalination systems	3 MED ,	Pugsley , 2016
totally solar membrane distillatio processes (500 L / day)	18 to 36 $/m3	Khayet, 2013 Saffarini, 2012



The unit cost is generally exorbi ar technologies, we must take into account that this water will be pr here is no infrastructure.

The productivity of the system designed can be improved by the development of materials that are better adapted to this application, so this unit cost will be expected to decrease following the increase in production.

Conclusion

Estimation of the potential of a large number of configurations coupling the VMD process with different solar technologies.

These configurations are distinguished, in addition to the types of module and solar collector used, by the arrangement of the module with respect to the collector (integrated or separate).

This study also showed that the internal-external arrangement of fibers is better than the external-internal arrangement.

Following this study we have chosen to realize a 100% solar installation where the membrane module is separated from a field of flat solar collectors.

The average daily production of this facility is estimated at 432 L of distilled water with a unit cost of around 11.7$ /m3.

Desalination using solar energy coupled with membrane techniques is a very interesting alternative for the production of drinking water especially for rural and arid areas.

Thank you for your attention