EVALUATION OF A SOLAR POWERED DISTILLATION UNIT AS A MITIGATION TO WATER SCARCITY AND CLIMATE CHANGE

Marios C. Georgiou
PhD Student / Research Assistant

Το Πρόγραμμα συγχρηματοδοτείται
από την Ευρωπαϊκή Ένωση (ΕΤΠΑ)
και από Εθνικούς Πόρους
της Ελλάδας και της Κύπρου

ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ ΕΥΡΩΠΑΪΚΗ ΕΝΩΣΗ ΚΥΠΡΙΑΚΗ ΔΗΜΟΚΡΑΤΙΑ

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Outline

➢ Introduction

- *Water situation in Cyprus*
- *Seawater desalination as a mitigation technique – Multiple Effect Distillation*
- *Seawater desalination powered by solar thermal energy*

➢ Experimental procedure

- *Experimental Setup / Data acquisition and analysis*

➢ Experimental results

- *Single effect distillation for constant heat input / for different seawater feed temperature for constant heat input / for three different heat input conditions*

➢ Analysis of forward feed MED

- Mass / Energy balance equations
- *Comparison with experimental data*

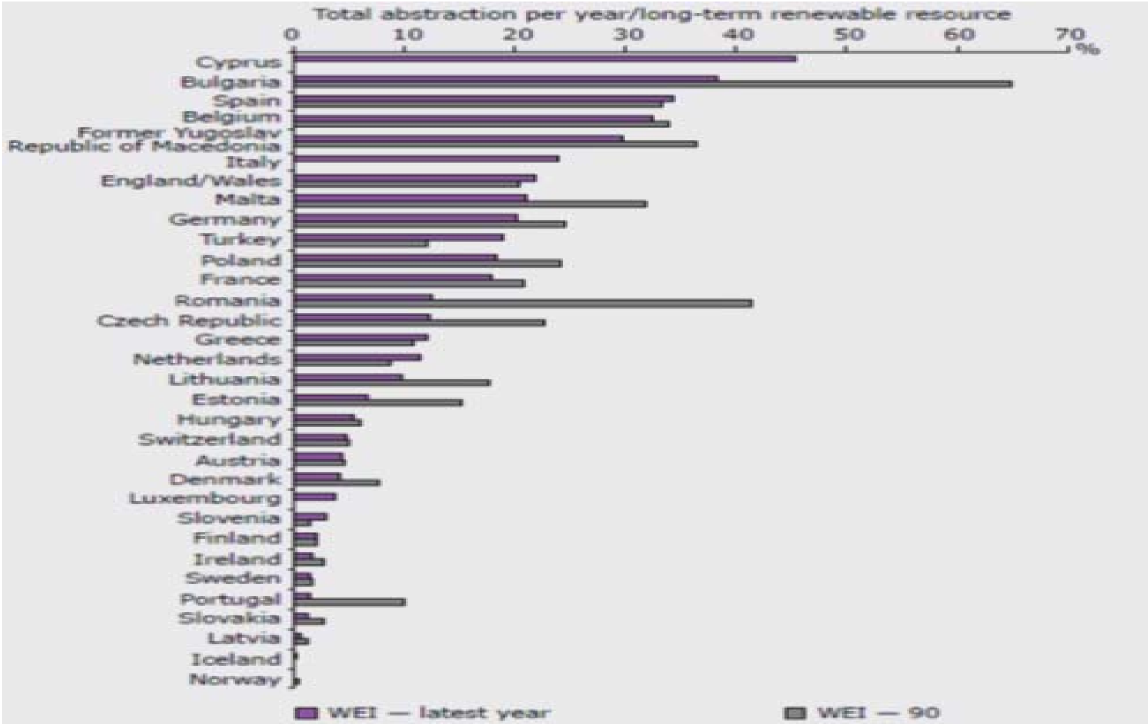
➢ Conclusion

➢ Water situation in Cyprus

- Cyprus : faced several periods of water scarcity

  limited availability excess demand

- Water Exploitation Index : Cyprus had an index above 40% (2007)

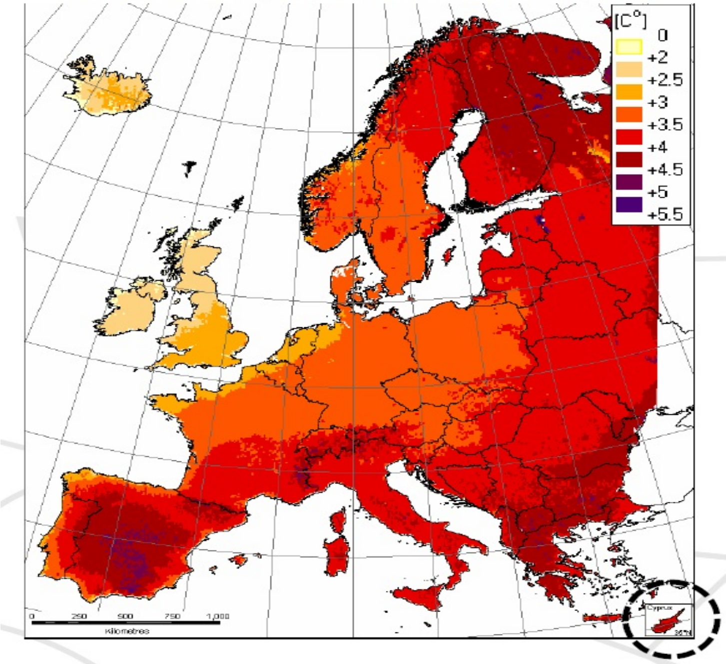


http://www.eea.europa.eu/data-and-maps/indicators/water-exploitation-index-1

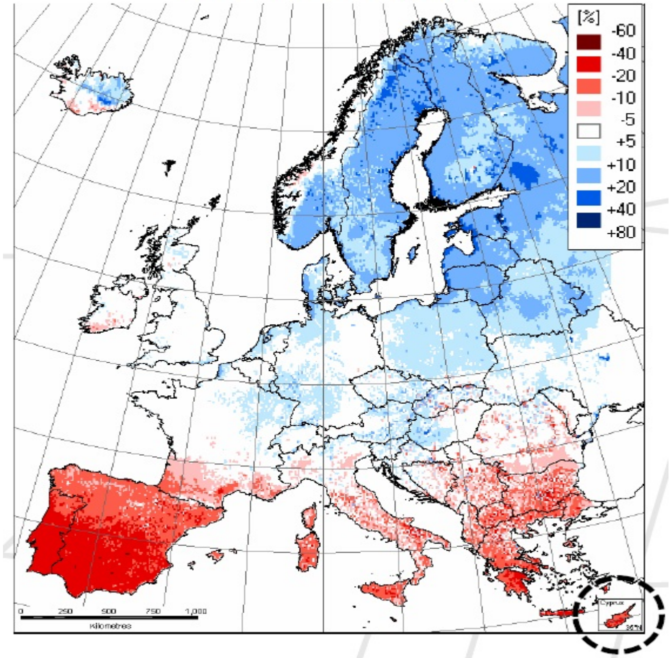
➢ Climate change impact

- Climate change: a change in the state of the climate that can be empirically identified (IPCC)
- IPCC SRES scenario A2 : increase in both minimum and maximum temperatures
- Annual precipitation levels are forecasted to decline by 15-25%

Temperature: Change in mean annual temperature by the end of the century (C°)



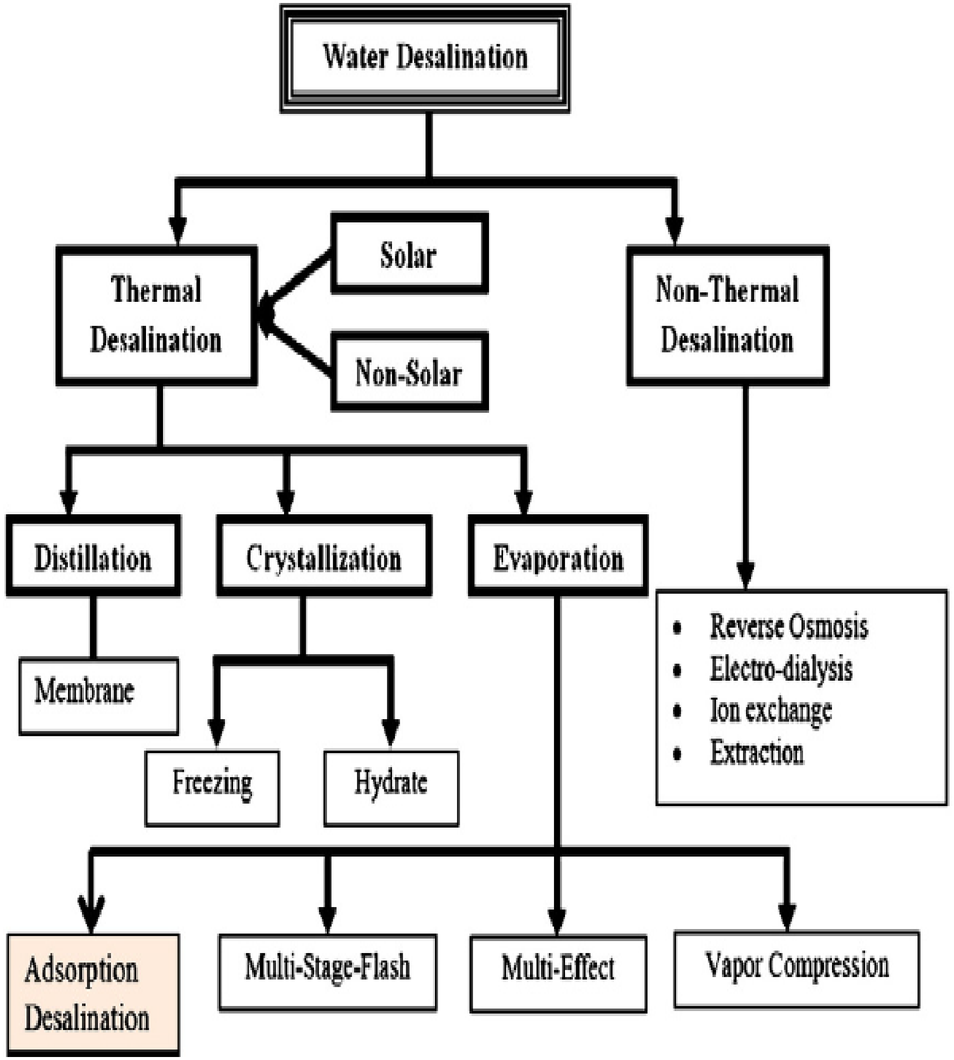
Precipitation: Change in annual amount by the end of the century (%)



European Commission Green Paper on Adapting to Climate Change in Europe, Report, 2007

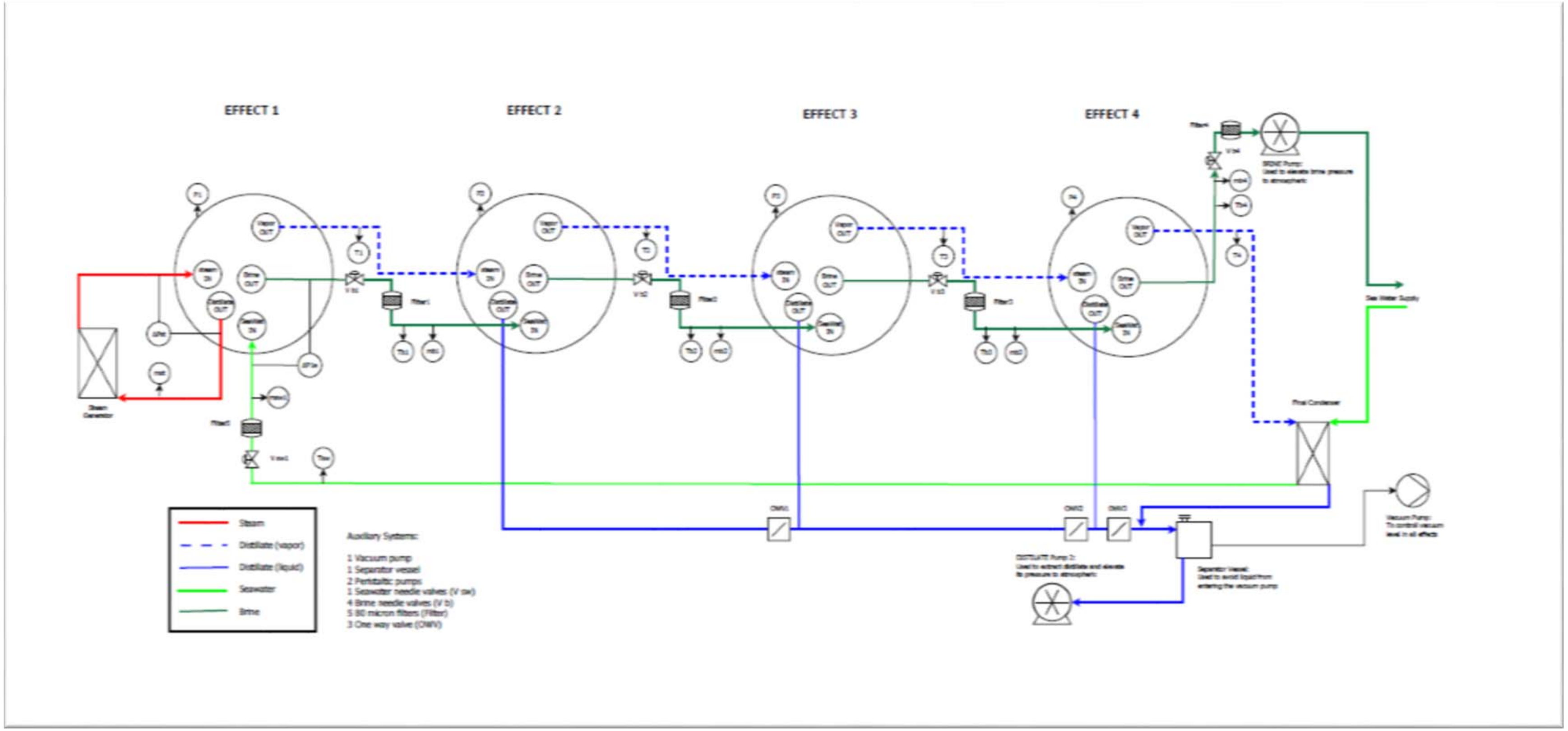
➢ Seawater desalination methods

- Three main approaches to desalination
  - **Thermal**
    - *Cause a phase change to separate fresh water from brine*
      - Multi-Effect Distillation (**MED**)
      - Multi-Stage Flash (**MSF**)
      - Vapor Compression (**VC**)
  - **Membrane**
    - *Physically separate salts from water via a filter*
      - Reverse Osmosis (**RO**)
      - Electrodialysis (**ED**)
  - **Chemical**
    - *Remove dissolved solids via chemical reaction*
      - Ion exchange



➢ Multi – Effect Distillation

- Several consecutive chambers, called effects
- Maintained at decreasing levels of pressure and temperature
- Typically operating temperature range : 100°C to 35°C
- Operates at sub-atmospheric pressures



Why MED ?

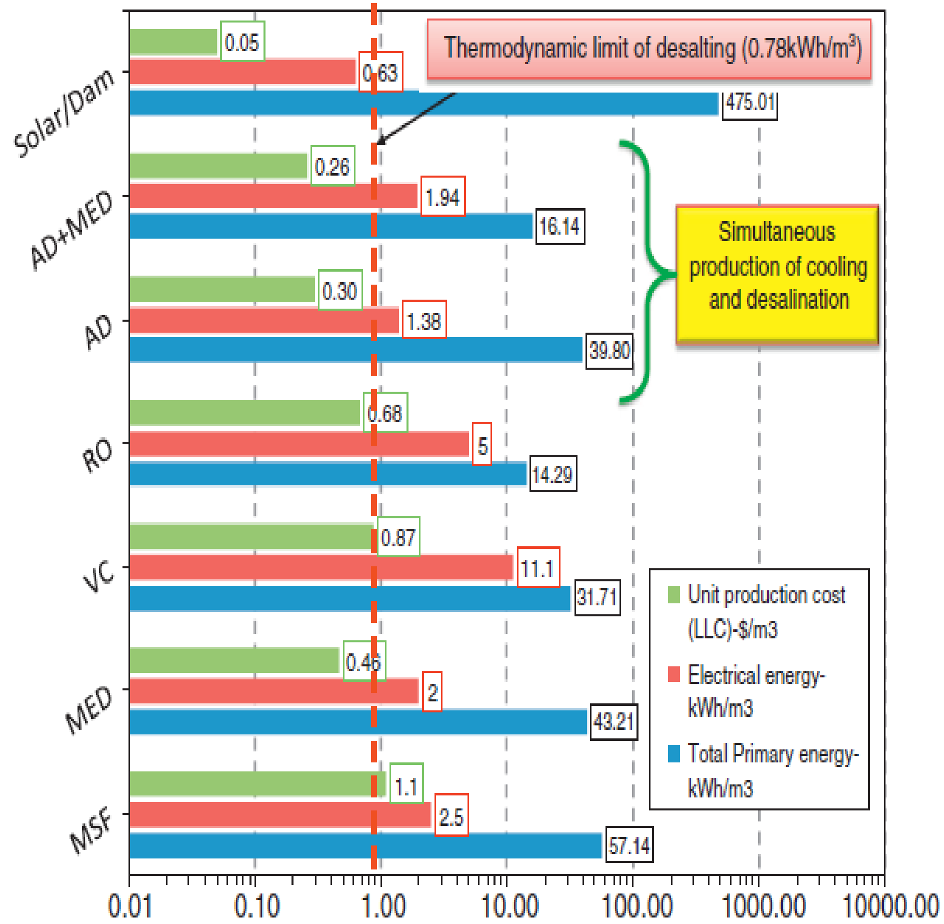
- Basic advantage: Thermal input energy
- Energy in MED itself is less than in MSF as during evaporation
- Higher Gain Output Ratio (G.O.R) and lower power consumption

⇓

Lower overall energy costs

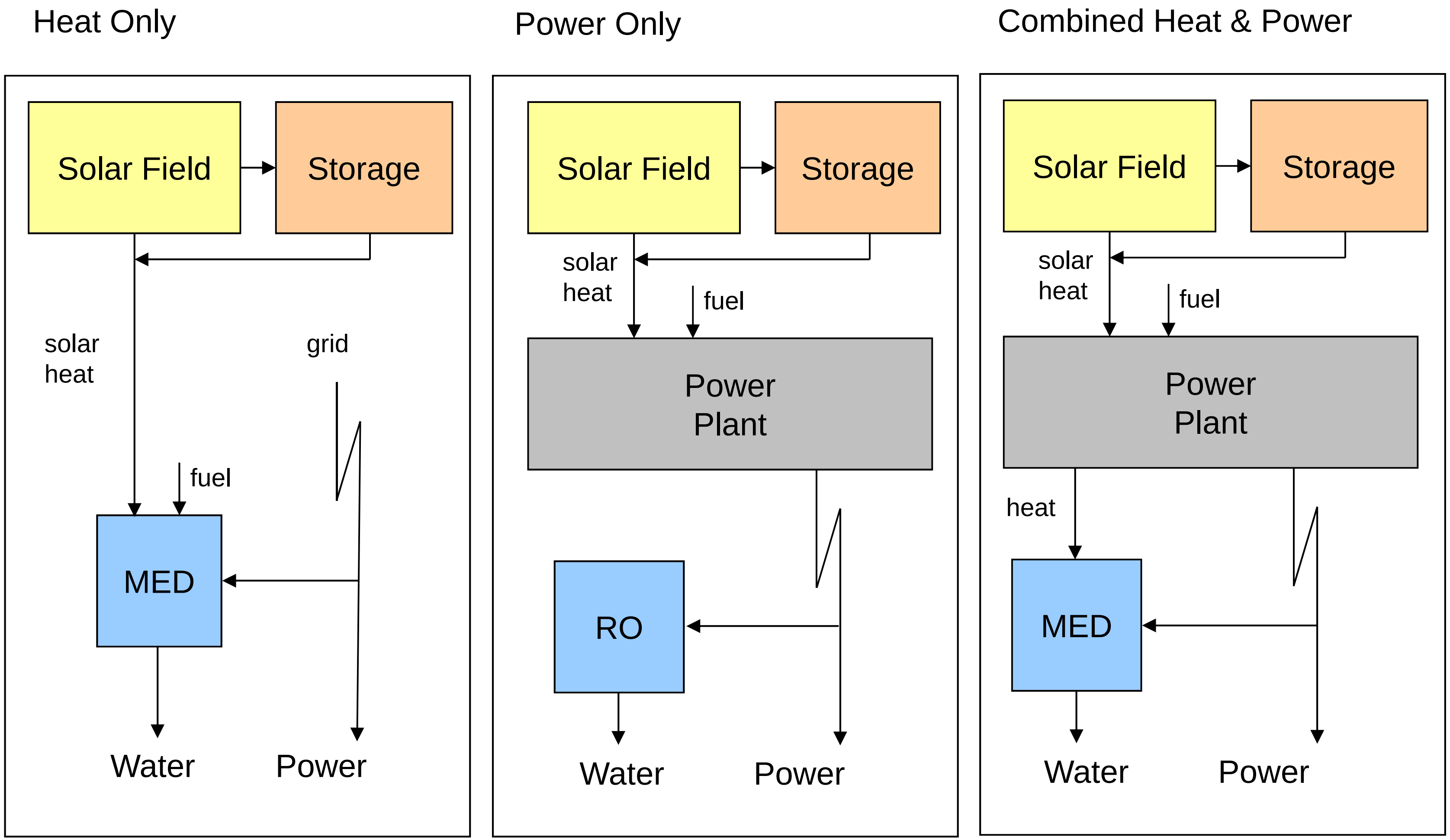
- Usage of Plate Heat Exchangers

(lighter weights, smaller space requirements, higher heat transfer coefficients, lower fouling resistances)



Concentrating Solar Thermal Desalination

- **Main configurations**



➢ Experimental Setup

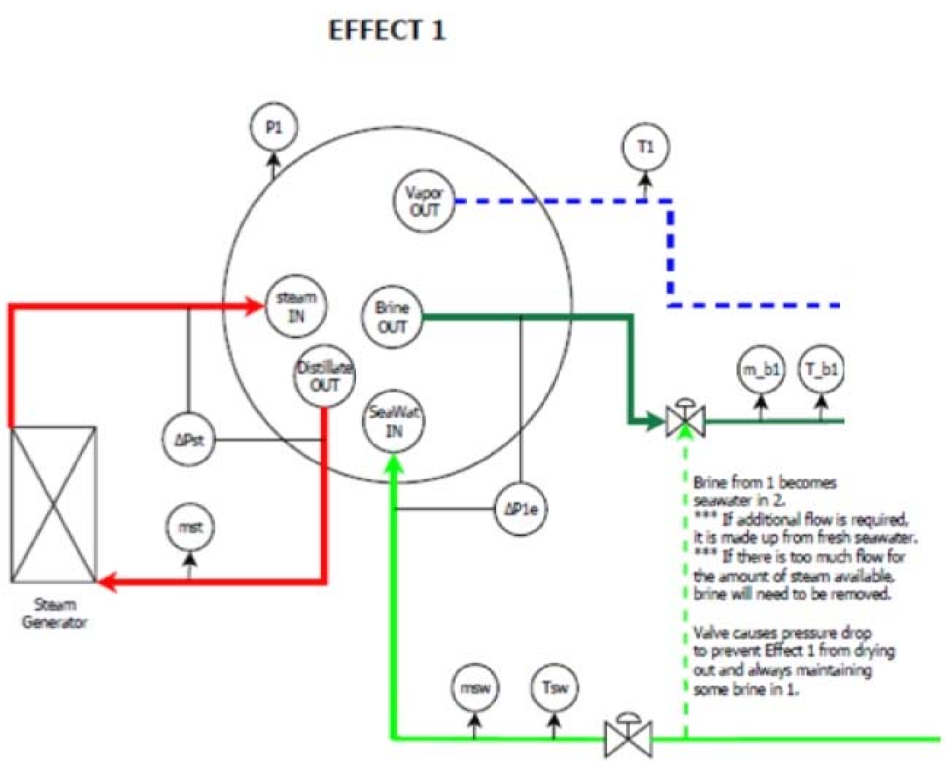
Instrumentation and Data Acquisition

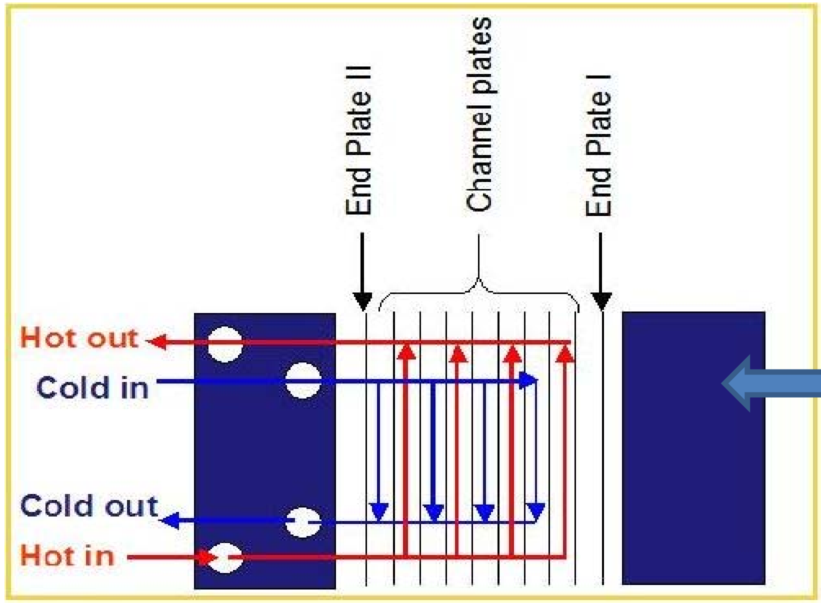
Experimental Equipment

- Steam Generator (LAVOR GV30)
- Peristaltic pumps (MASTERFLEX L/S)
- Plate Heat Exchangers (ALFA LAVAL)
- Vacuum Pump (EDWARDS)
- Data Acquisition (DAQ)
- Ice point Calibrator (OMEGA TRCIII-A)
- Power Supply (EXTECH)

Experimental Measurements

- Temperature: K-type thermocouples
- Pressure: Pressure sensors (PX 209)
- Mass flow: Ultra –Low Flow Sensors (FTB600B), (FTB601B)
- Water level: Liquid level sensor (VEGA)




End Plate II
Channel plates
End Plate I
Hot out
Cold in
Cold out
Hot in

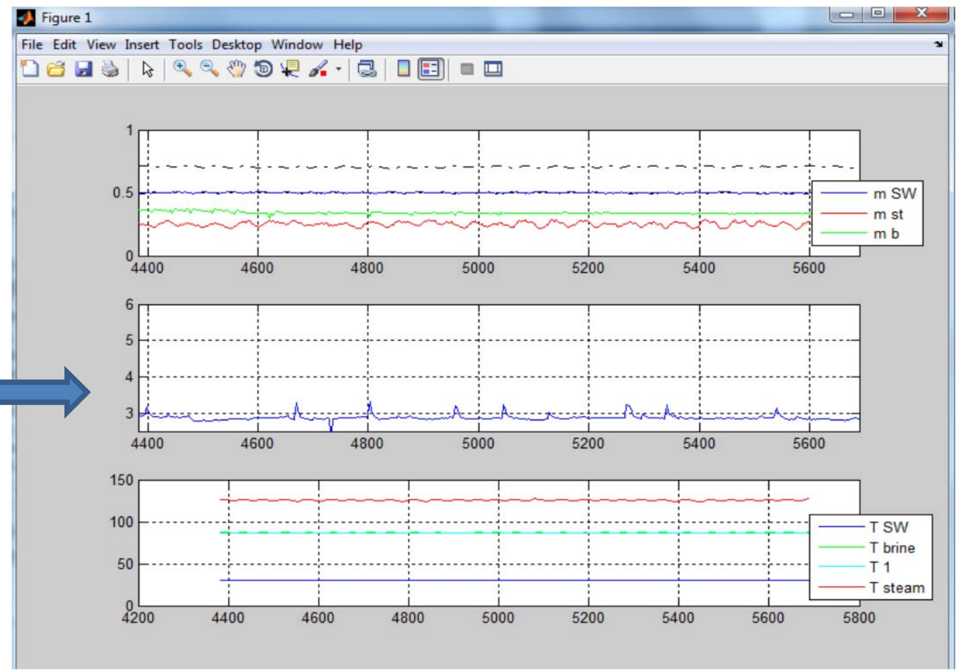
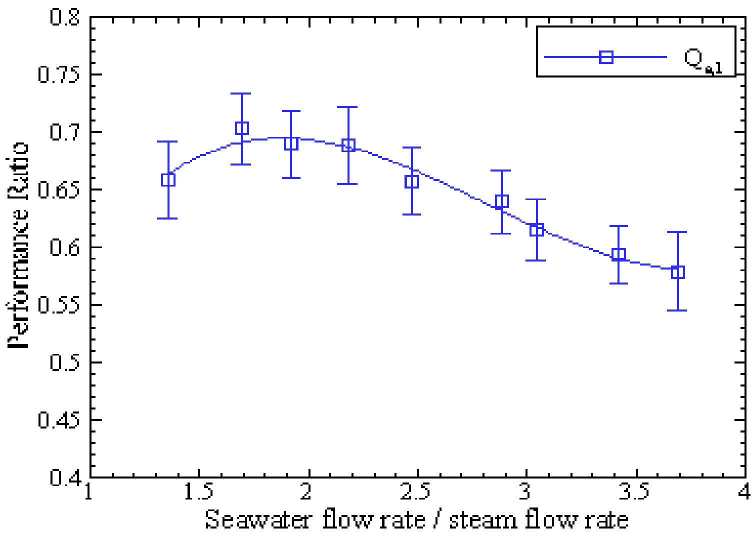


Figure 1
File Edit View Insert Tools Desktop Window Help
m SW
m st
m b
T SW
T brine
T 1
T steam

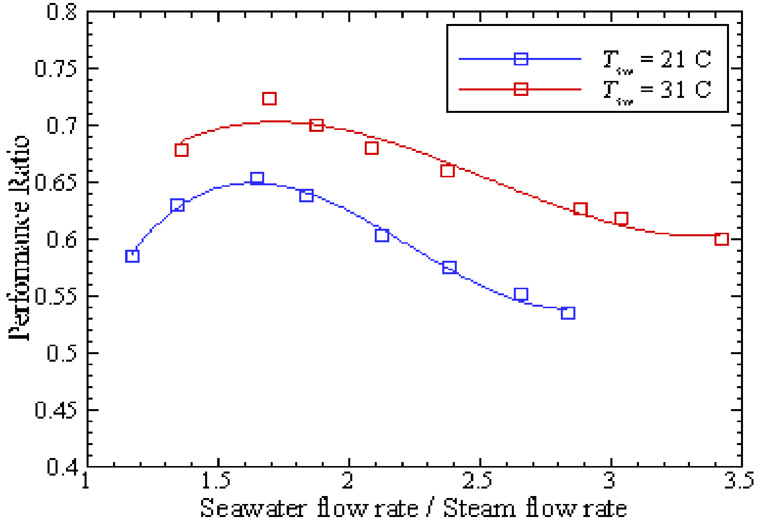
➢ Single effect experimental results (i)

- Varying the seawater flowrate for a given thermal input ($Q_{e,1}$)
- Performance Ratio(PR) : the ratio between the distillate and steam flows fed to the evaporator.
- A maximum *PR* is observed for a normalized seawater flowrate of 1.8
- Seawater flow rate: decreased → dry spots
- *Seawater flow rate:* increased → lower PR



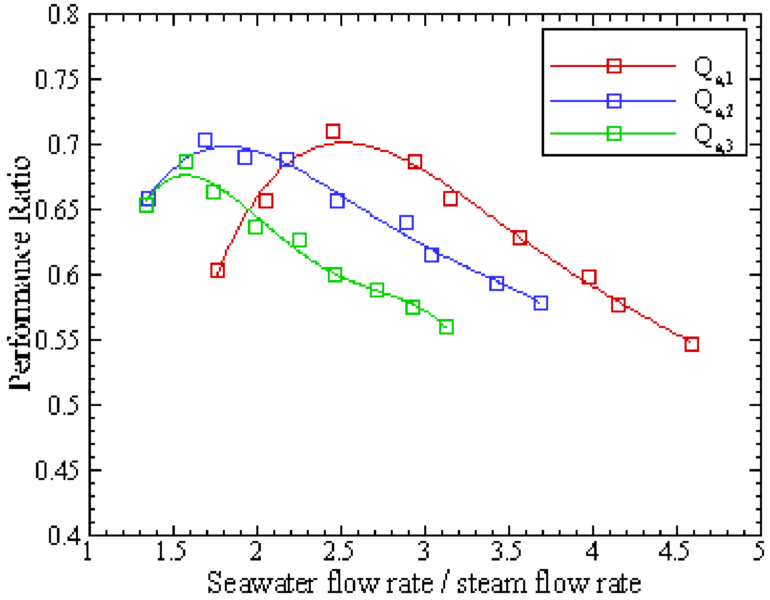
➢ Single effect experimental results (ii)

- Seawater feed temperature depended on the outdoor conditions
- Two different seawater feed temperatures
- $T_{sw,1}$ = 21 °C and $T_{sw,2}$ = 31 °C
- The shape of the two curves and the location of the maximum *PR* are similar
- $T_{sw,2} > T_{sw,1}$ → higher *PR*



➢ Single effect experimental results (iii)

- Three different thermal input conditions (Q_{e1},Q_{e2},Q_{e3})
- Maximum *PR:* almost constant at 0.71
- Small variations in the magnitude of the *PR* are attributed to different seawater feed temperatures
- Thermal input: increased → the maximum *PR* shifts to the left



➢ Mathematical model (i)

- Model: mass and energy balance.
- Assumptions: steady state operating conditions, zero salinity for the product water.
- Conservation of mass and species equations:

$$m_{sw} = m_d + m_b$$

$$m_{sw}\, x_{sw} = m_{br}\, x_{br}$$

- Heat exchanger model:

$$Q_e = A_e\, U_e\, (T_{st} - T_b)$$

- Evaporator:

$$Q_e = m_{st}\, \lambda_{st} = m_{sw}\, C_p\, (T_b - T_{sw}) + m_d\, \lambda_v + Q_{loss,e}$$

- Condenser:

$$Q_c = m_d\, \lambda_v = (m_{sw} + m_{cw})\, C_p\, (T_{sw} - T_{cw}) + Q_{loss,c}$$

Mathematical model (ii)

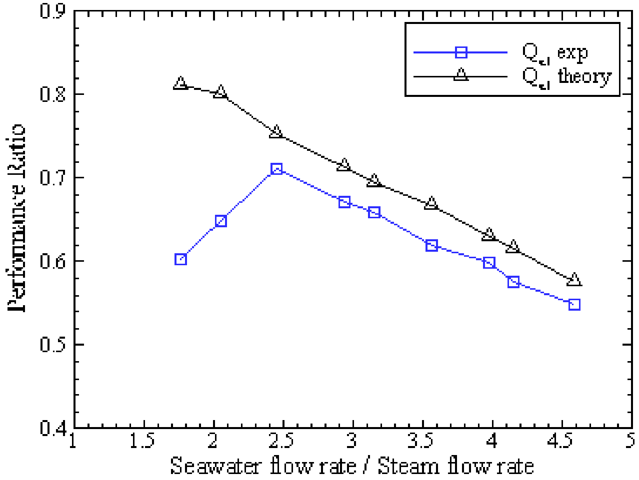
- Overall energy balance:

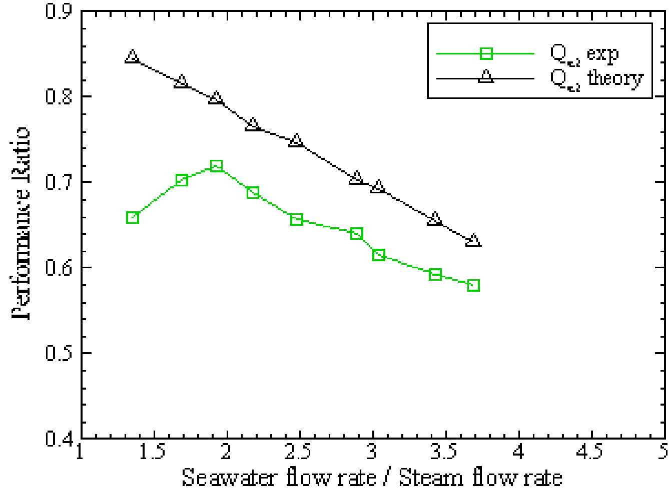
$$m_{st} \lambda_{st} = m_b C_p (T_v - T_{sw}) + m_d \lambda_v + m_d C_p (T_d - T_{sw}) + Q_{loss}$$

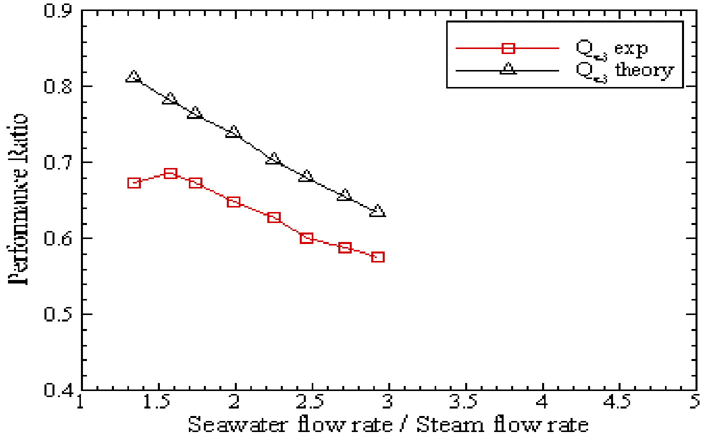
- Performance Ratio:

$$PR = M_d / M_{st}$$

Comparison of theoretical and experimental results using a control volume model







Conclusion

- A maximum performance ratio exists for each thermal input condition.
- Increasing the seawater results to dry spots.
- Decreasing the seawater reduces the amount of distillate produced.
- Increasing the temperature of the seawater feed increases the performance ratio.
- The predictions of the one-dimensional theoretical model developed overall are satisfactory.
- The model is unable to capture the maximum in the performance ratio since it cannot capture the physics of the dry out on the heat exchanger plates.
- A full (four) effect MED system it is designed and will be evaluated based on the results gained through the characterization of the single effect MED.
- Facing the challenges dealing with the coupling of MED desalination unit to a renewable energy source (CSP), such as operational instabilities, or dynamic range of operation of the MED are the next steps of this research.

Thank you

Marios C. Georgiou
m.c.georgiou@cyi.ac.cy
22 208 686
www.cyi.ac.cy

➢ Range of parameters varied in experimental studies

Parameter	Units	Range
$Q_{e,1}$	$[kW_{th}]$	4.2 ± 0.2
$Q_{e,2}$	$[kW_{th}]$	5.7 ± 0.3
$Q_{e,3}$	$[kW_{th}]$	7.6 ± 0.4
m_{sw}	[lpm]	0.20 – 0.72
$T_{sw,1}$	[°C]	19 – 22
$T_{sw,2}$	[°C]	30 – 32

- a larger fraction of the available thermal energy is required for elevating the feed temperature to the boiling temperature, and so less energy is available for the phase change process, leading to less distillate production and a lower *PR*.
- , e.g. to a lower seawater flowrate, as more thermal energy is available for the same quantity of seawater and thus evaporation and dry out will occur at lower flowrates.