DESALINATION & SUSTAINABILITY: RENEWABLE ENERGY DRIVEN DESALINATION & BRINE MANAGEMENT

D. Xevgenos, K. Moustakas, D. Malamis, M. Loizidou
Unit of Environmental Science & Technology
School of Chemical Engineering
National Technical University of Athens

konmoust@central.ntua.gr

ADAPTtoCLIMATE Conference
27-28 March 2014, Filoxenia Conference Centre, Nicosia, Cyprus
Fresh Water Availability (2007)

Source: FAO, Nations unies, World Resources Institute (WRI).

Scarcity
Stress
Vulnerability

Freshwater availability, cubic metres per person and per year, 2007.

Data non available

0 1000 1700 2500 6000 15000 70000 684000
Fresh Water Availability (2025)

Projection for 2025

500 1,000 1,700 4,000 10,000 m³ per capita

Scarcity Stress Sufficient quantities
Global Water Distribution & Water Classification

Water Natural Resources

- Surface water
- Groundwater
- Ocean Water

<table>
<thead>
<tr>
<th>Water Source</th>
<th>Salt Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brackish Water</td>
<td>&gt;1,000, high brackish, up to 11,000</td>
</tr>
<tr>
<td>Seawater</td>
<td>~35,000</td>
</tr>
</tbody>
</table>
Fresh water availability
Although the absolute quantities of freshwater on earth have always remained approximately the same, the uneven distribution of water and human settlement continues to create growing problems on freshwater availability and accessibility.

Seawater and brackish water desalination has been proven to be a technologically sound and promising option for combating the coming water crisis.
Processes for water desalination

Note: The dashed boxes contain early R&D or not widely used technologies.
Parameters for technology selection

- Quality of the feeding water (sea water, brackish)
- Quantity and quality of produced water
- Investment cost
- Space availability
- Energy requirements and availability
- Personnel availability and experience
## Technical characteristics of the main desalination technologies

<table>
<thead>
<tr>
<th>Process</th>
<th>Thermal</th>
<th>Mechanical</th>
</tr>
</thead>
<tbody>
<tr>
<td>State of the art</td>
<td>MSF</td>
<td>MED/TVC</td>
</tr>
<tr>
<td></td>
<td>Commercial</td>
<td>Commercial</td>
</tr>
<tr>
<td>Heat consumption</td>
<td>250-330</td>
<td>145-390</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>3-5</td>
<td>1.5-2.5</td>
</tr>
<tr>
<td>Plant cost</td>
<td>1,500-2,000</td>
<td>900-1,700</td>
</tr>
<tr>
<td>Time to commissioning</td>
<td>24 months</td>
<td>18-24 months</td>
</tr>
<tr>
<td>Production unit capacity</td>
<td>&lt;75,000</td>
<td>&lt;36,000</td>
</tr>
<tr>
<td>Conversion freshwater/seawater</td>
<td>10-25%</td>
<td>23-33%</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.5-1</td>
<td>1-2</td>
</tr>
<tr>
<td>Pre-treatment of water</td>
<td>Simple</td>
<td>Simple</td>
</tr>
<tr>
<td>Operation requirements</td>
<td>simple</td>
<td>simple</td>
</tr>
<tr>
<td>Product water quality</td>
<td>&lt;10 ppm</td>
<td>&lt;10 ppm</td>
</tr>
</tbody>
</table>

### Source
AQUA-CSP project, 2007

### Note
- **ED**: Electrodiagnosis
- **MED**: Multiple Effect Distillation
- **MSF**: Multi-Stage Flash Distillation
- **RO**: Reverse Osmosis
Installed desalination capacity by process

World (Source: Mezher, 2011)
- RO: 53%
- MSF: 25%
- MED: 8%
- ED: 3%
- Other: 11%

United Arab Emirates (Source: Mezher, 2011)
- MSF: 63%
- RO: 12%
- MED: 6%
- Other: 19%

Note
- ED: Electrodialysis
- MED: Multiple Effect Distillation
- MSF: Multi-Stage Flash Distillation
- RO: Reverse Osmosis
Electricity consumption in RO plants depending on feedwater quality

The per m³ consumption of electric energy depends on the feedwater as follows:

- Seawater: 4 - 7 kWh/m³
- Brackish water: 1 – 3 kWh/m³
Desalination & Energy

- Expensive, high energy demand, combined use of fossil fuels and the grid

- CO$_2$ emissions and dependence on the availability of grid
Renewable Energy Sources

- Energy autonomy, low operational costs and operation capacity in isolated areas.

- Improvement of the carbon footprint, reduction of the emissions.
Renewable Energy Sources

Renewable Energy Source – Desalination, RES-D):

- Solar Energy
- Wind Energy
- Geothermal Energy
- Wave energy
Wind Energy - Desalination

Wind turbine – RO
(Irakleia, 2007)
Geothermal Energy-Desalination

Geothermal pump–MED

(Kimolos, 2007)
Wave energy - Desalination

(Orkney, Scotland, 2009)
Solar Multiple Effect Humidification

Jeddah, Saudi Arabia
FPC - MEH
Solar MED

Almeria, Spain
PTC - MED
Solar-Membrane Distillation

Grand Canaria, Spain
FPC - MD
PV - RO

Amellou, Morocco
PV - RO
PV - RO

Tazekra, Morocco
PV - RO
PV - RO

Tangarfa, Morocco
PV - RO
PV - RO

Azla, Morocco
PV - RO
RES – Desalination Combinations

- 3% HYBRID
- 3% PV ED/EDR
- 7% SOLAR MSF
- 9% SOLAR MEH
- 9% SOLAR MED
- 11% SOLAR MD
- 12% WIND RO
- 15% OTHERS
- 31% PV RO
**SOL-BRINE: Concept**

Diagram showing a SOL-BRINE system with inputs, processes, and outputs involving solar energy, brine feed stream, and resulting end-products of water and solid salt with a note on zero waste.
Innovative aspects of the project

- **Total brine elimination.** The system has been designed in line with the Zero Liquid Discharge principle.

- **Water Recovery (>90%)**

- **Production of useful end-products.** Through the operation of the prototype system the following two products are produced: (a) distilled water of high quality and (b) dry salt. These products have potential market opportunities.
Innovative aspects of the project

- **Energy autonomous operation.** Solar thermal collectors are used for delivering hot water (10 kW\textsubscript{th} at approximately 70°\textdegree C) and a photovoltaic generator (10 kW\textsubscript{el}) for electricity. All energy requirements are covered exclusively through the use of solar energy.

- **Use of state-of the art technology:** the evaporation of water is realized through custom designed vacuum evaporation technology (evaporator and crystallizer) and solar dryer.
The innovative SOL-BRINE system comprises:

(a) the energy supply system and
(b) the brine treatment system
Single line diagram
Mass Balance

500kg/day

(465kg H₂O/day)

(35kg Salt/day)

170kg/day

65kg/day

330kg H₂O/day

105kg H₂O/day

35kg Salt/day

30kg H₂O/day
Brine treatment system

The brine treatment system (capacity: ~ 1m³/day) is consisted of the following units:

(a) Evaporator
(b) Crystallizer
(c) Solar Dryer
Evaporator unit

Figure: View of the evaporator (installed on site)
Crystallizer

Both the crystallizer and the evaporator unit are based on the physical process of vacuum evaporation. The crystallizer is consisted of a single vessel maintained at lower levels of pressure (normal operating conditions: 5kPa 0.05 atm(a)). The crystallizer unit is equipped with scraping blades inside the boiling vessel for allowing high evaporation rates through cleaning of the heat transfer surfaces from the formed salt crystals and good agitation.
**Crystallizer**

Its purpose is to crystallize the brine effluent, producing a slurry (magma) with humidity levels of approximately 50%. The whole process is characterized by energy efficiency through the combined use of vacuum technology and heat pump.
Crystallizer unit (installation)

Transportation (JCB vehicle, photos on the top) and placement (chain pulley block, photo on the left) of the crystallizer unit – 16/10/2012
Crystallizer unit

**Figure:** View of the crystallizer (installed on site)
Solar Dryer (installation)

Installation of the dryer – 12-13/10/2012
Dryer unit

Figure: View of the dryer (installed on site)
Thank you for your attention!

konmoust@central.ntua.gr