NEGST

New generation of solar thermal systems

Advanced applications

Solar desalination technologies

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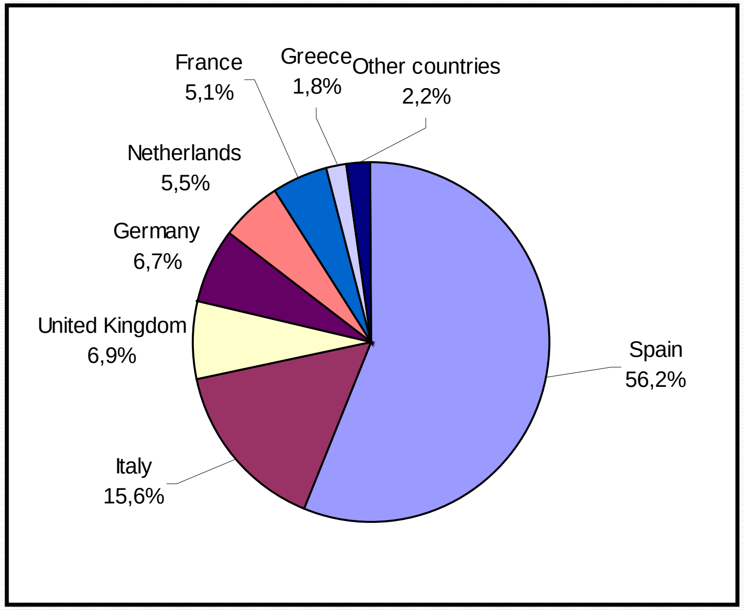
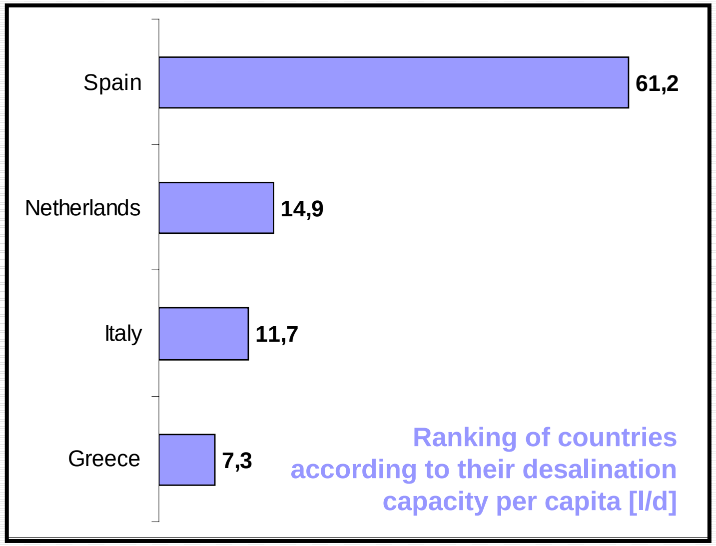
Status of desalination in EU-15

- Total installed capacity is ~ 4.3 Mm^3/d
- Related energy consumption is 104 GWh per year (estimation)
- Leading technology is reverse osmosis (almost 75% of installed capacity)
- Spain and Italy together cover > 70% of installed capacity
- In Spain only contribution to water need is significant





***Source: IDA Worldwide Desalting Plants Inventory*, Report No,18, 2004**

Solar desalination potential

- Countries with fresh water shortage can generally rely on high values of solar irradiance
- Solar energy availability is maximum in the hot season when fresh water demand increases and reserves are reduced
- Water is a medium allowing the long-time storage of possible energy surplus, economically and without significant losses
- Water shortage usually occurs in remote areas (rural regions, small islands), where soil occupation is not critical and cost of traditional systems for provisions may dramatically rise

additional benefits for small scale applications (<1,000 m^3/d)

- low capital cost
- reduced construction time
- utilization of local manpower and materials
- simple management

Contribution of solar desalination

- Total installed capacity (all applicable technologies) is around 250 m³/d
- Contribution to desalination total capacity is negligible (0.006 %)
- Almost half of installed capacity concerns reverse osmosis (then driven by PV)
- Operating plants are 19 mostly for demonstration or research purposes
- Capacity is very low (< 100 m³/d); in most cases < 10 m³/d
- Most part of applications (12) are concentrated in Greece

Location	Country	Capacity [m³/d]	Process
Almeria	Spain	72	ME
Cadarache	France	60	RO
Berken	Germany	20	MSF
Patmos	Greece	20	OTHER
San Nicola	Italy	12	RO
Kimolos	Greece	6	OTHER
Megisti	Greece	6	OTHER
Symi	Greece	6	OTHER
Aegina	Greece	5	OTHER
Fiskardo	Greece	5	OTHER
Kionion	Greece	5	OTHER
Symi	Greece	5	OTHER
Bari	Italy	5	MSF
Marettimo	Italy	5	RO
Aegina	Greece	4	OTHER
Nisyros	Greece	4	OTHER
Lavrio Attiki	Greece	3	RO
Salamis	Greece	2	OTHER
Las Marinas	Spain	2	OTHER

***Source: IDA Worldwide Desalting Plants Inventory*, Report No,18, 2004**

Desalination process selection

Main thermal desalination processes (requiring heat as main energy input) are:

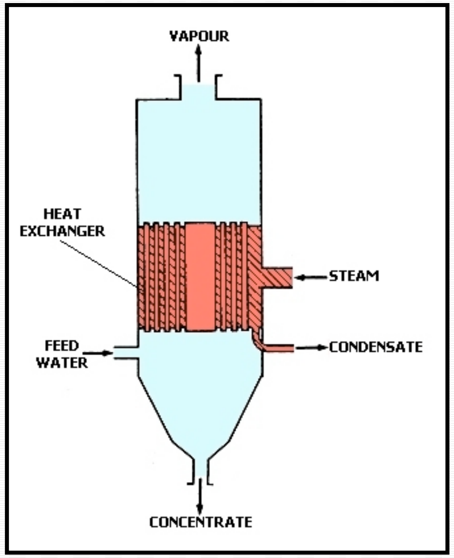
- multi-stage flash evaporation
- multiple effect evaporation

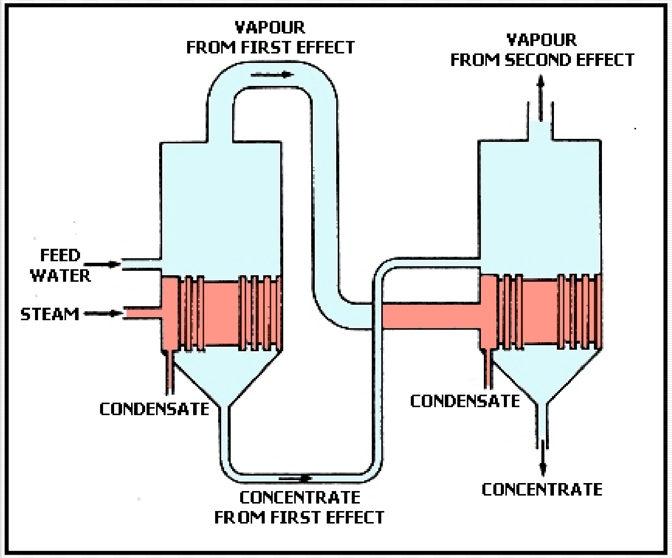
advantages of ME process

- Driving heat is required at a relatively low temperature, thus collector can work with a good efficiency
- The process operates stably in a wide large range of loads, thus the intermittent nature of the feeding source is not so critical
- The power consumption for pumping (1-2 kWh/m^3) is lower thus stand-alone applications are less challenging

Multiple Effect operation principle

A single-effect evaporator is essentially a heat exchanger in which feed seawater is boiled to give a vapour almost free of salt: the needed heat is supplied by the condensation of the motive steam





The low pressure steam generated by the evaporator can be used for further heating in the following effect

The evaporation in the second effect via the steam provided by the first one requires a lower boiling temperature and hence a minor pressure, so the feed water evaporates in a minor part also by flashing

Efficiency of the ME process

The characterizing parameter is the performance ratio (PR), which depends on the number of effects and the motive steam temperature:

$$PR = \frac{\dot{m}_D}{\dot{m}_S} = f(N, T_S)$$

Reference process:

- Number of effects: *12*
- Driving heat source temperature: *70 °C*
- Boiling temperature in the last effect: *35 °C*
- Performance Ratio: *9*

For a given T_S, PR is approximately a linear function of N according to a coefficient equal to 0.7-0.8.

In theory a high number of effects (up to 18) may be included, but, the ΔT_{tot} being limited, this leads to a dramatic reduction in the ΔT of each effect and consequently to an increase in the heat transfer area:

$$\Delta T = \frac{\Delta T_{tot}}{N} = \frac{\dot{m}_D h_v}{U_D A}$$

PR shall be the best trade-off between investment cost and steam economy.

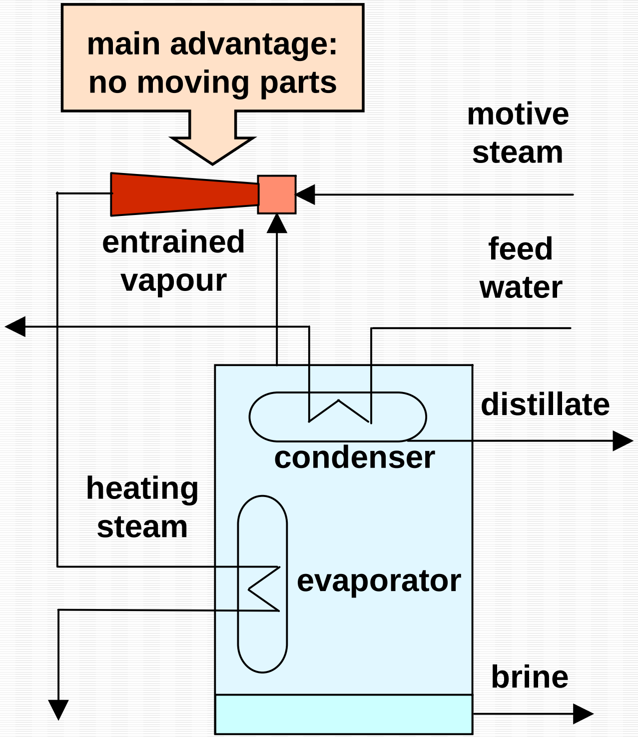
ME + Vapour Thermo-Compression

Operational principle:

⇒ a relatively high pressure steam is expanded in an nozzle to high velocity and low pressure thus entraining the vapour from the last effect and mixing with it in a violent and rapid manner

⇒ the mixture flows through the diffuser section, slows down and the discharge pressure rises to a value in-between motive and suction pressure; then it is used as heating steam in the first effect

$$PR = N\left(1 + w - \frac{w}{N}\right) \quad \text{with:} \quad w = \frac{\dot{m}_{EV}}{\dot{m}_{MS}}$$



Reference Systems		
Motive steam pressure	3 bar	10 bar
Motive steam temperature	130 °C	180 °C
PR	14	15

A similar effect can be achieved by using a Double-Effect Absorption Heat Pump (DEAHP). Reference system:

- Motive steam temperature: 180 °C
- PR: 20

Applications for small users

Application of ME process for small users leads to significant restrictions:

- minimum single-unit capacity on industrial scale is ~ 500 m^3/d
- cost is very sensitive to system size
- grid-connection is required for the covering of power needs

⇩

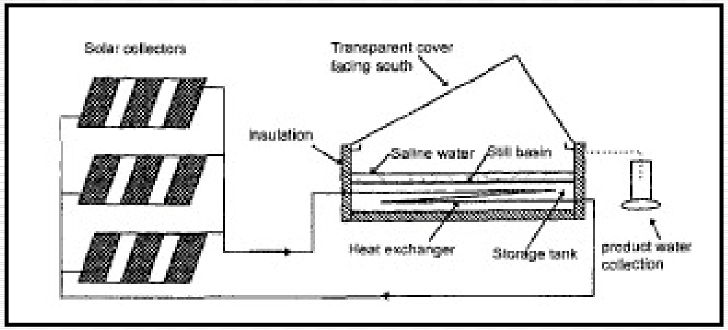
Applicable technologies for small scale solar desalination are in addition:

- active solar still, consisting in a conventional solar still coupled with solar collectors and hot water storage tank
- humidification-dehumidification, generally termed multi-effect humidification (MEH) to denote that the PR > 1

Active solar still

Suitable for decentralized applications thanks to:

- ease of construction
- use of locally available materials
- minimum operation and maintenance requirements



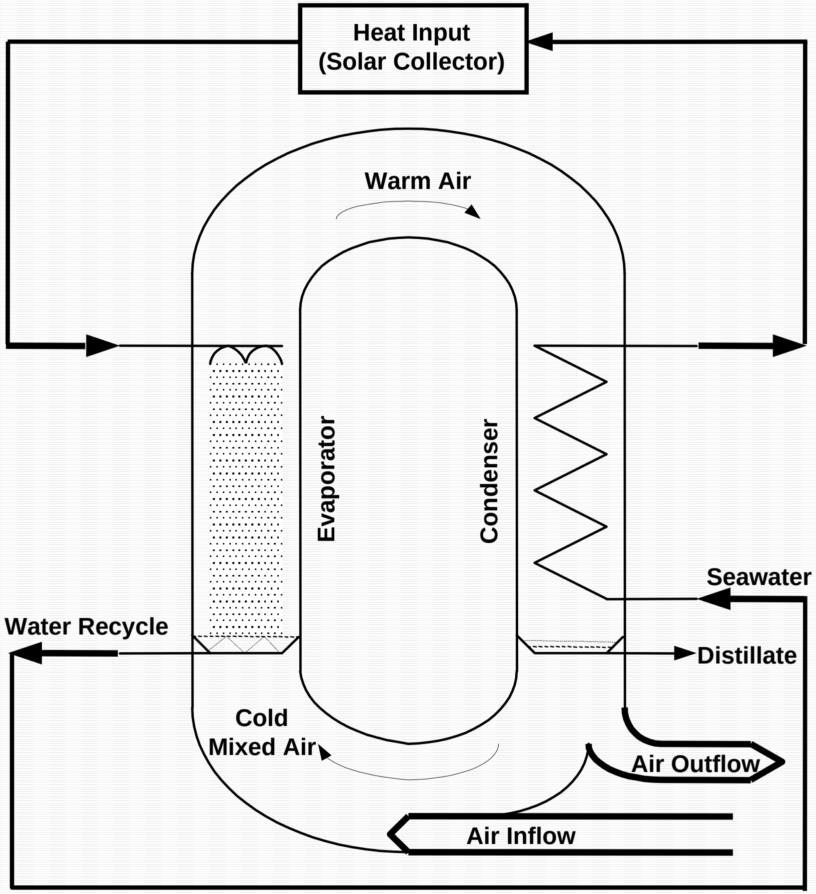
Several systems installed worldwide during the past decades for small communities located in remote areas (capacities < $20 m^3/d$)

- performance of a simple solar still is low if compared to other desalination processes, and space requirements is considerable (2-3 lt/d per m^2): productivity can be doubled by the coupling with solar collectors, but both installation cost and system complexity increase as well
- the direct contact between the heating element (solar absorber) and salt water may cause scale formation and corrosion, thus deteriorating system performance and imposing strict limitations on the materials of the collector

Humidification-dehumidification

Basic principle is the humidification of ambient air through seawater evaporation and condensation of water vapour from humid air by contact with a cooling surface

- technology is viable for small capacity desalination systems, up to 10 m^3/d
- efficiency is improved when compared to active solar stills
- coupling with solar energy (flat-plate collectors) is a proven solution
- construction and maintenance are simple
- power requirements are reduced (a PV driven pump may be used)
- direct heated systems are more energy effective, but restrictions to the collector materials may arise



Reference system:

- Driving heat temperature: 85 °C
- PR: 6

The methodology for energy comparison

- The selected location is Palermo: this hypothesis is not restrictive being desalination mostly concentrated in the South of Spain and Italy
- The analysis is performed via the $\bar{\varphi}$, *f-Chart* method, relevant to a general solar heating system
- The load is calculated by assuming a thermal energy consumption of 2300 kJ (rounded off value of the heat of vaporization of water at 70-85 °C) for the production of water equal to the system PR
- The collector area per m^3/d of capacity for each system is determined by iteration, until the solar fraction is equal to 1 only in the month with the best weather conditions
- The annual solar fraction allows to calculate the specific water production: an high solar fraction indicates that system capacity is almost fully exploited

Main parameters used in the calculation

collector parameters

TYPE OF COLLECTOR	Flat plate selective (FPC)	Evacuated tubular (ETC)	Parabolic trough (PTC)
Test intercept [-]	0.78	0.76	0.74
Test slope [W/m²K]	4.3	1.8	0.56
Collector orientation	South	South	N-S
Collector slope	45°	45°	45°
Concentration ratio	-	-	60

general solar heating system parameters

Storage volume to collector area ratio	70 litres/m²
UA of auxiliary storage tank	Negligible
Pipe heat loss	Negligible
Collector-store heat exchanger	• Tank-side flow-rate/area: 0.015 kg s^{-1} m^{-2} • Heat exchanger effectiveness: 0.7
Load heat exchanger effectiveness	0.7

Energy comparison results

SYSTEM	Type of collector	Solar fraction	Specific area $m^2/(m^3/d)$	Specific water production $(m^3/year)/m^2$
MEH	FPC	0.76	84	3.3
MEH	ETC	0.82	41	7.3
ME basic	FPC	0.77	44	6.4
ME basic	ETC	0.82	25	12.0
ME + SE (3 bar)	ETC	0.80	23	12.7
ME + SE (3 bar)	PTC	0.85	14	22.2
ME + SE (10 bar)	PTC	0.84	14	21.9
ME + DEAHP (H_2O/LiBr)	PTC	0.86	11	28.5

- ME with DEAHP driven by PTC collectors is the best performing system but suitability for small scale applications is questionable
- productivity of ME with Steam Ejector driven by PTC collectors does not appear to be affected by the motive steam pressure
- addition of SE to ME basic process driven by ETC collectors does not improve significantly its performance
- MEH driven by FPC is the more simple system but an enormous collector area per m^3/d is required

Economics

For a full cost assessment the comparison should be made with:

- traditional systems of water supply
- conventional desalination systems
- systems driven by other renewables (PV, wind)

comparison between solar thermal

- for small scale applications MEH driven by ETC is profitable for a collector cost up to the double of FPC cost (ETC are more sensitive to severe working conditions)
- for large scale applications ME with DEAHP is profitable for a PTC cost up to 2.3 and 4 times as high as ETC and FPC cost, respectively (cost of the DEAHP must be added)

Barriers to solar desalination

- Impact on energy consumption in EU-15 is not excessive
- Interest is limited to few countries (Spain and Italy)
- Competition concerns traditional systems of water supply, conventional desalination systems, other renewables
- Minimum capacity for ME is ~ 500 m^3/d, corresponding to the potable water needs of around 3,000 people
- Power requirements of ME process is significant
- Productivity of systems for small scale applications is very low above all if FPC are used
- Application under severe conditions (coastal regions) may lead to restrictions to collectors materials
- Commercialisation of pre-assembled solar desalination system, easy to install and manage is remote

Conclusions

- Solar desalination appears to be feasible in order to meet the potable water needs of small communities located in remote areas and in presence of harsh feed water characteristics
- Multiple Effect with Double-Effect Absorption Heat Pump driven by PTC collectors is the most effective system and it is suitable for stand-alone installations
- For capacities > 100 m^3/d, Multiple Effect basic process driven by ETC shows a good trade-off between simplicity and efficiency
- For capacities < 10 m^3/d Multiple Effect Humidification driven by ETC may offer an interesting solution
- Research must concern principally the improvement and cost reduction of small capacity solar desalination systems

→ an opportunity to increase the market of solar thermal collectors ↔ Main target of the NEGST Project!!!

For additional information…

NEw Generation of Solar Thermal systems

Work Package 5 – Advanced applications

http://www.swt-technologie.de/html/negst.html

Italian National Agency for New Technologies, Energy and Environment

TRISAIA Research Centre

Solar Collector Testing Laboratory

http://www.enea.it - http://www.trisaia.enea.it

End of presentation

Thank you

for your

attention!!!