“Capacity Building and Strengthening Institutional Arrangement”

Analysis and sampling of water and water pollution

Optimization of sustainable use of water, including desalination technology

Mr. Antonio De Maio

APAT

Agency for Environmental Protection and Technical Services

WATER RESOURCES IN CRISIS

Both the availability and use of water are changing in Mediterranean Countries that are undergoing intensive demographic, social, cultural, economic and environmental changes.

The relevant problems

- Population growth
- Intensive urbanisation
- Agricultural demand
- Economic and industry growth
- Tourism
- Pollution
- Climate changes

THE PRESENT WATER MANAGEMENT IS UNSUSTAINABLE

Models currently in use for water management are based upon the "open cycle logic"

This approach in general does not take into proper account the unbalance between water demand and input

The increasing demand of water is too often satisfied by means of excessive withdrawal of groundwater

↓

saline water intrusion, subsidence….

THE PRESENT WATER MANAGEMENT IS UNSUSTAINABLE

In addition water use is still far from efficient. In the Mediterranean countries as a whole, nearly half of the water supplied is lost in trasport and distribution or is badly used, especially in irrigation.

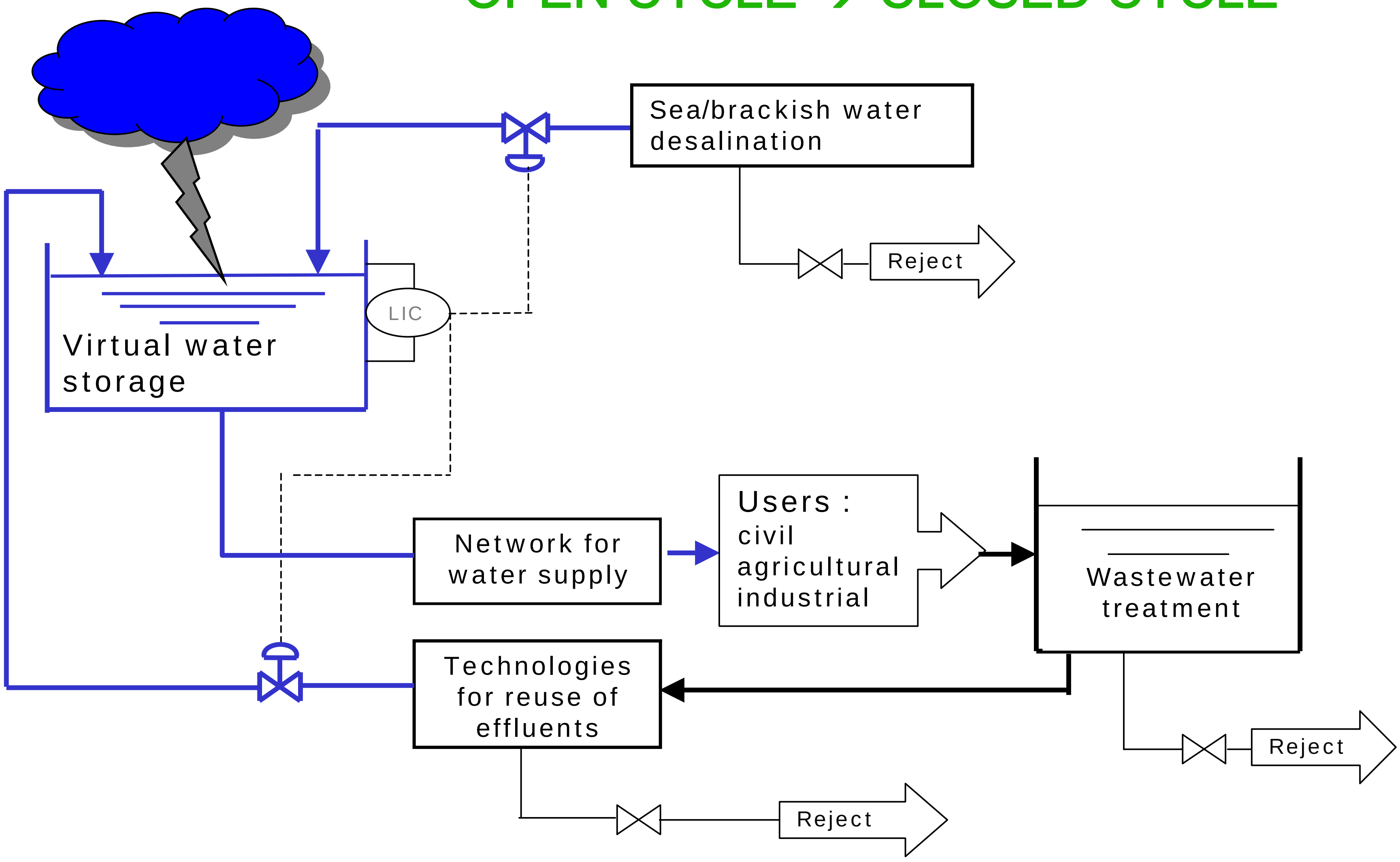
Current water management does not take into account a very important aspect regarding impacts on environment on a global scale: large energy consumption to collect, supply and to treat water.

WATER AVAILABILITY IN THE FUTURE DEPENDS ON REDUCTION OF LOSSES AND WATER SAVING EFFORTS IN ALL SECTORS

BUT MAINLY ON THE CHANGE IN WATER MANAGEMENT

THE APPROACH FOR WATER CYCLE MANAGEMENT HAS TO SHIFT FROM THE “OPEN-CYCLE” TO THE “CLOSED-CYCLE”

OPEN CYCLE → CLOSED CYCLE



DESALINATION TECHNOLOGIES

DESALINATION TECHNOLOGIES

One convenient and useful way to classify desalination processes is to separate them into those which involve a change of phase to separate the pure water from the feed water and those which accomplish this separation without a change of phase

Those in the single-phase category **(membrane processes)** include:

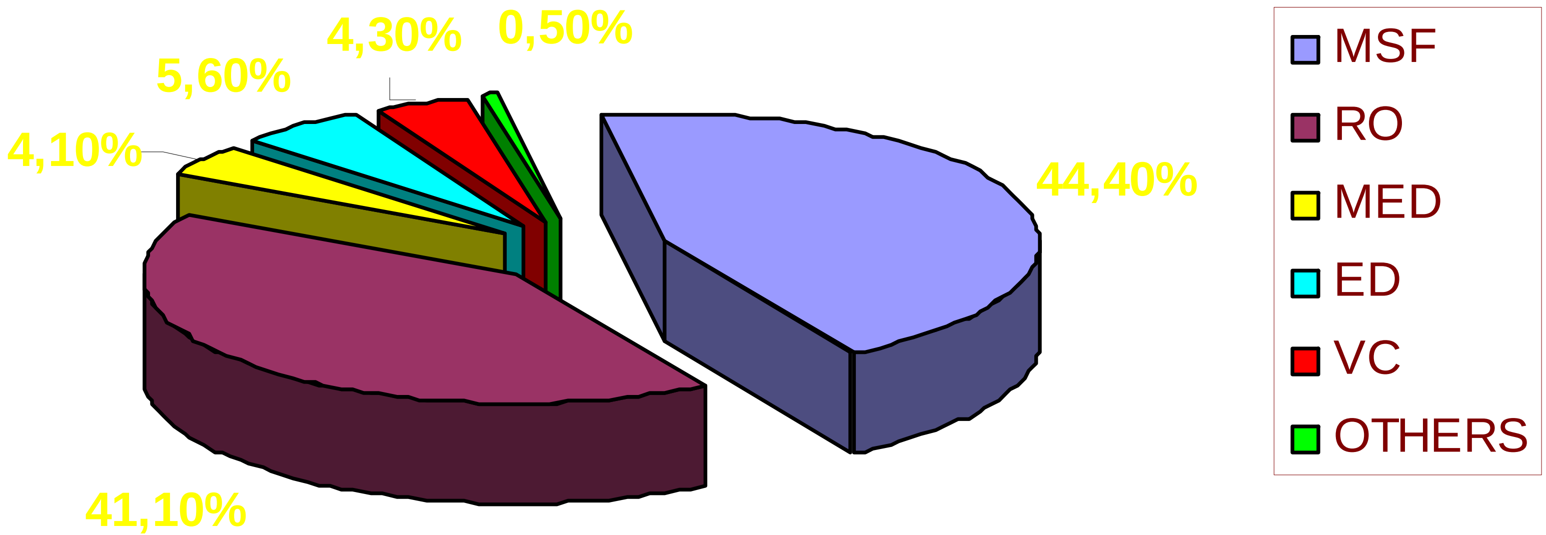
- Reverse Osmosis (RO)
- Electrodialysis (ED)

The phase-change processes **(distillation processes)** include:

- Multi-Stage Flash (MSF)
- Multi-Effect Distillation (MED)
- Vapour compression (VC) Thermal and Mechanical
- Solar Distillation

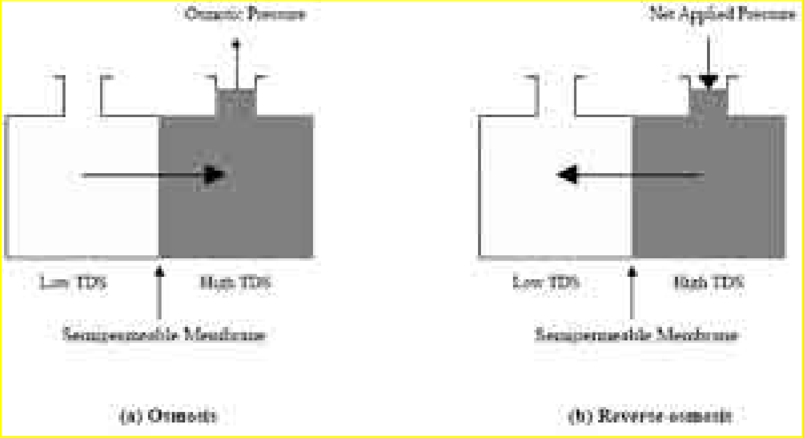
WORLD-WIDE DESALINATION CAPACITY

Global distribution of installed desalination capacity by technologies



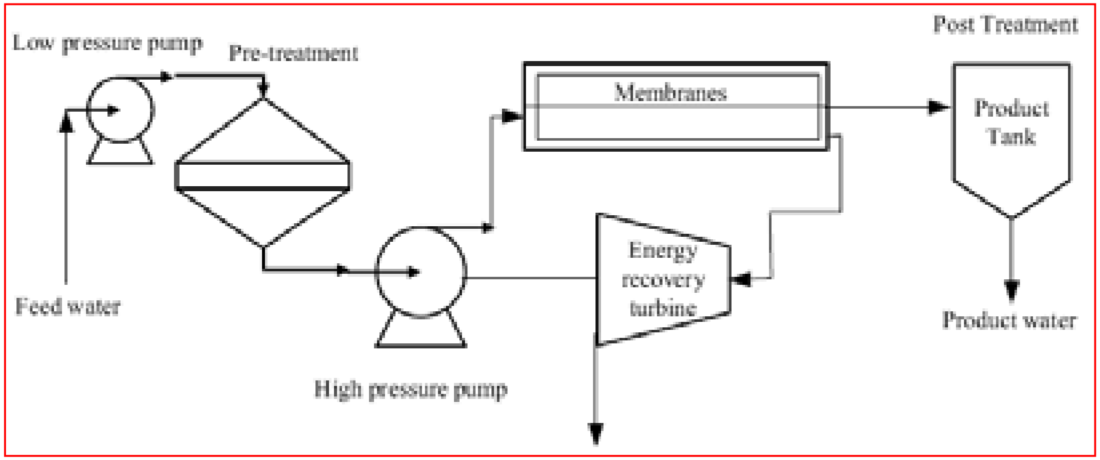
REVERSE OSMOSIS (RO)

Reverse osmosis (RO) is a membrane separation process that recovers water from a saline solution pressurized to a point greater than the osmotic pressure of the solution. Semipermeable membrane rejects salts, allowing only the water to pass.



Pressurizing the saline water accounts for most of the energy consumed by RO. Since most of energy losses for RO result from realising the pressure of the concentrated brine, large scale RO system are now equipped with device to ***recover the mechanical compression energy*** from the discharged concentrated stream

SCHEMATIC PRESENTATION OF RO PLANT



RO-ADVANTAGES

- Energy consumption is low
- RO plants are quick and cheap to build and simple to operate
- It has a high space/production capacity ratio
- It can handle a large range of flow rates due to the modular design of the plant
- The recovery ratio is high therefore the feed water required to produce the same amount of product is limited
- It can remove other contaminants in the water as well as the salt
- There is no need to shut-down the entire plant for scheduled maintenance due to the modular design of the plant. The start up and shut down of the plant does not take long

RO-DISADVANTAGES

- RO membranes are expensive and have a life expectancy of 2-5 years, it is necessary to maintain an extensive spare parts inventory
- The product quality, using seawater, is limited to 300-500 ppm. This salt content is often incompatible with industrial uses
- RO membranes are very sensitive to fouling caused by suspended solids, plugging, chemical scaling and colloidal material. They require an efficient pre-treatment of the feed water by filtration to decrease turbidity and fouling index, chemical or anti-scalant addition to increase solubility of salts of calcium (bicarbonates, sulphates), barium sulphate and strontium sulphate
- RO membranes are very sensitive to bacterial contamination (biofouling). They require an efficient chemical pre-treatment of the feed water. This contamination would be retained in the brine stream, but bacterial growth on the membrane itself can cause the introduction of tastes and odours into the product water
- If the plant uses sea water there can be interruption to the service during stormy . This can cause resuspension of particles, which increases the amount of suspended solids in the water
- The plant operates at high pressure and sometimes there are problems with mechanical failure of equipment due to the high pressure used

RO-MAIN FEATURES

ENERGY NEEDS for 1 m^3 of fresh water produced:

- 1.5 kWh for brackish water
- 6.0 kWh for seawater, without energy recovery systems
- 2.5-4.0 kWh for seawater, with energy recovery systems

RECOVERY FACTOR:

- 70 to 75 % for brackish water
- 40 to 50 % for seawater

OPERATING PRESSURE:

- 15 to 25 bar for brackish water
- 50 to 80 bar for seawater

PRODUCT WATER QUALITY:

- 300-500 ppm

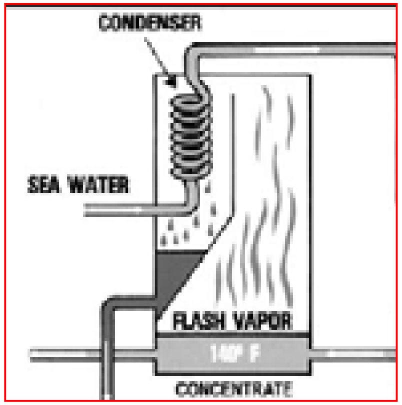
RO-CURRENT TRENDS

Research and development efforts in RO desalination are concentrated on the following aspects

- **Decrease sensitivity** of membranes regarding fouling (smoother surfaces, negative charged or neutral membranes);
- **Increase rejection** rate of salts
- **Develop new membranes** that would be resistant to oxidising agents
- **Improve energy recovery**
- Develop an **improved methodology for achieving optimal pretreatment**.

MULTI-STAGE FLASH (MSF)

MSF is a distillation process that involves evaporation and condensation of water. The evaporation and condensation steps are coupled so that the latent heat of evaporation is recovered for preheat the incoming water. There are two distinct sections in each stage: the flashing chamber (where the vapors are produced) and the condensing section (where the vapors are condensed)



The MSF process consists of a series of stage in wich “flash” evaporation takes place from brine flowing across the bottom of the stage. The vapour released in flashing, passes through demisters to remove brine droplets and condenses on heat transfer tubes at the top of the stage. Each stage of an MSF unit operates at a successively lower pressure. The heat to operate the process is supplied by heating steam, condensing in the brine heater.

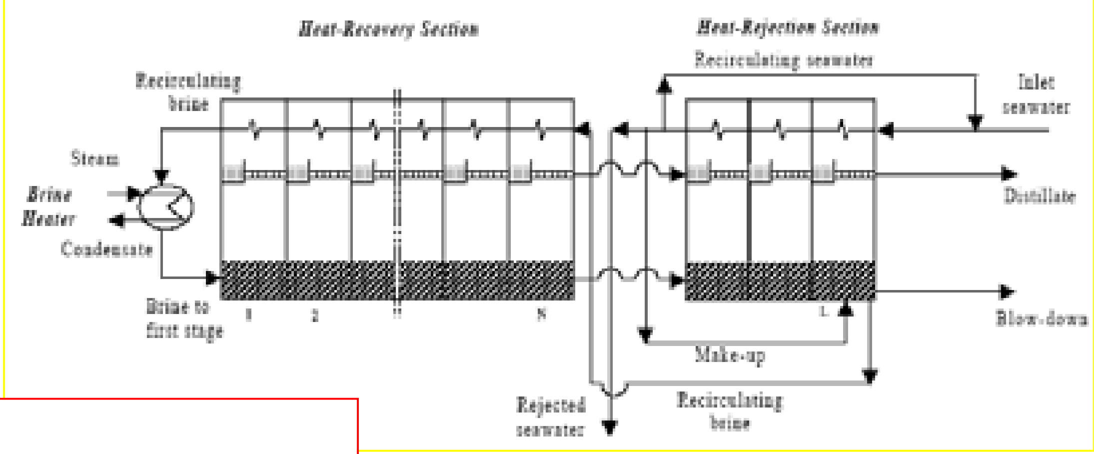
There are tow process arrangements for the MSF process:

- ❑ ONCE-THROUGH DESIGN
- ❑ RECYCLE DESIGN

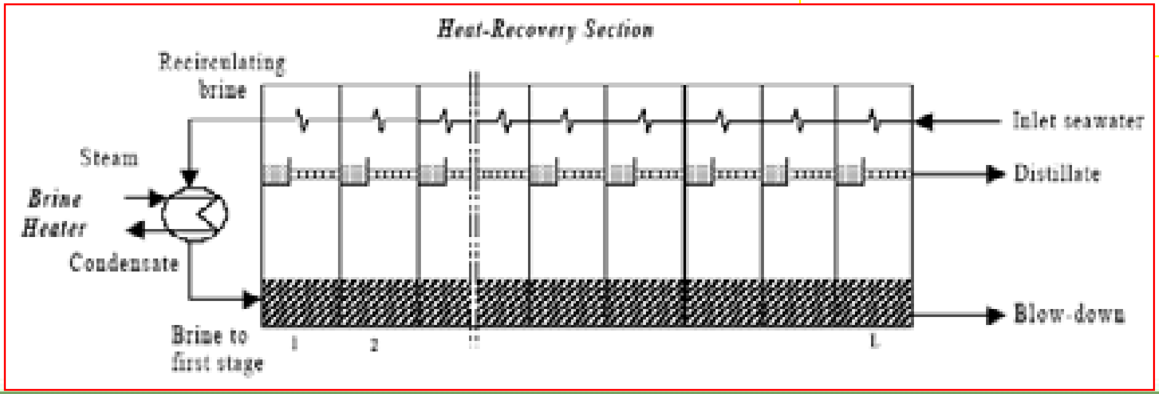
MULTI-STAGE FLASH (MSF)

In **ONCE-THROUGH DESIGN** the feed water is pumped through the recovery section and brine heater, then passes through the flash chambers without recycling

In **RECYCLE DESIGN** the evaporator is broken into two distinct sections: the *rejection section* and the *recovery section*. The rejection section is the "heat sink" of the process, whereas the recovery section allows to raise the temperature of the recycle stream



ONCE-THROUGH DESIGN



RECYCLE DESIGN

SCHEMATIC PRESENTATION OF MSF PLANT

MSF-ADVANTAGES

- MSF plants can be constructed to handle large capacities
- It produces very high quality product water with a salt content less than 10 ppm
- There is a minimal requirement for pre-treatment of feed water
- The salinity of the feed water does not have much impact on the process or costs
- There is a long history of commercial use and reliability
- It can be combined with other processes, eg using the heat energy from an electricity generation plant

MSF-DISADVANTAGES

- MSF process is highly energy intensive
- MSF plants are expensive to build and operate, requiring a high level of technical knowledge
- The recovery ratio is low, therefore more feed water is required to produce the same amount of product water
- Amount of water production depends on operating temperature; as higher is the top brine temperature, as more the water production
- Tube scaling, which occurs at high temperatures, introduces a limit to the top brine temperature and consequently to the efficiency
- The plant can not be operated below 70-80% of the design capacity
- Due to the high purity of desalted water, blending is required for civil use

MSF-MAIN FEATURES

ENERGY NEEDS for 1 m^3 of fresh water produced :

- 3.5 to 4 kWh

SPECIFIC THERMAL ENERGY CONSUMPTION:

- 7 to 9 m^3 of fresh water for tonn of steam

RECOVERY FACTOR :

- 8 to 10%

TOP BRINE TEMPERATURE :

- 100-110°C

PRODUCT WATER QUALITY:

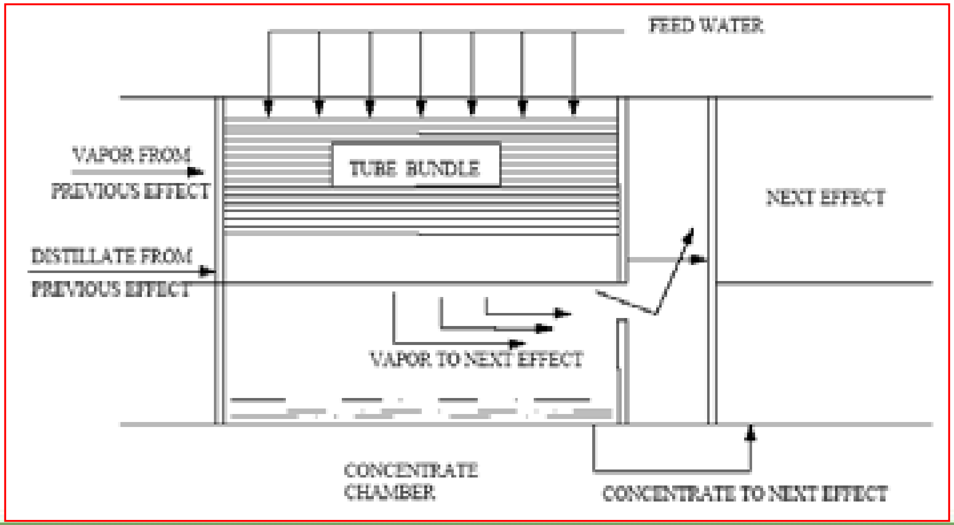
- <10 ppm

MULTI-EFFECT DISTILLATION (MED)

This process takes place in a series of **effects** (vessels) and uses the principle of reducing the ambient pressure in the successive effects. This causes the feed water to undergo boiling in a series of effects without supplying additional heat after the first effect. Vapor generated in the first effect gives up heat to the second effect for evaporation and is condensed inside the tubes. This continues for several effects. Three arrangements have evolved for MED process:

- HORIZONTAL TUBE ARRANGEMENT
- VERTICAL TUBE ARRANGEMENT
- VERTICALLY STACKED TUBE BUNDLE

SCHEMATIC PRESENTATION OF MED HORIZONTAL TUBE ARRANGEMENT



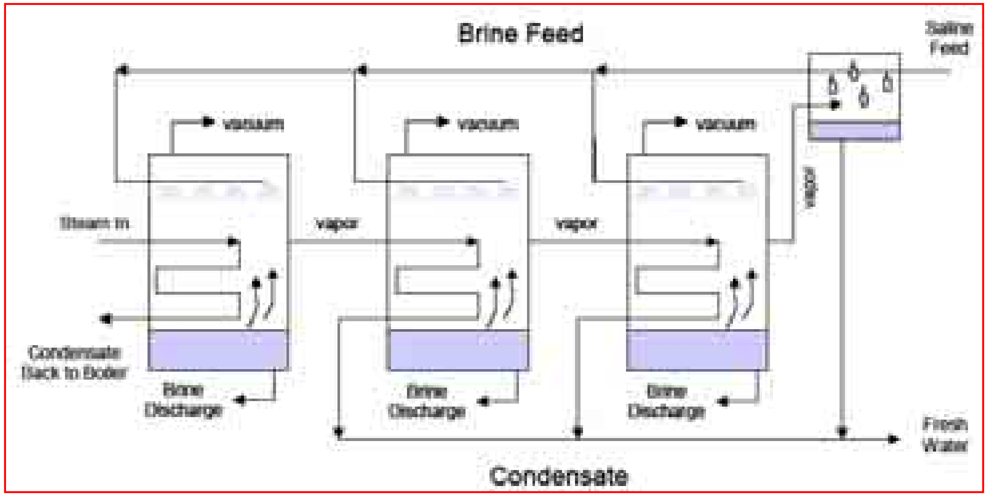
The seawater is either sprayed, or otherwise distributed onto the surface of evaporator tubes in a thin film to promote rapid boiling and evaporation

MULTI-EFFECT DISTILLATION (MED)

It can use **low-temperature, low pressure steam** as the main energy source. The primary steam is used to evaporate heated seawater and to generate more steam at a lower pressure while the primary steam condensate is taken back to the generation chamber, or to the steam generator of the power station. The condensate from the boiler steam is recycled to the boiler for reuse.

The process of producing vapor in each effect and using it to heat the next lower effect, continues throughout all the effects until the vapor from the last effect is condensed in the main condenser. The distillate produced in each effect is joined with the condensate from the main condenser and becomes the product water

SCHEMATIC PRESENTATION OF MED PLANT



MED-ADVANTAGES

- It produces very high quality product water with a salt content less than 10 ppm
- The amount of water produced do not depend on maximum operating temperature; this characteristic allows to operate at lower temperature than MSF.
- The low temperature operation makes possible to use low-cost/low grade heat, available through cogeneration schemes, to minimize the energy cost component.
- The process can give lower capital costs, lower power requirements and higher thermal performance than MSF.
- Development of a unique design of a falling film horizontal tube evaporator gives high heat transfer coefficient
- The salinity of the feed water does not have much impact on the process or costs
- Due to the low temperature operation, there is less probability of scale formation and corrosion thus reducing cost of pretreatment and allowing the utilization of economical and durable material of construction

MED-DISADVANTAGES

- They are expensive to build and operate
- The recovery ratio reaches medium value (well higher than MSF) comparable with sea water RO process
- Due to the high purity of desalted water, blending is required for civil use

MED-MAIN FEATURES

ENERGY NEEDS for 1 m^3 of fresh water produced :

- 2.5 to 3 kWh

SPECIFIC THERMAL ENERGY CONSUMPTION

- 5 to 6 m^3 of fresh water for tonn of steam

RECOVERY FACTOR :

- 30 to 40%

TOP BRINE TEMPERATURE :

- 60-70°C

PRODUCT WATER QUALITY:

- <10 ppm

THERMAL PROCESS-CURRENT TRENDS

Research and development efforts in thermal desalination processes are concentrated on the following aspects

- Develop concepts and schemes for optimal integration, by cogeneration or otherwise, of various energy sources and thermal technologies (hybrid systems, solar energy integration)
- Identify novel schemes for improving desalination processes and/or energy recuperation
- Develop improved designs and manufacturing technologies for heat transfer bundles and containment vessels that reduce investment costs
- Develop improved pretreatment methods for controlling scaling and fouling

COMPARISON OF DISTILLATION AND MEMBRANE PROCESSES

ADVANTAGES OF USING MEMBRANE OVER DISTILLATION PROCESSES

- Membrane plants normally have lower energy requirements than thermal processes
- The capital cost for membrane plants is lower than distillation plants
- Membrane plants have a high space/production capacity ratio
- Membrane plants have higher recovery ratios than distillation plants
- Membrane plants operate at ambient temperature minimizing corrosion potential, which increase with higher temperature

ADVANTAGES OF USING DISTILLATION PROCESSES OVER MEMBRANE

- Distillation processes do not need high exergy energy such as electricity, but only low entalpy (low exergy) heat of low value, which is, from an energy efficiency point of view, not comparable to the highly valuable expensive electricity, required for membrane processes. The use of waste heat, reduces the energy cost and makes water production by thermal processes, much more competitive in particular for MED process for which the heating steam temperature can be reduced to 60-70 °C
- Distillation plants produce higher quality product water than membrane plants
- The performance of membrane plants tend to decline progressively with time due to fouling of the membrane
- Distillation plant benefits much from scale economy; as a result thermal plants generally tend to be larger than membrane
- Membrane processes may require further pre and post-treatment due to the high sensitivity of membranes to organic and inorganic fouling and to the lower water quality. Membrane plants need to be cleaned more regularly than distillation plants
- Distillation plants have been estabilished for a long time and have proven to be a reliable process
- Distillation plants only require a minimal amount of operating staff

PRETREATMENTS COMPARISON OF DISTILLATION AND MEMBRANE PROCESSES

PRETREATMENTS FOR DISTILLATION PROCESSES

-Antiscale or acid control to prevente calcium and magnesium salts scaling
-Minimization of corrosive gases entering the evaporator using a decarbonator and deaerator
-Addition of sodium bisulfite or similar oxygen scavenger to ensure removal of all oxygen

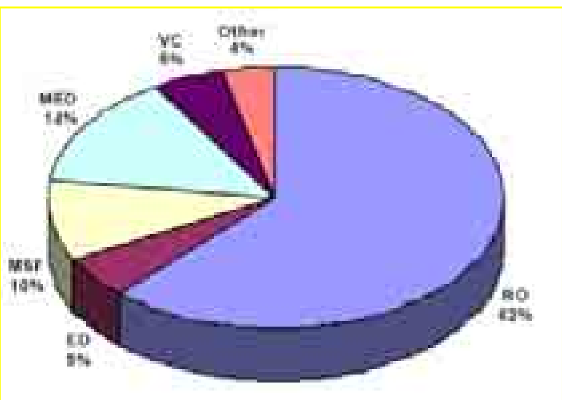
PRETREATMENTS FOR MEMBRANE PROCESSES

-Addition of acid to prevent calcium carbonate and other salts scaling
-Coagulation with alum, ferric chloride or other coagulant prior to filtration
-Steps of filtration to remove any kind of suspended solids
-Feed water disinfection (usually chlorine followed by dechlorination or other), to prevent biofouling
-Removal of organic from the feed water by using powdered activated carbon; ultrafiltration has also proven to be effective in reducing colloidal organic material

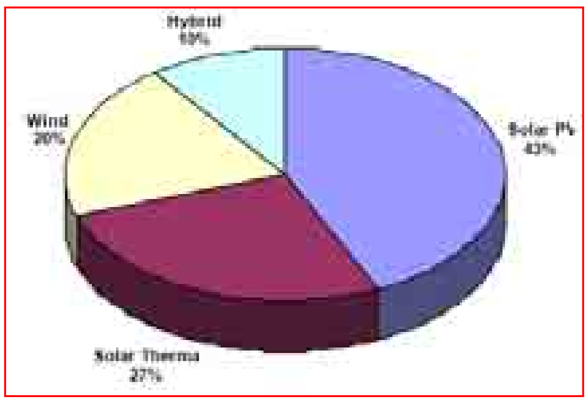
COUPLING RENEWABLE ENERGY SOURCE TO A DESALINATION PROCESS

Most desalination techniques consume a large amount of energy, therefore finding methods of using renewable energy to power the desalination process is desirable. Solar collectors or wind energy devices can be used to provide the heat or electrical energy requirements to operate a standard desalination plant.
Solar energy can be used in two forms. Either as thermal energy by heating a fluid or by converting it into electricity using photovoltaic arrays (PV).
Alternatives have been developed to produce higher grade energy in the form of hot fluids which can then be used to drive more thermally efficient desalination processes such as MSF and MED.

DESALINATION PROCESSES USED IN CONJUNCTION WITH RENEWABLE ENERGY



RENEWABLE ENERGY SOURCE FOR DESALINATION



A large example of solar power desalination is the Abhu Dhabi solar distillation plant in the United Arab Emirates. This plant was commissioned in 1984 and has an output of 85 m^3/d of fresh water. The solar collectors take up an area of 1862 m^2 and the recovery ratio of such plants range from 43-55%

COMPARISON OF THE ECONOMICS OF THE DESALINATION PROCESSES

The capital and operating costs of seawater desalination plants have decreased significantly over the last 10 years due to process design improvements, membrane performance development, process performance augmentation, energy efficiency improvements ecc.

In table a comparison of the economics of the desalination processes is presented for medium-large size plants:

- plant capacity 30,000m3/day;
- interest rates 7%;
- project life 20 years;
- price electricity 0.065US$/kWh;
- cost of manpower 45,000US$/year;

		MSF	MED	VC	RO
Specific Investment Cost	US$/m3/Day	1,200-1.500	900-1,000	950-1,000	700-900
Total Cost Product	US$/m3	1.10-1.25	0.75-0.85	0.87-0.95	0.68-0.82

DESALTED WATER COST FROM VARIOUS AUTHORS

Reference	MSF	MEE	VC	Seawater RO	Brackish RO	Brackish ED
A	1.10-1.50	0.46-85	0.87-0.92	0.45-0.92	0.20-0.35	
B	0.80	0.45		0.72-0.93		
C	0.89	0.27-0.56		0.68		
D	0.70-0.75			0.45-0.85	0.25-0.60	
E				1.54	0.35	
F				1.50	0.37-0.70	0.58
G	1.31-5.36			1.54-6.56		
H	1.86	1.49				
I		1.35		1.06		
J				1.25		
K	1.22					
L					0.18-0.56	
M			0.46			
N				1.18		
O		1.17				
P			0.99-1.21			
Q				0.55-0.80	0.25-0.28	
R				0.59-1.62		
S				1.38-1.51		
T				0.55-0.63		
U				0.70-0.80		
V					0.27*	
W				0.52		

A. R. Semiat, Water International 25 (2000) 54.
B. J. Bednarski, M. Minamide, O.J. Morin, Proc., IDA World Congress on Desalination and Water Science, Madrid, 1 (1997) 227.
C. G. Kronenberg, Proc., IDA World Congress on Desalination and Water Science, Abu Dhabi, 3 (1995) 459.
D. O.K. Buros, "The ABCs of Desalting, Second ed." International Desalination Association, Topsfield, Mass, 2000.
E. F.I.A. Cortes and A.M. Dominguez, Ingenieria Hidraulica En Mexico 15 (2000) 27.
F. K.S. Spiegler and Y.M. El-Sayed, A Desalination Primer, Balaban Desalination Publications, Santa Maria Imbaro, Italy (1994).
G. R.V. Wahlgren, Wat. Res. 35 (2001) 1.
H. O.J. Morin, Desalination 93 (1993) 343.
I. G. Hess and O.J. Morin, Desalination 87 (1992) 55 – updated to 1997 $ in Al-Juwayhel, H. El-Dessouky, H. Ettouney, Desalination (1997) 253.
J. E. Drioli, F. Lagana, A. Criscuoli, G. Barbieri, Desalination 122 (1999) 141.
K. T.M. Leahy, Int. Desalination and Water Reuse 7 (1998) 2832.
L. J.S. Taylor and E.P. Jacobs in Water Treatment Membrane Processes, Mallevialle, Odendaal, Wiesner, eds. McGraw-Hill, New York (1996).
M. Z. Zimerman, Desalination 96 (1994) 51.
N. "Survey of U.S. Costs and Water Rates for Desalination and Membrane Softening Units" U.S. Bureau of Reclamation Desalination and Water Purification Research and Development Program Report No. 24, July, 1997.
O. V. Dvornikov, Desalination 127 (2000) 261.
P. Y.M. El-Sayed, Desalination 125 (1999) 251.
Q. J.A. Redondo, Desalination 138 (2001) 29.
R. G. F. Leitner, Desalination 81 (1991) 39.
S. A. Malek, M.N.A. Hawlader, J.C. Ho, Desalination 105 (1996) 245.
T. P. Glueckstern, M. Priel, Desalination 119 (1998) 33.
U. M. Wilf, K. Klinko, Desalination 138 (2001) 299.
V. D.L. Brown, Desalination and Water Reuse Quarterly 6 (1996) 20. * Capital costs not included.
W. G. Leitner, Desalination 102 (1995) 199.