PRODES
Promotion of Renewable Energy for Water production through Desalination

Desalination Technologies (I)

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PRODES

Part of the presentation is prepared with the contribution of ProDes partners

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The Water
The Need for Water Demand Management

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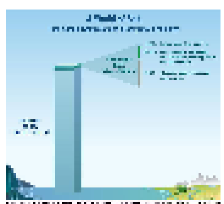
Global Water Distribution

Throughout history, water has been the essential element for economic and social development and for the stability of cultures and civilization.

Water Natural Resources

- Fresh Water (Surface, Ground Water) 2.5%
  - Lakes & river storage
  - Ground water
  - Glaciers & permanent snow cover
- Ocean Water 97.5%



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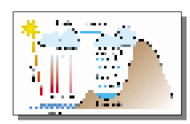
Water Conservation & Demand Management

- **Water conservation** measurements have not been widely applied in most countries of the region.
- Reducing loss of water both in urban and irrigation networks can provide from 30-50% saving in irrigation water and from 28-50% in urban water.
- **Water demand management** is on the policy agenda of most countries
- Introduction of **water saving devices** is important. These are:
  - use of incentives (metering, pricing, subsidies and penalties)
  - information (extension services and education campaigns)
  - regulatory measures (control of water and quotas)

Non-conventional Water Resources

- **Wastewater reuse** (water for gardens, irrigation, etc)
- **Desalination** (for potable and distillate water production)



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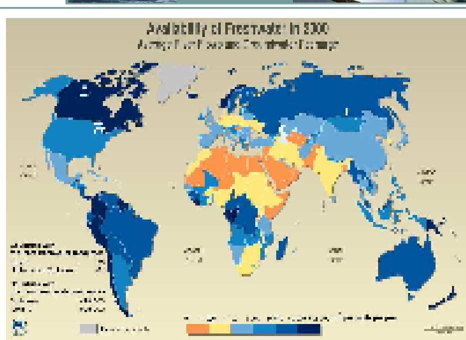

m3/capita/year
0-1000
50,000-605,000

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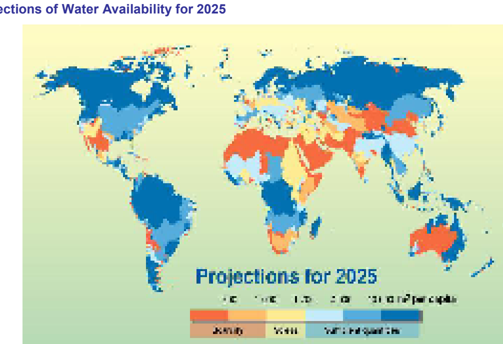
Projections of Water Availability for 2025



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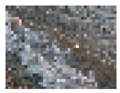
The Water Problem

- Water in most countries and regions of the Mediterranean is a limiting factor
- The level of exploitation of water resources is generally high in most countries and pressure over water resources is increasing.
- Exploitation ratios over 50%, or even 100% in many parts of Mediterranean countries (Egypt, Palestinian Authority, Libya, Israel, Malta)
- Exploitable amounts of water are decreasing, and may become scarce in time or region



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Factors increase the water consumption are:

- Growing of population
- Growing of industry
- Tourism
- Agriculture / Irrigation needs

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Desalination Technology

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What is Desalination ?

Desalination is the removal of dissolved salts and other impurities from salt water.

A desalination plant turns salt water (brackish or seawater) into fresh water (potable or distillate water).

Water Classification

Water Source	Approximate Salt Concentration (mg/lt)
Brackish water	>1000, high brackish up to 11.000
Seawater	~35.000
Atlantic Ocean	35.000
Pacific Ocean	38.000
Persian Golf	45.000
Dead Sea	~ 300.000

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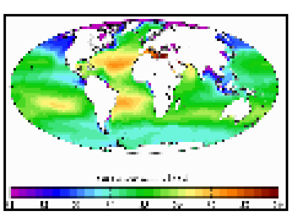
Seawater chemistry

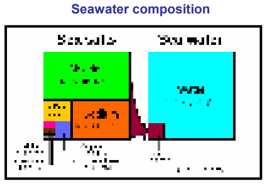
Θαλασσινό Νερό
- Άλατα 3.5%
- Νερό 96.5%

Χλωριούχα	55%
Νάτριο	30.6%
Θειούχα	7.7%
Ασβέστιο	1.2%
Μαγνήσιο	3.7%
Κάλιο	1.1%
Λοιπά Συστατικά	0.7%

Variation of salinities in the seas



Seawater composition



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Seawater Composition

Chemical Ion	Concentration ppm, mg/kg	Part of salinity %	mmol/ kg
Chloride Cl^-	19345	55.03	546
Sodium Na^+	10752	30.59	468
Sulfate SO_4^{2-}	2701	7.68	28.1
Magnesium Mg^{2+}	1295	3.68	53.3
Calcium Ca^{2+}	416	1.18	10.4
Potassium K^+	390	1.11	9.97
Bicarbonate HCO_3^-	145	0.41	2.34
Bromide Br^-	66	0.19	0.83
Borate BO_3^{3-}	27	0.08	0.46
Strontium Sr^{2+}	13	0.04	0.091
Fluoride F^-	1	0.003	0.068

It should be well observed that although salinity of seawater may well vary depending on the specific region of the world, **the percentage composition of seawater is essentially constant** throughout the world (i.e. the proportions of the major constituents are constant).

Seawater Temperatures

$0°C<T<35\text{-}40°C$

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Fresh water composition

WHO Standards for drinking Water	Contents in mg/l	
	min acceptable	max permissible
Total dissolved solids, TDS	500	**1500**
Cl	200	600
SO_4^{2+}	200	400
Ca^{2+}	75	100
Mg^{2+}	30	150
F^-	0.7	1.7
NO_3^-	<50	100
Cu^{2+}	0.05	1.5
Fe^{3+}	0.10	1.0
NaCl	250	-
pH	7.0-8.5	6.5-9.2

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Desalination History

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Short History of Desalination

- Throughout history, people have continually tried to treat salty water so that it could be used for drinking and agriculture. Seawater desalination was already used centuries ago on ships in order to produce fresh water by evaporation.
- The first big industrial desalination plants were built at the beginning of the 20th Century, the first probably being built in 1912 in Egypt with a 6 stages Multiple Effects Evaporator, producing about 75 m^3/d of desalinated water.
- Further commercial development of land based seawater distillation units took place in the late 1950s, and initially relied on the technology developed for industrial evaporators (such as sugar concentrators) and for the shipboard distillation plants which were built during World War.

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Desalination Development

- A dramatic increase in the desalination industry followed the petroleum industry boom in the '70s, in particular in the Gulf area where several thermal plants were built in order to satisfy the quickly growing water demand of the local population and given the large availability of thermal energy at very low cost.
- Mostly thermal-driven units were used to desalt seawater, but in the 1970s, commercial membrane processes such as Electrodialysis (ED) and Reverse Osmosis (RO) began to be used more extensively.
- By the 1980s, desalination technology was a fully commercial enterprise.
- By the 1990s, the use of desalting technologies for municipal water supplies had become commonplace.

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- Seawater desalination is the most preferred technology regarding the feed water type, mainly because of its availability.
- In 2007, the **total capacity** of installed **seawater desalination** plants worldwide was about **30 million m^3/d** of which about 85 % is still in operation.
- This total capacity is continuously increasing with a very rapid trend.
- Desalting equipment is now used in over 100 countries, although 10 countries have about 75 percent of all the capacity.
- Almost **50%** of this desalting capacity is used to desalt seawater in the **Middle East** and **North Africa**.

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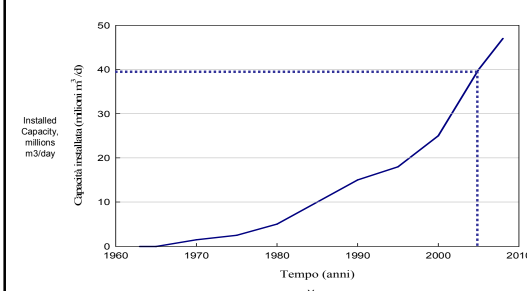
The Development of Desalination



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Water Desalination Applications

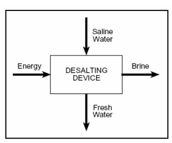
- Domestic or Municipalities purposes
- Heavy Industry
- Pharmaceutical Industry
- Irrigation
- Marine
- Military
- Food & Dairy
- Home drinking water, etc.

Desalination Processes

Water Desalination Process

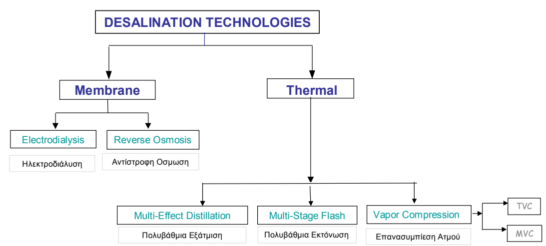
A wide variety of desalination technologies effectively remove salts from salty water (or extract fresh water from salty water), producing a water stream with a low concentration of salt (the product stream) and another with a high concentration of remaining salts (the brine or concentrate).

Most of these technologies rely on either distillation (thermal processes) or membranes to separate salts from the product water.

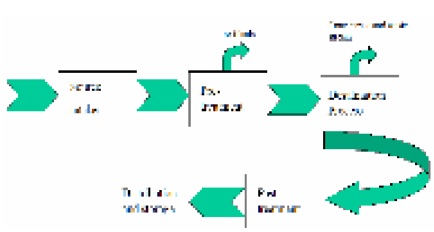


Process classification

The commercially available desalination processes are divided in two main categories:



Typical sequence of desalination treatment and distribution processes



WHO Report, 2007

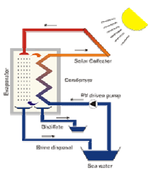
Other Desalination Processes

Other Desalination Processes

A number of other processes have been used to desalt saline water. Most of these processes have not achieved the level of commercial success that RO and distillation have.

These are:

- Freezing
- Humidification – Dehumidification
- Solar stills
- Membrane Distillation
- Dual purpose plants - Co-generation
- Hybrid



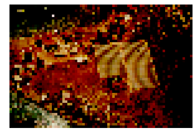
Multi-Effect Humidification

Source: TINOX, Germany

Solar Stills

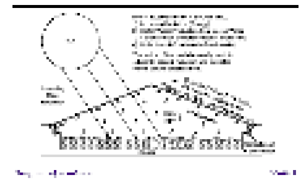
Solar distillation is a process in which the energy of the sun is directly used to evaporate fresh water from sea or brackish water. The process has been used for many years, usually for small scale applications.

Well designed units can produce around 2.5 l/m² per day with a thermal efficiency of 50%.



Source: E. Tzen, CRES

Kastelorizo island, Greece



Solar stills are simple in operation and maintenance. The only maintenance required is the cleaning of the plant, especially of the glass roof.

Membrane Distillation

Membrane distillation (MD) combines the use of both thermal distillation and membranes and was introduced commercially on a small scale in the 1980s. The process relies primarily upon thermal evaporation and the use of membranes to pass vapor, which is then condensed to produce fresh water.

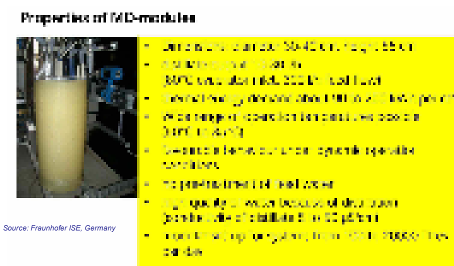
In the process, saline water is warmed to enhance vapor production, this vapor is exposed to a membrane that can pass water vapor but not liquid water. After the vapor passes through the membrane, it is condensed on a cooler surface to produce fresh water. In the liquid form, the fresh water cannot pass back through the membrane, so it is trapped and collected as the output of the plant.

Thus far, MD has been used only in a few facilities, since it requires more space, more pumping energy per unit of fresh water produced, and more money than other approaches. The main advantages of MD lie in its simplicity and the need for only small temperature differentials to operate.

MD is probably best suited for desalting saline water where inexpensive low-grade thermal energy (60-80°C) is available, such as from industries or solar collectors.
Commercially it is of little significance.

Once the vapor has passed through the hydrophobic membrane, it can be extracted or directly condensed in the channel on the other side of the membrane.

MD Module



Source: Fraunhofer ISE, Germany

Dual Purpose - Co-generation Plants

In some situations, it is possible to use energy so that more than one use can be obtained from it as the energy moves from a high level to an ambient level.

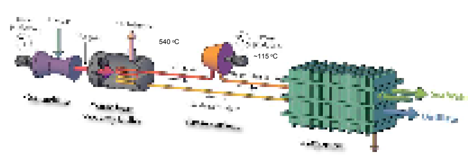
This occurs with co-generation where a single energy source can perform several different functions.

Certain types of desalination processes, especially the distillation process, can be structured to take advantage of a co-generation situation.

Most of the distillation plants installed in the Middle East and North Africa have operated under this principle since 1960s and are known in the field as dual purpose plants (water plus power). These units are built as part of a facility that produce both electric power and desalted seawater for use in a particular country.

The main advantage of a co-generation system is that it can significantly reduce the consumption of fuel when compared to the fuel needed for two separate plants. Since energy is a major operating cost in any desalination process, this can be an important economic benefit.

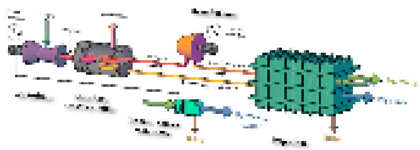
One of the disadvantages is that the units are permanently connected together and, for the desalination plant to operate efficiently, the steam turbine must be operating.
This permanent coupling can create a problem with water production when the demand for electricity is reduced or when the turbine or generator is down for repairs.



Source: SIDEM, France

Hybrid Plants

Another method of reducing the overall costs of desalting can be the use of hybrid systems.
Such hybrid systems are not applicable to most desalination installations, but can prove to be an economic benefit in some cases.
A hybrid system is a treatment configuration made up of two or more desalination processes. An example is using both distillation and RO processes to desalt seawater at one facility and to combine the different characteristics of each process productively.



Desalination Technologies (I)

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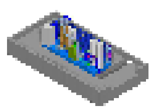
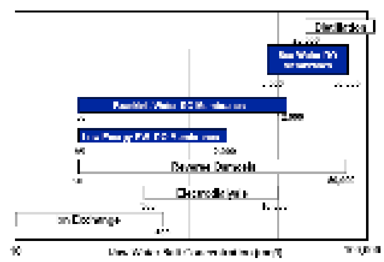
Membrane Processes

Electrodialysis
Reverse Osmosis



Major desalination processes



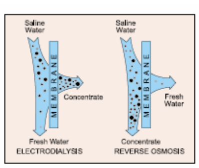
Source: Dow/FilmTec

Membrane Processes

Membranes are used in two commercially important desalting processes: Electrodialysis (ED) and Reverse Osmosis (RO). Each process uses the ability of the membranes to differentiate and selectively separate salts and water.

ED is a **voltage driven** process and uses an electrical potential to move salts selectively through a membrane, leaving fresh water behind as product water.

RO is a **pressure-driven** process, with the pressure used for separation by allowing fresh water to move through a membrane, leaving the salts behind.



Electrodialysis

ED / EDR

Electrodialysis Process Description

ED is an electrochemical process and a low cost method for the desalination of brackish water.
Due to the dependency of the energy consumption on the feed water salt concentration, the ED process is not economically attractive for the desalination of sea water.

In Electrodialysis (ED) process, ions are transported through a membrane by an electrical field applied across the membrane. An ED unit consists of the following basic components:

- pre-treatment system
- membrane stack (κελί μεμβρανών)
- low pressure circulation pump
- power supply for direct current (rectifier)
- post-treatment

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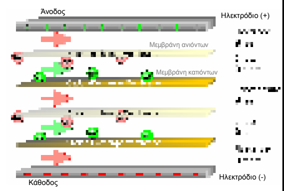
The Principle of Electrodialysis

When electrodes are connected to an outside source of direct current like a battery and placed in a container of saline water, electrical current is carried through the solution, with the ions tending to migrate to the electrode with the opposite charge.

If between electrodes a pair of membranes (cell), anion permeable membrane followed by a cation permeable membrane is placed, then, a region of low salinity water (product water) will be created between the membranes.

Between each pair of membranes, a **spacer sheet** (διαχωριστής ή χώρισμα ροής) is placed in order to permit the water flow along the face of the membrane and to induce a degree of turbulence. One spacer provides a channel that carries feed (and product water) while the next carries brine. By this arrangement, concentrated and diluted solutions are created in the spaces between the alternating membranes.



Μεμβράνη ανιόντων: επιτρέπει τη δίοδο μόνο των φορτισμένων αρνητικά ιόντων

Μεμβράνη κατιόντων: επιτρέπει τη δίοδο μόνο των φορτισμένων θετικά ιόντων

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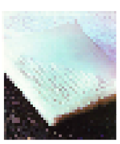
An anion membrane, a diluting spacer, a cation membrane, and a concentrating spacer comprise a repeating unit called a "cell pair" (ζεύγος στοιχείων). ED cells can be stacked either horizontally or vertically.

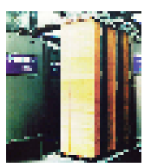
Multiple cell pairs between an anode and a cathode comprise a "stack".

Several membrane pairs are used between a single pair of electrodes, forming an ED stack. Feed water passes simultaneously in parallel paths through all the cells, providing a continuous flow of product water and brine to come out from the stack. Stacks on commercial ED plants contain a large number, usually several hundred of cell pairs.



ED membrane spacer

Στοιχείο Ηλεκτροδιάλυσης



ED stack
Κελιά
Ηλεκτροδιάλυσης

Source: IONICS

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EDR Process

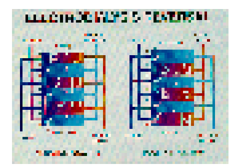
A modification to the basic Electrodialysis process is the **Reversal Electrodialysis**, EDR.

In this process the polarity of the electrodes changes periodically of time, reversing the flow through the membranes. Immediately following the reversal of polarity and flow, the product water is dumped until the stack and lines are flushed out and the desired water quality is restored.

This flush takes only 1 or 2 minutes, and then the unit can resume producing water.

The **reversal process is useful in breaking up and flushing out scales**, **slimes, and other deposits** in the cells before they can build up and create a problem.

Flushing **allows the unit to operate with fewer pretreatment chemicals and minimizes membrane fouling**.



Source: IONICS, USA

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Output & Degree of Desalination

The rate of salt removal from the dilute streams is essentially controlled by Faraday's Law, being proportional to the amount of charge passing (i.e. current) per unit time.
For the situation comprising flow of a single-salt (NaCl) solution through one pair of perfect membranes and with no other current losses, the application of Faradays Law yields:

$$\Delta C = \frac{I}{F * U_D * n}$$

where

ΔC: reduction of concentration of salt, mole/lt

I: current flowing, Amp

F: Faraday's constant, 96,500 Coulombs per equivalent

U_D: dilute stream flow rate, lt/sec

n: total number of positive or negative charges per molecule, for NaCl , n=1,for $CaCl_2$, n=2

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Electrodialysis Process Characteristics

ED has the following main **characteristics** that make it suitable for a number of applications:

- Capability for **high recovery** (more product and less brine)
- Energy usage that is **proportional to the salts removed**
- **Low chemical usage** for pretreatment

ED units are normally used to desalinate brackish water. The major energy requirement is the direct current used to separate the ionic substances in the membrane stack.

In general, the total energy consumption, under ambient temperature conditions and assuming product water of **500 ppm** TDS, would be around **1.5 and 4 kWh/m³** for a feed water of **1,500 to 3,500 ppm TDS**, respectively. Additionally, pumping energy requirements are minimum.

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Process and Cost analysis

Investment costs for Electro Dialysis plants

Ref.	Investment cost [$]	Plant capacity [m^3/d]	Notes	Specific plant cost [$/($m^3$/d)]
IDA World Inventory (2002)	3,490,000	3,788	USA (1999)	921
IDA World Inventory (2002)	40,870,000	45,420	USA (1994)	900
IDA World Inventory (2002)	620,000	600	Japan (2000)	1,033
IDA World Inventory (2002)	13,300,000	15,000	Iran (1994)	887
IDA World Inventory (2002)	7,320,000	8,000	Spain (1987)	915
IDA World Inventory (2002)	13,900,000	14,400	Italy (1992)	965

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Electrodialysis Reversal drinking water plant in Texas

Source: IONICS, USA

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Reverse Osmosis

RO

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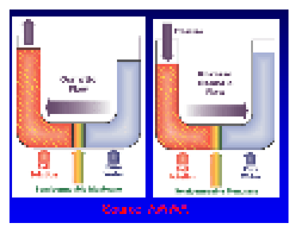
Osmosis and Reverse Osmosis (RO)



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RO Process

RO is the most widely used process for seawater desalination.

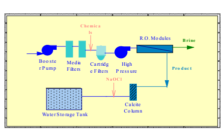
RO process involves the forced passage of water through a membrane against the natural osmotic pressure to accomplish separation of water and ions.

In practice, the saline feed water is pumped into a closed vessel where it is pressurized against the membrane.

The major energy required for desalting is for pressurizing the feed water.

As a portion of the water passes through the membrane, the remaining feed water increases in salt content.

At the same time, a portion of this feed water is discharged without passing through the membrane.



Source: METITO

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PRODES — Promotion of Renewable Energy for Water production through Desalination — sun sea water

Osmotic Pressure

The osmotic pressure, P_{osm}, of a solution can be determined experimentally by measuring the concentration of dissolved salts in solution:

$$P_{osm} = 1.19(T + 273) * \sum(m_i) \qquad (1)$$

Where

P_{osm}: osmotic pressure in psi

T: temperature, C°

$\Sigma(m_i)$: sum of molar concentration of all constituents in a solution*

An approximation of P_{osm} may be made by assuming that 1000 ppm TDS equals about 0.76 bar of osmotic pressure.

Salinity [g/lt]	Molarity (≈NaCl) [mol/lt]	P @ T=25°C ≈ [atm]
5	0.086	4
10	0.172	8
35	0.603	29
50	0.862	42
70	1.207	59

*Molarity is defined as moles of solute per litre of solution

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Water Transport (1)

The rate of water passage through a semi-permeable membrane is:

$$Q_W = (\Delta\Pi - \Delta P_{osm}) * K_W * \frac{S}{d} \qquad (2)$$

Where

- Q_w: rate of water flow through the membrane
- ΔP: hydraulic pressure differential across the membrane
- ΔP_{osm}: osmotic pressure differential across the membrane
- K_w: membrane permeability coefficient for water
- S: membrane area
- d: membrane thickness

Water Transport (2)

The above equation could be simplified by

$$Q_W = (NDP) * A \qquad (3)$$

Where

- Qw: rate of water flow through the membrane
- NDP: net driving pressure
- A: a constant for each membrane material type

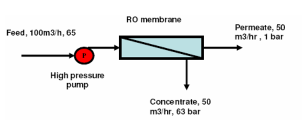
The NDP required for any given membrane application in RO is a function of both the osmotic pressure change and hydraulic resistance

$$NDP = P_F + \Pi_P - \Pi_F - P_P \qquad (4)$$

Reverse Osmosis Technology

Reverse osmosis **uses pressure** on solutions with concentrations of salt to force fresh water to move through a **semi-permeable** membrane, leaving the salts behind.

The amount of desalinated water that can be obtained (**recovery ratio**) ranges between **30% and 75%** of the volume of the input water, depending on the initial water quality, the quality of the product needed, and the technology and membranes involved.



Recovery ratio , R - is an important parameter in the design and operation of RO systems. Recovery ratio affects salt passage and product flow and is defined as follows:

$$R = \frac{Qp}{Qf} * 100\,\% \qquad (5)$$

$$Q_f = Q_P + Q_b \qquad (6)$$

Where

- Qp: permeate flow rate
- Qf: feed water flow rate
- Qb: brine flow rate

RO Performance Parameters

Factors influence RO performance

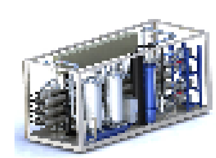
The permeate flux and the salt rejection are the key performance parameters. Mainly they are influenced by variable parameters such as:

- Pressure
- Temperature
- Recovery
- Feed water salt concentration

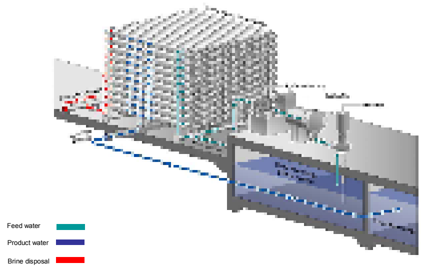
Reverse Osmosis System Description (1)

An RO system is made up of the following basic components:

- Intake system
- Pretreatment system
- High-pressure pump
- Membrane assembly
- Post-treatment system
- Brine Disposal



- Instrumentation and control
- Electric system
- Membrane cleaning system



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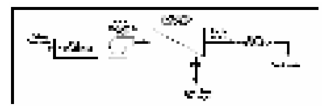
RO Description (2)

The pre-treated feed water is forced by a high-pressure pump to flow across the membrane surface.
RO operating pressure typically varies from 14-25 bar for brackish water and from 55-80 bar for sea water.

Part of the feed water, the product or permeate water, passes through the membrane, removing from it the majority of the dissolved solids.

The post-treatment system consists of sterilisation, stabilisation and mineral enrichment of the product water.



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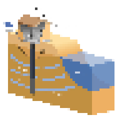
RO Description (3)

• **Intake System (for seawater desalination)**
- Open intake
- Beach wells



• **Pretreatment Procedure**
- Filtration
- Chemicals Dosing

Usually, the pretreatment consists of fine filtration and the addition of acid or other chemicals to inhibit precipitation and the growth of microorganisms. Purpose: reduction of contamination of the membrane surfaces (calcium precipitates, metal oxides, organics and biological matters).

• **High-pressure pumping unit**
The high-pressure pump supplies the pressure needed to enable the water to pass through the membrane and have the salts rejected.

• **Energy recovery device**
The pressure of the brine disposal is high and around 2-5 bar less the pressure of the feed water.

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RO Description (4)

• **Post-treatment procedure**
- Enrichment (Ca, Mg)
- Stabilization
- Sterilization

• **Brine disposal (outfall system)**

Brine outfall, Spain

Source: WWF, Spain

Beach well in Spain

Source: WWF, Spain

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Reverse Osmosis Membranes

Membrane system

Two types of RO membranes are used commercially. These are:
- the Spiral Wound (SW) membranes (σπειροειδή περιέλιξη) and
- the Hollow Fibber (HF) membranes (κοίλων ινών)

SW and HF membranes are used to desalt both sea water and brackish water.
The choice between the two is based on factors such as cost, feed water quality and product water capacity.

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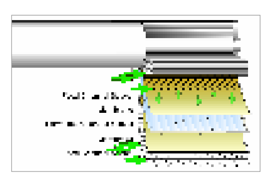
Spiral wound membranes



Source: Dow/FilmTec

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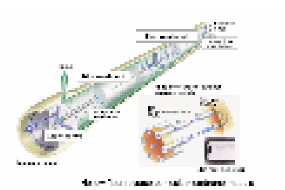
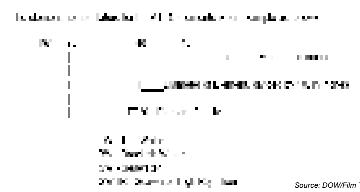
Hollow fibres module



Source: DuPont

RO Membrane Characteristics

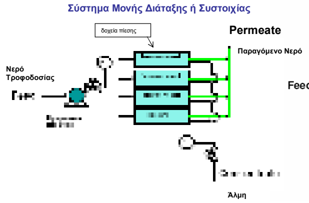
TW30-4040



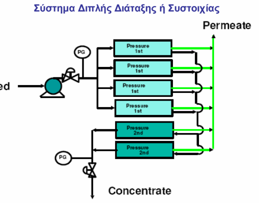
Source: DOW/Film Tec

RO Configurations

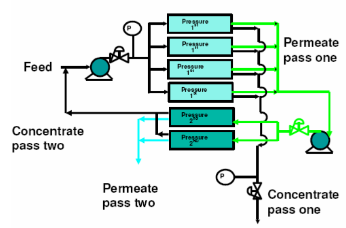
Single array RO system
Σύστημα Μονής Διάταξης ή Συστοιχίας



Two array RO system
Σύστημα Διπλής Διάταξης ή Συστοιχίας



Two pass RO system



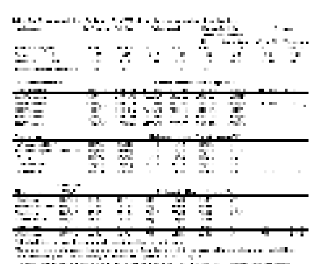
RO Membranes

An significant number of Reverse Osmosis membrane manufacturers exit around the world

Dow FilmTec (USA) - www.dow.com
GE Osmonics (USA) www.gewater.com
Hydranautics (USA) - www.membranes.com
Toray Japan - www.appliedmembranes.com

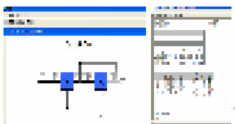
RO Membranes

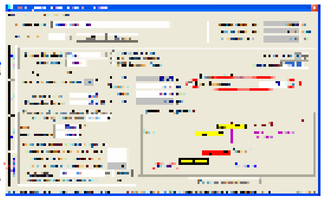
All the major RO membrane manufacturers maintain computer programs to design and predict the performance of their membranes when placed in an RO desalination plant.



Membrane Modeling Software

FILMTEC Modeling Software





Energy Requirements (1)

The **energy requirements** of RO depend directly on the **concentration of salts** in the feed water and, to a lesser extent, on the **temperature of the feed water**.

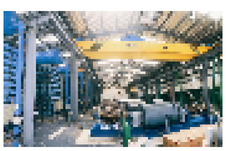
Because **no heating or phase change** is necessary for this method of separation, the major use of **energy is for pressurizing** the feed water.

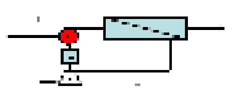
The **main load** of an RO unit is the **high-pressure pumps**. In seawater systems, usually the high pressure pumping unit provides the major contribution (over 85%) to the combined power consumption of the process.

Other loads are:
- Booster pump
- Dosing Pumps
- Membrane Cleaning Pump
- Permeate Pump

Energy Requirements (2)

The efficiencies of pumps, electric motors and power recovery devices have been improved considerably during the last few years. Due to these improvements, power consumption in the range of 3 – 4 kwhr/m^3 is quite common in seawater desalination systems.



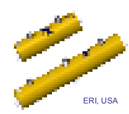


Energy Recovery Devices

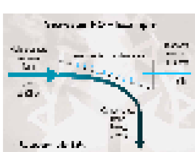
The fraction of power, recovered by the power recovery device, depends on the type and efficiency of the power recovery equipment used. Energy recovery devices connected to the concentrate stream as it leaves the pressure vessel at about 1 to 5 bar less than the applied pressure from the high-pressure pump.

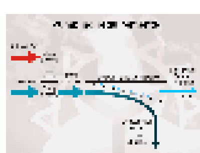
Energy recovery devices are mechanical and generally consist of work or pressure exchangers, turbines, or pumps of some type that can convert the pressure difference to rotating or other types of energy that can be used to reduce the energy needs in the overall process. The most known ERD are:

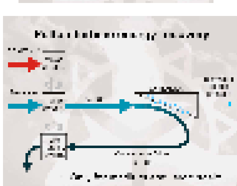
- Pelton wheel
- Pressure Exchanger
- Work Exchanger
- Hydraulic Turbocharger

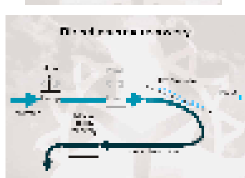


ERI, USA

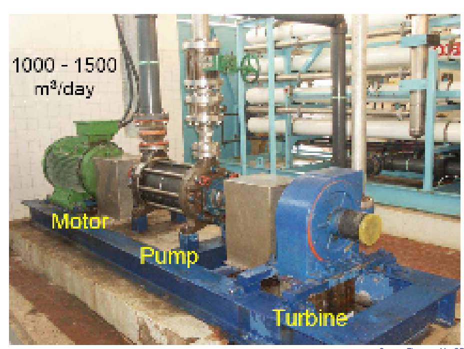




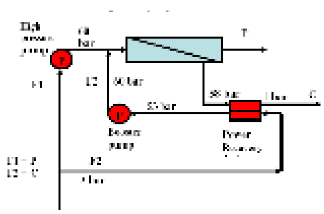




Source: Thomson M., CREST



Source: Thomson M., CREST



Pressure Exchanger energy recovery system

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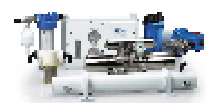
Energy Recovery Devices for small RO units

- PX Pressure Exchanger (ERI)
- Clark Pump (Spectra)
- Ultra Whisper (Sea Recovery) and
- Ingeniatec system



Very small energy recovery devices are not very efficient, improvement is required.

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Energy Requirements Modeling (1)

Booster pump: the power required to run a booster pump is given by

$$P_{bp} = \frac{\rho * g * h * Qf}{n_p}$$

Where

ρ:	Feed water density, at 25ºC, kg/m³
h:	Manometric height, m
g:	Acceleration due to gravity, 9.81 m/sec²
Qf:	Feed flow rate, m³/sec
n_p:	Pump efficiency, %

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Energy Requirements Modeling (2)

High-pressure pump : The power required to run a high-pressure pump is given by

$$P_{HPP} = \frac{P_f * Q_f}{n_p}$$

Where

P_{HPP}:	Power of HPP, kW
Pf:	Feed pressure, N/m²
Qf:	Feed flow rate, m³/sec
n_p :	Pump efficiency, %

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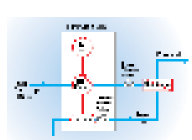
Energy Requirements Modeling (3)

Energy Recovered: The energy recovered by an energy recovery device is:

$$ER = \Pr_b * Q_b * n_t$$

Where

P_{rb}:	brine pressure, N/m²
Q_b:	brine flow rate, m³/sec
n_t :	turbine efficiency, %



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Energy Requirements Modeling (4)

Specific Energy Consumption: The energy consumption per m³ of water produced

$$Sp.En.Con.(kWh/m3) = \frac{(P_{bp} + P_{HPP} - ER) * 24\,hours}{Q_P}$$

Where

P_{pb}:	booster pump power, kW
P_{HPP}:	high-pressure pump power, kW
ER:	energy recovered, kW
Q_p:	permeate flow rate, m³/day

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Energy Requirements Modeling (5)

Membrane Cleaning pump: the energy required to drive the pump for the flushing procedure after the shutdown of the plant.

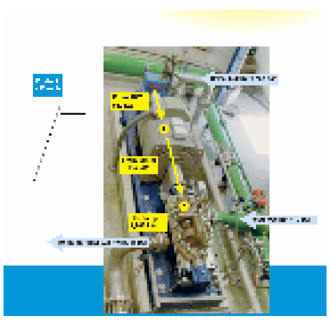
$$P_{MFP} = \frac{P * Q}{n_p}$$

Where
P: pressure, N/m²
Q: flow rate, m³/sec
n_p : pump efficiency, %

Energy Recovery Example

[illegible]	[illegible]

Specific Energy Consumption



Typical RO feed pump power consumption

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Source: Bureau of Reclamation

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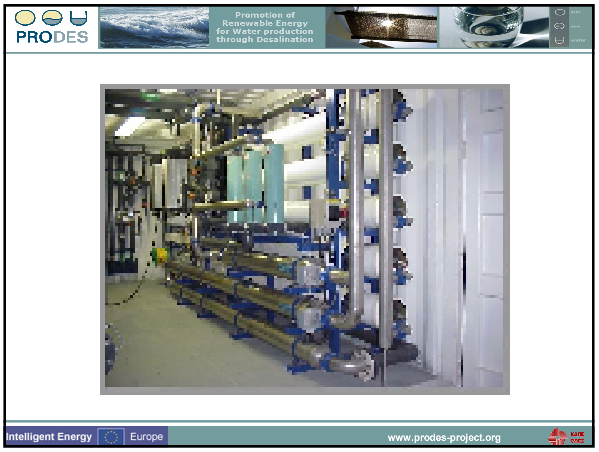
Summary of Reported First-Year Cost of Produced Water for RO Plants

Source: Pacific Institute, 2006

RO main advantages

Reverse Osmosis unit is characterized by:

- Modularity/Compactness
- No empirical technical staff is required
- Satisfactory performance in all sizes
- Easy operation
- Low energy requirements (use of energy recovery devices)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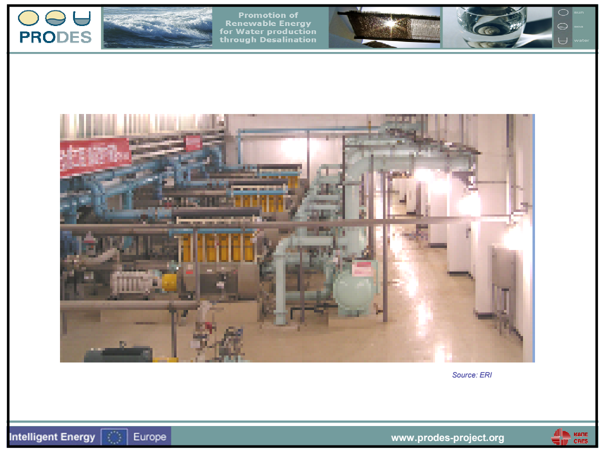
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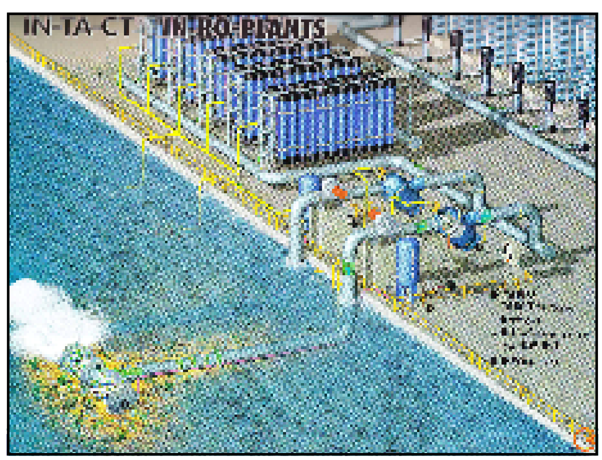
IN-TA CT IN RO-PLANTS

Gela site RO site, Sicily

RO units (15000 m³/d)

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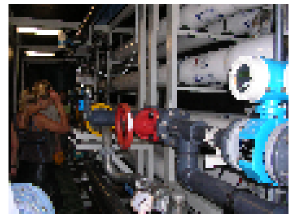

RO plant in Giglio Island (Italy)

- Capacity: 1800m³/d;
- Desalinated ater cost: 0.76 €/m³
- Water cost with ships: 10÷15 €/m³

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CRES RO plant (1)

Seawater water RO desalination unit

Input Data

Qp=	0.130 lt/hr = 3.1 m³/day
Cf=	37,000 ppm TDS
R=	13%
Tf=	20°C
Pop.=	53 bar
Qf=	991 lt/hr= 23.8 m³/day=0.99m³/h

Output Data

Qf=0.95 lt/hr= 23 m³/day

$$R = \frac{Qp}{Qf} * 100\,\%$$

P_{BP} =0.294 kW

$$P_{bp} = \frac{\rho * g * h * Q_f}{n_p} = \frac{1.026 * 9.81 * 85 * (0.99/3600)}{0.8} = 0.294\,kW$$

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CRES RO plant (2)

$$P_{HPP} = \frac{P_f * Q_f}{n_p} = \frac{53 * (0.99/36)}{0.85} = 1.7kW$$

P_{HPP} = 1.7 kW

P_T =1.7 + 0.294 = 2 kW

Sp.En. Consumption = 2 kW * 24/3.1= 15.4 kWh/m³

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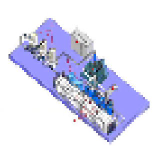
Tutorial

INPUT DATA

- Seawater RO unit
- Product Water Capacity = 50 m³/day= 2,08 m³/hr
- R = 28%
- Pop = 64 bar
- 3 membranes of 8'' each
- Manometric height: 85 m
- P=1.026



Calculate the total installed power of the RO unit and the specific energy consumption with energy recover device and without.

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Solution

- R=Qp/Qf ⇒ Qf =2,2/0.28= 7,85 m³/hr

$$P_{bp} = \frac{\rho * g * h * Q_f}{n_p} = \frac{1.026 * 9.81 * 85 * (7.85/3600)}{0.8} = 2.3kW$$

$$P_{HPP} = \frac{P_f * Q_f}{n_p} = \frac{64 * (7.85/3600)}{0.85 * 1000} * 100000 = 16.41kW$$

P_T =2.3 + 16.4 = 18.7 kW

Spec. En. Consumption = 18.7 kW * 24/50= 8.9 kWh/m³

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$Q_f = Q_p + Q_b \Rightarrow Q_b = Q_f - Q_p = 7.85 - 2.2 = 5.65\ m^3/hr$

$P_b = 62$ bar

$$ER = \Pr_b * Q_b * n_t = 62 * (5.65/36) * 0.85 = 8.2kW$$

$P_T = 2.3 + 16.4 =$ **18.7 kW** without energy recovery device

$P_T = 2.3 + 8.2 =$ **10.5 kW** with energy recovery device

Spec. En. Consumption = 10.5 kW * 24/50= 5.04 kWh/m³

Thermal Desalination Processes - Distillation
ΘΕΡΜΙΚΕΣ ΜΕΘΟΔΟΙ ΑΦΑΛΑΤΩΣΗΣ

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Μέθοδοι Απόσταξης - Ορισμός

Η απόσταξη είναι μια μέθοδος αλλαγής φάσης στην οποία το αλμυρό νερό θερμαίνεται για να δημιουργήσει ατμό, το οποίο στη συνέχεια συμπυκνώνεται και παράγει αποσταγμένο νερό.

Οι κυριότερες μέθοδοι απόσταξης είναι:

- Πολυβάθμια Εκτόνωση, **MSF**
- Πολυβάθμια Εξάτμιση, **MED**
- Εξάτμιση με Επανασυμπίεση Ατμών, **VC**

Η κυριότερη ενεργειακή απαίτηση στη διαδικασία της απόσταξης είναι η θερμότητα που χρειάζεται για την εξάτμιση του νερού τροφοδοσίας (θαλασσινού νερού).

Στις μονάδες απόσταξης στόχος είναι με μια αρχική ποσότητα θερμικής ενέργειας να προκαλέσουμε την εναλλαγή των διαδικασιών εξάτμισης και συμπύκνωσης όσον το δυνατόν περισσότερες φορές.

Οι πιο κοινές διαδικασίες απόσταξης, λειτουργούν βάσει της αρχής της μείωσης της πίεσης του ατμού στη μονάδα ώστε να προκληθεί ο βρασμός του νερού τροφοδοσίας σε χαμηλότερες θερμοκρασίες, χωρίς καμία επιπλέον θερμότητα.

Ο ατμός μπορεί να παραχθεί από ένα διάλυμα που βρίσκεται στο σημείο βρασμού, είτε με προσθήκη θερμότητας ή με την ελάττωση της πίεσης (στιγμιαία εκτόνωση).

Water boiling point table

Pressure	1 bar	0.47 bar	0.32 (Top of Everest)	0.25	0.1
Boiling Point	100ºC	80ºC	70ºC	65ºC	45ºC

Source: SIDEM

*Ambient pressure at sea level = 1 atm=1.013 bar

- Για να μειώσουμε την ενέργεια που απαιτείται για την εξάτμιση του νερού, οι μέθοδοι της απόσταξης συχνά χρησιμοποιούν τη διαδικασία του πολλαπλού βρασμού σε στάδια, όπου το καθένα απο αυτά λειτουργεί σε χαμηλότερη πίεση και θερμοκρασία.

- Η μέγιστη θερμοκρασία λειτουργίας των μονάδων περιορίζεται στους 115ºC περίπου.
- Η λειτουργία της μονάδας σε θερμοκρασία άνω των θερμοκρασίες προκαλεί τη δημιουργία λεβητόλιθου (scale).
- Η κατακάθιση του λεβητόλιθου στους σωλήνες των εναλλακτών και των σωληνώσεων της μονάδας προκαλεί διάβρωση των μεταλλικών τους μερών και μείωση της απόδοσης της μονάδας.

Υπάρχουν 2 βασικά είδη λεβιτόλιθου:

- *Αλκαλικός λεβιτόλιθος* – σχηματίζεται από τα ανθρακικά άλατα του ασβεστίου και του μαγνησίου
- *Όξινος Λεβιτόλιθος* – σχηματίζεται από το θειικό ασβέστιο

Πολυβάθμια Εκτόνωση
ή
Πολυβάθμια Εκρηκτική Εξάτμιση

Multi Stage Flash Distillation Process
MSF

MSF Technology Description

Η μέθοδος της Πολαπλής Εκτόνωσης, Multi Stage Flash (MSF), χωρίζεται σε 2 τύπους συστημάτων:

•The Once through MSF (Απευθείας Εξάτμιση)

•The Brine recirculation MSF (Με Επανακυκλοφορία της άλμης)

Στα συστηματα MSF με επανακυκλοφορία ένα ποσοστό της άλμης αφού αναμιχθεί με το εισερχόμενο θαλασσινό νερό επανακυκλοφορεί σαν νερό τροφοδοσίας.

Η επανακυκλοφορία της άλμης ελαττώνει σημαντικά το κόστος επεξεργασίας του νερού τροφοδοσίας

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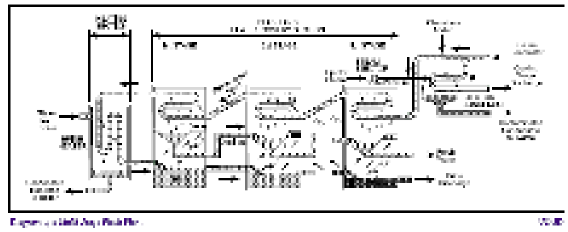
Το σύστημα χωρίζεται στα παρακάτω τμήματα:
- Τμήμα Απόρριψης θερμότητας (μόνο στο σύστημα με επανακυκλοφορία της άλμης)
- Τμήμα Ανάκτησης θερμότητας και
- Τμήμα Εισόδου θερμότητας



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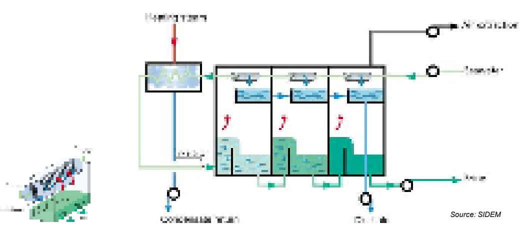
MSF με απευθείας εξάτμιση



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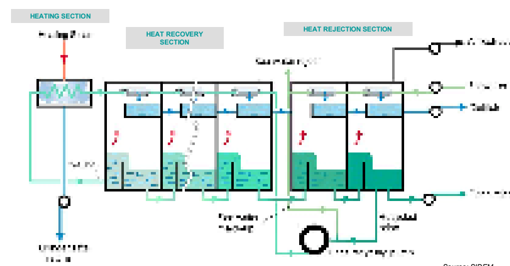
MSF με Επανακυκλοφορία Άλμης



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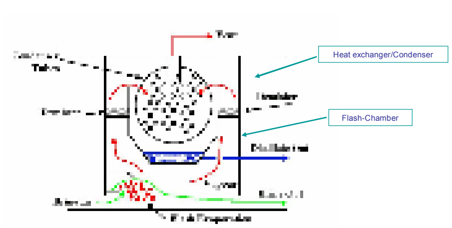
Κάθε στάδιο αποτελείται από τους θαλάμους έκρηξης, τους εναλλάκτες θερμότητας/συμπυκνωτές, όπου ο εκεί ο ατμός εκτονώνεται και συμπικνώνεται.

Ο θάλαμος έκρηξης χωρίζεται από τον συμπικνωτή με έναν διαχωριστή (demister) και το δοχείο συλλογής αποσταγμένου νερού.



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MSF - Βαθμός Απόδοσης Μονάδων (Performance ratio, P_R)

$$P_R = \frac{Md}{Ms}$$

όπου
Md = μάζα παραγόμενου νερού, kg
Ms = μονάδα μάζας του καταναλισκόμενου ατμού, MJ

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Οι μονάδες MSF λειτουργούν σε μέγιστη θερμοκρασία νερού τροφοδοσίας από 90-115°C. Η λειτουργία μιας μονάδας σε υψηλότερη θερμοκρασία αυξάνει την απόδοση του συστήματος αλλά αυξάνει και τη πιθανότητα δημιουργίας λεβητόλιθου να επιταχύνει τη διάβρωση των μεταλλικών επιφανειών.

Μια μονάδα MSF μπορεί να περιλαμβάνει από 4 έως 50 στάδια. Μια τυπική μονάδα με PR=8 συνήθως έχει 16-18 στάδια ανάκτησης ενέργειας και τρία στάδια απόρριψης ενέργειας.

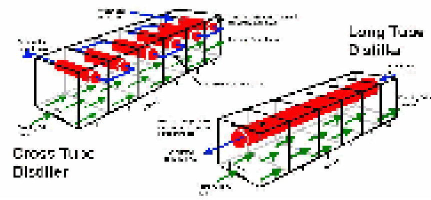
Οι MSF έχουν αναπτυχθεί και εφαρμοστεί σε μεγάλα μεγέθη, συνήθως από 5,000 – 50,000 κμ/ημ.

Η κύρια πηγή ενέργειας για τη λειτουργία τους είναι η θερμική ενέργεια. Οι κατανάλωση είναι υψηλή, της τάξεως των 290kJ/kg.

Οι ηλεκτρικές καταναλώσεις στις μονάδες MSF αφορούν στις: αντλίες μεταφοράς του θαλασσινού νερού, δοσομετρικές αντλίες, ανακυκλοφορίας της άλμης, σύστημα εκκένωσης (vacuum ejectors), κλπ.

Η ηλεκτρική κατανάλωση συνήθως κυμαίνεται από 3.5 to 6 kWh/m³.

Διάταξη Μονάδων MSF



MSF Process Characteristics

Item	Once-through *	Recycle
Maximum operating temperature (°C)	90.6	110
Process recovery (percent)	10 to 15	10 to 20
Performance ratio (kg/MJ)	3.44 to 4.30	3.44 to 5.17
Heat transfer coefficients (watts per square meter-Kelvin) (W/m^2-K)	2,271 to 3,407	2,207 to 3,407
Concentrate concentration (mg/l)	58,000	62,500
Energy consumption (mega joules/liter) - High-pressure steam - Low-pressure steam - Electricity	NA 0.24 to 0.29 0.026	0.20 to 0.29 NA 0.026
Distillate quality (mg/l)	0.5 to 25.0	0.5 to 25.0
Pretreatment - Chemical	Polyphosphate	Acid or polymer
- Dose rate (mg/l)	4.0 to 6.0	Acid = 140 Polymer = 5 to 10

NA = not available

Source: Bureau of Reclamation

*The maximum temperature is usually limited to 90.6 °C

MSF Materials of Fabrication

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

Source: Bureau of Reclamation

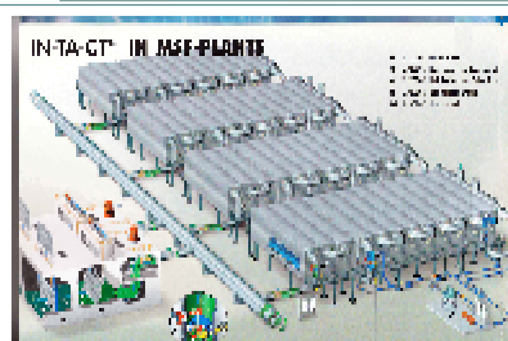
Multi Stage Flash

Cross Tube (Shuweihat, 76500m³/day)

Source: Unipa, Italy

Long Tube (Gela, 4x14400m³/day)

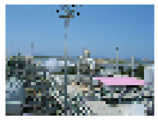
Source: Unipa, Italy



Source: TAPROGGE

Πολυβάθμια Εξάτμιση

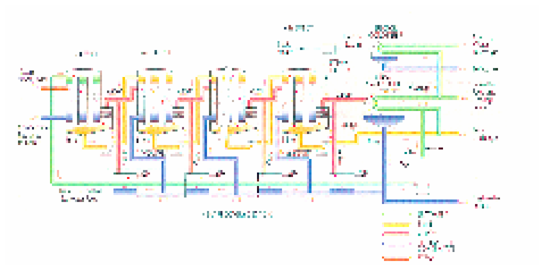
Multi Effect Distillation Process
MED



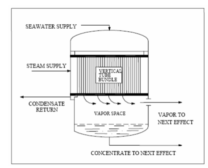
Μέθοδος MED

Η διαδικασία απόσταξης στην MED, όπως και στην MSF μέθοδο λαμβάνει χώρα σε μια σειρά σταδίων (effects) χρησιμοποιώντας την αρχή της εξάτμισης και της συμπύκνωσης κάτω από μειωμένη πίεση του περιβάλλοντος, στα διάφορα στάδια.

Η κύρια διαφορά μεταξύ της μεθόδου MSF και MED είναι στον τρόπο της εξάτμισης και της μεταφοράς θερμότητας.



MED horizontal tube arrangement



MED vertical tube bundle arrangement

MED vertically stacked tube bundles

Source: Bureau of Reclamation

Οι μονάδες MED έχουν συνήθως μικρότερο αριθμό βαθμίδων (σταδίων), 8-16 βαθμίδες, σε σχέση με τις μονάδες MSF.

Το PR (παραγωγή νερού/καταναλισκόμενο ατμό) είναι σχεδόν πάντα ίσο με των αριθμό των βαθμίδων μείον 1. Εαν ο PR μιας μονάδας ανέχεται στο 8 ο αριθμός των βαθμίδων θα είναι 9.

MED Process Characteristics

Item	Low temperature horizontal tube design	Low temperature vertical tube design	Stacked vertical tube design	High temperature horizontal tube design	High temperature vertical tube design
Maximum operating temperature (°C)	71.7	71.7	110	110	110
Process recovery (percent)	20 to 35	20 to 35	67	20 to 35	20 to 35
Performance ratio (kg/MJ)	3.44 to 5.17	3.44 to 4.30	10.33	3.44 to 6.46	3.44 to 6.46
Heat transfer coefficient (w/m^2-K)	1,703 to 3,407	1,703 to 3,407	4,542 to 11,356	1,703 to 4,259	1,703 to 4,259
Concentrate (mg/l)	54,000	54,000	106,000	54,000	54,000
Electrical consumption (MJ/m^3)	0.00132 – 0.0026	0.00132 – 0.0026	0.000528 – 0.00106	0.00132 – 0.0026	0.00132 – 0.0026
Distillate quality (mg/l)	0.5 to 25.0	0.5 to 25.0	0.5 to 25.0	0.5 to 25.0	0.5 to 25.0
Pretreatment chemical	Polyphosphate	Polyphosphate	Acid or polymer	Polymer	Acid or polymer
Pretreatment dose rate (mg/l)	0.5 to 4.0	0.5 to 4.0	Acid at 140 Polymer at 1 to 2	1.0 to 2.0	Acid at 140.0 Polymer at 5 to 10

Note: MJ/m^3 = Mega joules per cubic meter, w/m^2-K = watts per square meter-Kelvin.

Source: Bureau of Reclamation

MED Materials of Fabrication

Item	Horizontal tube design	Vertical tube design	Stacked vertical tube design
Effect vessels	Carbon steel, epoxy coated	Carbon steel, epoxy coated	Concrete
Effect tubing	Aluminum	Aluminum brass, copper nickel	Aluminum
Effect tube sheets	Aluminum	Aluminum brass, copper nickel	Aluminum
Preheater tubing	Aluminum	Aluminum brass	Titanium
Pumps	Stainless steel, grade 316	Stainless steel, grade 316	Aluminum brass
Deaerator	Carbon steel, epoxy coated	Carbon steel, epoxy coated	Concrete, aluminum
Decarbonator	Carbon steel, epoxy coated	Carbon steel, epoxy coated	Concrete, aluminum
External structural shapes	Carbon steel	Carbon steel	Not required
Internal supports	Carbon steel, epoxy coated	Carbon steel, epoxy coated	Aluminum
Demisters	Stainless steel, grade 316	Stainless steel, grade 316	Stainless steel, grade 316

Source: Bureau of Reclamation

MED unit

Trapani, Italy

Source: UNIPA, Italy

Επανασυμπίεση Ατμών

Vapor Compression

VC

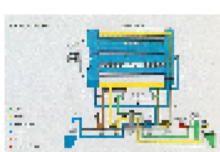
Η μέθοδος Επανσυμπίεσης Ατμών (VC) είναι μια θερμική διαδικασία που συνήθως χρησιμοποιείται για μικρής και μεσαίας κλίμακας μονάδες αφαλάτωσης θαλασσινού νερού.

Οι μονάδες αυτές επίσης επωφελούνται από την αρχή της μείωσης της θερμοκρασίας βρασμού με τη μείωση της πίεσης του περιβάλλοντος, αλλά η θερμότητα για την εξάτμιση του νερού προέρχεται από συμπίεση ατμού και όχι από τη διαδικασία ανταλλαγής της θερμότητας από ατμό που παράγεται σε λέβητα. (Αδιαβατική μεταβολή στη θερμοκρασία από την αλλάγή της πίεσης ενός αερίου χωρίς την προσθήκη θερμότητας).

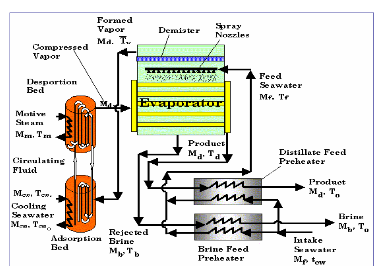
Ο ατμός μπορεί να συμπιεστεί είτε με μηχανικό συμπιεστή ή με τη χρήση ενός ατμοθερμοσυμπιεστή.

Χωρίζεται στις μεθόδους:

- Μηχανική Επανασυμπίεση Ατμών [MVC]
- Θερμική Επανασυμπίεση Ατμών [TVC]



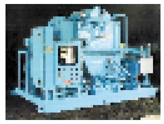
Μέθοδος MVC



Adsorption Vapor Compression

Μονάδες VC

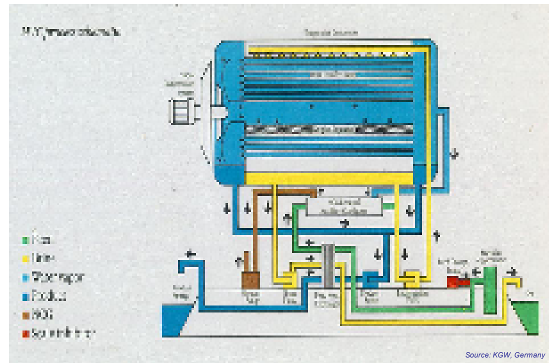
MVC



Source: SIDEM, France

MVC

Source: SIDEM, France



Source: KGW, Germany

VC Process characteristics

Item	Low temperature (MVC)	High temperature (MVC)	Low temperature (TVC)
Maximum operating temperature (°C)	46.1	101.7	46.1
Process recovery (percent)	40	40	40
Performance ratio (kg/MJ)	3.44 to 5.17	NA	NA
Heat transfer coefficient (W/m^2-K)	1,703 to 2,271	NA	NA
Concentrate (mg/l)	58,000	58,000	58,000
Energy consumption (MJ/m^3)			
High-pressure steam	None	None	0.0159 to 0.0238
Electricity use	0.0172 to 0.0252	0.0172 to 0.0252	0.00132
Distillate quality (mg/l)	<25	<10	<25
Pretreatment			
Chemical	Polyphosphate	Acid or polyphosphate	Polyphosphate
Dose rate (mg/l)	0.5	4 to 10	0.5

NA = not available

Source: Bureau of Reclamation

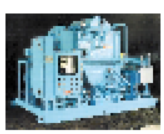
VC Materials of Fabrication

Item	Low temperature operation	High temperature operation
Evaporator shell	Carbon steel, epoxy coated	Carbon steel, clad with 316L stainless steel or all 316L stainless steel
Heat exchanger tubing	Aluminum	Titanium
Tube plates	Aluminum	Carbon steel, clad with titanium
Interconnecting piping	Nonmetallic	Stainless steel, grade 316L
Feed heater	Titanium	Titanium
Pumps	Bronze	Stainless steel, grade 316
External structural shapes	Carbon steel	Carbon steel
Demisters	Stainless steel, grade 316	Stainless steel, grade 316

Source: Bureau of Reclamation

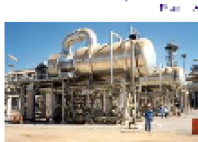
VC Plants

MVC



Source: SIDEM, France

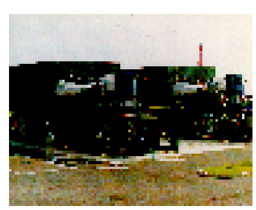
MVC



Source: SIDEM, France

MVC plant

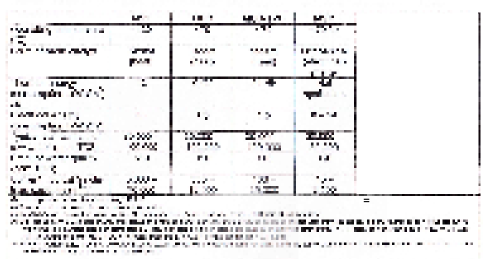
TVC Plant



Source: SIDEM, France

Source: Weir Westgarth Ltd, U.K.

Distillation Processes Comparison



Source: Wangnick, IDA, 2004

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Desalination Market

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Wind Energy Department
Email: etzen@cres.gr

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Desalination Industry (1)

In some countries, the cost of water produced in even seawater desalination plants is already lower than from any other method, (especially in cases where the natural resources are limited).

Saudi Arabia ranks first in total capacity (about 24% of the world's capacity), with most of it being made up of seawater desalting units that use the distillation process.

The United States of America (USA) ranks second in overall capacity, with about 16 %. Most of the capacity in the USA consists of plants in which the RO process is used to treat brackish water.

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Desalination Industry (2)

The world's installed capacity consists mainly of the MSF distillation and RO processes.

These two processes make up about 84% of the total capacity.

In recent years, the industry has achieved great advances in RO technology, and since the 1970s new membrane capacity has exceeded new distillation capacity.

The remaining 15% is made up of the Multiple Effect, Electrodialysis, and Vapor Compression processes, while the minor processes amounted to less than 1%.

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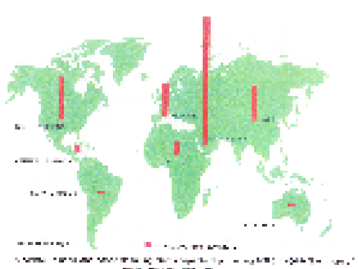
Capacity of land-based desalting plants capable of producing 100m³/day/unit or more of fresh water vs Region



Source: Wagnick K., 2004

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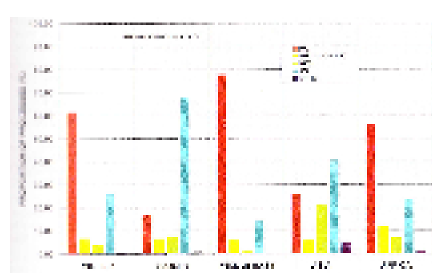
The majority of the desalination plants, especially in the Middle East, operate according to the MSF process, whereas in Europe, the majority operate according to the RO process.



Source: Wagnick K., 2004

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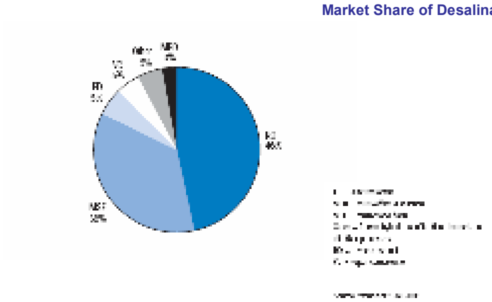
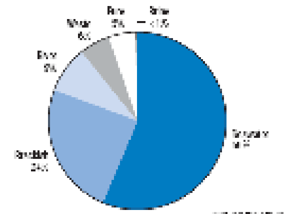
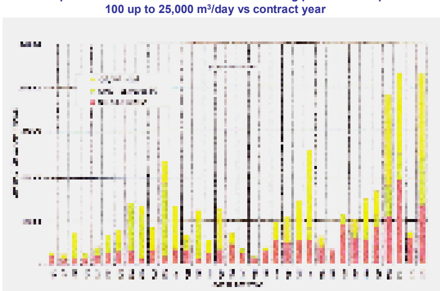
Market Share of Desalination



Global Desalination Capacity by Source Water

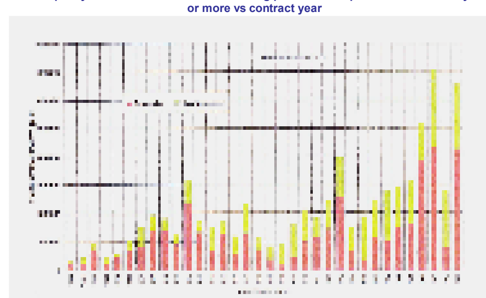


Proportion of all land-based seawater desalting plants with capacities from 100 up to 25,000 m³/day vs contract year



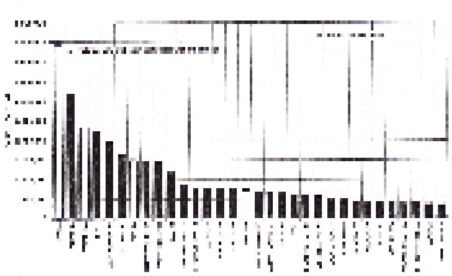
Source: Wagnick K., 2004

Capacity of land-based seawater desalting plants with capacities of 100 m³/day or more vs contract year



Source: Wagnick K., 2004

Market Share



Source: Wagnick K., 2004

Desalination Economics
Water Cost

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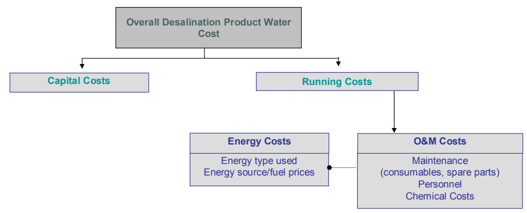
Desalination Water Cost

Over the years, the cost of water produced in seawater desalination has dropped considerably, but the cost of water produced from the "conventional "treatment plants has risen, due to the over – exploitation of aquifers and the intrusion of saline water, and also to the generally increasing contamination of ground water.



Capital Cost

Many factors enter into the capital and operating costs for desalination:

- capacity and type of plants
- plant location
- feed water
- labor
- energy
- financing
- concentrate disposal and
- plant reliability

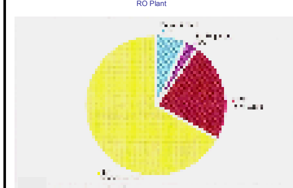
In general, the cost of desalted **seawater** is about **3 to 5** times the cost of desalting **brackish** water from the same size plant.

Typical Capital Costs of Desalination Units

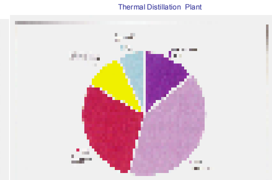
- For MSF projects typical costs are of the order of US$5 to US$6 per installed IGD (imperial gallon per day)
- For MED projects typical costs are of the order of US$3.5 to US$4.5 per installed IGD (imperial gallon per day). – Limited capacity to around 5MIGD
- For SWRO projects typical costs are of the order of US$5 to US$6 per installed IGD (imperial gallon per day)

Capital Cost Distribution - RO vs Thermal processes

RO Plant



Thermal Distillation Plant

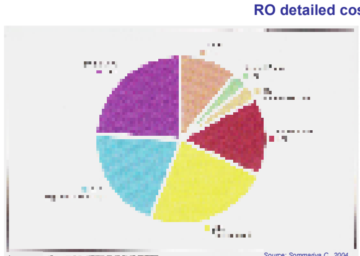


Source: Sommariva C., 2004

Μηχαν. Εξοπλισμός: 67%
Ηλεκτρολογικός Εξοπλισμός: 7%
Εργα Υποδομής: 3%
Κατασκευαστικές εργασίες: 23%

Εξατμιστής: 40%
Σωληνώσεις: 29%
Ηλεκτρική υποδομή : 7%
Μηχανολογικός Εξοπλισμός: 10%
Εγκατάσταση : 14%

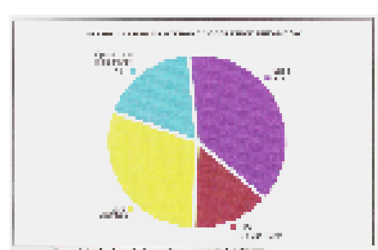
RO detailed cost breakdown



Source: Sommariva C., 2004

Μεμβράνες: 24%
Επεξεργασία νερού τροφ: 24%
Αντλία Υψηλής Πίεσης: 20%
Είσοδος/Εξοδος Νερού: 15%
Αντλία Παραγόμενου: 3%
Εγκατάσταση: 3%
Λοιπός Εξοπλισμός: 11%

O&M Cost Distribution for thermal plants

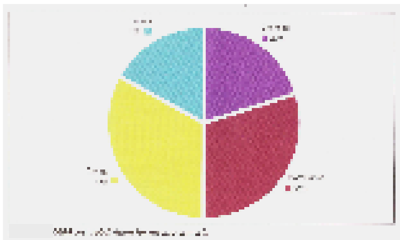


Source: Sommariva C., 2004

Θερμ.Ενέργεια: 38%
Χημικά : 30%
Ηλ Ενέργεια: 14%
Προσωπικό: 18%

PRODES — Promotion of Renewable Energy for Water production through Desalination

O&M Cost Distribution for RO



Μεμβράνες: 30%
Χημικά : 20%
Ενέργεια: 33%
Προσωπικό: 17%

PRODES — Promotion of Renewable Energy for Water production through Desalination

Desalination Unit Water Cost

The total production costs, including capital recovery, is estimated

• for brackish water systems with capacities of 4,000 to 40,000 m^3/d typically ranges from \$0.25 to \$0.60/m^3.

• for seawater desalination plants ranging from 4,000 to 100,000 m^3/d, the total cost of water estimated at \$3 to \$0.75/m^3.

These amounts give some idea of the range of costs involved, but the site- and country-specific factors will affect the actual costs.

PRODES — Promotion of Renewable Energy for Water production through Desalination

The Water Price

The price of water is increasing—sometimes dramatically—throughout the world. Over the past five years, municipal water rates have increased by an average of 27% to around 60%, For instance 27% in the United States, 45% in Australia, 50% in South Africa, and 58% in Canada, (www.earth-policy.org).

- Water costs = cost of exploitation and extraction +
  cost of treatment (cleaning, desalination) +
  cost of distribution (transportation, pipeline, losses) +
  cost of sewerage

- Water price = Water costs - *Subsidies*

Typical real costs (worldwide):

Exploitation and extraction:	0.05 … 0.8 €/m^3	0.5 … 20 €/m^3
Desalination (large installations):	0.43 … 2.0 €/m^3	
Distribution:	0.2 … 15.0 €/m^3	
Sewerage:	0.3 … 2.0 €/m^3	

PRODES — Promotion of Renewable Energy for Water production through Desalination

Water prices and consumptions in Europe

Country	Consumption (liter/ day / person)	Mean water price per m^3 Water + sewerage + taxes (€/m^3)
Spain	130	1,0
Ireland	135	0
Luxembourg	150	0,90
UK	150	1,6
Italy	160	0,8
Sweden	180	1,15
Portugal	190	1,0
Greece	**200**	**1,1**
France	113	2,6
Finland	116	2,5
Germany	118	3,6
Belgium	120	1,9
Netherlands	126	2,7
Danmark	138	4,3
Austria	150	2,6

Source: IWA Statistic 2005