Desalination Technologies (I)

PRODES

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

ΚΑΠΕ CRES | CENTRE FOR RENEWABLE ENERGY SOURCES AND SAVING

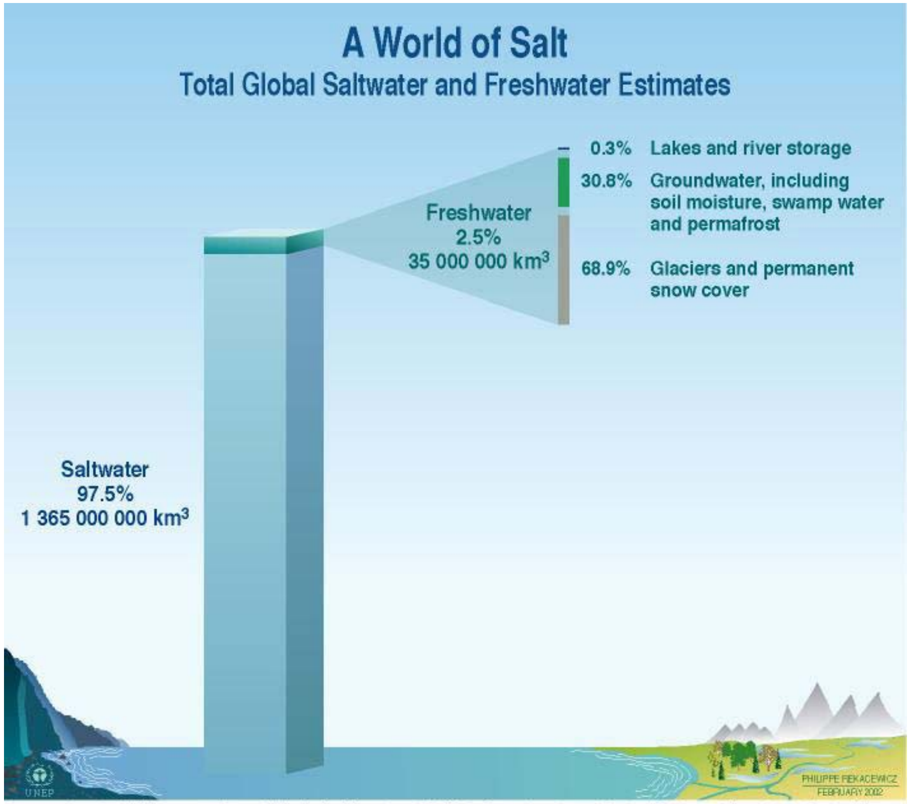
The Water
The Need for Water Demand Management

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

- Surface water
- Groundwater
- Ocean Water



Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999.

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:

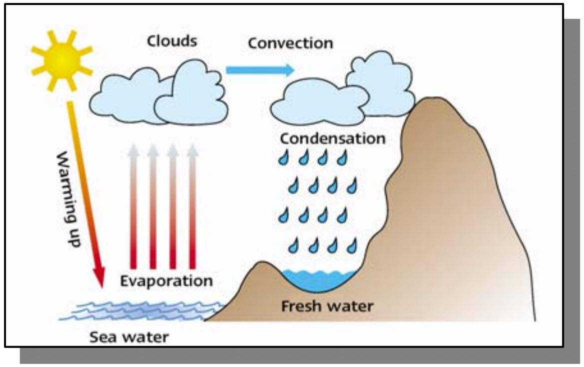
  - use of incentives (metering, pricing, subsidies and penalties)

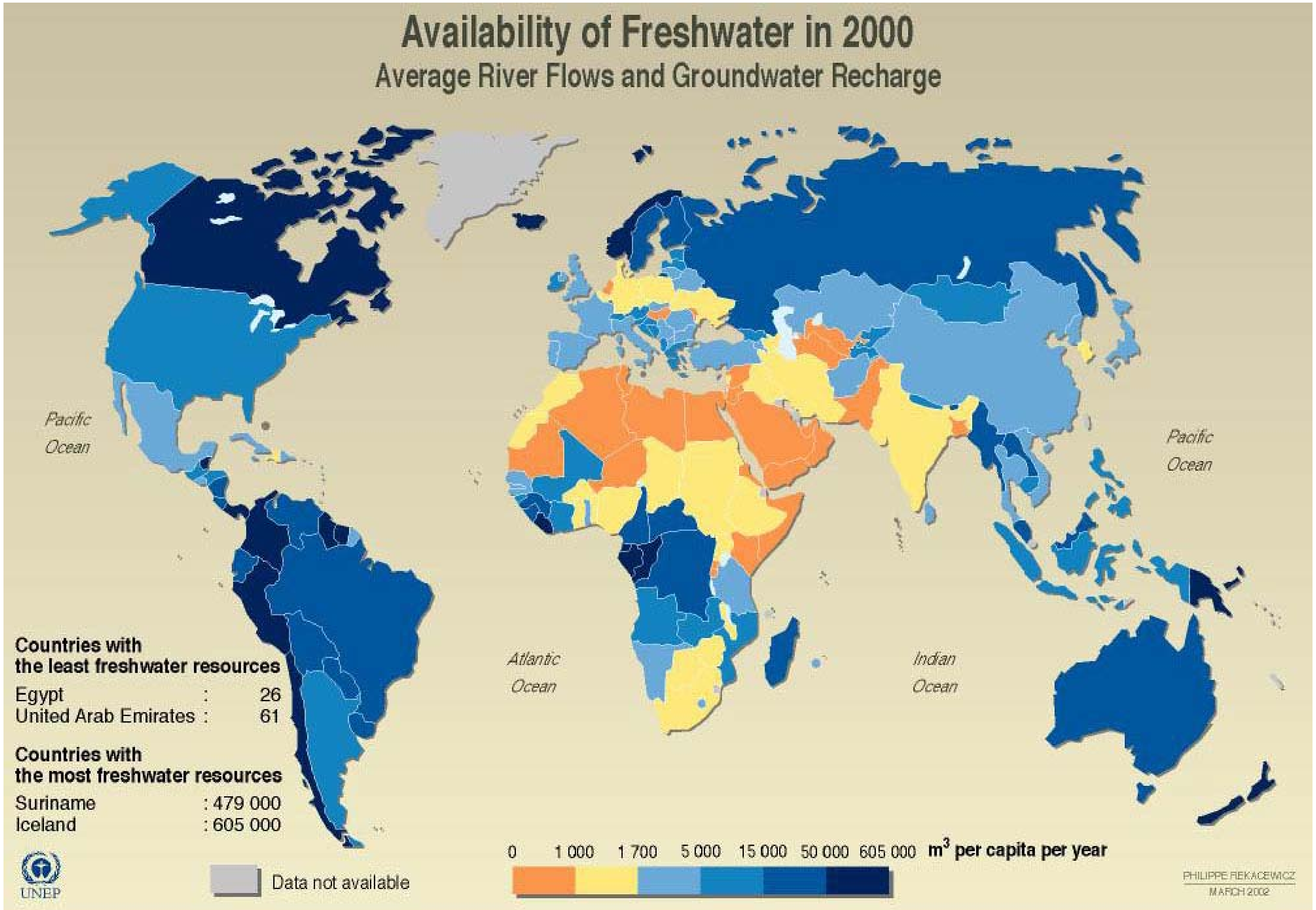
  - information (extension services and education campaigns)

  - regulatory measures (control of water and quotas)

Non-conventional Water Resources

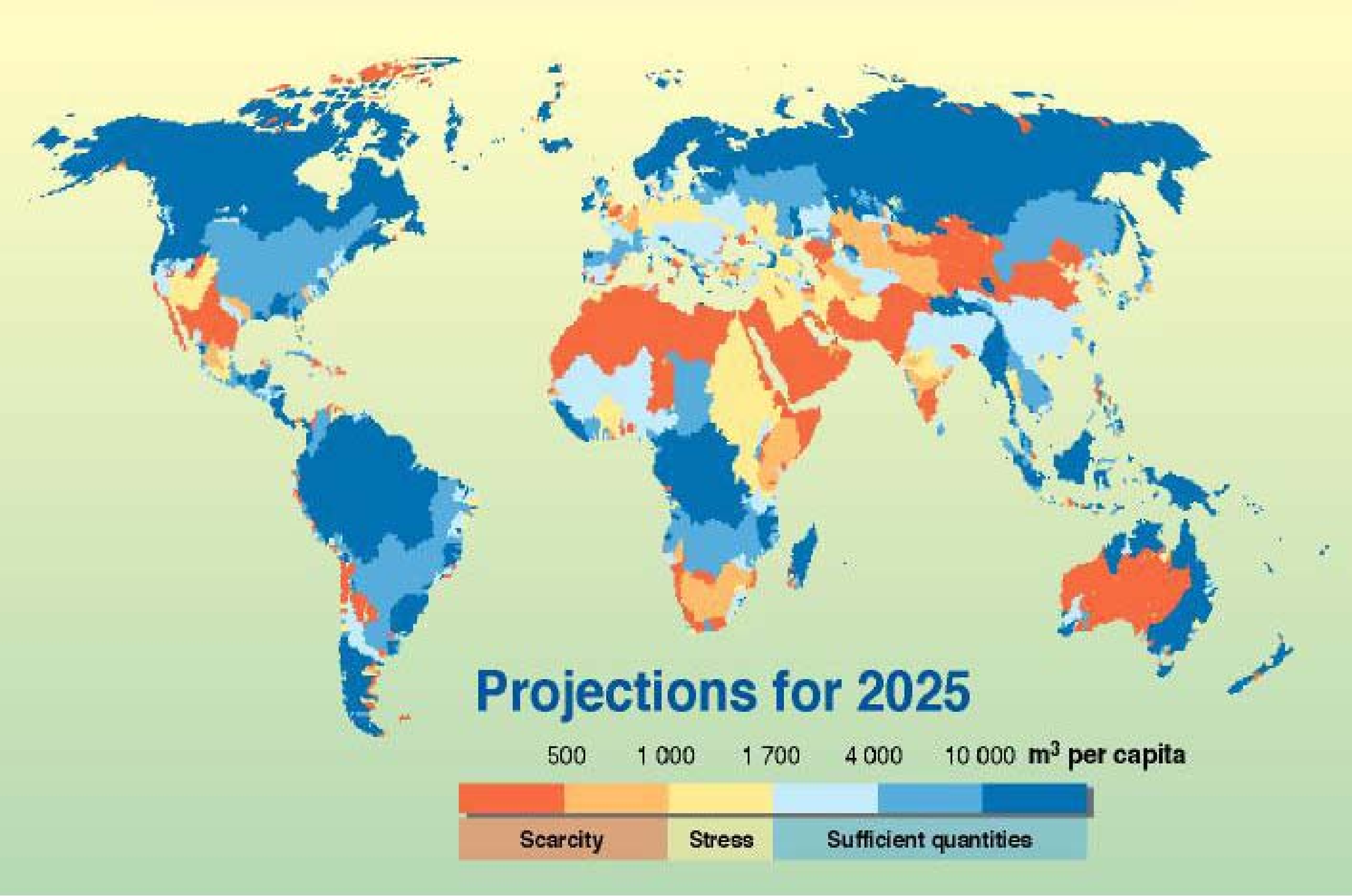
- **Wastewater reuse** (water for gardens, irrigation, etc)
- **Desalination** (for potable and distillate water production)





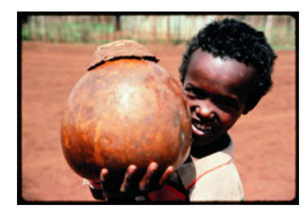
Source: *World Resources 2000-2001, People and Ecosystems: The Fraying Web of Life*, World Resources Institute (WRI), Washington DC, 2000.

Projections of Water Availability for 2025



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
- Factors increase the water consumption are:
  - Growing of population
  - Growing of industry
  - Tourism
  - Agriculture / Irrigation needs



Desalination Technology

What is Desalination ?

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

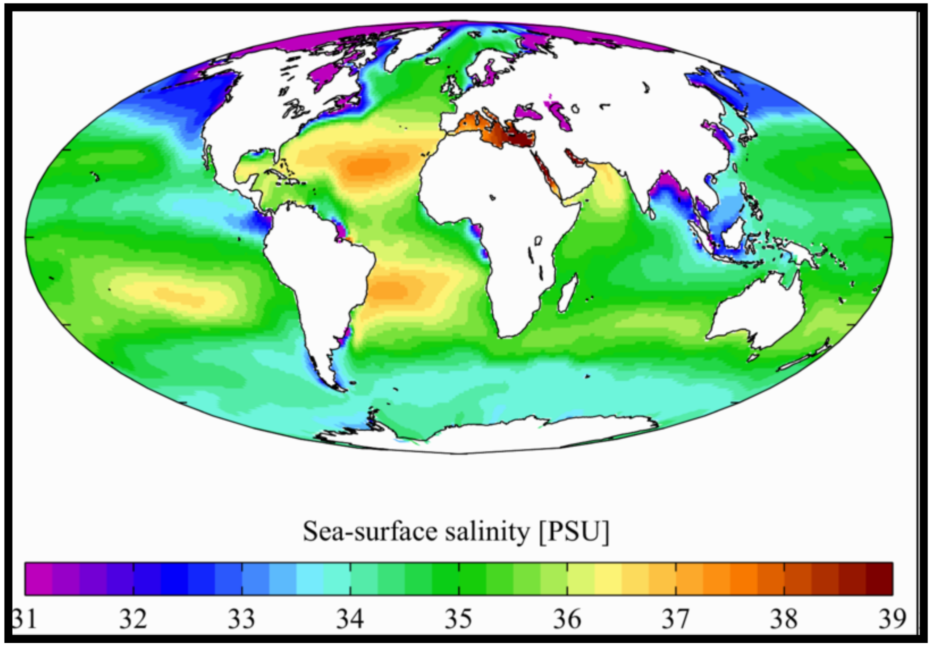
A desalination plant turns salt water (brackish or seawater) into fresh water (potable or distillate water).

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

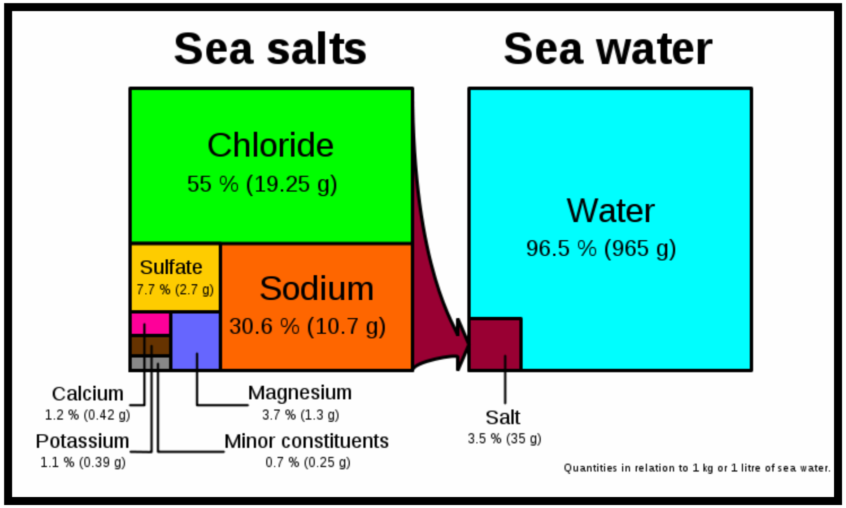
Seawater chemistry

Variation of salinities in the seas



Source: World Ocean Atlas

Seawater composition



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

$0°C<T<35\text{-}40°C$

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

Desalination History

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

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.

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.

- Seawater desalination is the most preferred technology regarding the feed water type, mainly because of its availability.

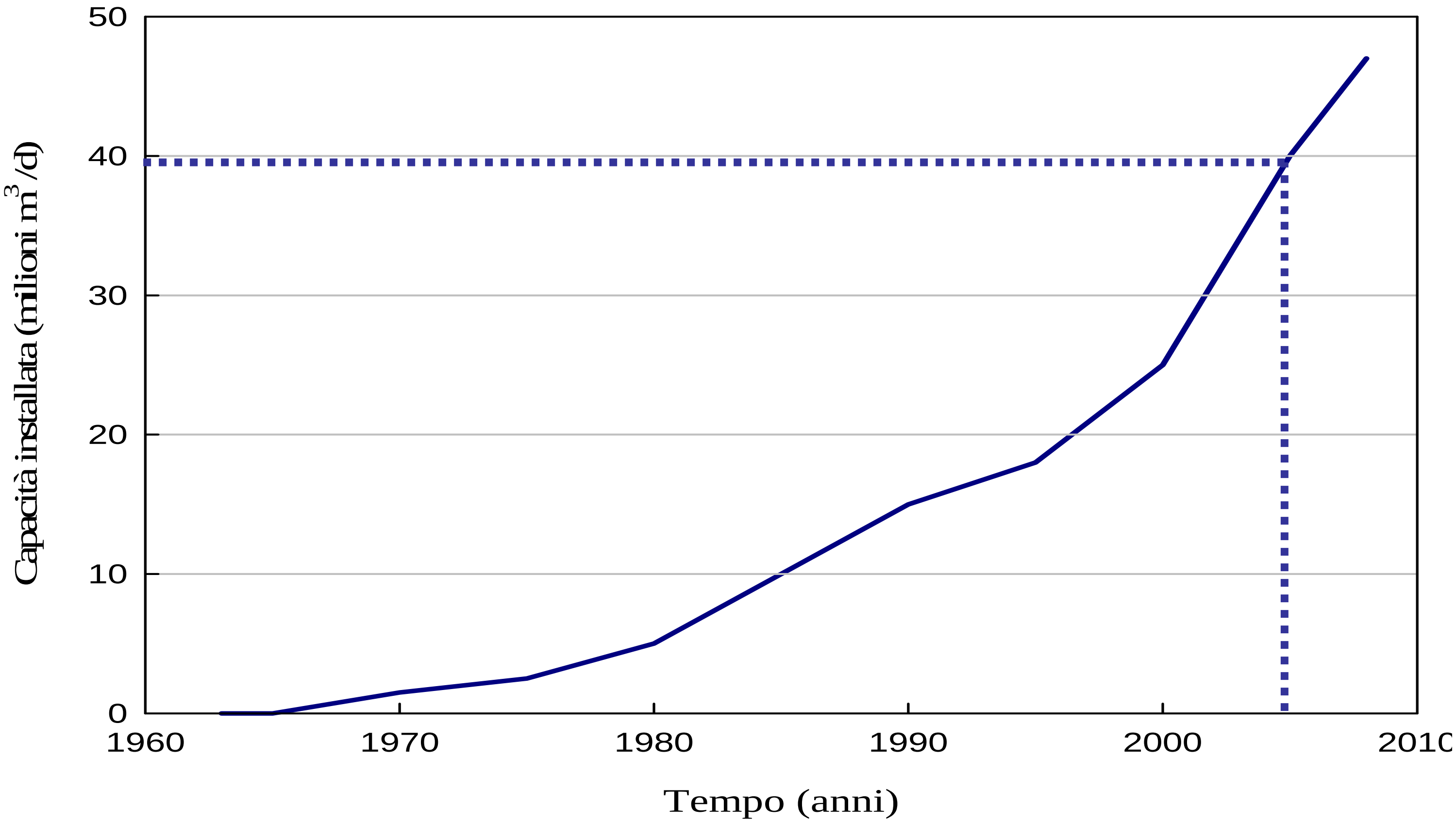
- In 2007, the **total capacity** of installed **seawater desalination** plants worldwide was about **30 million m^3/d** of which about 85 % is still in operation.

- 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**.

The Development of Desalination



Water Desalination Applications

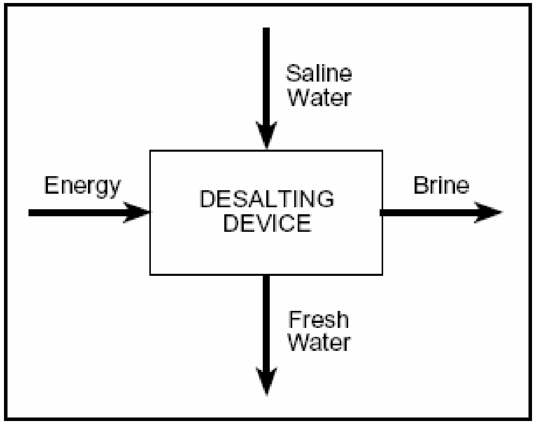
- Domestic or Municipalities purposes
- Heavy Industry
- Pharmaceutical Industry
- Irrigation
- Marine
- Military
- Food & Dairy
- Home drinking water, etc.

Desalination Processes

Water Desalination Process

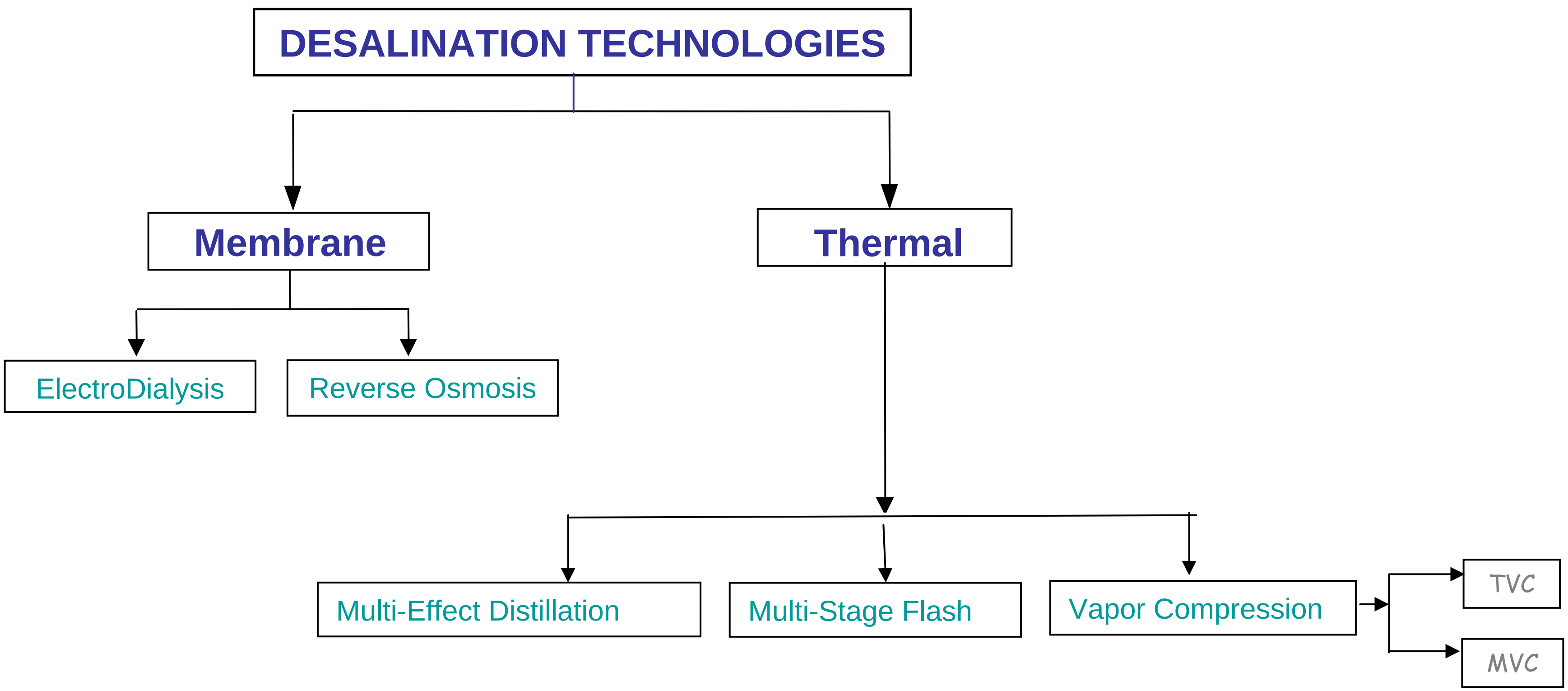
A wide variety of desalination technologies effectively remove salts from salty water (or extract fresh water from salty water), producing a water stream with a low concentration of salt (the product stream) and another with a high concentration of remaining salts (the brine or concentrate).

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:



Desalination Processes Synoptic Table

	Thermally-driven processes			Electrically-driven processes	
MSF	Multi-Stage Flash		RO	Reverse Osmosis	
	Cross flow	Long tube			
	Antiscale treatment	Acid or mixed treatment		Hollow fibres	Spiral wound
	Once through With-Without brine rec.				
MED	Multiple Effect Distillation		M-VC	Mechanical Vapour Compression	
	With Thermo-compression MED-TVC	Condensing			
	– Horizontal tubes – Vertical submerged tubes – Plate heat exchangers			– Horizontal tubes – Vertical submerged tubes – Plate heat exchangers	
	Various stage configurations				
SS	Simple stills		ED	Electrodialysis	

Source: Sommariva C., 2004

Thermal Processes / Distillation

Definition of Distillation

Distillation is a **phase-change** method whereby saline water is heated to produce water vapor, which is then condensed to produce fresh water.

The most common distillation processes, including MSF, MED, and VC, all generally operate on the principle of reducing the vapor pressure of water within the unit to permit boiling to occur at lower temperatures, without any extra heat.

Distillation units routinely use designs that converse as much thermal energy as possible by interchanging the heat of condensation and heat of vaporization within the units.

The major energy requirement in the distillation process thus becomes providing the heat of vaporization to the feed water.

To boil, water needs two important conditions:
• the proper temperature (related to ambient pressure*), and
• the energy for vaporization

When water is heated to its boiling point and then the heat is turned off, the water will continue to boil only for a short time because the water needs additional energy (the heat of vaporization) to permit boiling.

Once the water stops boiling, boiling can be renewed by either adding more heat or by reducing the ambient pressure above the water.

If the ambient pressure were reduced, the water would be at a temperature above its boiling point (because of the reduced pressure) and would flash to produce vapor (steam), then the temperature of the water will fall to the new boiling point.

If more vapor can be produced and then condensed into fresh water with the same amount of heat, the process tends to be more efficient.

Water boiling point table

Pressure	1 bar	0.47 bar	0.32 (Top of Everest)	0.25	0.1
Boiling Point	100^{o}C	80^{o}C	70^{o}C	65^{o}C	45^{o}C

Source: SIDEM

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

The Distillation Process

The distillation process mimics the natural water cycle in that salt water is heated, producing water vapor that is in turn condensed to form fresh water. In a laboratory or industrial plant, water is heated to the boiling point to produce the maximum amount of water vapor.

To do this economically in a desalination plant, the applied pressure of the water being boiled is adjusted to control the boiling point because of the reduced atmospheric pressure on the water, the temperature required to boil water decreases as one moves from sea level to a higher elevation.

For instance in Alaska at elevation of 620m, water can be boiled at a temperature about 16°C lower than it would boil at sea level. This reduction of the boiling point is important in the desalination process for two major reasons: **multiple boiling** and **scale control**.

- To significantly reduce the amount of energy needed for vaporization, distillation desalting processes often use multiple boiling in successive vessels, each operating at a lower temperature and pressure.

- This process of reducing the ambient pressure to promote additional boiling can continue downward and, if carried to the extreme with the pressure reduced enough, the point at which water would be boiling and freezing at the same time would be reached.

- Aside from multiple boiling, the other important factor is scale control. Although most substances precipitate more readily in cooler water, some precipitate more readily in warmer water.

- Unfortunately, some of these substances, like carbonates and sulfates, are found in seawater.

One of the most important is calcium sulfate ($CaSO_4$), which begins to leave solution when sea water approaches about 115 °C.

This material forms a hard scale that coats any tubes or surfaces present.

Scale creates thermal and mechanical problems and, once formed, is difficult to remove. One way to avoid the formation of this scale is to control the concentration level of seawater and to control the top temperature of the process.

Another way is to add special chemicals to the sea water to reduce scale precipitation.

These two concepts have made various forms of distillation successful in locations around the world.

Multi Stage Flash Distillation Process
MSF

MSF Technology Description

Multi Stage Flash (MSF) separated in two main types:

- The Once through MSF
- The Brine recirculation MSF

MSF Process Description

The MSF system is divided into the following sections:

- Heat-rejection section (only in Brine Recirculation MSF)
- Heat recovery and
- Heat input or heating section

The rejection and the heating sections are both made up of a series of stages.

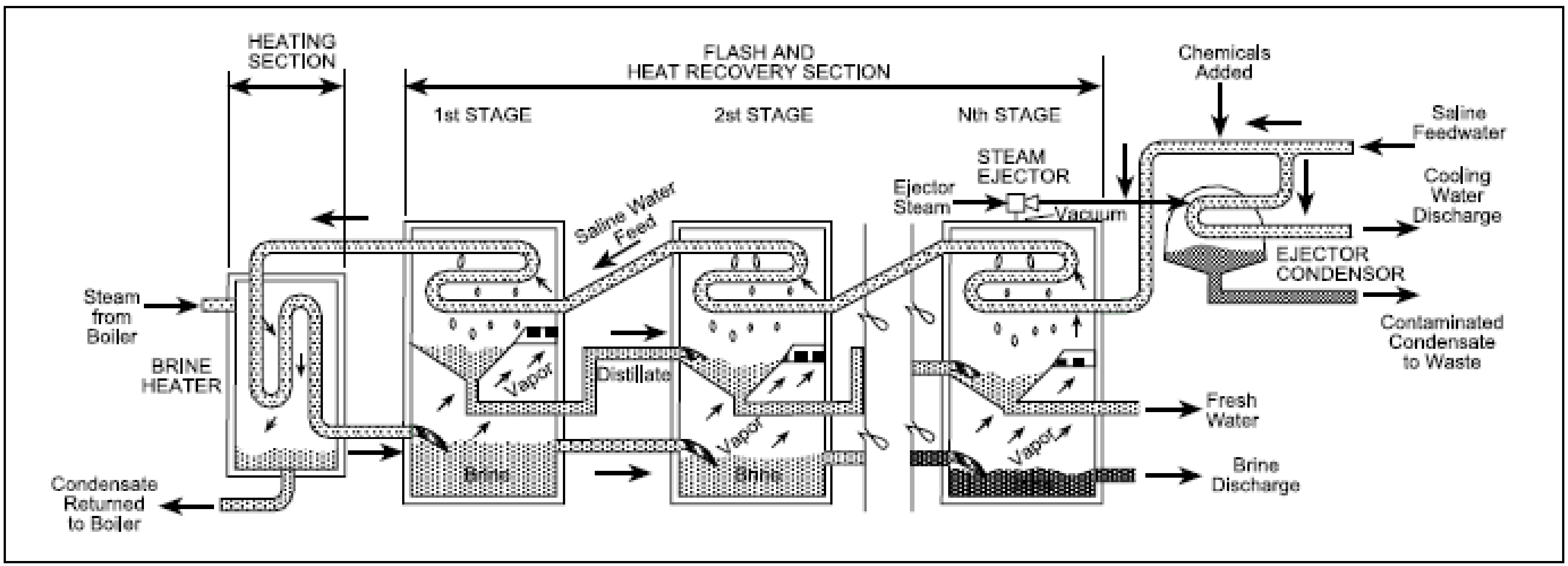
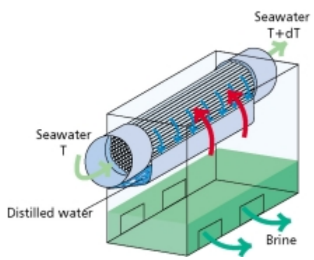
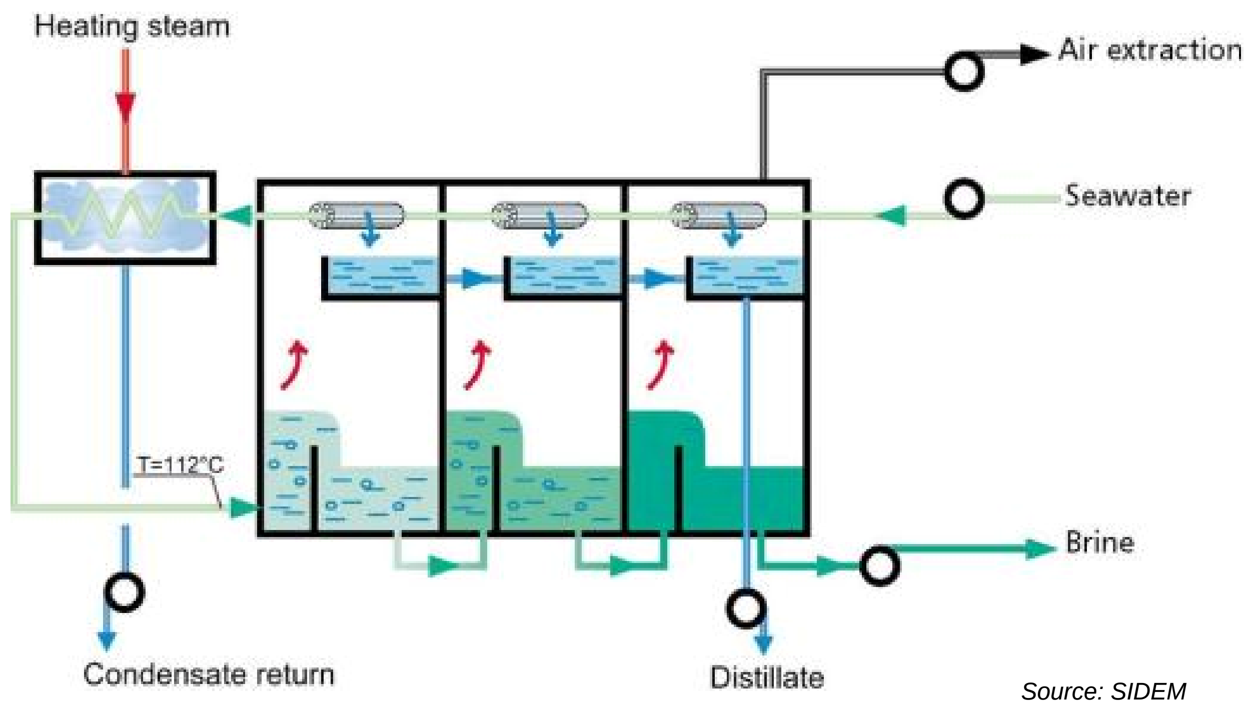


Diagram of a Multi-Stage Flash Plant *USAID*

Once through Multi Stage Flash Distillation (MSF)

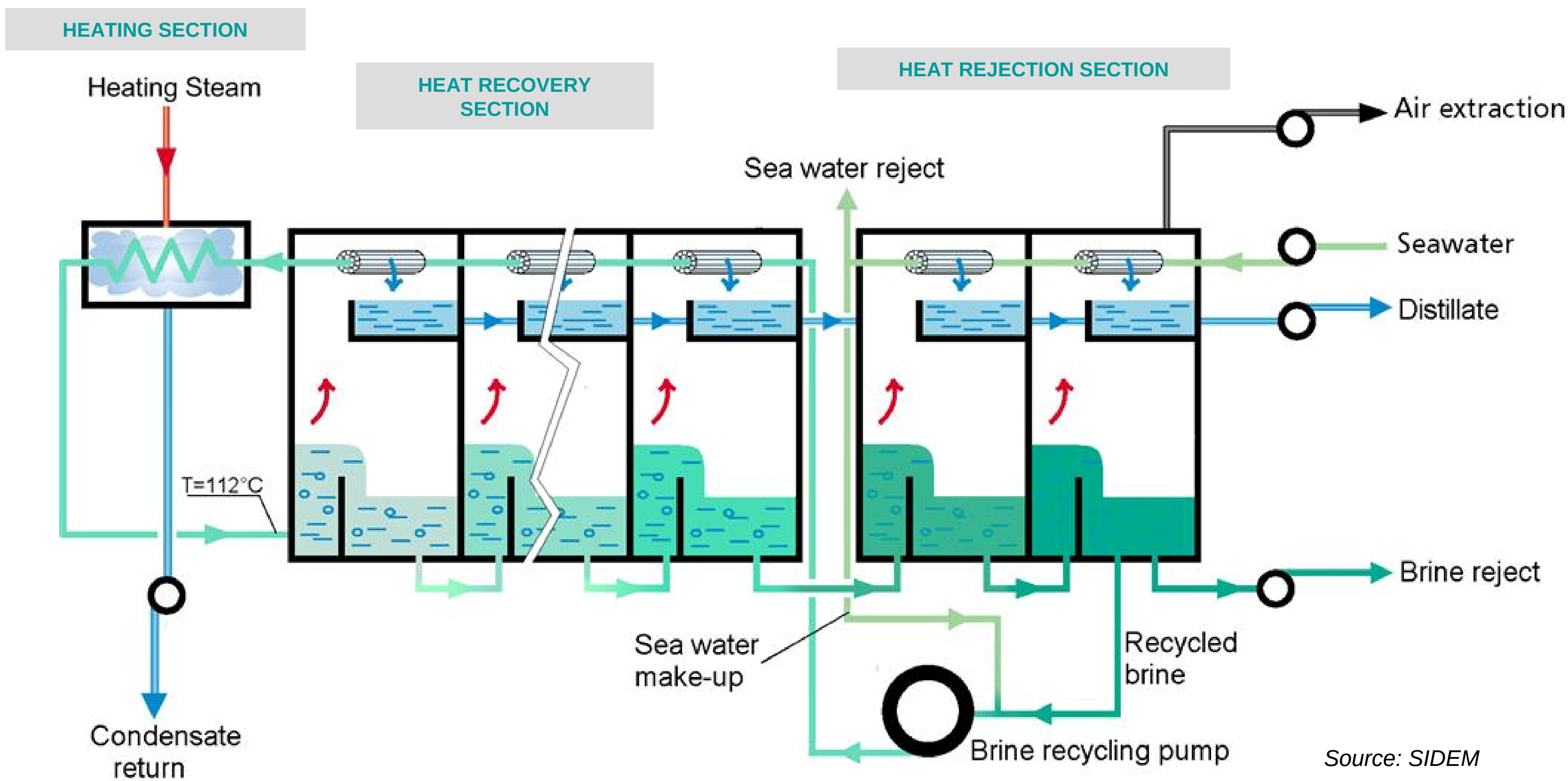




Source: SIDEM

In once through MSF there is no specific heat rejection section. The feed directly enters the heat recovery section – is pre-heated, passing up through the condensers - is heated finally in the brine heater and then passes down through the flash chambers. At the bottom stage the total brine flow is rejected.

Brine recirculation Multi Stage Flash Distillation (MSF)

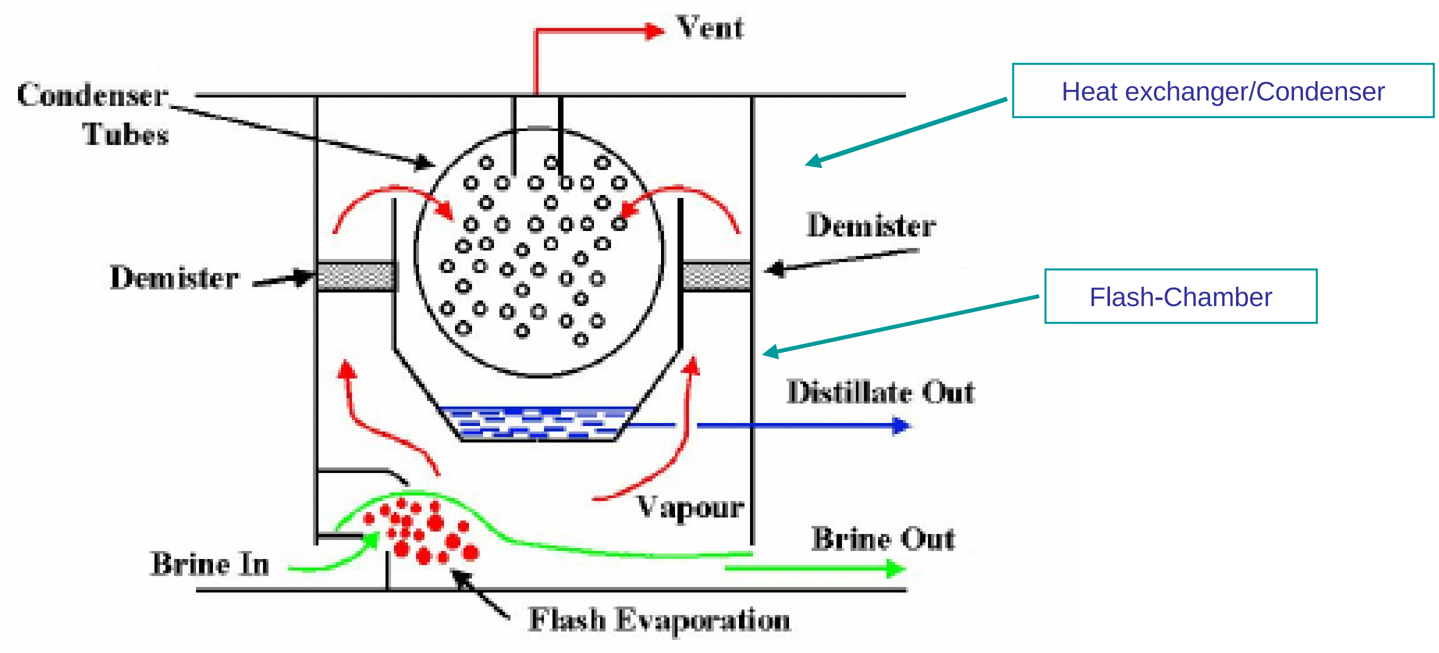


Source: SIDEM

The advantages of the "brine recirculation" configuration are that the seawater pre-treated is in the order of only one third of the once-through design, the majority of the tube bundles work with deaerated brine water with lower corrosion and the incondesable gases released are reduced thus achieving higher efficiency of the stages.

Each stage consists of a flash chamber and a heat exchanger/condenser, in which vapour flashed off in the flash chamber is condensed.

The flash chamber is separated from the condenser by a demister (to remove entrained brine droplets from the flashing vapour) and a distillate trough (to select the condensate from the condenser above).



B.R. MSF Description

The function of the rejection section is to reject thermal energy from the plant and to allow to the product water and brine to exit the plant at the lowest possible temperature. The feed water is mixed with the large mass of water, which is recirculated round the plant, known as the “brine recirculation” flow. Then the feed water passes through a number of heat exchangers (stages), raising its temperature.

In the recovery section the released by condensation of vapour is used to heat the recirculating brine flow, which is recirculated from the bottom stage of the rejection section.

After passing through the last stage of the recovery section the water is heated up to its terminal Temperature in the brine heater. The flow then passes through a restriction into the top flash stage where the reduction of pressure causes a small fraction to flash off as vapour, which then passes up through a demister into the condenser where the vapour is condensed.

The distillate condensed in each of the condensers is collected in a distillate train.

Vapour produced in the flashing chambers is then condensed on the tube surface, thus transferring the Latent heat to the preheating re-circulated brine and the distillate produced is dripped into a collector.

The vapor pressure in each of these stages is controlled so that the heated brine enters each chamber at the proper temperature and pressure to cause instantaneous and violent boiling/evaporation. The process is repeated stage by stage, with decreasing pressures and temperatures and increasing brine salt concentration.

As the process continues right down to the bottom stage of the plant in the rejection section, a part is rejected as “blowdown” and the rest is mixed with the incoming make up (feed water) and then recycled Once again via the brine recirculation pump.

The distillate condensed in each of the condensers is collected in a distillate train.

The brine recirculation flow rate in MSF is about nine times the production flow.

MSF Design Parameters

In practice, MSF plants are designed for various performance ratios (PR):

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

where
Md = mass of distillate produced, kg
Ms = unit mass of steam consumed, MJ

The Ms is related to Q, the heat input to the brine heater by:

$$Ms = \frac{Q}{L'}$$

Where L' is the latent heat of steam condensing in the brine heater.

The PR may be written as:

$$P_R = \frac{Md * L'}{Q}$$

The MSF plants usually operate at top feed temperatures (after the brine heater) of 90° – 110°C. One of the factors that affect the thermal efficiency of the plant is the difference in temperature from the brine heater to the condenser at the cold end of the plant. Operating a plant at the higher temperature limits of 110°C tends to increase the efficiency but also the potential for detrimental scale formation and accelerated corrosion of metal surfaces.

An MSF plant can contain from 4 up to 50 stages. A typical plant of a PR= 8:1 would have 16 to 18 heat recovery stages and three heat reject stages.

MSF has been developed and adapted to **large scale applications,** usually from 5,000 to 50,000 m^3/d.

The main energy requirement is thermal energy.

Electricity demand is low and is used for auxiliary services such as pumps, dosifiers, vacuum ejectors, etc.

For instance, for a plant that operates at a performance ratio equal to 8 the thermal energy consumption is around 290 kJ/kg of produced water while the electricity consumption can be ranged from 3.5 to 6 kWh/m^3.

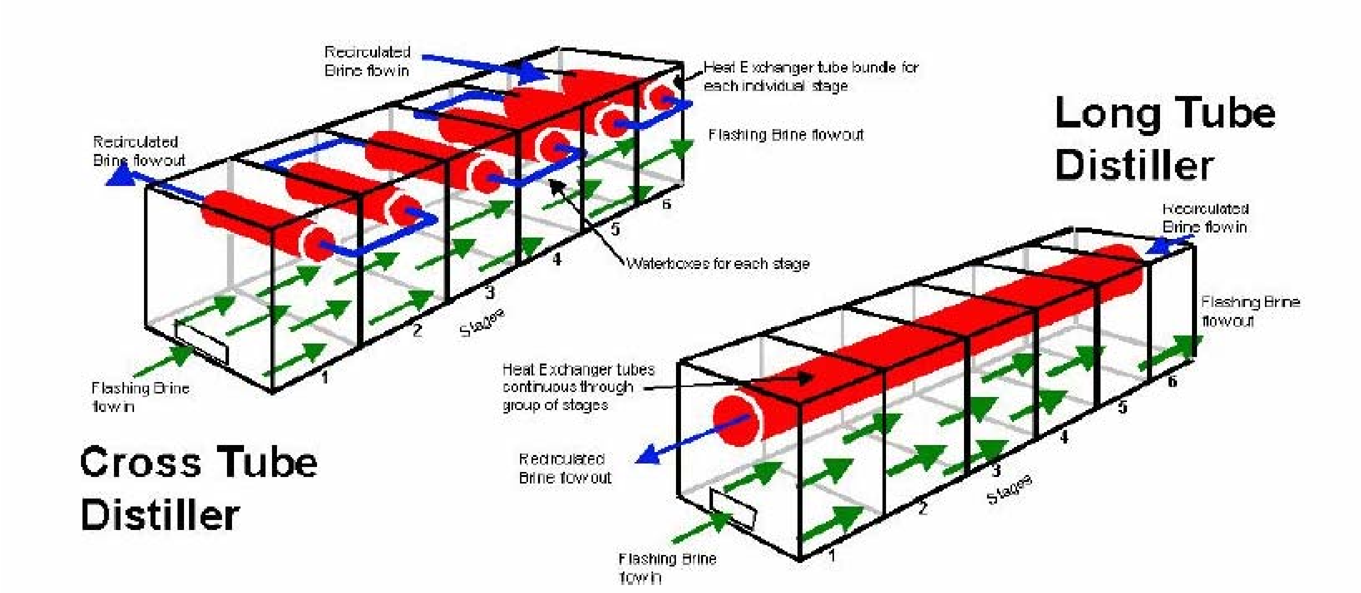
MSF Process Arrangements

Each of the Once through and Brine circulation MSF processes can be also arranged as a “long tube” or “cross tube” design.

In the long tube design, tubing is parallel to the concentrate flow in the vessel.

Tubing is perpendicular to the concentrate flow in the cross tube design

Most large modern MSF distillers are of the cross-tube design with a single deck of stages for ease of access to the stages and water boxes.



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	NA	0.20 to 0.29
- Low-pressure steam	0.24 to 0.29	NA
- Electricity	0.026	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

Item	Long tube design	Cross tube design
Flash chambers	Carbon steel, 316L stainless steel clad	Carbon steel (first three stages SS 316 clad)
Flash chamber internal supports	Stainless steel, grade 316	Carbon steel
Condensing section walls	Carbon steel, clad with stainless steel grade 316L	Carbon steel, clad with stainless steel grade 316L
Condenser tubing: - Rejection section - Recovery section - Concentrate heater	70-30 copper/nickel 90-10 copper/nickel, to 80 °C 70-30 copper/nickel above 80 °C 70-30 copper/nickel	70-30 copper/nickel 90-10 copper/nickel, to 80 °C 70-30 copper/nickel above 80 °C 70-30 copper/nickel
Interconnecting piping and water boxes	Carbon steel, 90-10 copper/nickel clad	Carbon steel, 90-10 copper/nickel clad
Tube plates: - Rejection section - Recovery section - Concentrate heater	70-30 copper/nickel 90-10 copper/nickel, to 80 °C 70-30 copper/nickel above 80 °C 70-30 copper/nickel	70-30 copper/nickel 90-10 copper/nickel, to 80 °C 70-30 copper/nickel above 80 °C 70-30 copper/nickel
Pumps	Bronze	Bronze
External structural shapes	Carbon steel	Carbon steel
Demisters	Stainless steel, grade 316	Stainless steel, grade 316
Deaerator/decarbonator	Carbon steel, rubber lined	Carbon steel, rubber lined

Source: Bureau of Reclamation

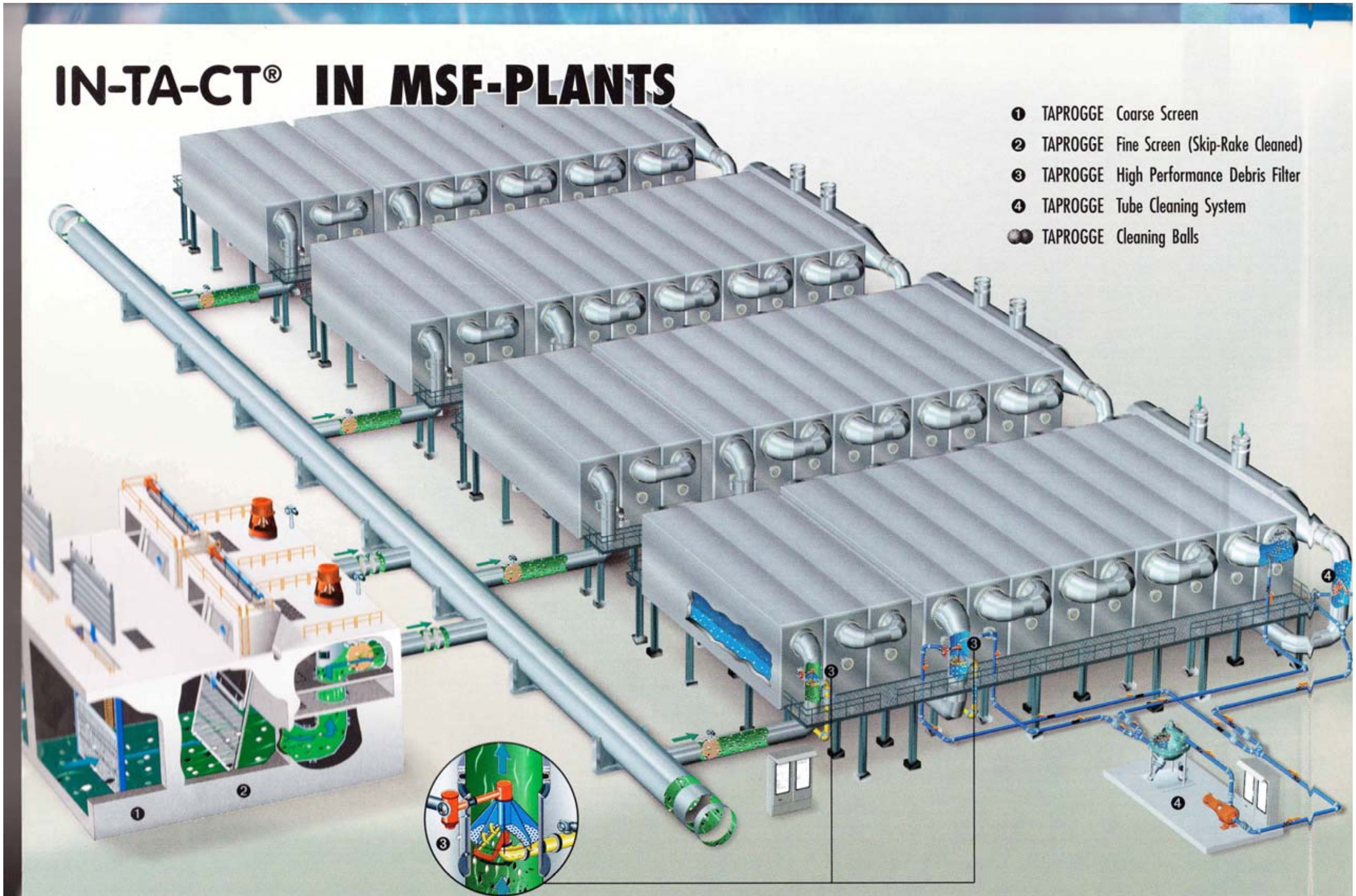
Multi Stage Flash

Cross Tube (Shuweihat, 76500m³/day)

Source: Unipa, Italy

Long Tube (Gela, 4x14400m³/day**)**

Source: Unipa, Italy



Source: TAPROGGE

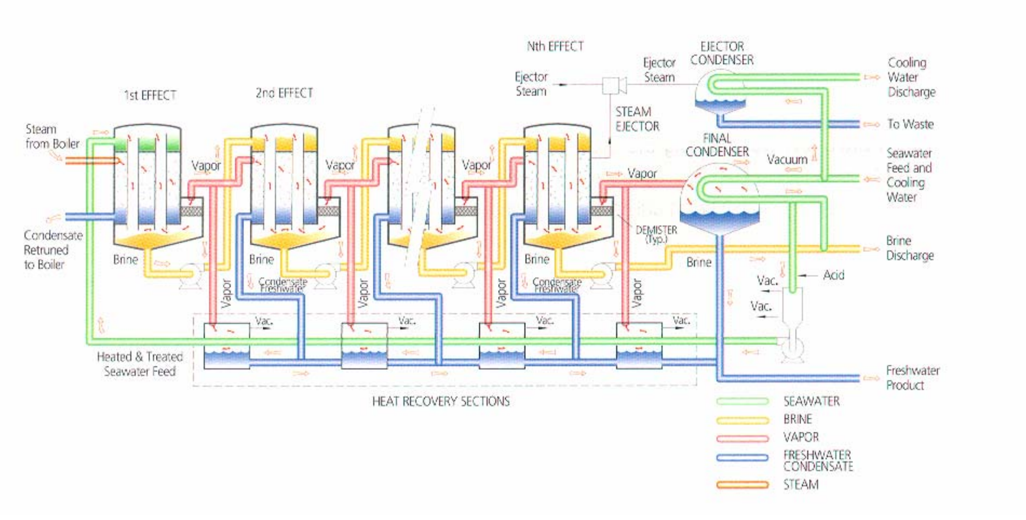
Multi Effect Distillation Process
MED

MED Process

MED, like MSF, takes place in a series of vessels (effects) and uses the principles of condensation and evaporation at reduced ambient pressure in the various effects.

The main difference between MSF and MED is in the method of evaporation and heat transfer.

In a MED plant, evaporation is from a seawater film in contact with the heat transfer surface, whereas in the MSF plant only convective heating of seawater occurs within the tubes and evaporation is from a flow of brine "flashing" in each stage to produce vapour.



Single Distillation

The unit is essentially made of two parts: an evaporator and a condenser.

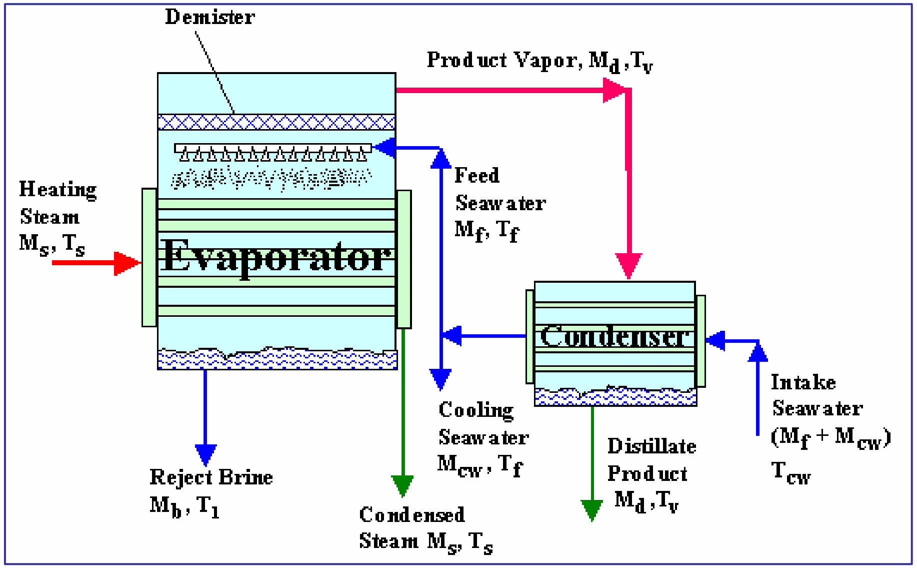
The evaporator is constituted by a tube bundle heat exchanger, a brine accumulation zone (in the bottom of the chamber) and a vapour zone.

In this latter zone a demister is used in order to avoid brine droplets entrainment in the vapour flow towards the condenser.

The condenser is a simple heat exchanger which is used to condense the vapour produced, but also to preheat the feed brine before it enters the evaporator.

This is the simplest distillation process, not very much used in the desalination industry, due to its low efficiency.

Nevertheless it is worth mentioning, as it is the fundamental part of all Multiple Effect Evaporation processes.



(Source El-Dessouky and Ettouney, 2002)

MED Process Description

- Feed seawater passes through the condenser, where it is preheated by the condensation heat of the vapour, which is condensing on the other side of tube bundle;
- Then the feed water passes through a number of pre-heaters located in each effect (evaporators) in order to raise its temperature.
- After passing through the last of these, the feed enters the “top” effect where the heating steam from a boiler or other source raises its temperature to the saturation temperature for the effect pressure.
- The preheated feed enters the evaporator and it sprayed onto the surface of the evaporator tubes to form a thin film to promote rapid boiling and evaporation.

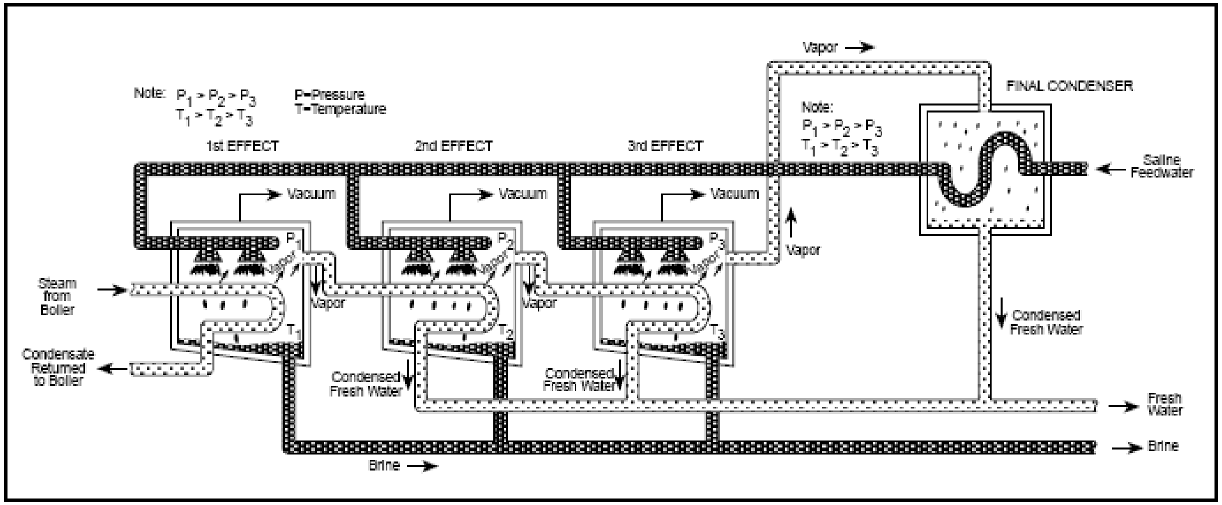
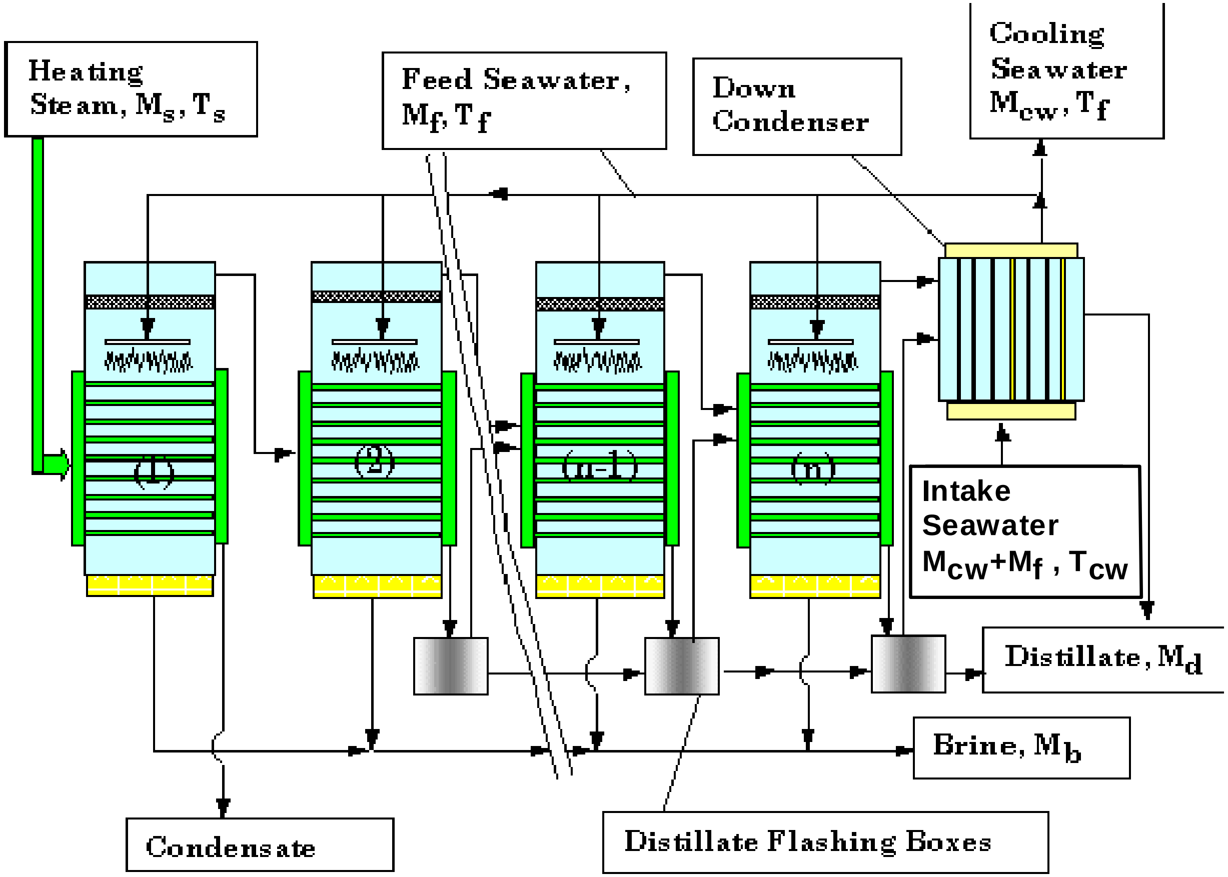


Diagram of a Multi-Effect plant with horizontal tubes. USAID

- Only a portion of the sea water applied to the tubes in the first effect is evaporated. The vapour produced then goes, in part, to heat the incoming feed and in part to provide the heat supply for the second effect, which is at lower pressure and receives its feed from the brine of the first effect.
- From the second effect the vapour itself is condensed (product water) while at the same time giving up heat to evaporate a portion of the remaining feed water in the next effect.
- This process is repeated all the way down the plant. The effects are gradually operated at lower temperatures. This is accomplished by maintaining the effects at successively lower pressure (or higher vacuum by means of an air ejector).
- The heating steam is condensed inside the evaporator and is re-circulated to a boiler for regeneration;
- Concentrated brine is collected in the bottom of the unit and then is discharged as blow-down.

Multi Effect Distillation (MED)



Three arrangements have evolved for MED process. They are based primarily on the arrangement of the heat exchanger tubing:

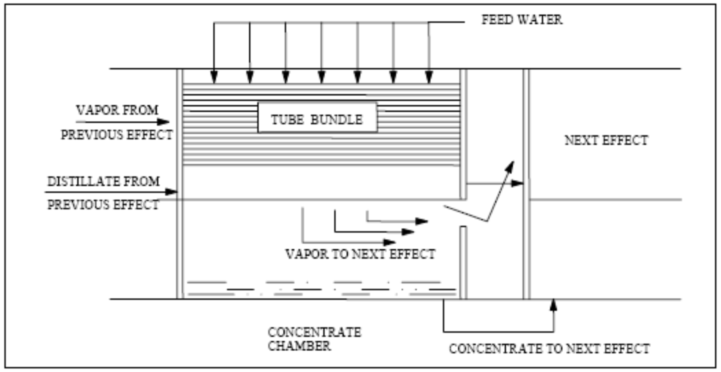
- Horizontal tube arrangement
- Vertical tube arrangement
- Vertically stacked tube bundles

Most modern large MED plants have a horizontal tube configuration (HTE), with the feed water film sprayed over the outside of the tubes and condensation inside.

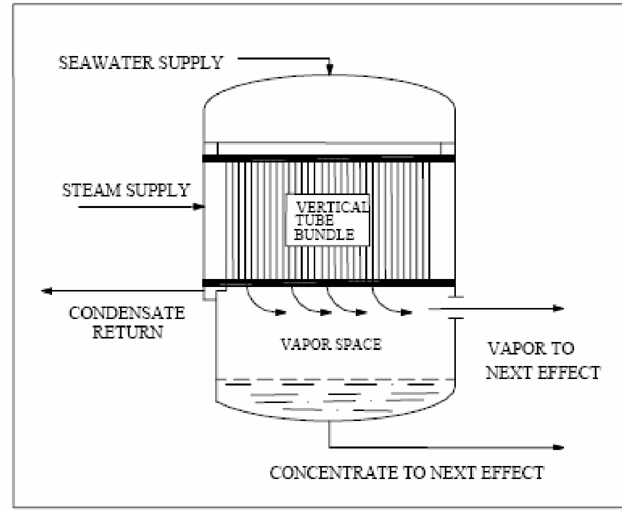
The horizontal tube design uses a system of spray nozzles or perforated trays to distribute the feed water evenly over the heat transfer tubes.

In the vertical tube or VTE configuration this is reversed, with the feed water flowing down the inside of the tubes.

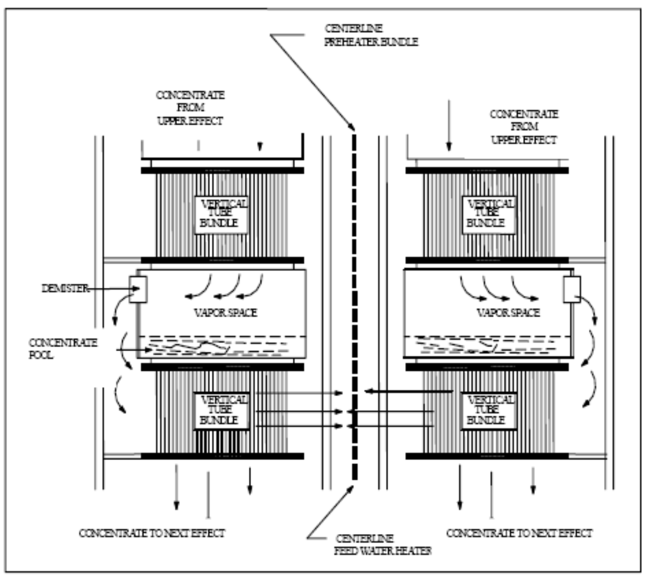
2,000 m³/d (0.5-mgd) vertically stacked MED plant in Japan
Photo — Sasakura



MED horizontal tube arrangement



MED vertical tube bundle arrangement



MED vertically stacked tube bundles

Source: Bureau of Reclamation

MED plants tend to have smaller number of effects than MSF stages. Usually 8-16 effects are used in typical large plants, due to the relation of the number of effects with the performance ratio.

The performance ratio (water production to steam consumption) of the MED plant is approximately equal to the number of effects minus 1(N-1) (always less than the No of effects). For an 8:1 performance ratio plant, the number of effects needed in a MED plant would be 9. This is much lower than in an equivalent MSF plant. The smaller number of effects in MED plants contributes to savings in capital cost compared with MSF.

The choice and optimization of the performance ratio and the number of effects in an MED plant is a matter of balancing the high energy costs inherent in a low performance ratio and number of effects and against the high capital costs of a large number of effects and large transfer surfaces in both the effects and the feed heaters.

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 (^oC)	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

- Multiple Effect Evaporation is widely used in all the process industry, where it represents the main option to concentrate solutions and to evaporate a solvent.

- In the desalination industry this was the first technology used to produce fresh water from seawater, but it was overtaken by the MSF technology due the problems of fouling and scaling of evaporators tubes, which are avoided in MSF units.

- Nowadays, due to the improvements in materials and technology, MED process is becoming one of the most efficient thermal desalination technology, especially when coupled to heat pumps or waste heat sources.

- MED is available with capacities of up to about 12000 m^3/day in a single unit with larger plants being realized by multiple unit installation.

The performance of MED plants can be improved still further by means of vapour compression whereby part of the vapour formed in a low-temperature effect is recompressed and reintroduced to the first effect. In large plants the method used is thermal vapour compression (TVC).

Source: CRES, 1998

MED unit

Trapani, Italy

Source: UNIPA, Italy

Vapor Compression (VC)

Vapor compression (VC) distillation is a thermal process that has typically been used for small-and medium-scale seawater desalting units.

These units also take advantage of the principle of reducing the boiling point temperature by reducing ambient pressure, but the heat for evaporating the water comes from the compression of vapor rather than the direct exchange of heat from steam produced in a boiler.

The vapor can be compressed by either a **mechanical compressor** or by the use of a **steam jet thermo-compressor.** In most cases, a mechanical compressor is used.

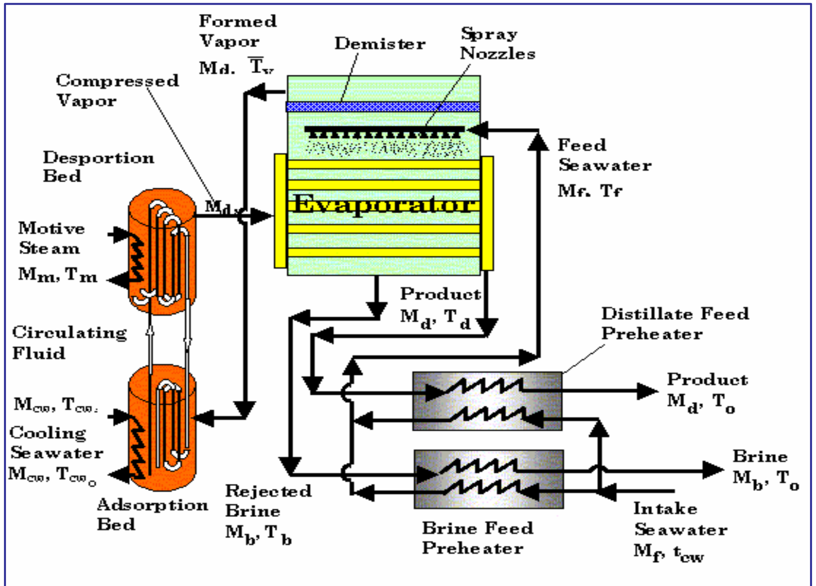
Two methods of compression are employed:

- Mechanical vapor compression [MVC]
- Thermal vapor compression [TVC]

VC Process

In MVC, the compressor is operated by an electric motor or diesel engine. High-pressure steam is used to compress the vapor generated in the vessel.
The compressed steam is then used as the heat source for further vaporization of the feed water.

In TVC, vapor is generated in the evaporator by the transfer of heat from the compressed vapor. Hot vapor lies on the inside of the tubes, while the feed water is sprayed on the outside surfaces.
The vapor thus generated is then compressed to be used for heat in the evaporator.



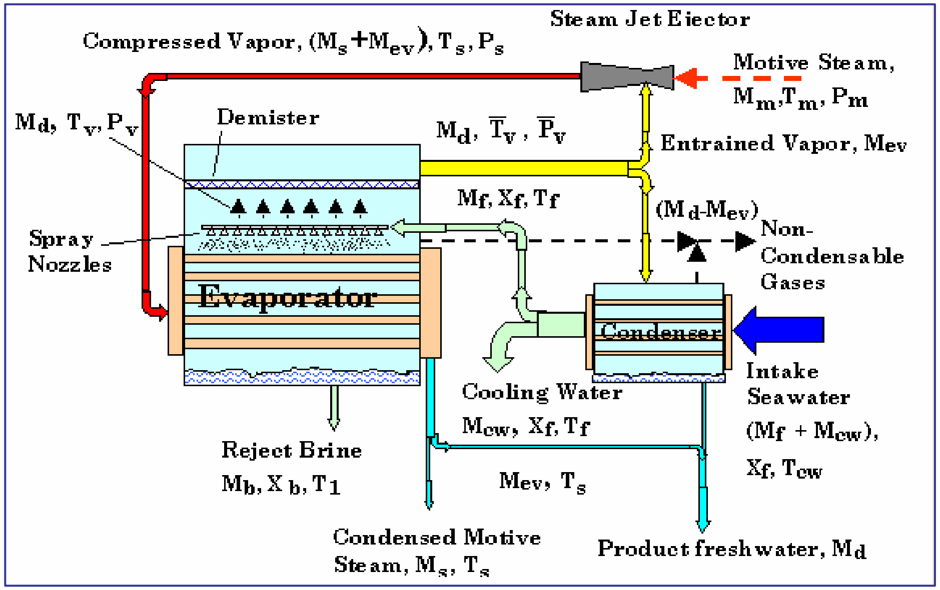
Adsorption Vapor Compression

Thermal Vapour Compression (TVC)

The main difference to the Single Effect Evaporator concerns the production of steam vapour to be fed to the evaporator tube bundle.

In TVC units a certain amount of the produced vapour exits from the chamber, is taken and recompressed by a medium pressure steam ejector, which regenerates the vapour before it enters again as heating steam in the evaporator.

The other part of the vapour produced is simply sent to the condenser where it condenses providing a partial preheating to the feed seawater.



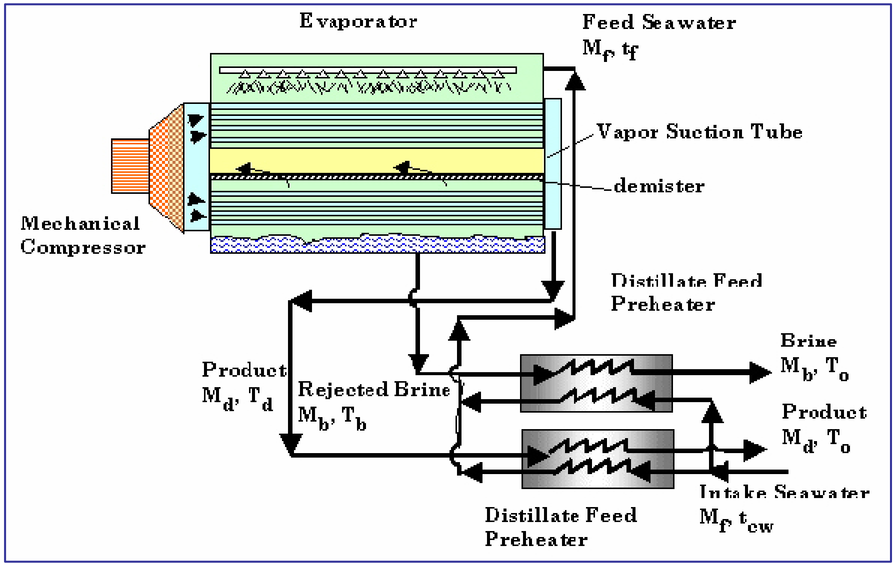
(source El-Dessouky and Ettouney, 2002)

MVC Process description

The unit consists of an evaporator, a vapour compressor and two heat recovery exchangers.

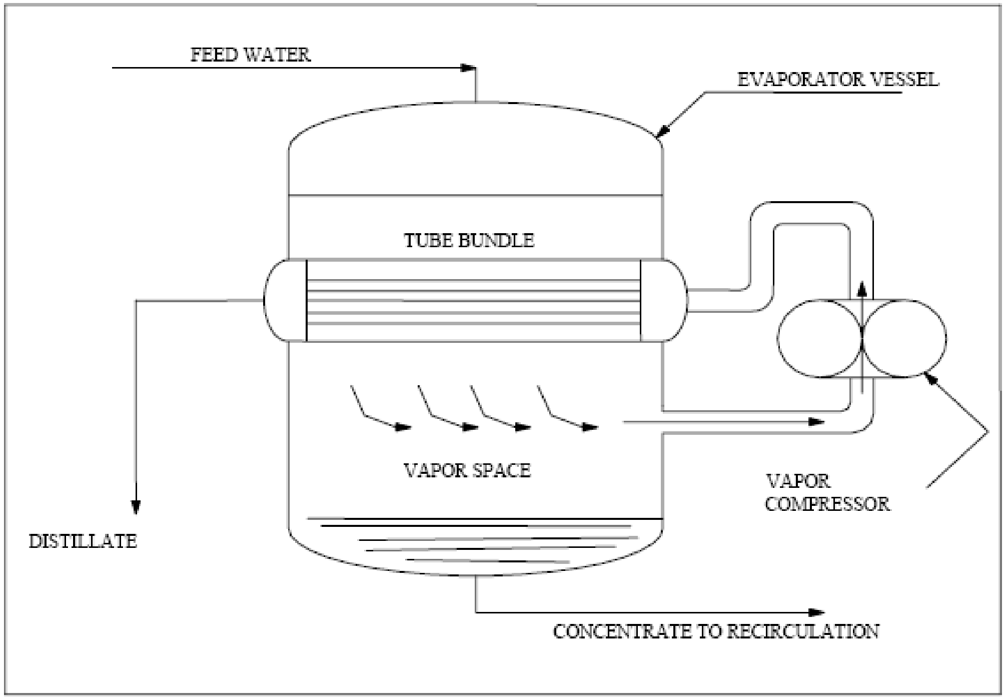
In the MVC process all the vapour produced inside the evaporator is directly withdrawn by the compressor which increases its enthalpy, thus allowing its use as heating steam.

The distillate condensed in the tube side of the evaporator is cooled by a plate heat exchanger (ideal to work with high salinity water and with low temperature differences) where the feed seawater is preheated.
The same is done for the exiting brine, thus recovering a quantitative amount of process heat.

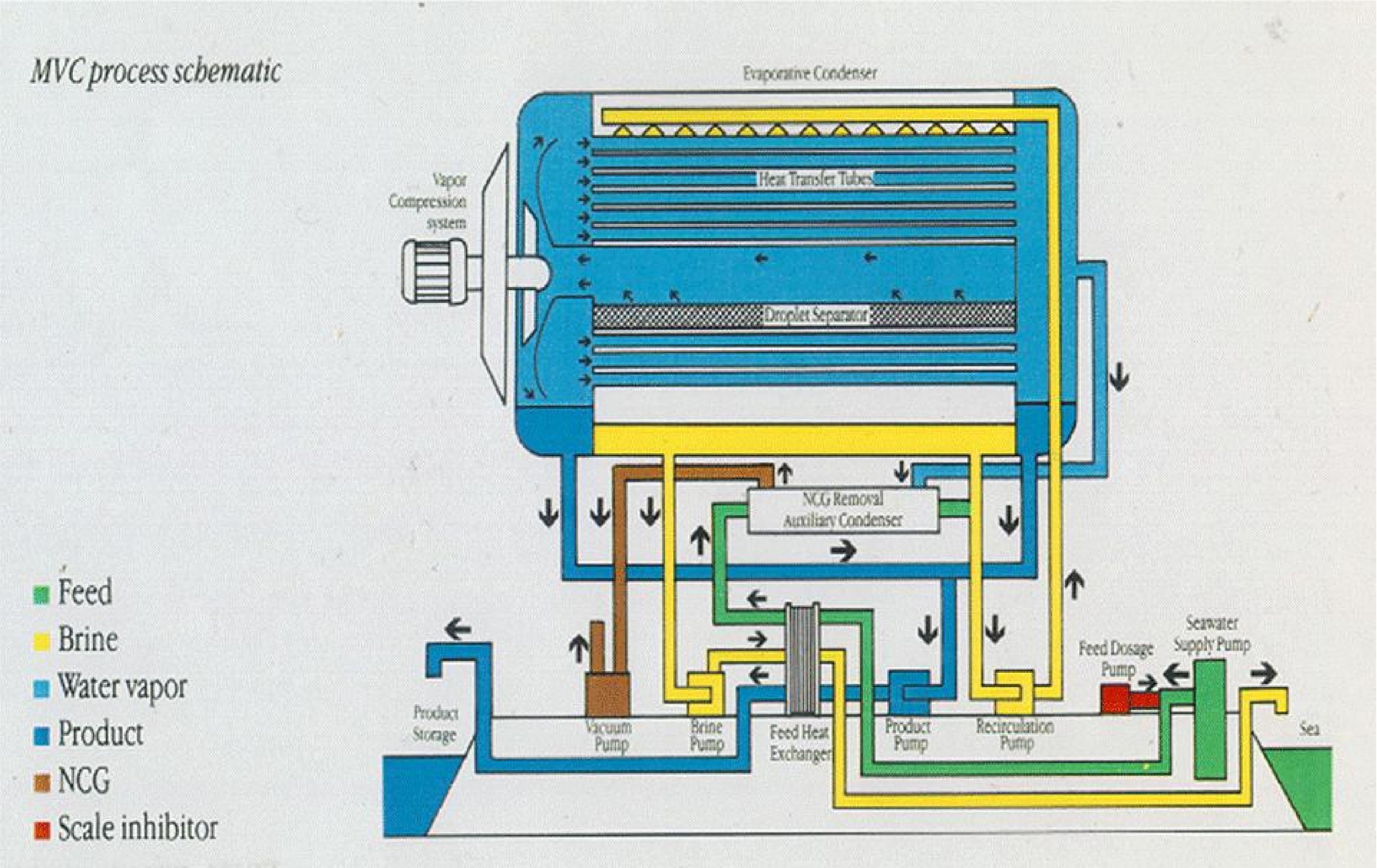


MVC units are usually built in the 250 to 2,500 m^3/d range and used for tourist resorts, small industries, and remote sites.

TVC units are usually built in the 500 to 20,000 m^3/d range.



Source: Bureau of Reclamation



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

Source: SIDEM, France

MVC

A mechanical vapor compression unit
Photo — MECO

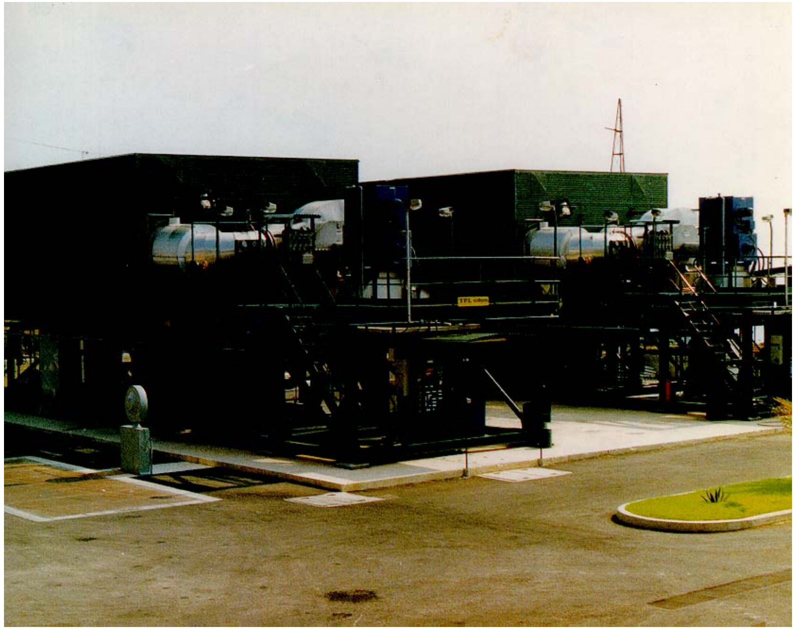
Thermal vapor compression unit in Saudi Arabia
Photo — Weir Westgarth

MVC

Source: SIDEM, France

MVC plant

TVC Plant



Source: SIDEM, France

Source: Weir Westgarth Ltd, U.K..

Distillation Processes Comparison

	MSF	MED	MED-TVC	MVC
Operating temperature (°C)	<120	<70	<70	<70 /1/
Form of main energy	Steam (heat)	Steam (heat)	Steam (heat)	Mechanical (electrical) energy
Thermal energy consumption (kWh/m^3) /4/	12	6 /5/	21 /5/	Not applicable
Electrical energy consumption (kWh/m^3)	3.5	1.5	1.5	8 – 14
Typical salt content of raw water (ppm TDS)	30,000 – 100,000	30,000 – 100,000	30,000 – 100,000	30,000 – 50,000
Product water quality (ppm TDS)	<10	<10	<10	<10
Current, typical Single-train capacity (m^3/d)	5,000 – 70,000	500 – 12,000	100 – 25,000	10 – 2,500

/1/ In exceptional cases with acid dosing: 100 °C
/2/ Seawater as raw water, otherwise lower consumption
/3/ Depending on salt content in raw water: at 1,500 ppm TDS (add 0.5 kWh for every 1,000 ppm of removed ions)
/4/ Expressed as the electrical energy that steam in a turbine-generator set cannot produce because of extraction from the process (performance ratio = 8 kg produced water per kg saturated steam in brine heater, resp. inlet steam ejector; steam pressure at inlet brine heater of MSF = 1.7 bara, at inlet first stage of MED = 0.4 bara, at inlet steam ejector of MED-TVC = 10 bara; pressure in "virtual" turbine condenser = 0.1 bara)
/5/ At equal performance ratio and selected heating steam pressures, investment costs for MED plants are considerably higher than for MSF plants and investment costs for MED-TVC plants are lower than for MSF plants

Source: Wangnick, IDA, 2004