2.500 Desalination and Water Purification
Spring 2009

Many of these pages were taken from the short-course material identified below. This material is provided courtesy of the European Desalination Society

THERMAL DESALINATION PROCESSES AND ECONOMICS

A 4-day intensive course

Lecturer Dr. Corrado Sommariva

23–26 July 2007
L'Aquila, Italy

International
Desalination
Association

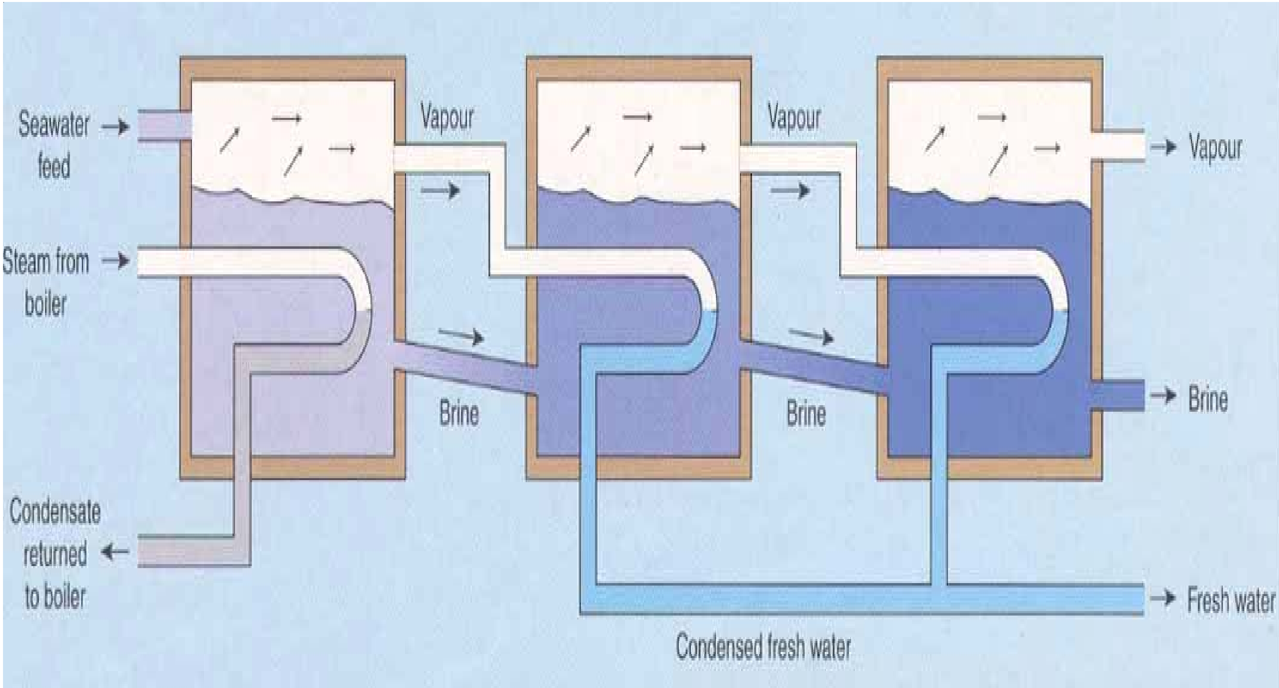
A number of pages were also taken from this presentation.

Future Directions in Integration of Desalination, Energy and the Environment

Leon Awerbuch,
President of Leading Edge Technologies,
Director of IDA

A seminar sponsored by
American Nuclear Society - Student Chapter
and
Department of Nuclear Science and Engineering
Massachusetts Institute of Technology
Boston, February 23rd, 2009

American Nuclear Society – MIT Section



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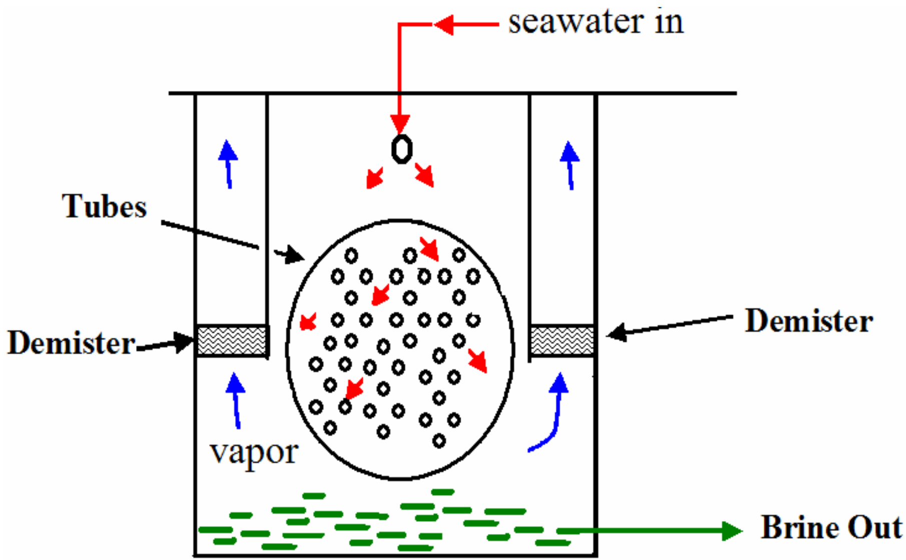
Thus the heat is “recycled” within the system. Energy efficiency is a function of the number of effects.

MED desalination plant

Typical stage arrangement of a large MED plant



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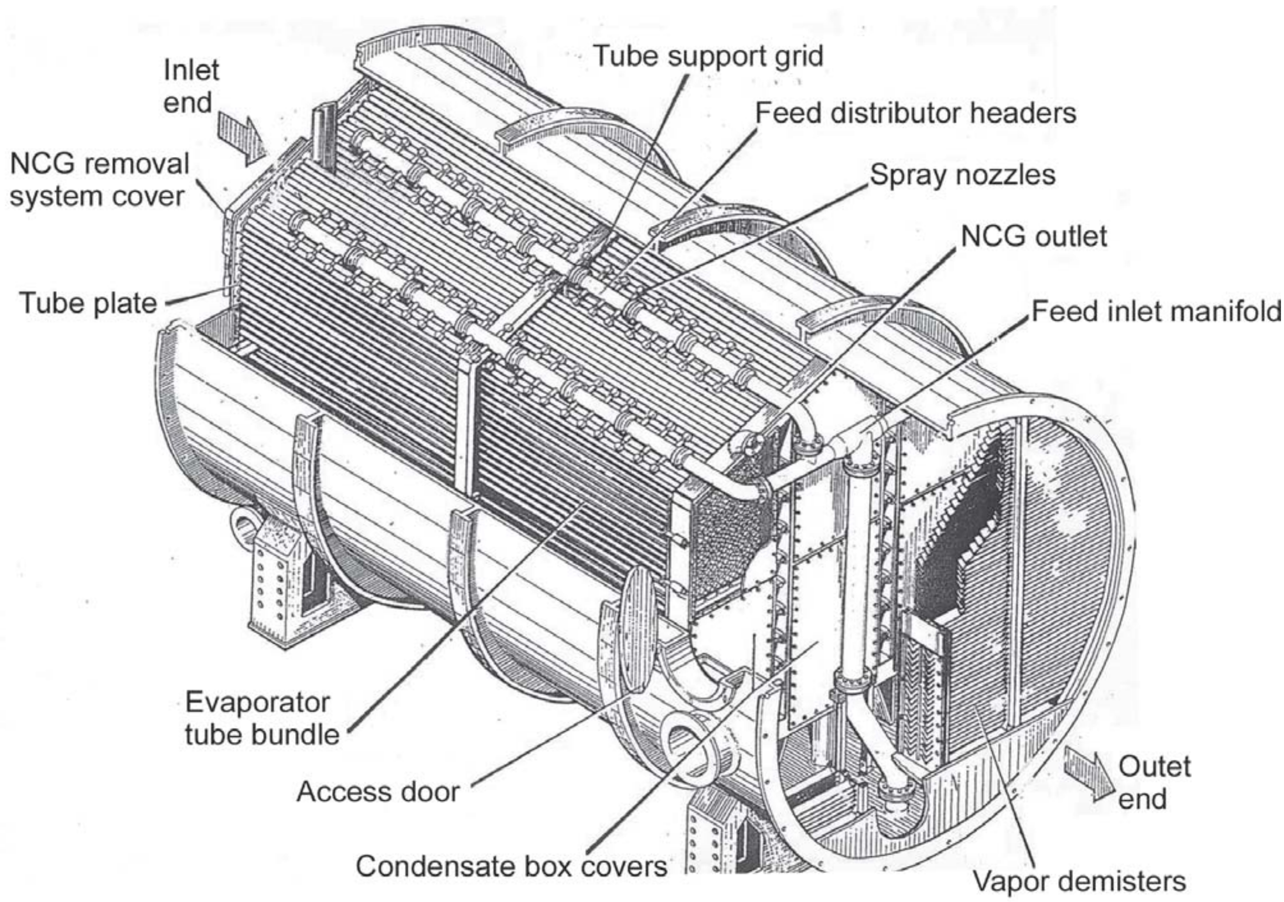
Multi-Effect Distillation (MED)

- Raw seawater total dissolved solids (TDS): 35-47,000 mg/L
- Top brine temperature: 63-75° C
- Performance ratio: 12
- Electrical power: 2 kWh/m^3
- Scale inhibitors used for scale control
- Dual purpose plant
- Unit size reached 8 MIGD in Sharjah, new design for unit sizes 10-15 MIGD

MED cross flow plant internal layout



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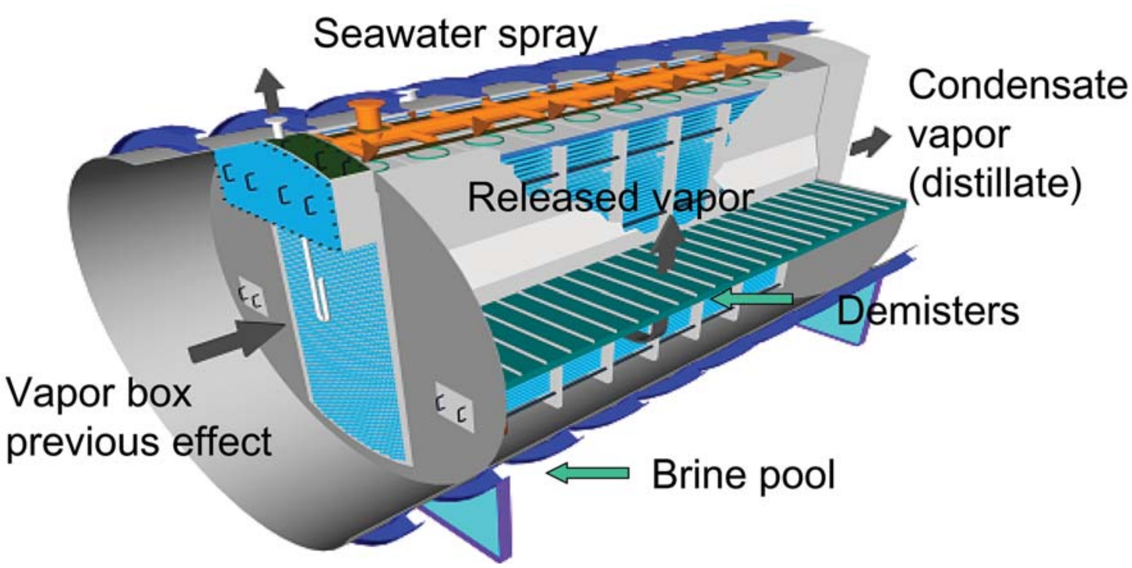

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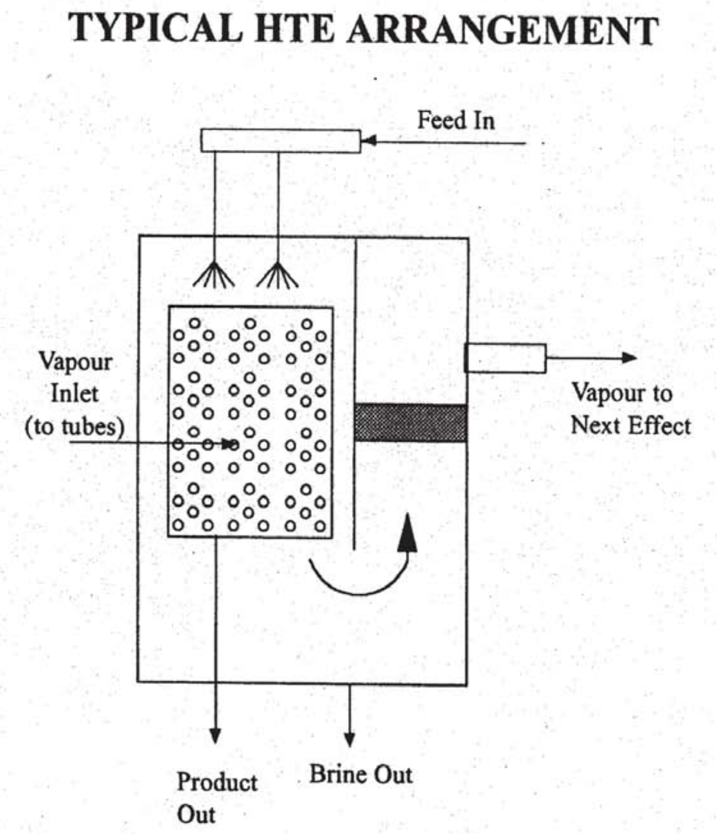
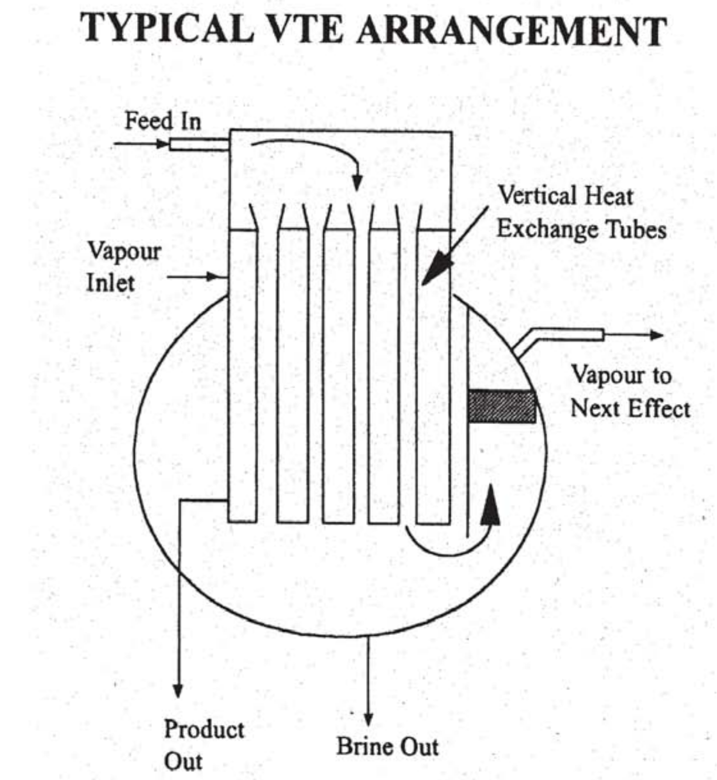
MED KEY PARAMETERS

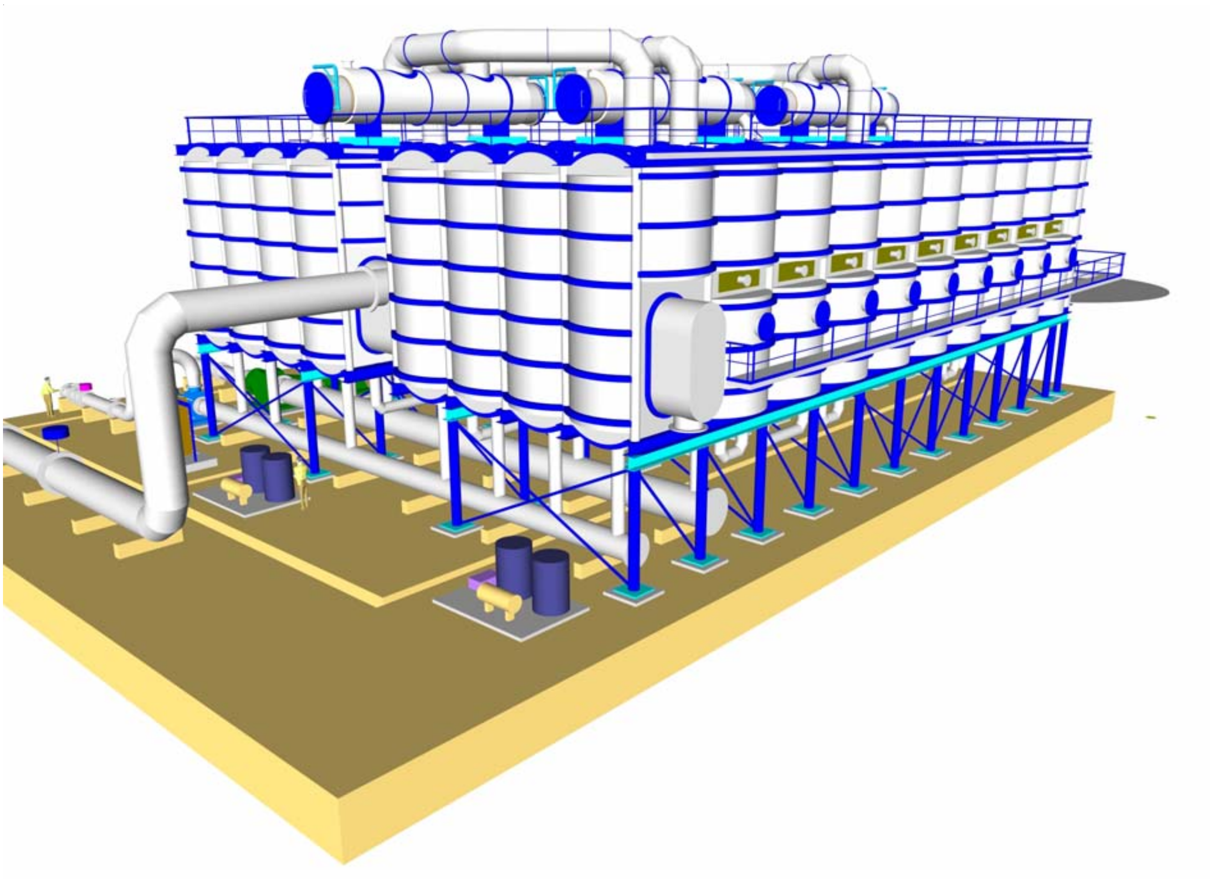
Capital Cost MED	4.5-9.0	US$ MM per MIGD
Capital Cost –Intake /Outfall	0.1-2.0	US$ MM per MIGD of cooling
MED GOR	12	Tons of product/ton of steam
LP Steam Supply	2.5-3	Bar A
Lost Power Potential	1.225	MW/MIGD
Power Consumption	1.8	KWh/m^3 of distillate
Steam Consumption	15.8	Tons/MIGD
Chemical Costs	40,000	US$/yr per MIGD
MED R&R	1%	TIC/yr
Labor	40,000	US$/yr per MIGD

MED arrangements





Desalination projects: MED layout



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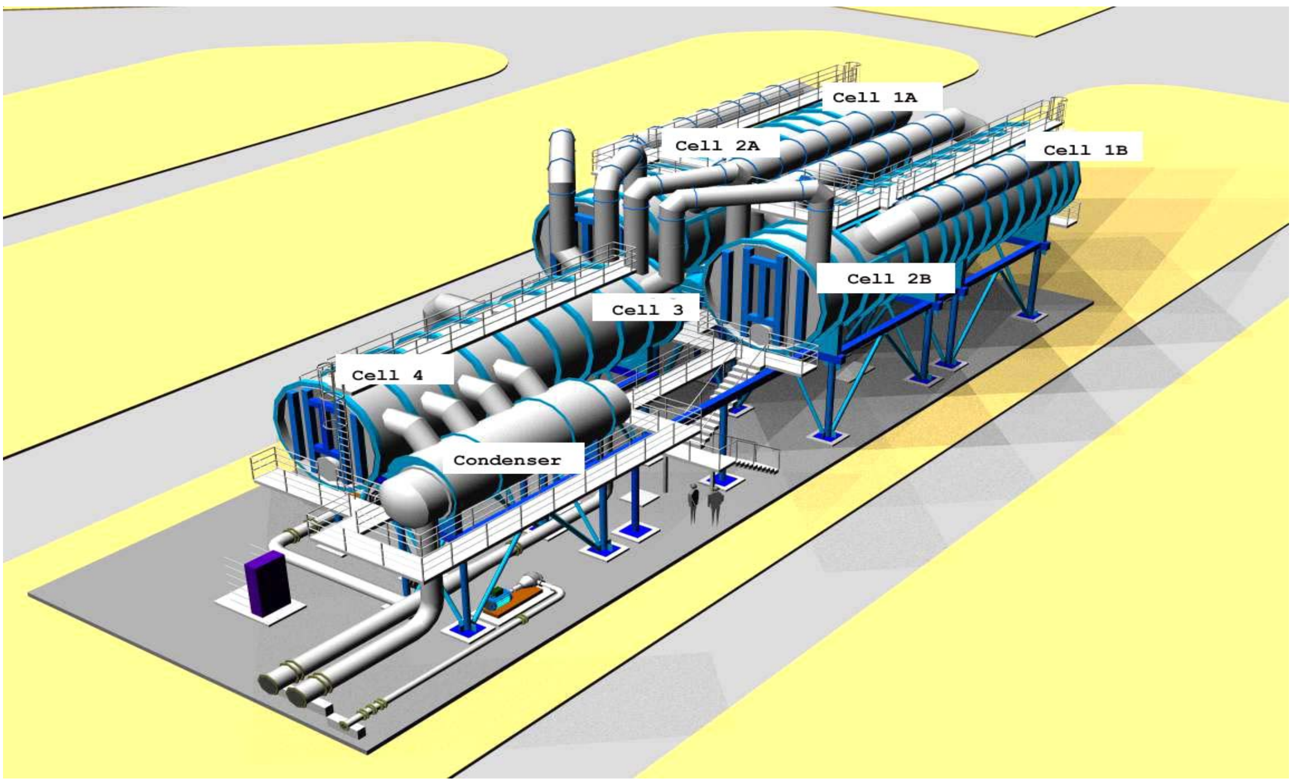

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Multiple effect desalination

Evolved from small installation

to relatively large unit size

With thermo compression

Condesing

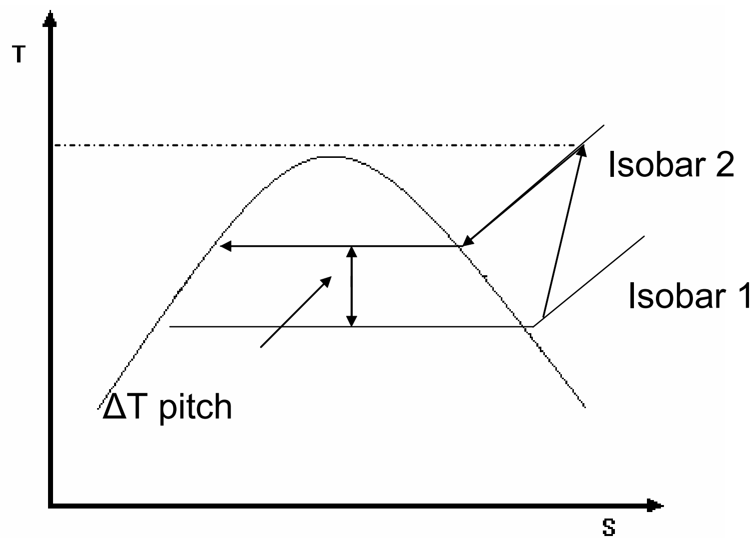
One of more efficient MED plants with Performance Ratio of 12 in Las Palmas

Courtesy of Leon Awerbuch. Used with permission.

The concept of thermo compression

If reduced pressure causes evaporation at a lower temperature, then compression should force condensation at a higher temperature.

The combination of these phenomena can yield useful (and efficient) desalination process.



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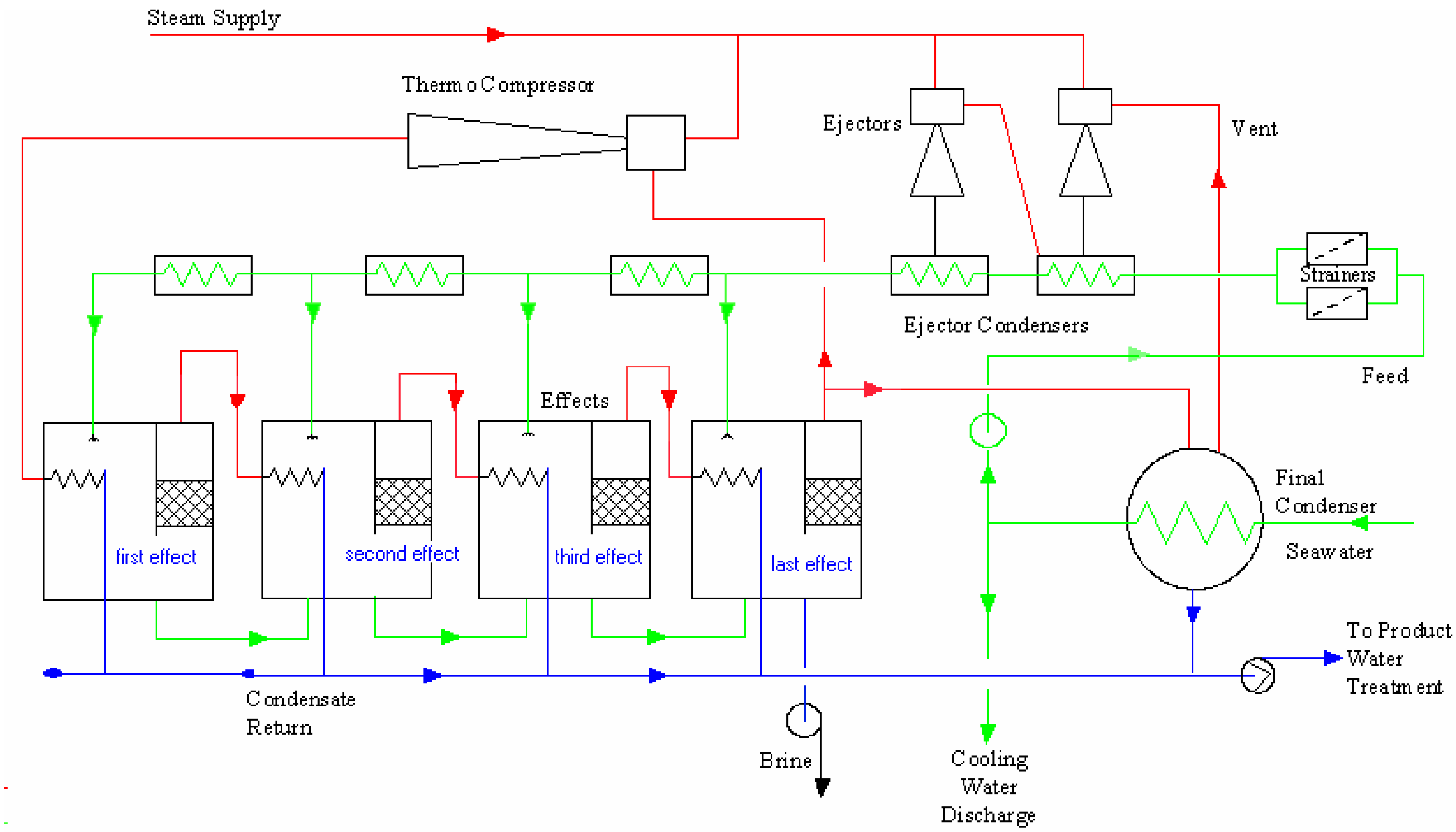
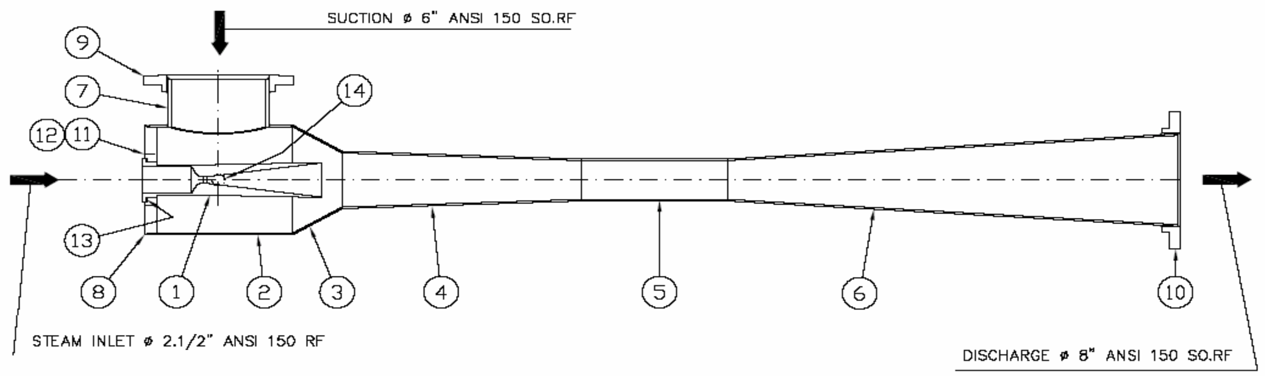
Flow sheets: Once through



Simple ejector-compressor



Pos. Pos.	Q.ty Q.ta'	Description Denominazione	Material Materiale	Note Note
14	1	COUPLING	ASTM A 182F-316L	
13	1	GASKET	GRAPHITE 92-R	
12	4	NUTS	ASTM A 194 Gr.2H	
11	4	STUD BOLTS	ASTM A 193 Gr.B7	
10	1	FLANGE	ASTM A 105+CLADDED	
9	1	FLANGE	ASTM A 105+CLADDED	
8	1	HEAD	ASTM A 240-316L	
7	1	NOZZLE	ASTM A 312-316L	
6	1	DIVERGENT	ASTM A 240-316L	
5	1	THROAT	ASTM A 240-316L	
4	1	CONVERGENT	ASTM A 240-316L	
3	1	CONE	ASTM A 240-316L	
2	1	SUCTION CHAMBER	ASTM A 240-316L	
1	1	NOZZLE	UNS N08904	

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Fluid flowing in the pipeline (the "motive fluid") speeds up to pass through the restriction and in accordance with Bernoulli's equation creates vacuum in the restriction.

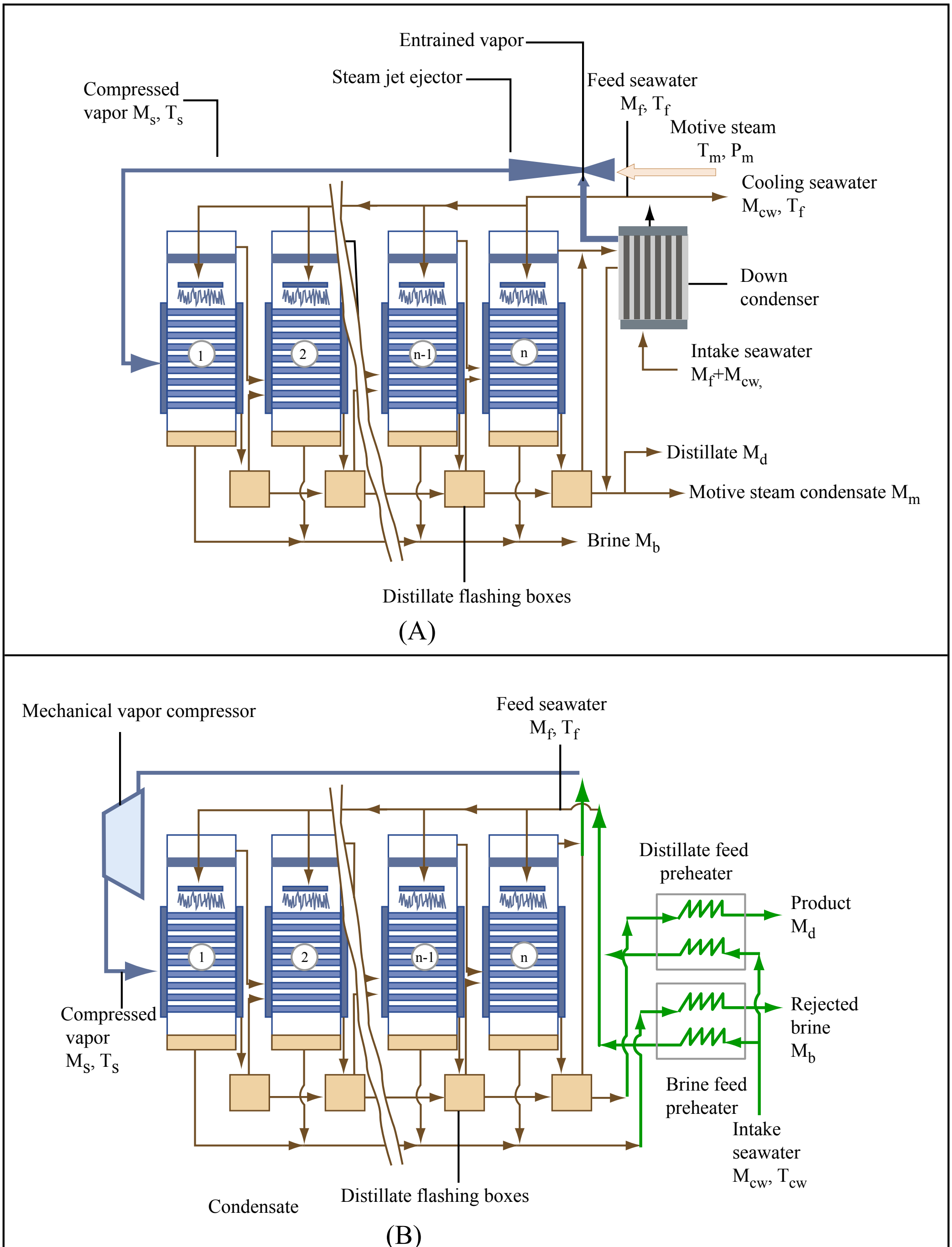
A side port at the restriction allows the vacuum to draw a second fluid (the "ejected") into the motive fluid through the port.

Turbulence downstream of the port entrains and mixes the ejected into the motive fluid.

The MED unit 22,700 m^3/d in operation over five years at Layyah Power Desalination in Sharjah

Courtesy of Leon Awerbuch. Used with permission.

LET Proprietary

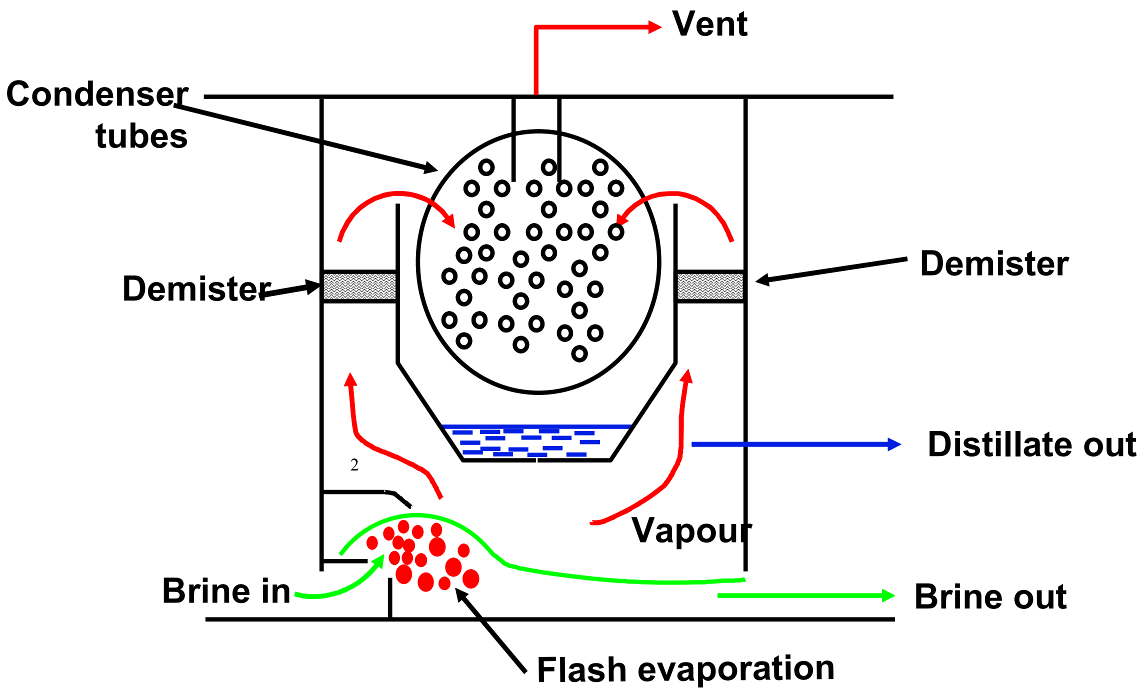


Schematic of multiple effect evaporation with vapor compression (A) parallel feed thermal vapor compression, (MEE-P/TVC) and (B) parallel feed mechanical vapor compression, (MEE-P/MVC).

Figure by MIT OpenCourseWare. Adapted from Fig. 1 in El-Dessouky, H. T., and H. M. Ettouney. "Multiple Effect Evaporation - Vapor Compression." Chapter 5 in *Fundamentals of Salt Water Desalination*. New York, NY: Elsevier, 2002.

MSF desalination plant

Typical stage arrangement of a large MSF plant



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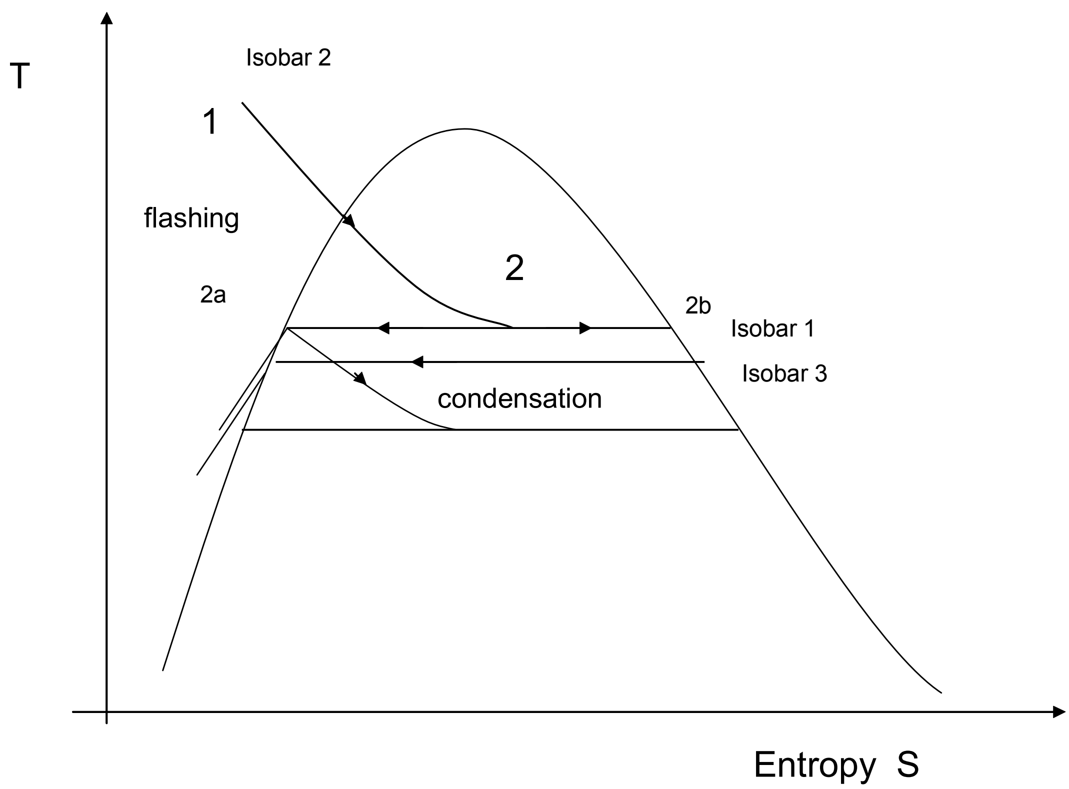
Stage modeling thermodynamic ideal case



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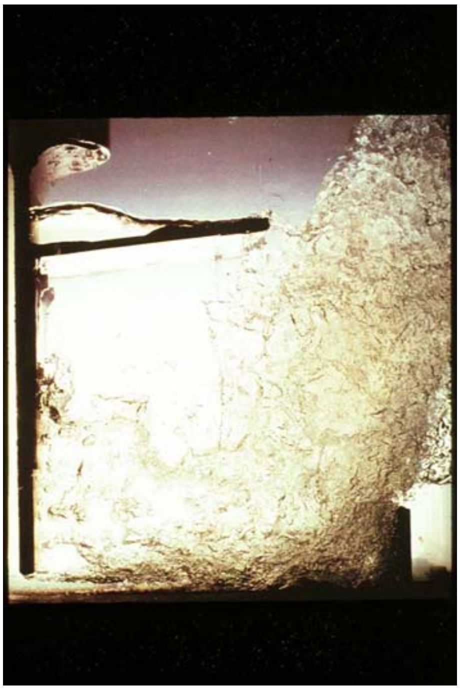
Process description: How did it begin?

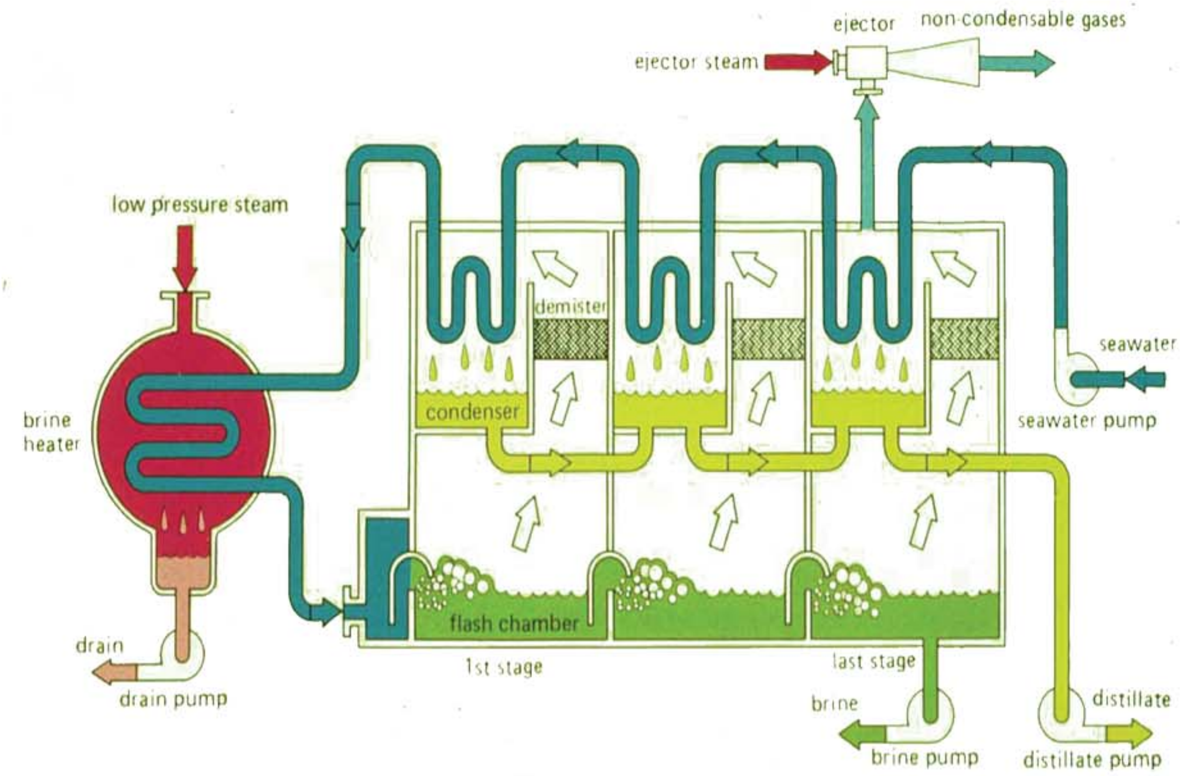
- It had long been known that water could be heated above its normal boiling point in a pressurized system.
- If the pressure was released, a portion of the water would boil off or "flash". The remaining liquid water would be cooled as the issuing vapor took with it its heat of vaporization.
- Since evaporation occurred from the bulk fluid rather than at a hot heat exchange surface, opportunities for scaling would be reduced.

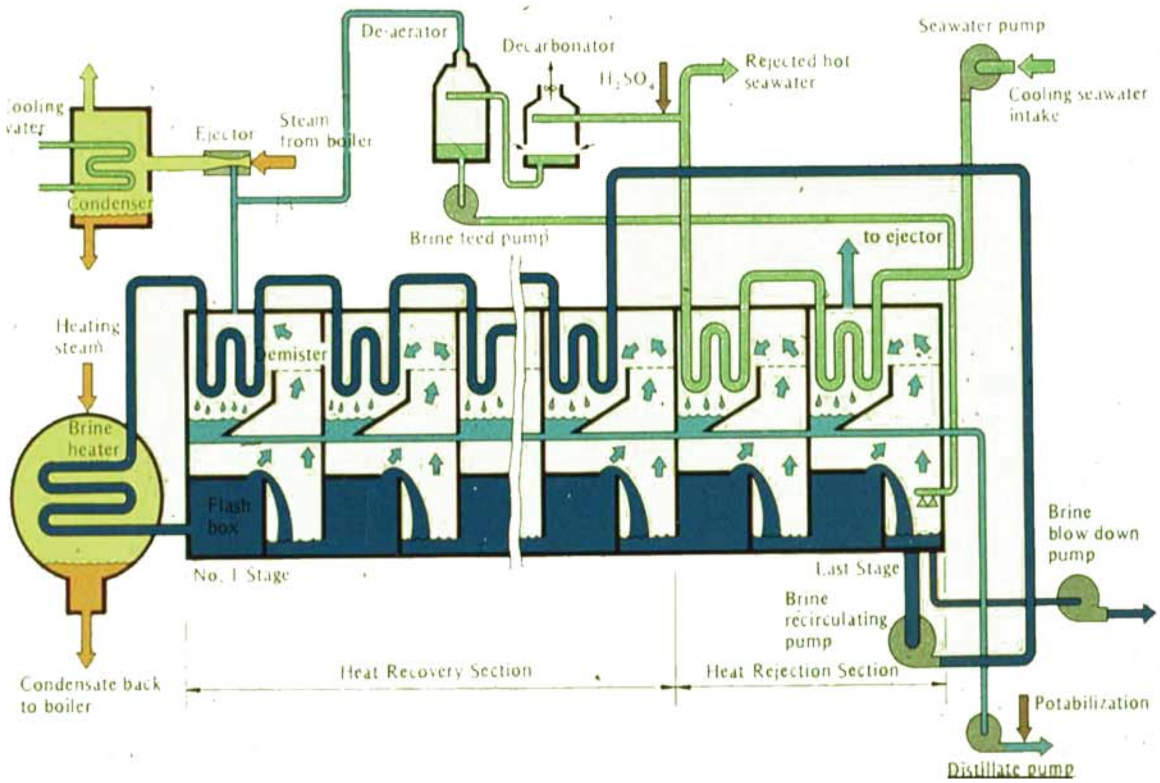
What flashing looks like

- Hot brine from the previous stage enters through slot at lower temperature and pressure stage
- It senses the new lower pressure environment, and
- Flashes!



MSF desalination plant





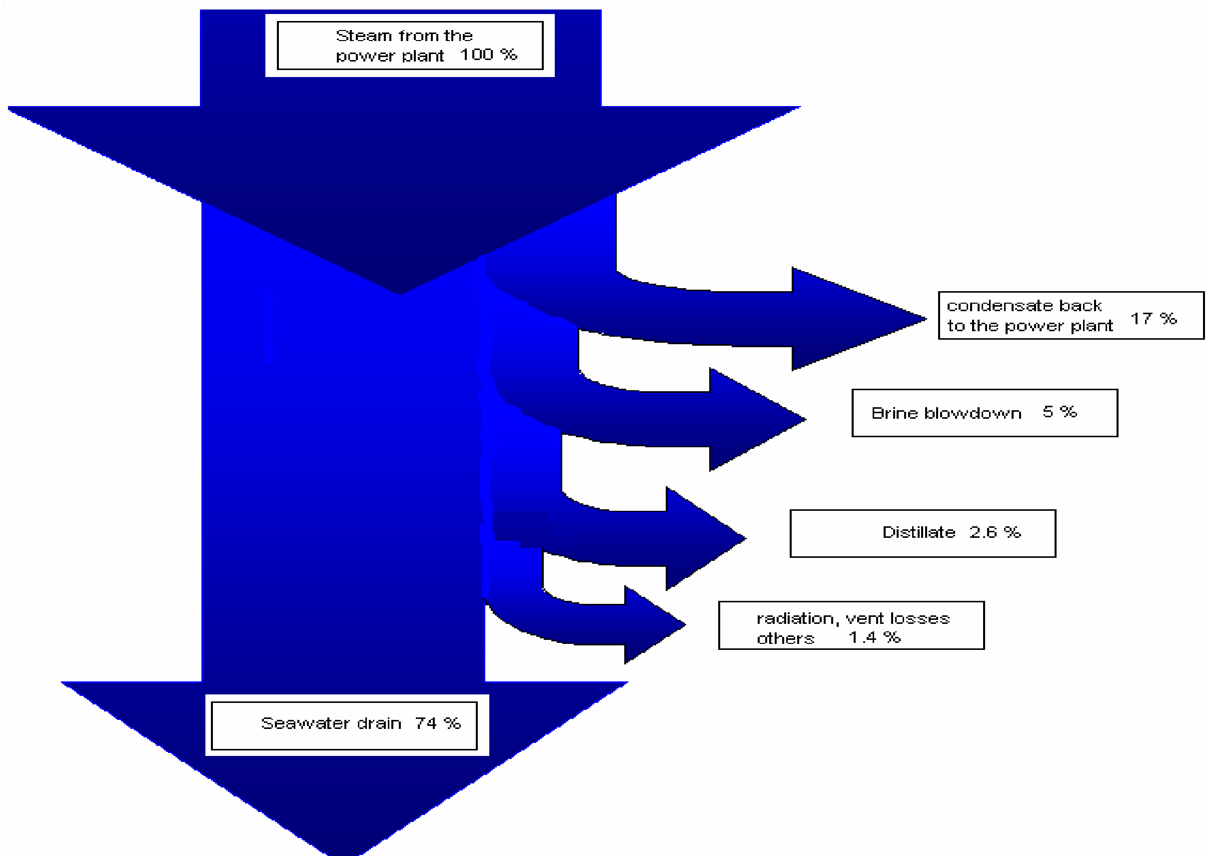
MSF what process?

Multistage Flash (MSF)

- Raw seawater total dissolved solids (TDS): 35-47,000 mg/L
- Top brine temperature: 100-112^{o} C
- Performance ratio: 8
- Electrical power: 3-4 kWh/m^3
- Scale inhibitors used for scale control
- Recycle type plant
- Dual purpose plant
- Unit size 16.7-20 MIGD

Energy effect

In fact, as it can be seen from the energy flow diagram below, the great part of the heat input to the MSF system is returned back to the sea with the seawater drain stream.



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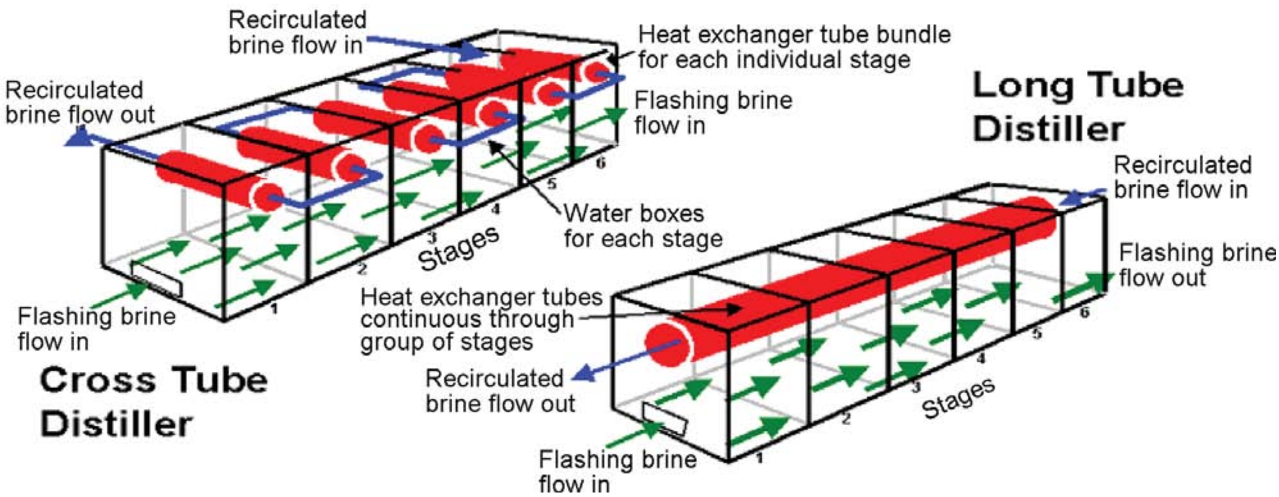
MSF KEY PARAMETERS

Capital Cost MSF	5.5-10	US$ MM per MIGD
Capital Cost –Intake /Outfall	0.1-2.0	US$ MM per MIGD of cooling
MSF GOR	8	Tons of product/ton of steam
LP Steam Supply	2.5-3	Bar. A
Lost Power Potential	1.225	MW/MIGD
Power Consumption	4	kWhr/m³ of distillate
Steam Consumption	23.7	Tons/MIGD
Chemical Costs	40,000	US$/yr per MIGD
MSF R&R	1%	TIC/yr
Labor	40,000	US$/yr per MIGD

Multi stage flash — dominant technology world-wide

Courtesy of Corrado Sommariva. Used with permission.

Cross-tube and long-tube MSF distillers



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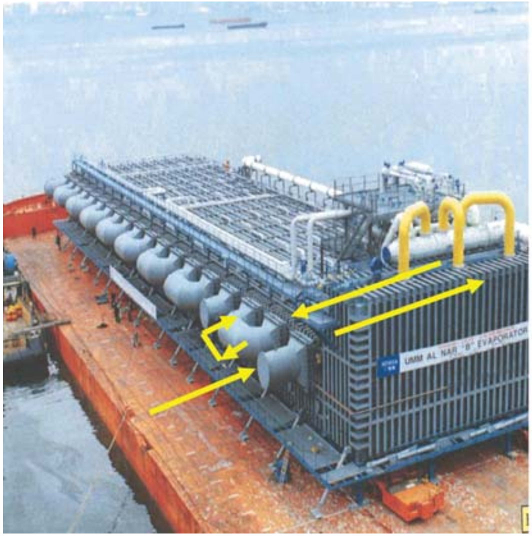
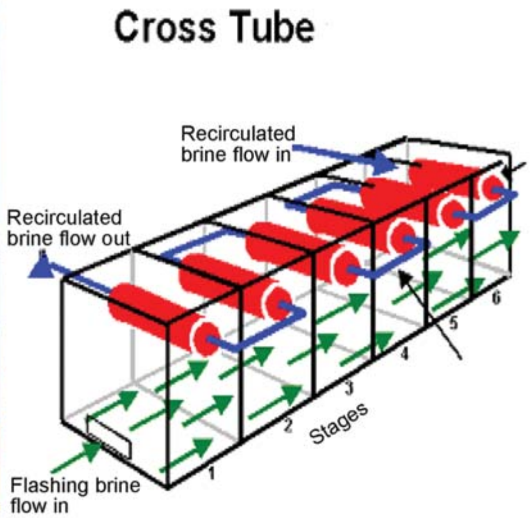
Multi stage flash





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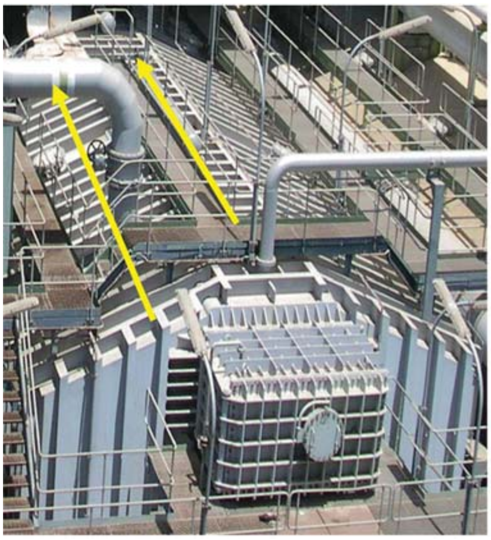

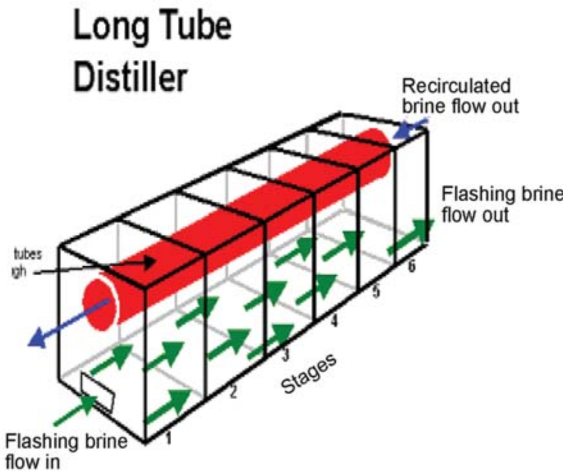

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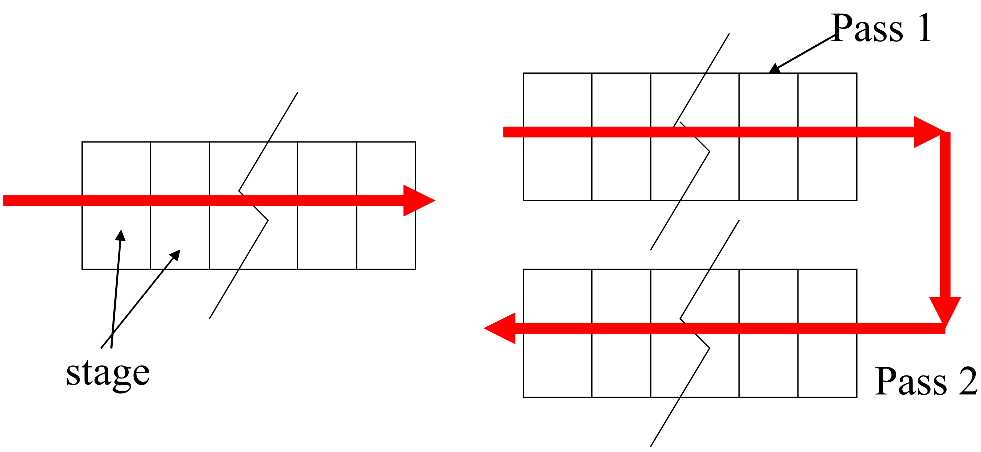
Long tube distillers:
we need to distinguish between the stages and the passes



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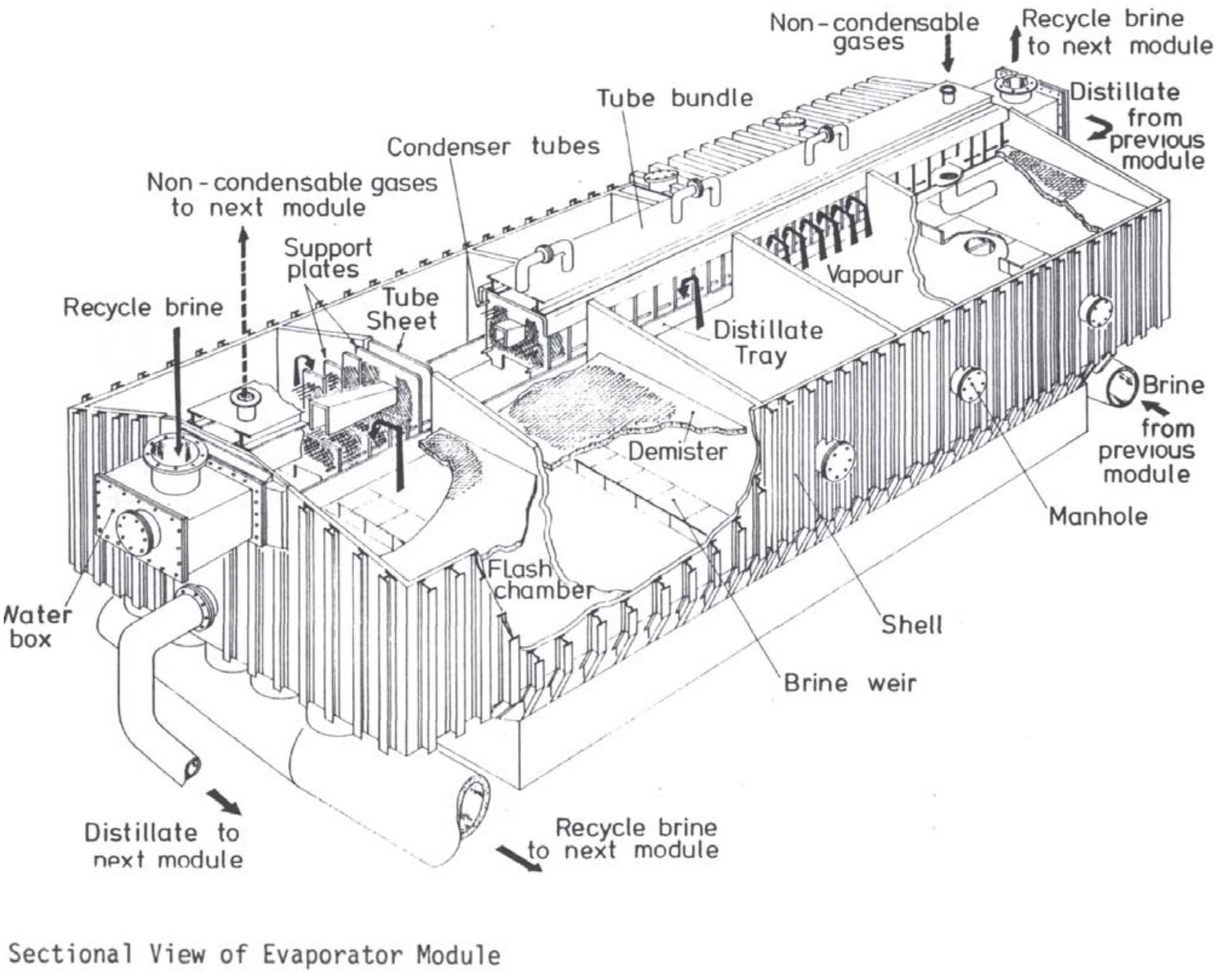
MSF long flow plant internal layout



THE JEBEL ALI K2 INSTALLATION

40 MIGD + 800 MW

3 * 13.33 MIGD
p.r. 8.0 – 8.5 kg/2326 kJ

Courtesy of Leon Awerbuch. Used with permission.

THE SHUWEIHAT INSTALLATION

100 MIGD + 1500 MW

6 * 16.7 MIGD

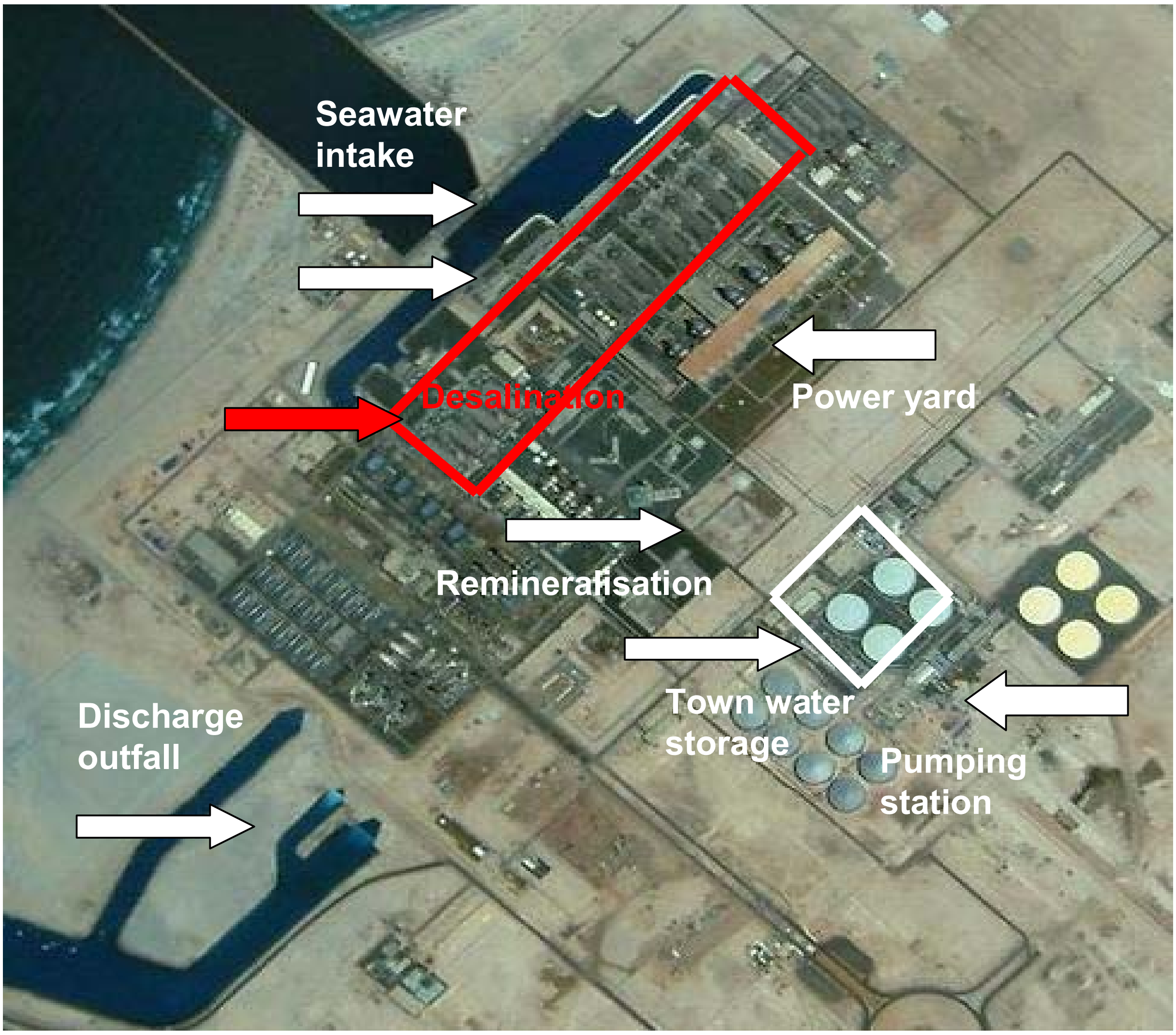
P.R. 9.0 kg/2326 kJ

Drain cooler

Courtesy of Leon Awerbuch. Used with permission.

Interfaces with the rest of the plant

Typical layout



Typical layout

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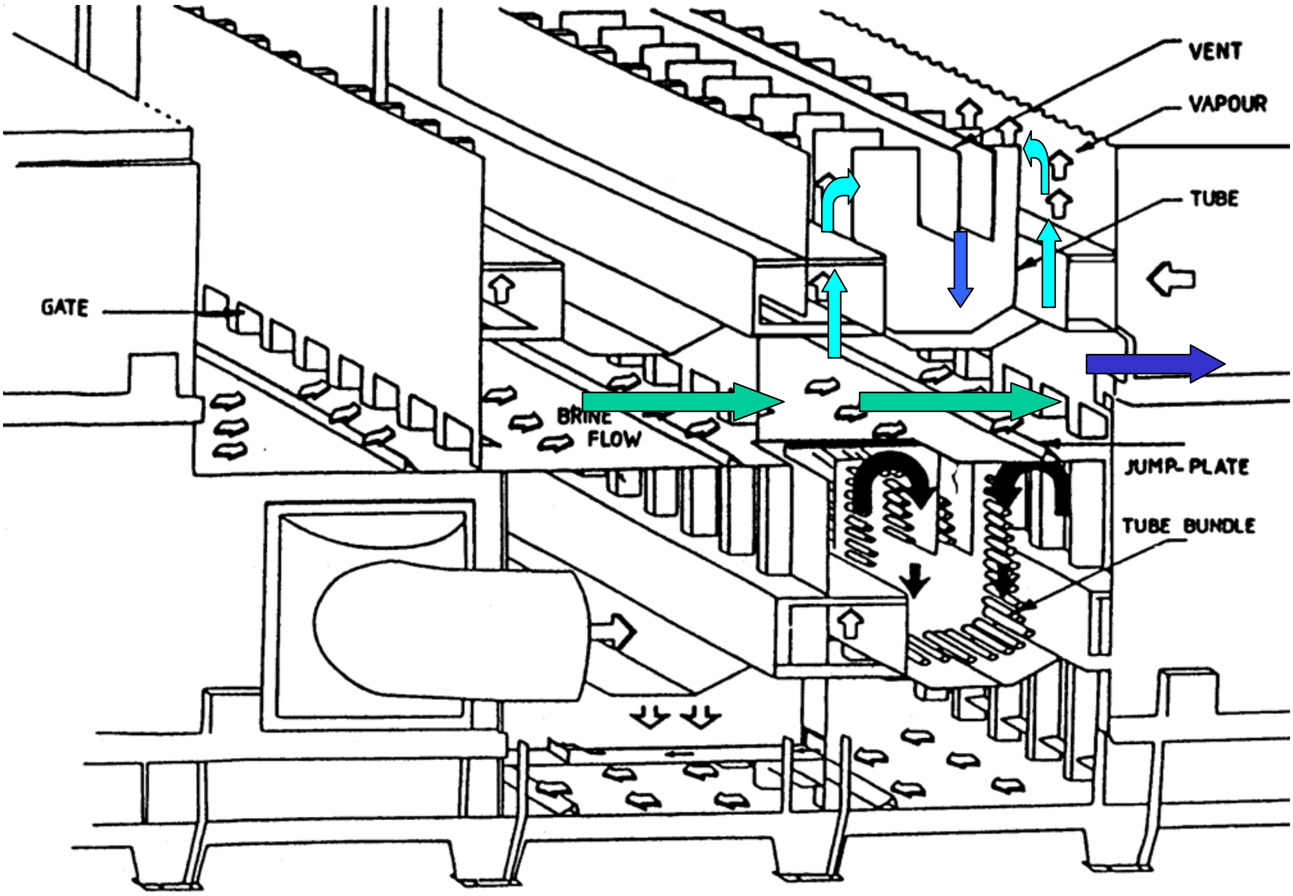
MSF cross flow plant internal layout



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How it really looks like - low side flash chamber

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How it really looks like - upper side

Tube bundle tube supports roof plates and incondensable extraction pipes

Details of tube bundle and tube support

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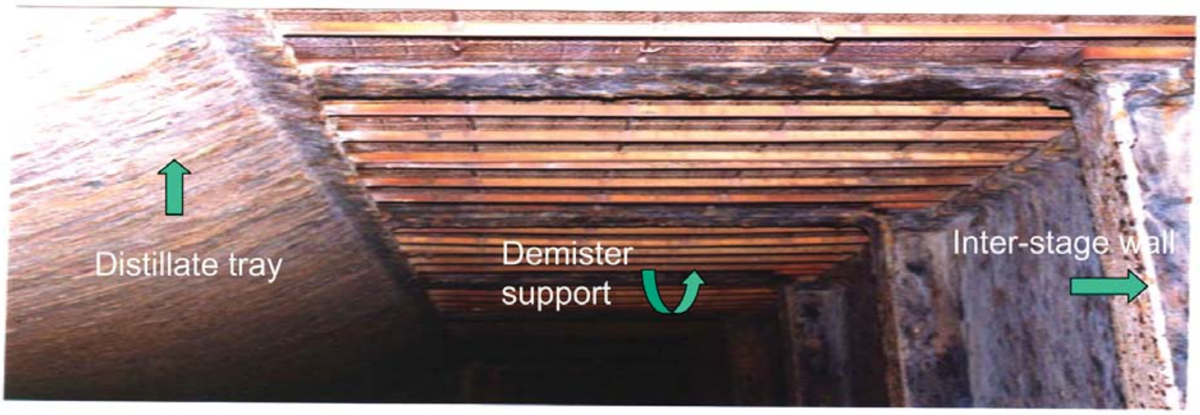
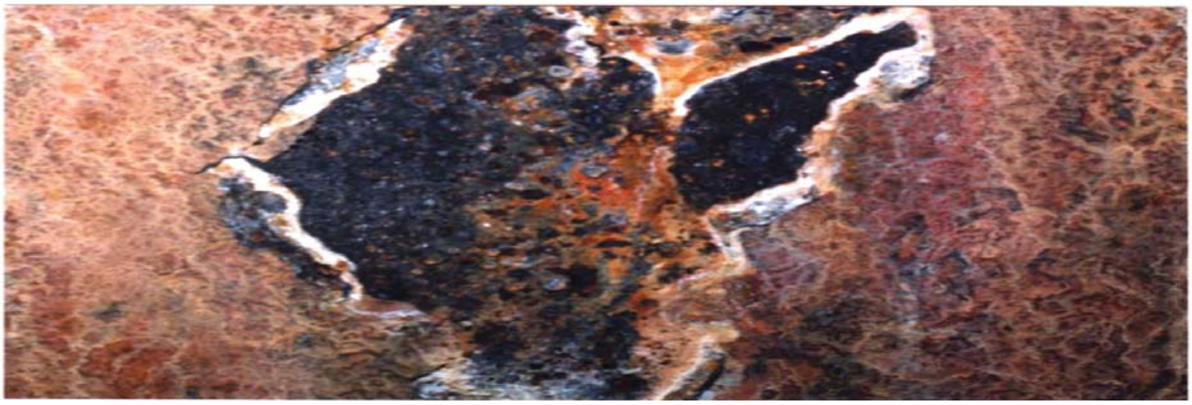


Distillate tray, demister supports and interstage walls



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MSF long flow plant internal layout: how it really looks like

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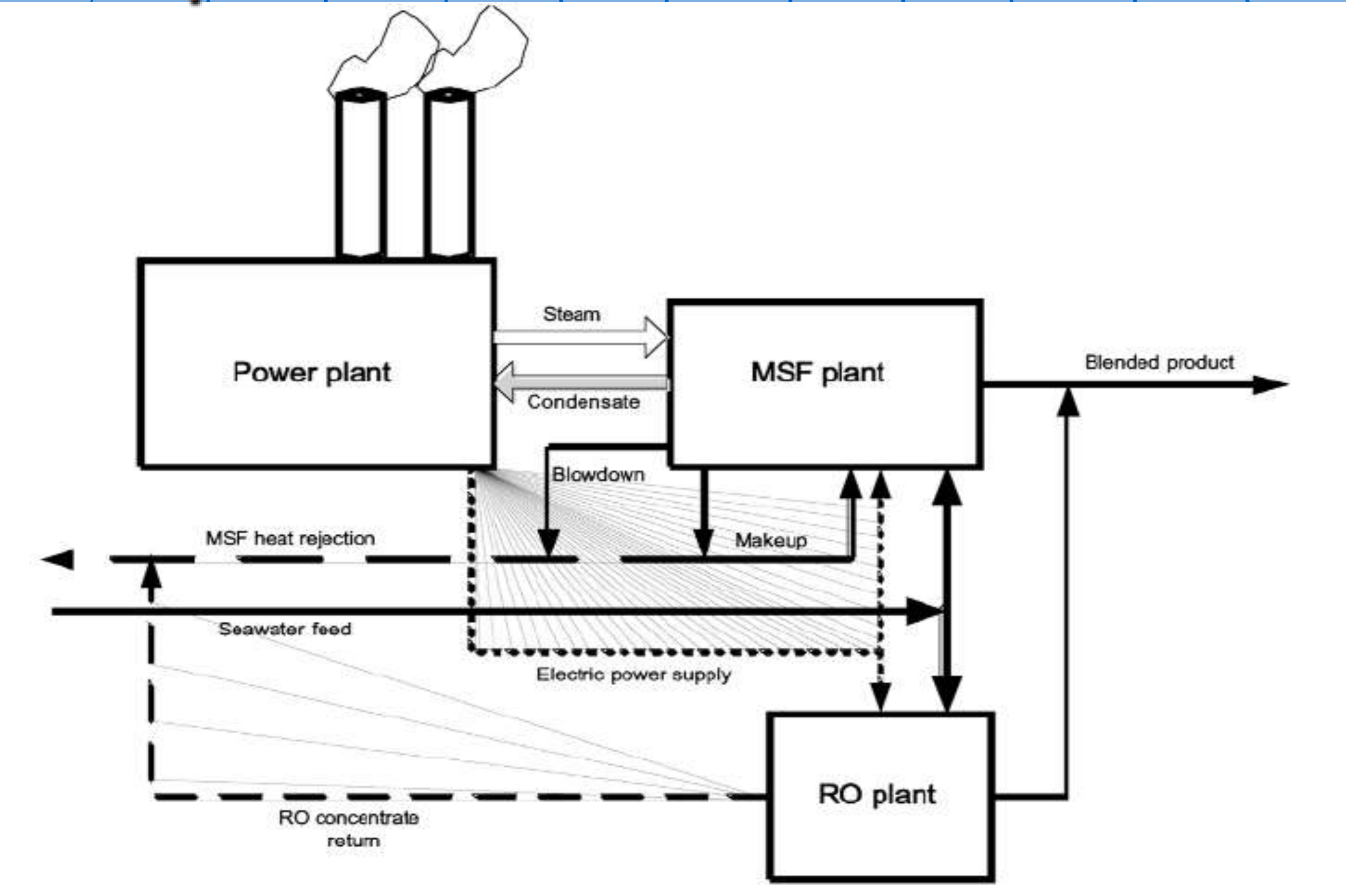
Improvements in distillation processes

- **TOP BRINE TEMPERATURE : The Increase of TBT can Allow Higher Production With Almost Same Desal Trains**
- **HYBRIDIZATION : The Application Of Hybrid Technologies (MSF + RO+NF, or MSF+RO+NF + MED) Can Improve Overall Efficiency**
- **THERMAL IMPROVEMENT : Better HTC , new materials, New MSF+MED Schemes And Ancillary Equipment.**

Potential for MED technology improvements

- Increasing TBT from 63° C to 80-100° C with Nanofiltration
- Increase efficiency to PR 12-16 from current 9.
- Increase unit size to 15 MIGD from current 8 MIGD
- Improve HTC by oval and corrugated plates
- Hybridize with MSF-RO-NF

Example of hybrid system components and their relations.



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Past Simple hybrid

- Product waters from the RO and Distillation plants are blended to obtain suitable product .
- Power to water ratio can be significantly reduced.

GOING TO THE NEXT STEP

- A single stage RO process can be used.
- Higher Recovery lower pretreatment

Integrated hybrid

- The feedwater temp. to the RO plant is optimized using cooling water from the heat-reject section of the MSF/MED or power plant condenser. Constant feed temperature
- The low-pressure steam from the MSF/MED plant is used to de-aerate or use de-aerated brine as a feedwater to the RO plant to minimize corrosion and reduce residual chlorine.

Integrated hybrid

- Blending distillate and membrane permeate will reduce requirements on Boron removal by RO.

  The RO and NF membrane life can be extended. (12 years)

Integrated hybrid environmental benefits

- Cool RO Reject and Feed to be used as a cooling source for heat reject section of distillation plants.
- The blend of reject stream from RO with warm seawater and blowdown from distillation or power plants reduces heavy density plume of RO outfall.
- Blend of RO permeate reduces temperature of distillate.
- A common, smaller seawater intake & outfall.

Fujairah Hybrid.

The Fujairah1 plant due to hybridization generates only 500 MW net electricity for export to the grid, and 662 MW gross for water production capacity of 100 MIGD. Otherwise similar MSF only plant in Shuweihat required 1500 MW for the same 100 MIGD capacity. The Fujairah desalination plant is split into 62.5 MIGD from the thermal part and 37.5 MIGD from the membrane process.

Fujeirah 2 will be 100 MIGD MED and 30 MIGD RO

Fujeirah Plant - Power Desalination Hybrid

LET Proprietary

Benefits of Nanofiltration

PREFERENTIALLY REMOVES SCALING (DIVALENT) IONS

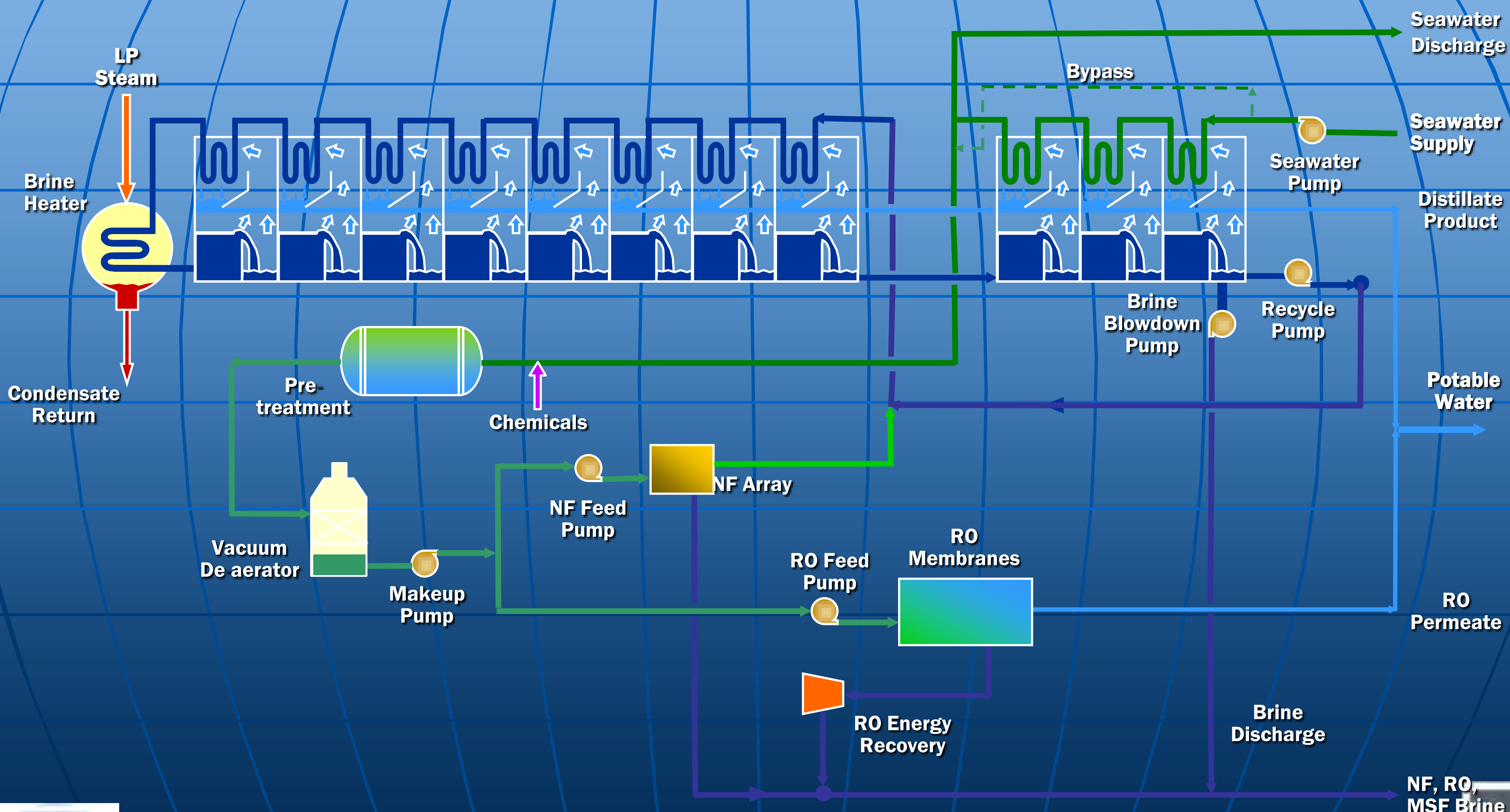
ALLOWS HIGHER TOP BRINE TEMPERATURE FOR MSF (121 vs. 105 ° C)

Higher Flash Range Increases Production

Reduced MSF Capital Costs

Reduced MSF Operating Costs

HYBRID WITH NF PRIOR TO MSF



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Energy Requirements (Steam/Electricity)

	Process Live Steam (ton product/ton steam)	Electricity kWhr/ton product
Multi Stage Flash	8	4
Vapour Compression	n/a	8
Multi Effect Distillation	12	2
Reverse Osmosis:		
with energy recovery	n/a	3.5-5.5
without energy recovery	n/a	8.5

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Energy Requirements for Desalination

Process/energy type	MED	MED - TVC	MSF	VC	RO
Steam pressure, ata	0.2 - 0.4	2.5-3.5	2.5-3.5	_	_
Electric energy equivalent, kWhr/m^3	4.5	9.5-11*	9.5-11.0	_	_
Electric consumption, kWhr/m^3	1.2--1.8	1.2--1.8	3.2-4.0	8.5	3.5-5.0
Total electric energy equivalent, kWhr/m^3	5.2-6.3	10.7-12.8	12.7-15	8.5	3.5-5.0

Power Generation Technologies

Back-pressure Steam Turbines

Extraction Steam Turbines

Gas Turbines

Combined Cycle Plants

Nuclear Energy

Alternative Energy

- Solar, Wind, Geothermal, OTEC, Tide, Wave, Biofuel, PRO-Forward Osmosis

Typical Power to Water Ratios for Different Technologies

Technology PWR=MW required/Million Imperial Gallons per day

Steam Turbine BTG - MSF	PWR = 5.0
Steam Turbine EST - MED	PWR = 7.0
Steam Turbine EST - MSF	PWR = 10.0
Gas Turbine GT - HRSG - MED	PWR = 6.0
Gas Turbine GT - HRSF - MSF	PWR = 8.0
Combined Cycle BTG - MED	PWR = 10.0
Combined Cycle BTG - MSF	PWR = 16.0
Combined Cycle EST - MED	PWR = 12.0
Combined Cycle EST - MSF	PWR = 19.0
Reverse Osmosis RO	PWR = 0.8-1.5

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