BASICS ON THERMAL DESALINATION

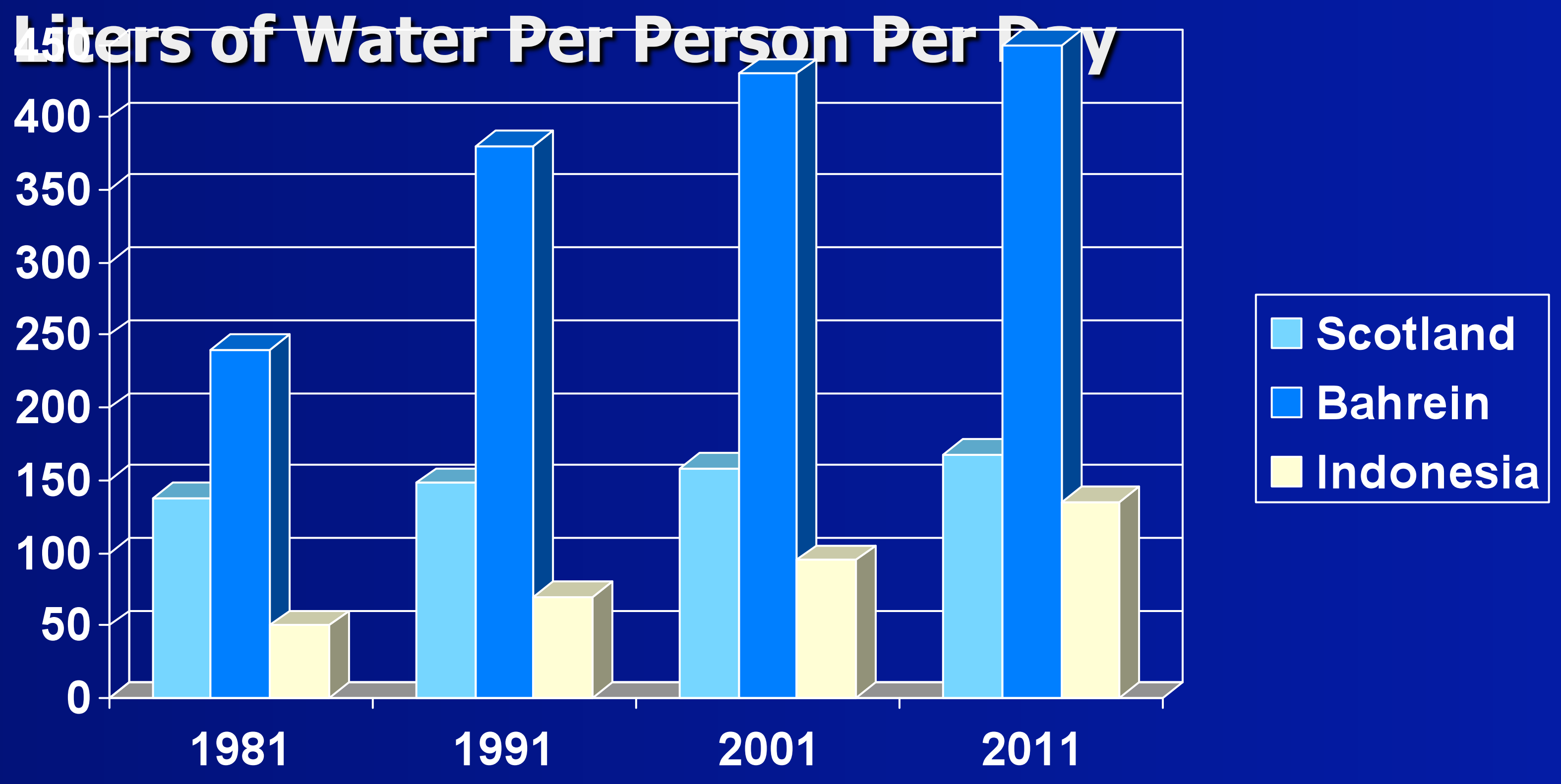
9.00 Introductions

9.15 Desalination Market

- General views of the desalination market

–General views of the desalination market

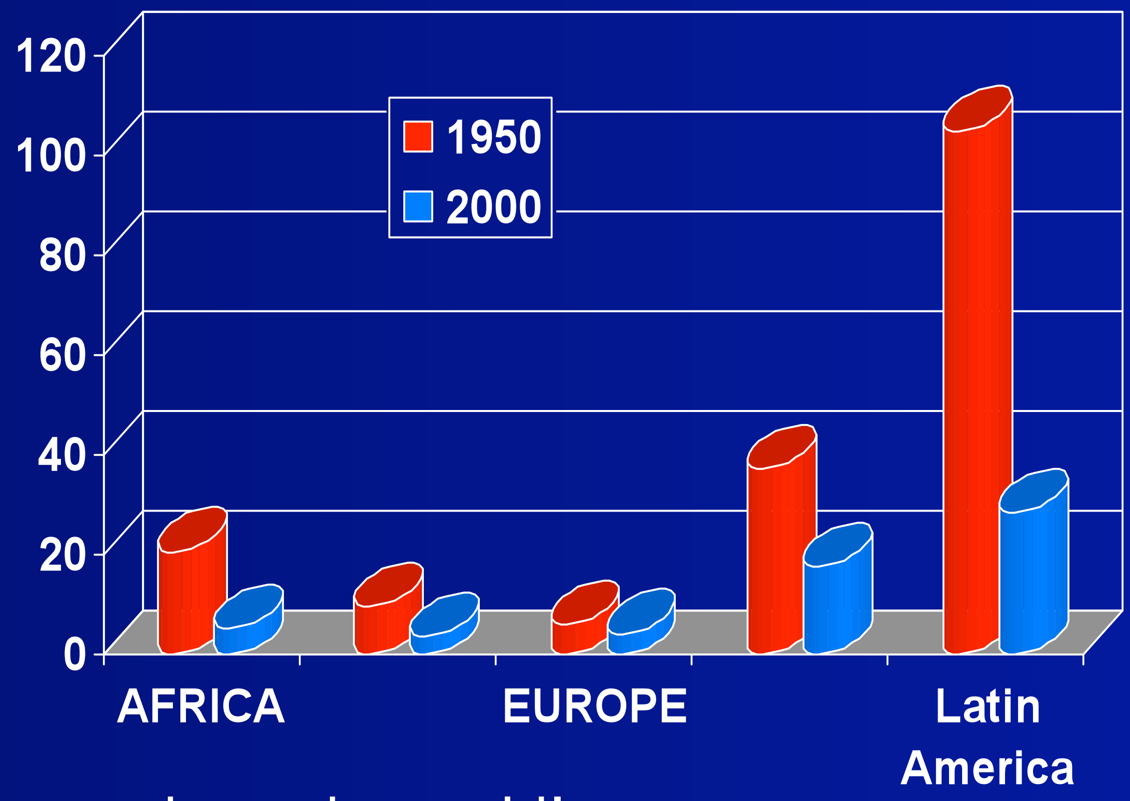
Rising standards of living



Rising Worldwide Population

000 m3 per caput

–General views of the desalination market



Increasing demands on the world's resources

World population - over 10 billion by 2050

–General views of the desalination market

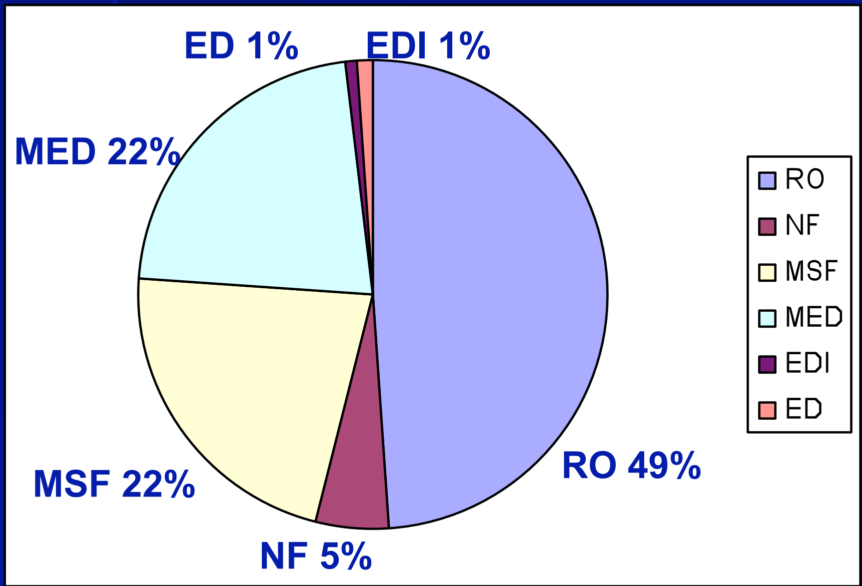
Increasing pressure on the environment

- Recent statistics indicates that currently 2.3 billion people live in water stressed areas.
- 1.7 billion live in water scarce areas with less than 1,000 cubic meters per person per year.

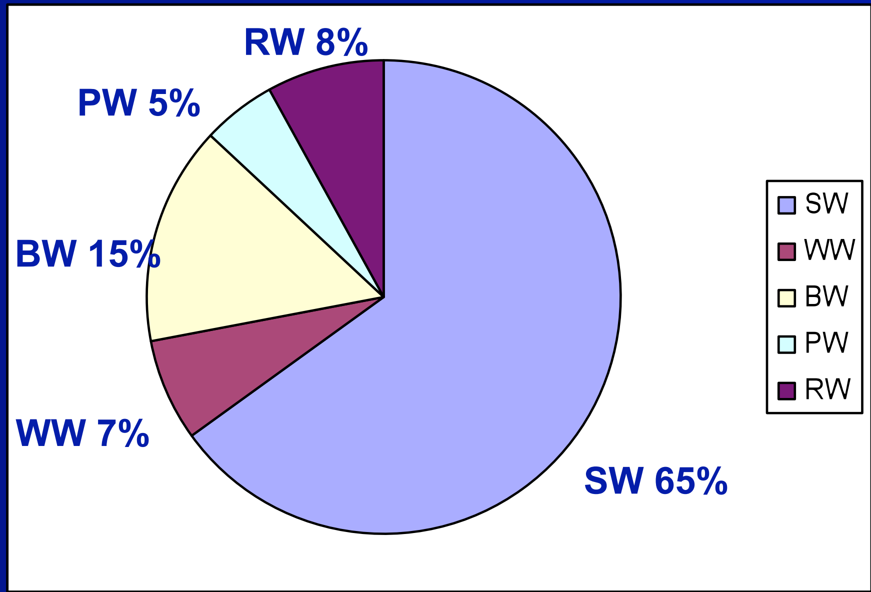
–General views of the desalination market

Global contracted capacity

By technology



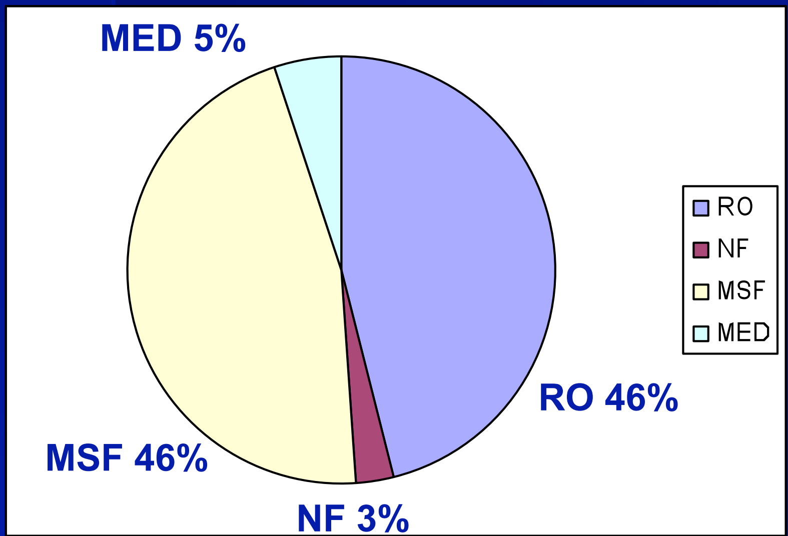
By water type



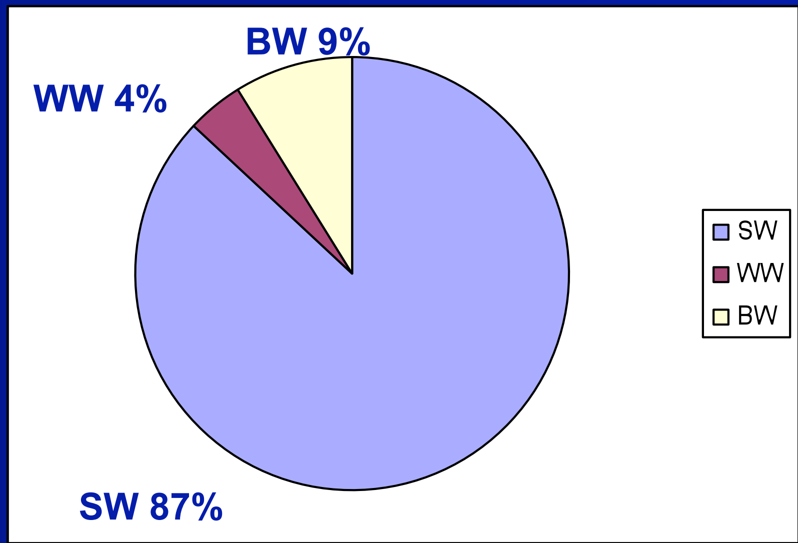
–General views of the desalination market

Contracted capacity in ME&A

By technology

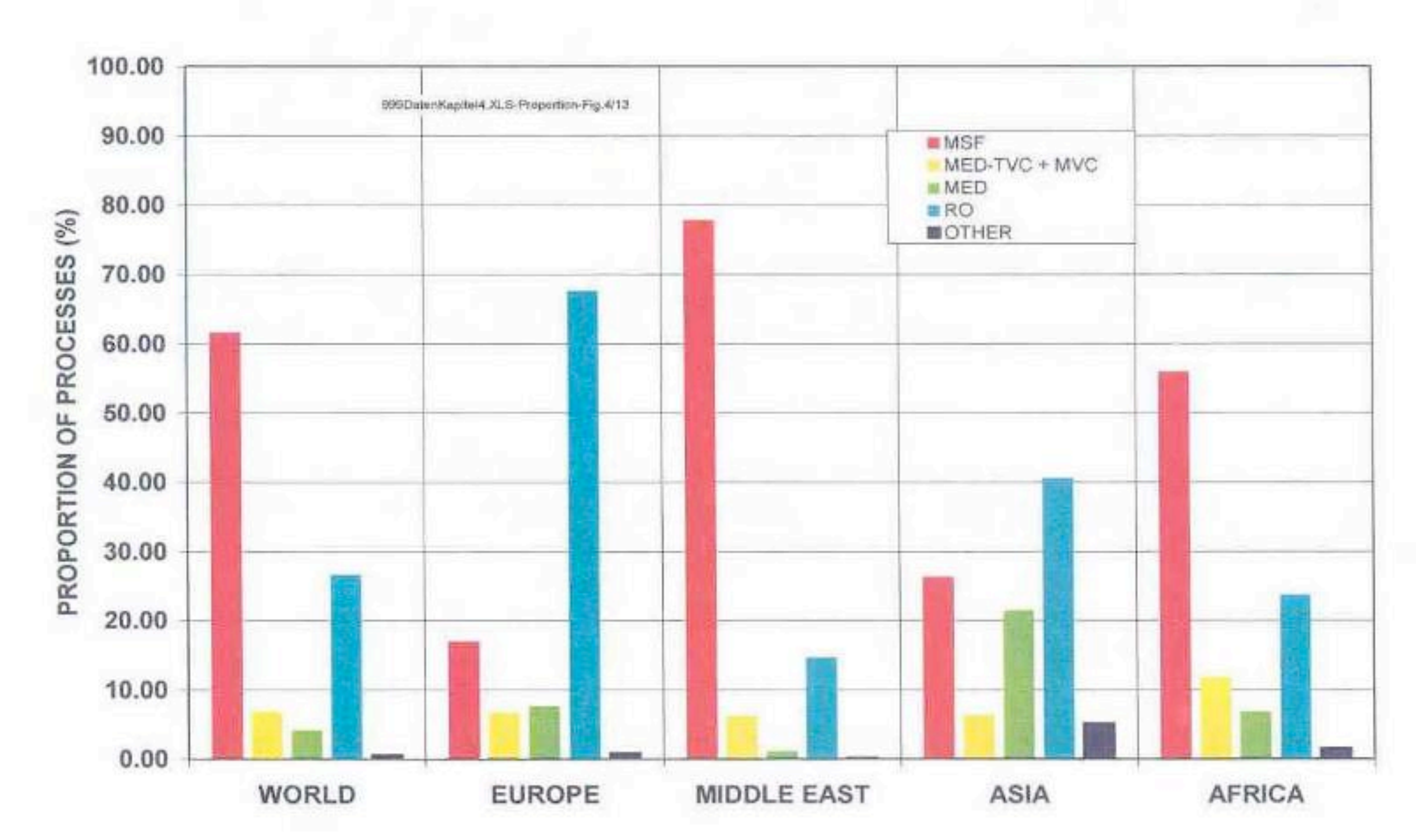


By water type



–General views of the desalination market

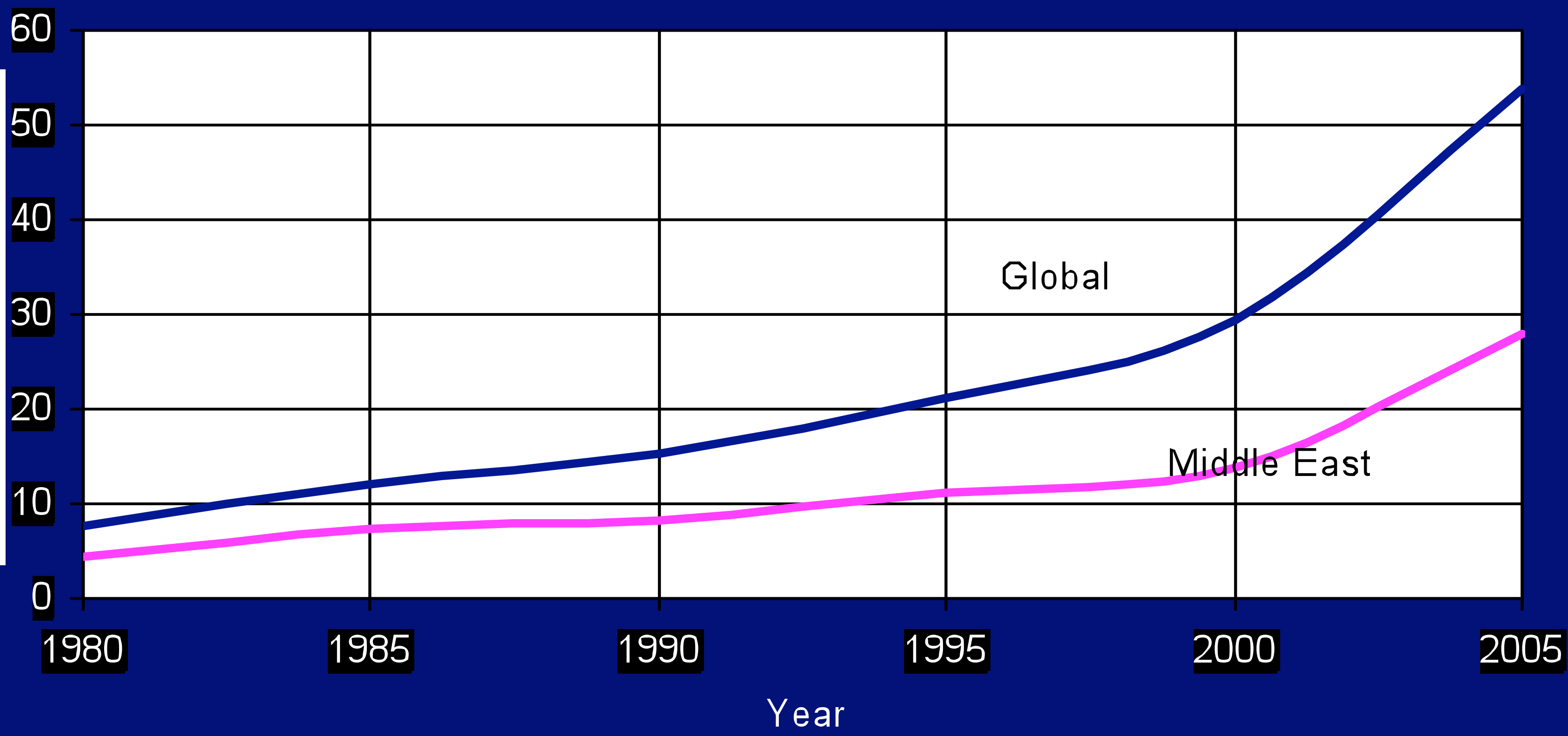
Proportions of the processes (seawater)



–General views of the desalination market

Growth of Desalination

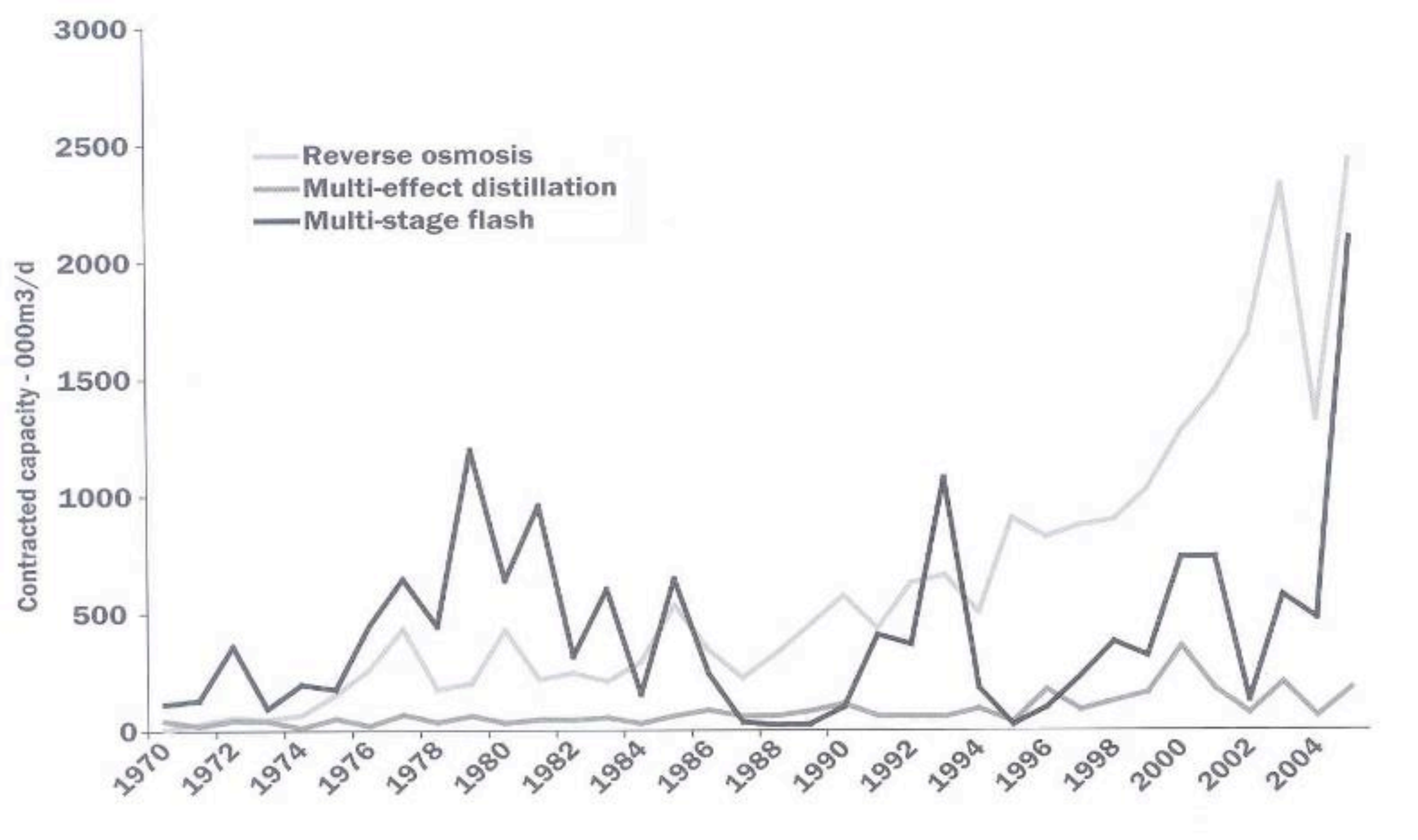
Growth > 25% per year for past 5 years



Growth of Desalination

–General views of the desalination market

Technology trends since 1970

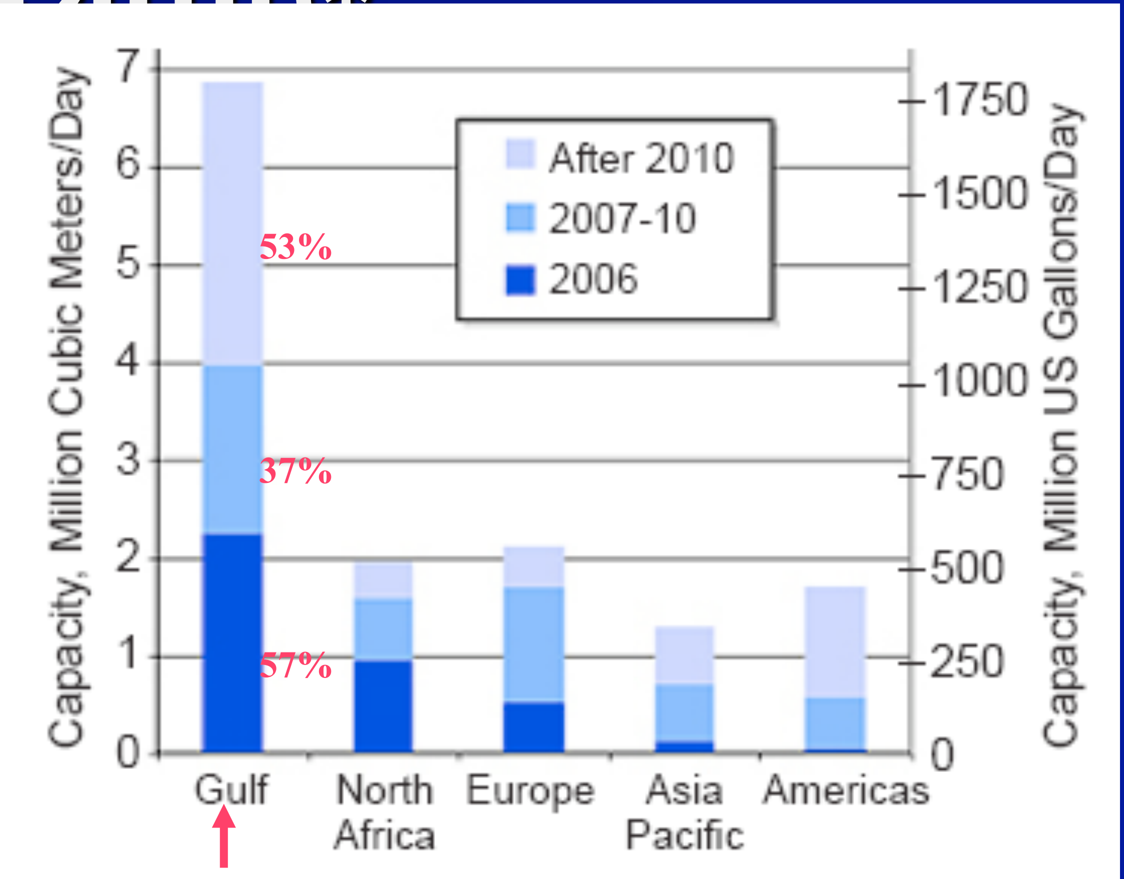


Energy prices reverse desal trends

- Thermal processes are likely to continue to dominate the industry in the Gulf region over the next decade. This is due to potential of cogeneration of power and water
- MED is gaining market share (from 15% to 21 % share of thermal market in new projects)
- Outside Gulf region, RO is dominant

* Water Desalination Report and Global Water Intelligence

Forecast desalination capacity by region – future projects (2006-2010)*



* Water Desalination Report

–General views of the desalination market

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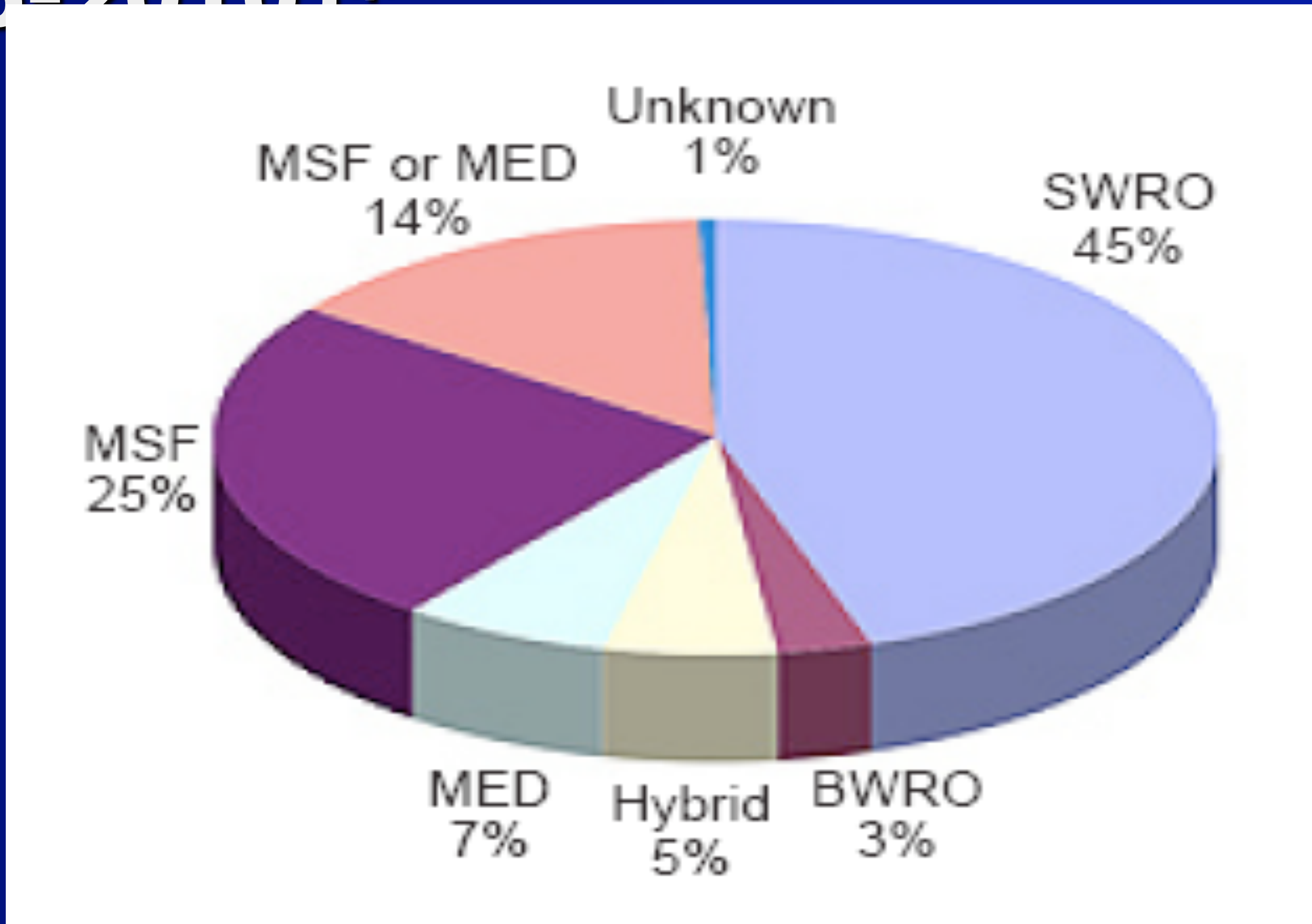


* Water Desalination Report

–General views of the desalination market

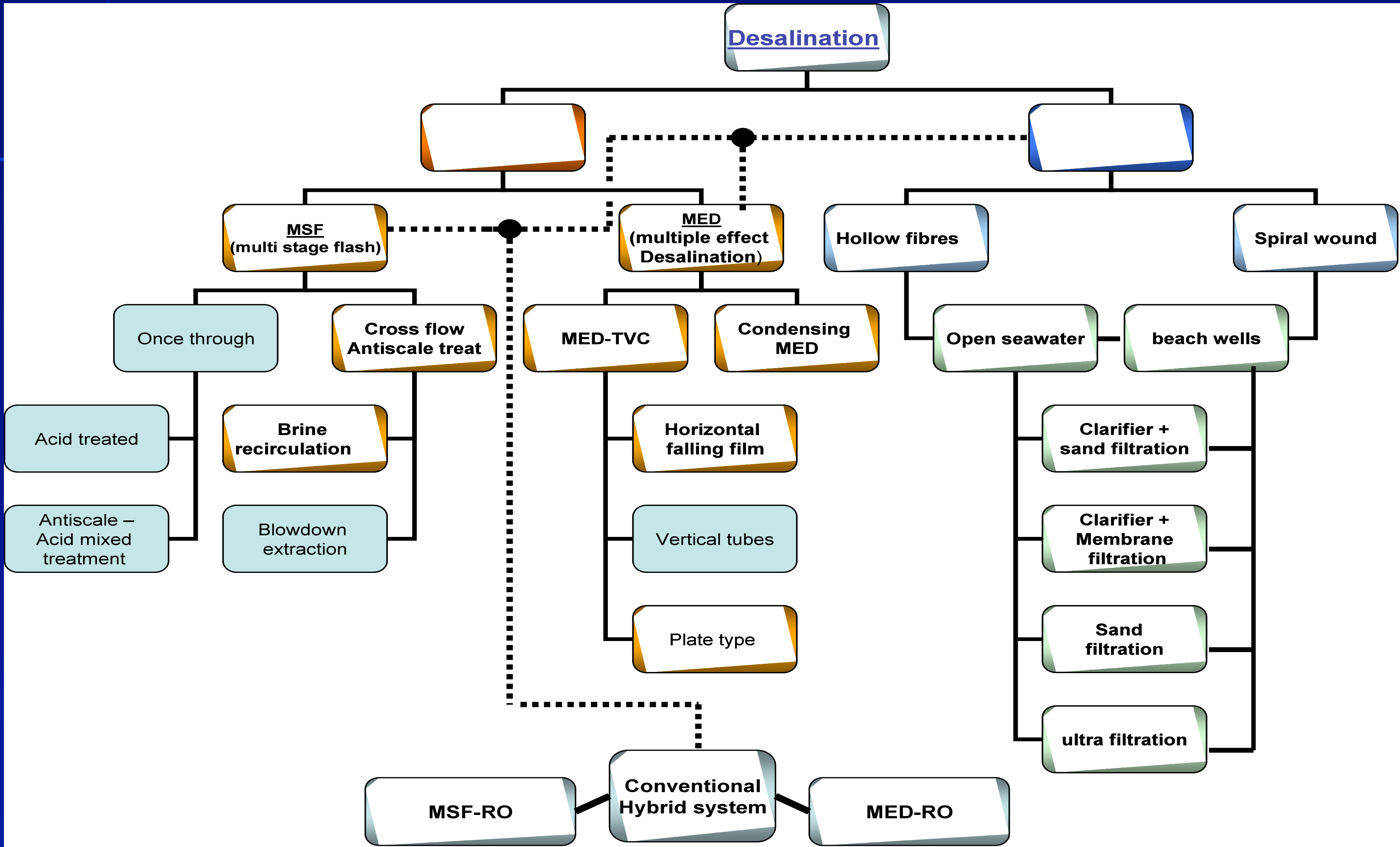
Top 10 countries in terms of proposed capacity (2006 – 2010)*

Country	Rank (2004)	Rank (2010)
Saudi Arabia	2	1
Spain	6	2
USA	3	3
Algeria	9	4
Kuwait	4	5
UAE	1	6
Libya	7	7
Bahrain	14	8
China	12	9
Qatar	8	10

* WDR

Overview of desalination technologies

Energy input : Desalination families



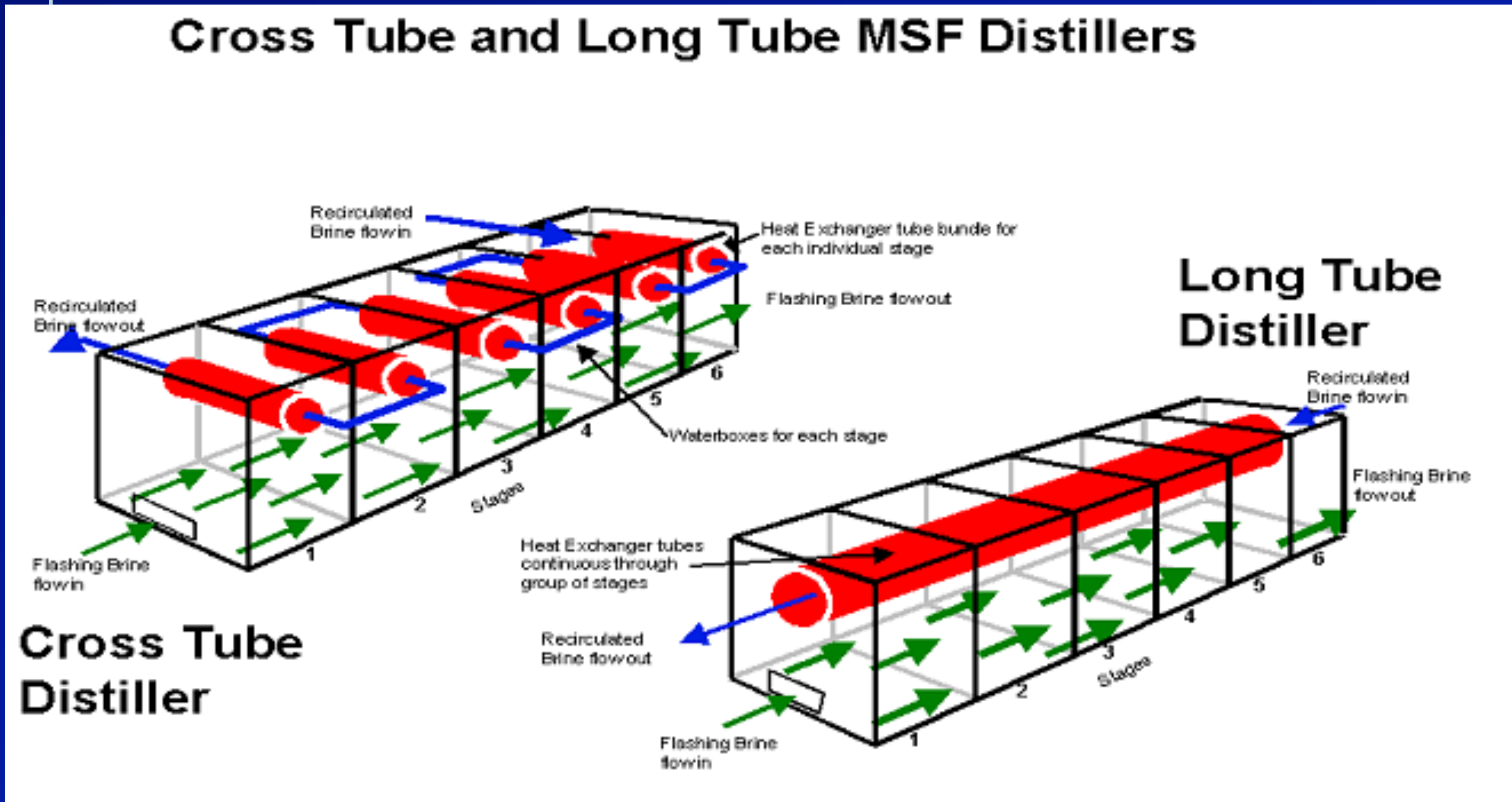
Overview of thermally driven technologies

Multi stage flash

Dominant technology world-

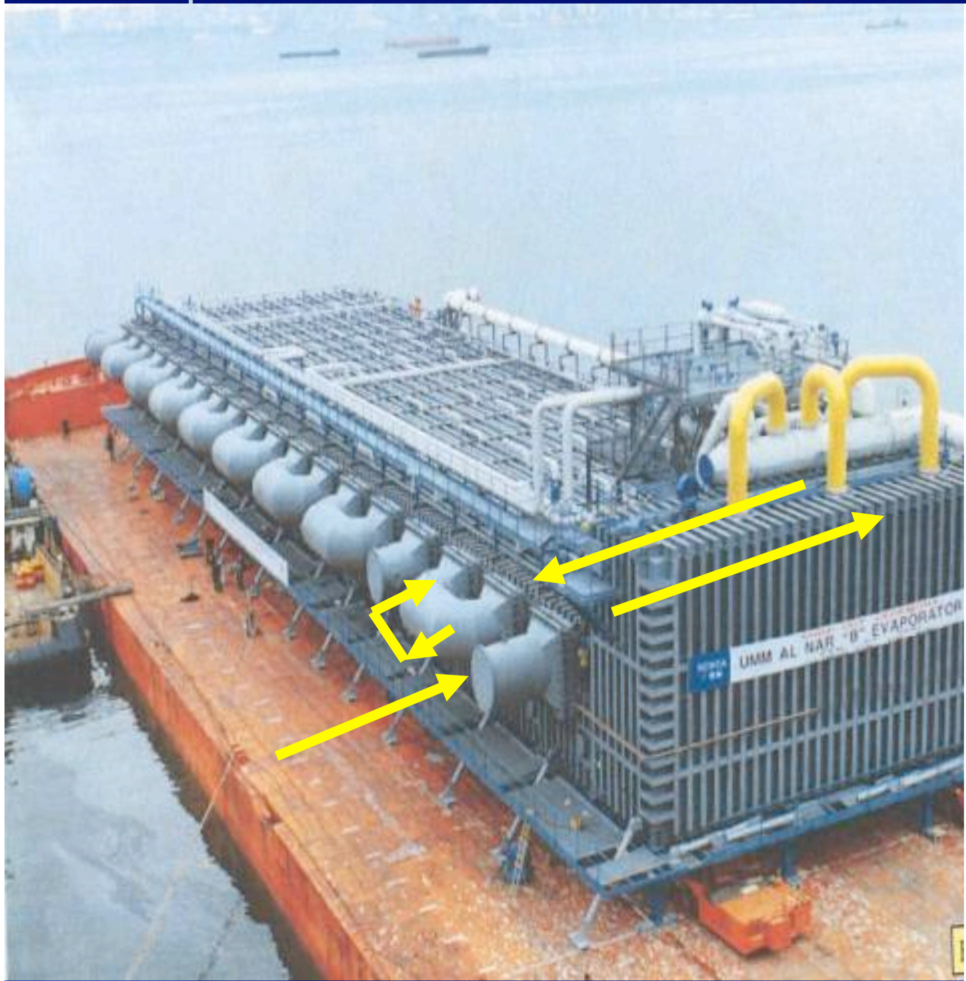
Overview of thermally driven technologies

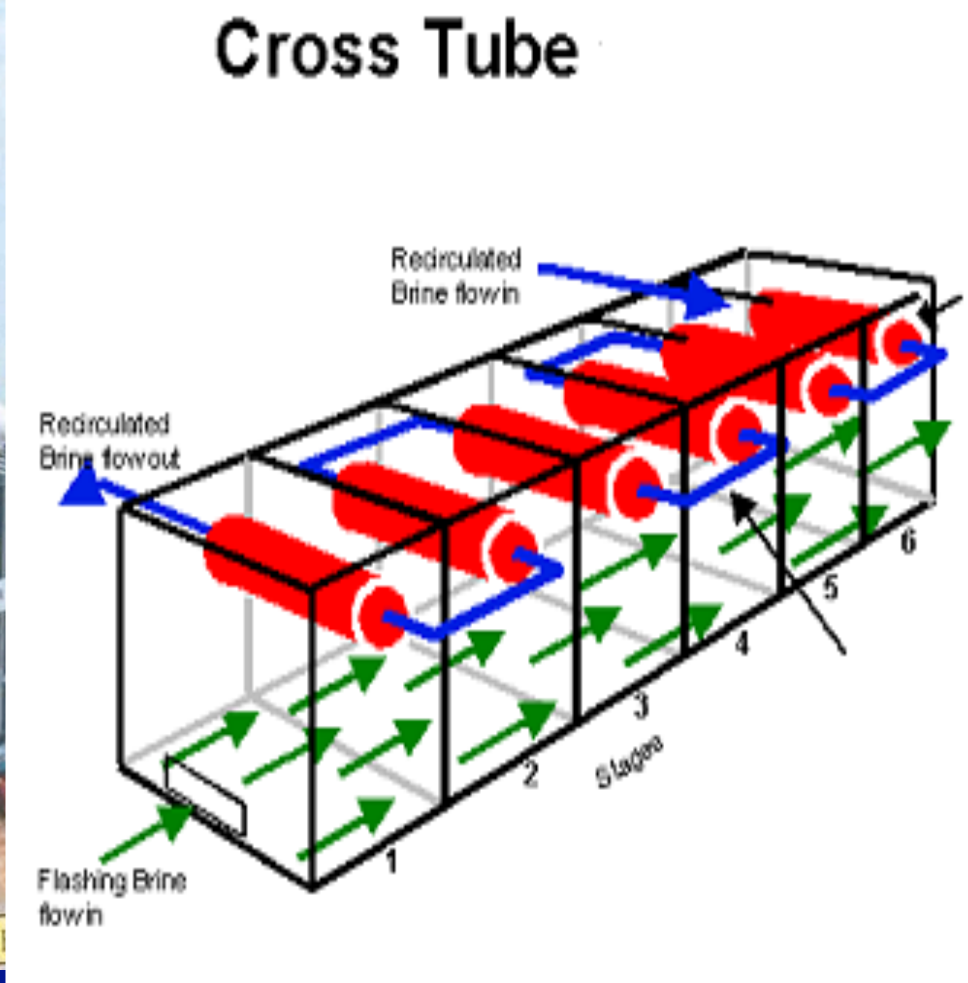
Multi stage flash



Overview of thermally driven technologies

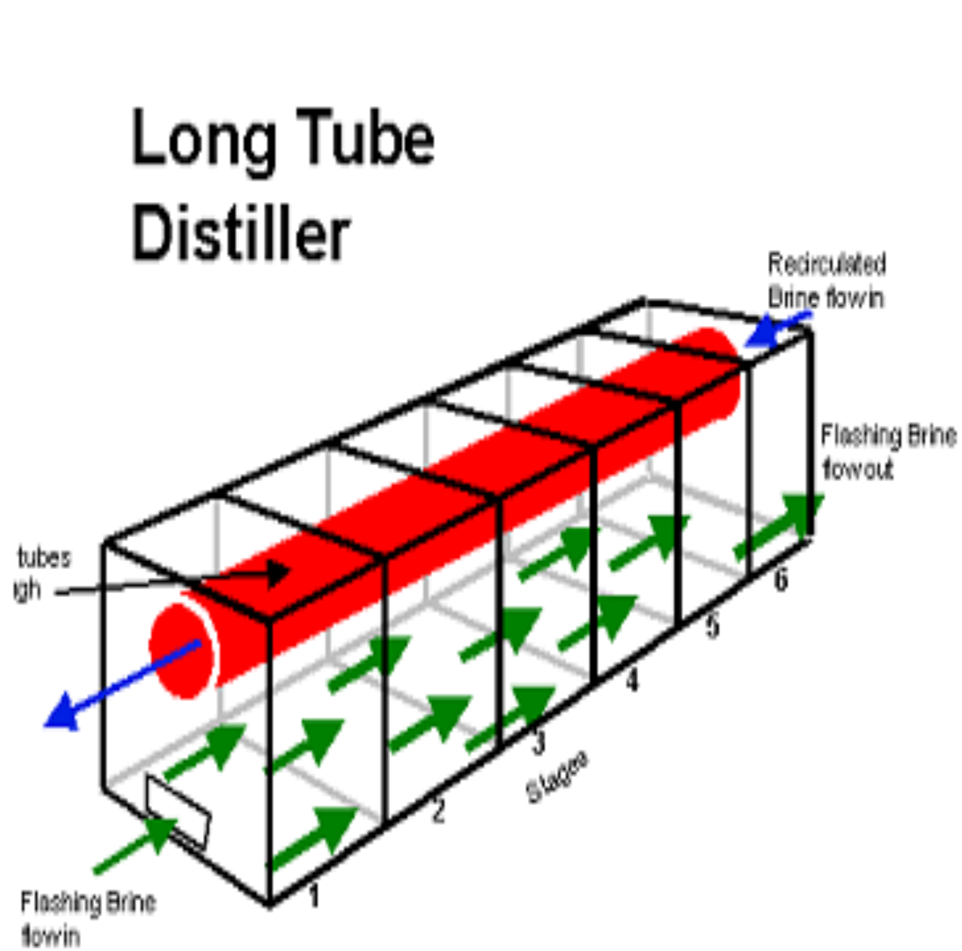
Multi stage flash





Overview of thermally driven technologies

Multi stage flash



Overview of thermally driven technologies

Multiple effect desalination

Evolved from small installation

To relatively large unit size

Overview of thermally driven technologies

Multiple effect desalination

Evolved from small installation

To relatively large unit size

Overview of thermally driven technologies

Multiple effect desalination

With Thermo compression

Condensing

- Overview of desalination technologies

Reverse osmosis

Dominant technology when power plant is not associated to desalination

SWRO technology process features

- In practise there are many hurdles

RO technology is extremely sensitive to :

- Sea water quality and site location
- Pollutants (oil, hydrocarbons) and bio-fouling
- Microelements in seawater (i.e Boron) which presence is totally irrelevant for thermal technologies

RO technology so far has demonstrated limited operational tolerance and deep understanding of engineering and water bio-chemistry aspects

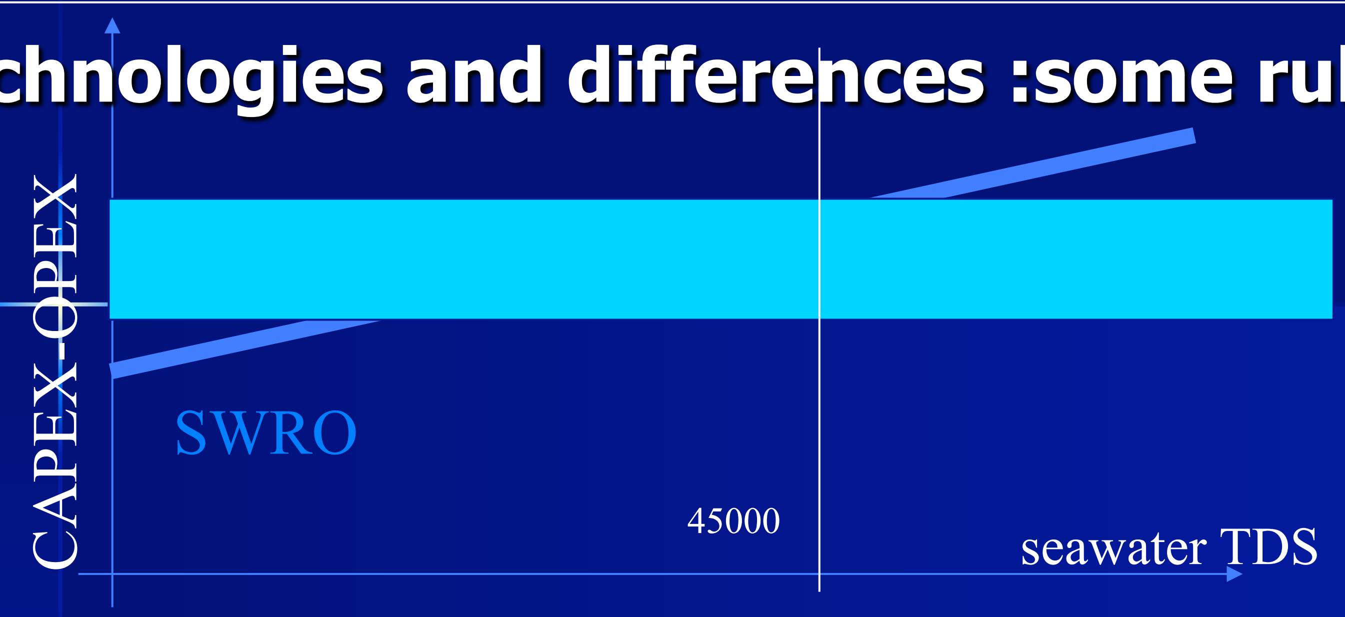
In particular the critical components leading to operational problems in the past have been the pre-treatment

Technologies and differences : some rule of thumb

- Cost effect : SWRO CAPEX and OPEX are greatly affected by :
  - seawater TDS
  - Potable water quality

- Cost effect : Thermal CAPEX and OPEX are only partially affected by :
  - seawater TDS
  - And practically not affected by potable water quality up to TDS of 25 ppm

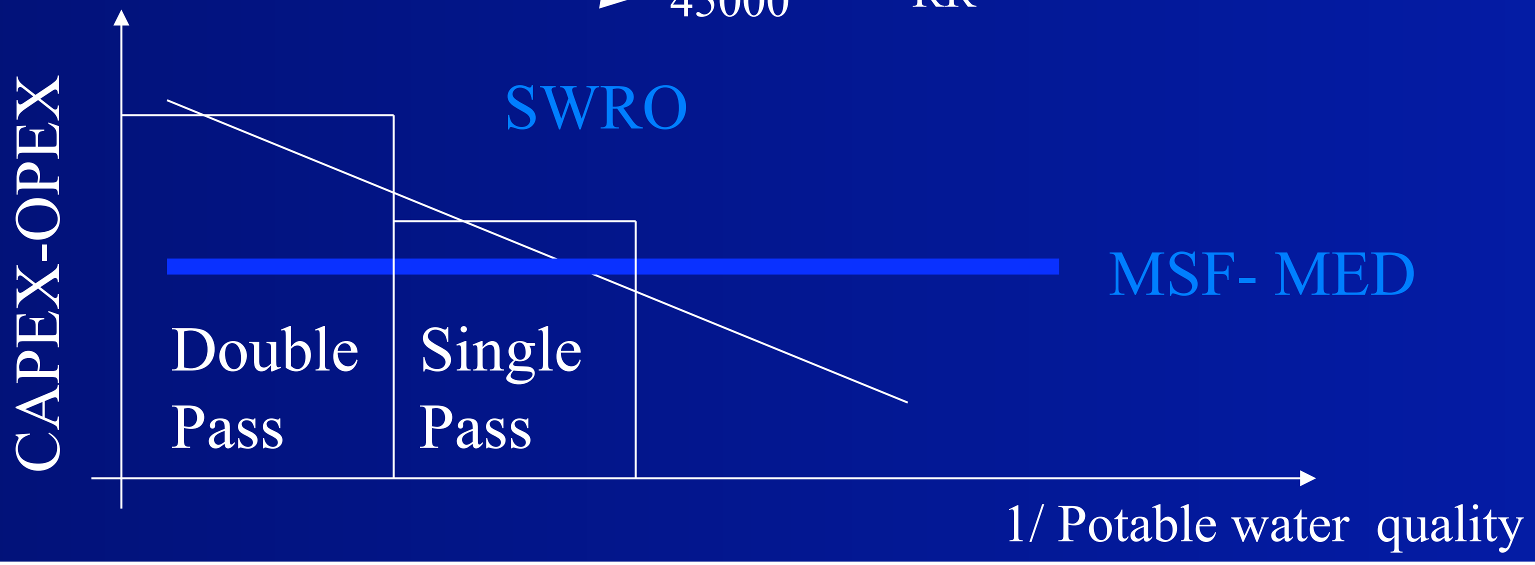
Technologies and differences :some rule of thumb



RR α 1/TDS

SW TDS → 5000 RR → 75%-85%

SW TDS → 45000 RR → 40-45%



Product quality obtained by different processes

Distillation	**5 - 30 mg/l**
Electrodialysis	**≥ 300 – 400 mg/l**
Reverse Osmosis (*)	**100 – 500 mg/l**

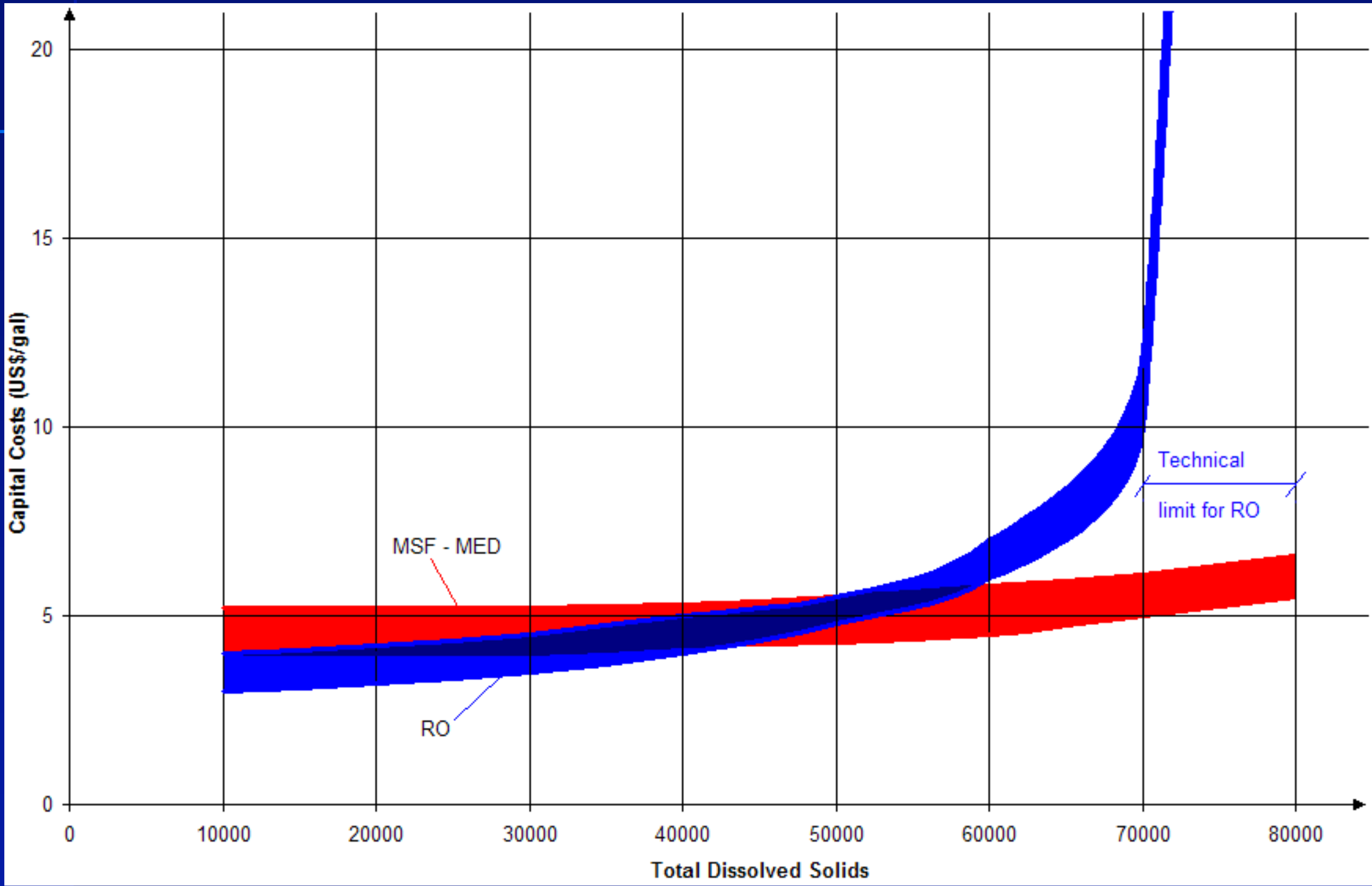
(*) less if second pass

Ex. ASHKELON < 40 mg/l,

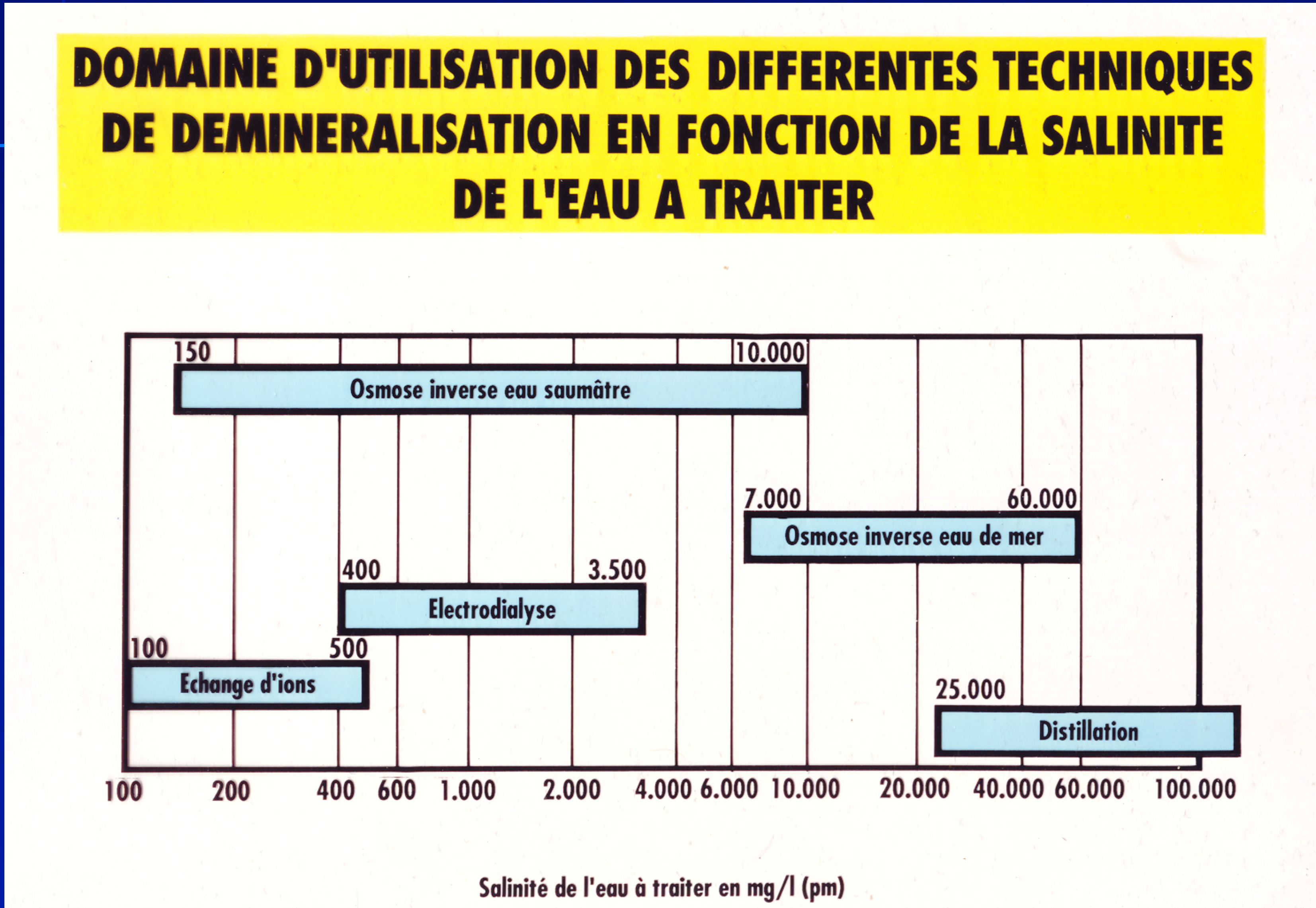
FUJAIRAH = 94 mg/l

Market segmentation

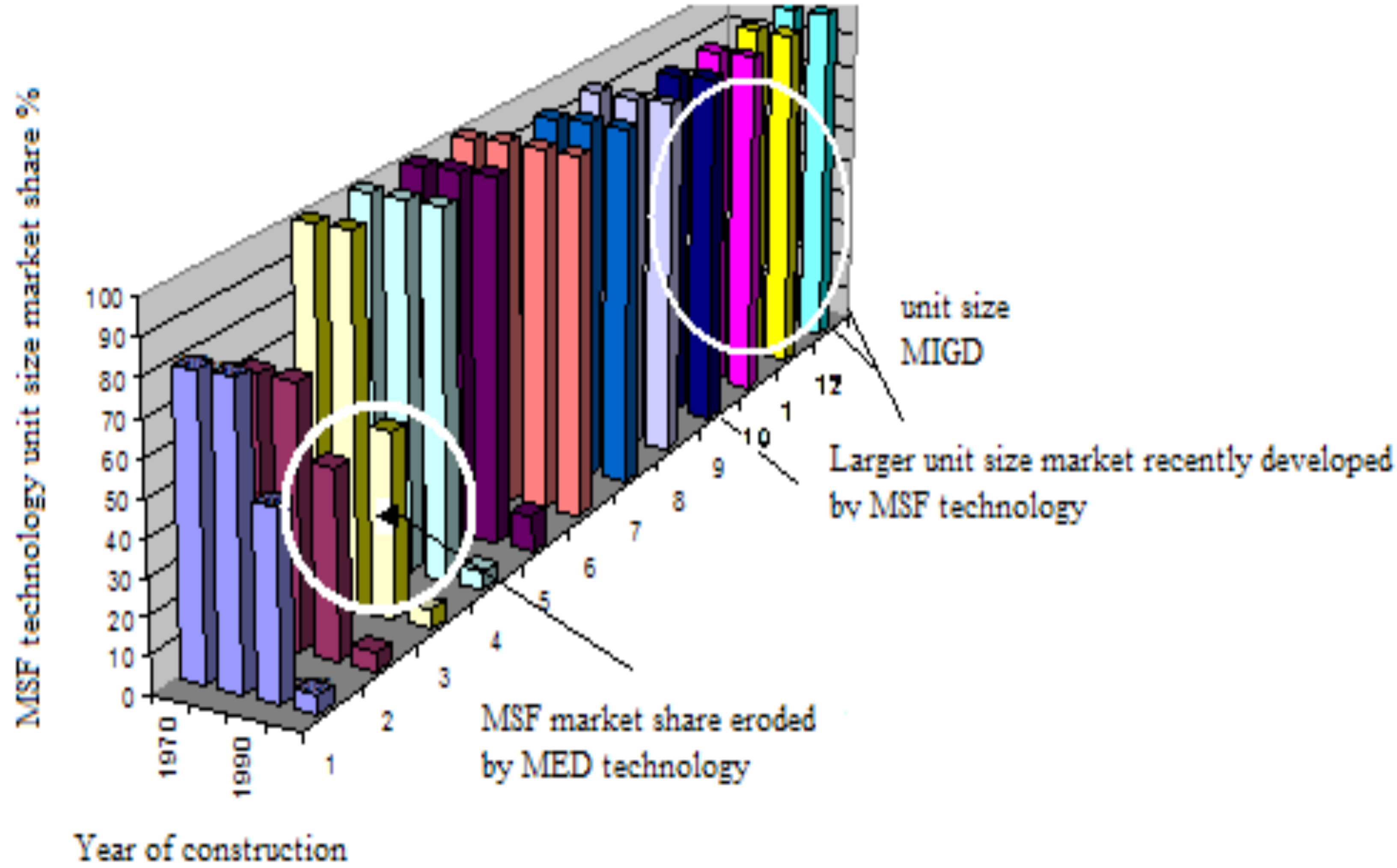
The market segmentation



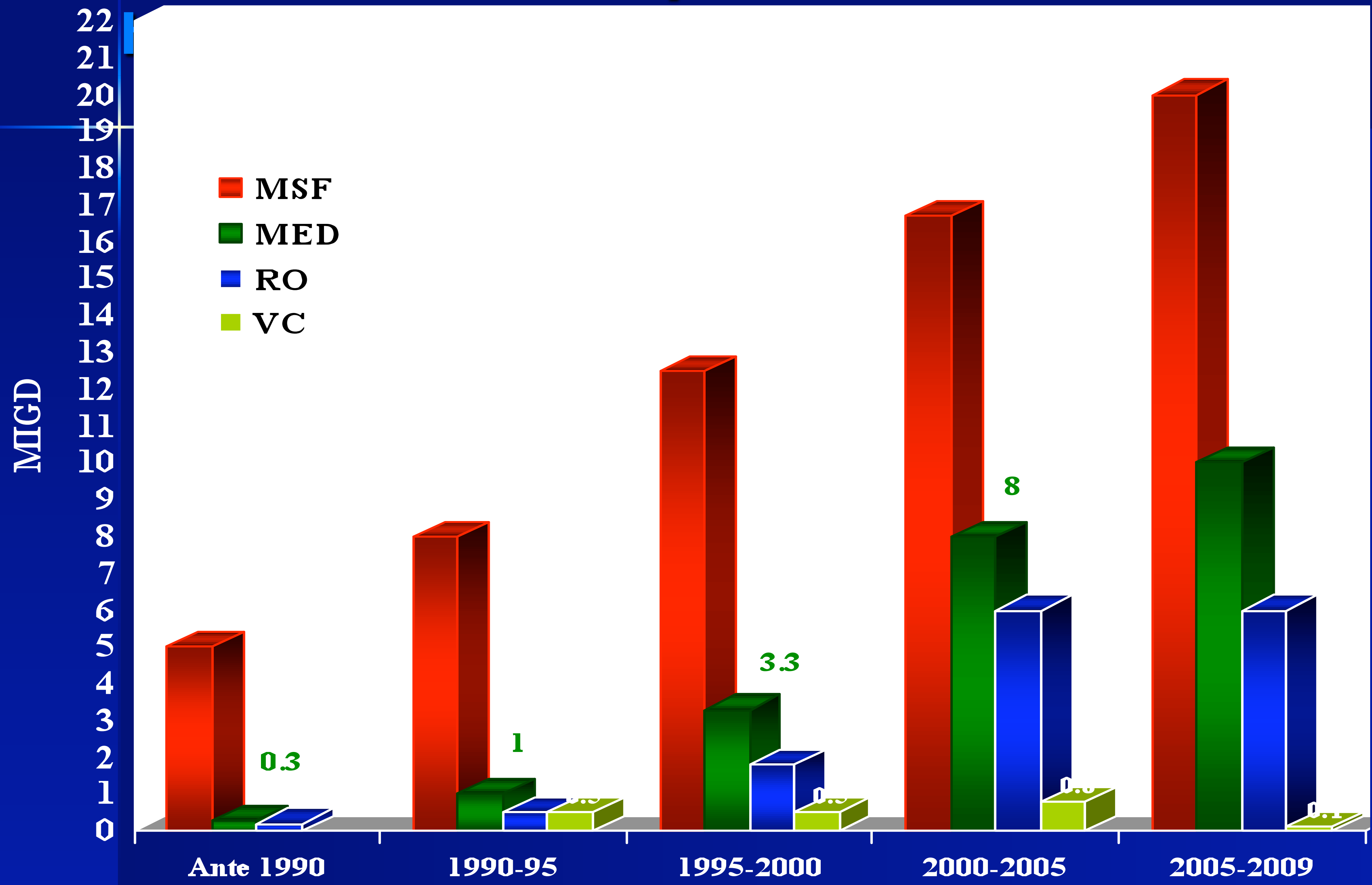
The market segmentation



Thermal desalination plants evolution history

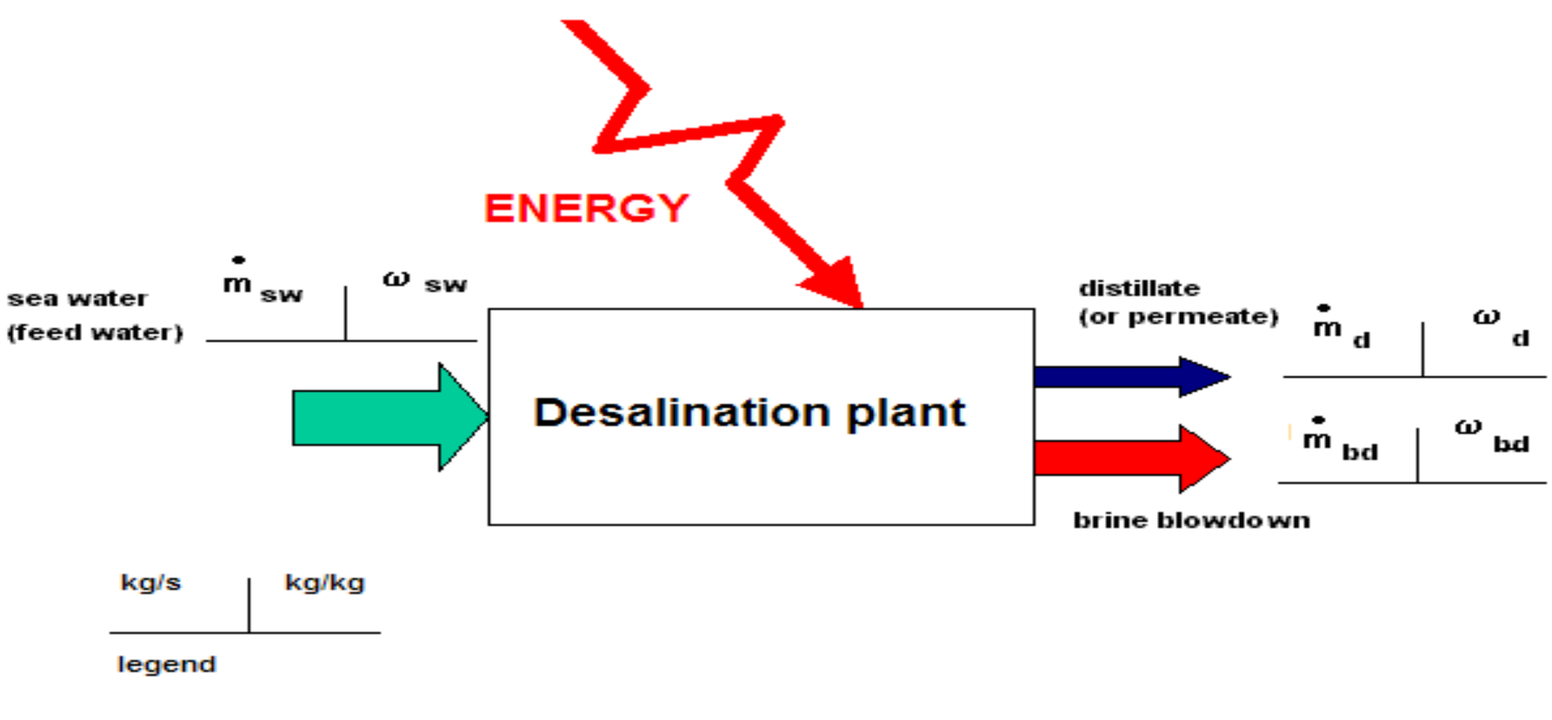


Thermal desalination plants evolution



Desalination plant Basic Mass Balances

Desalination plant Basic Mass Balances

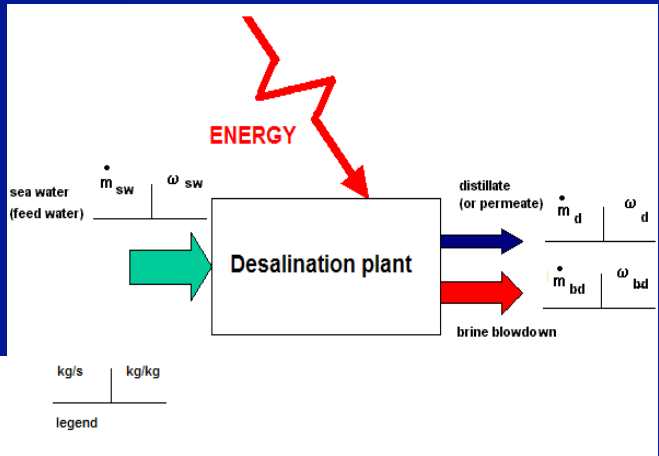


Regardless of the type of process adopted desalination transforms seawater into concentrated brine and distillate (or permeate) by using energy :

Mass Balances relationships

1) mass conservation (overall mass balance)

$$\dot{m}_{sw} = \dot{m}_{bd} + \dot{m}_{d}$$



22) salt conservation (overall salt balance)

$$\dot{m}_{sw} \cdot \omega_{sw} = \dot{m}_{bd} \cdot \omega_{bd} + \dot{m}_{d} \cdot \omega_{d}$$

ω = Salt concentration (kg / kg)

$\dot{m}$ = Mass flow rate (kg / sec)

Mass Balances relationships

Definition of concentration factor :

ratio between blowdown and seawater salt concentration

$$Cf_{bd} = \frac{\omega_{bd}}{\omega_{sw}}$$

Mass Balances relationships

Rearranging equation 1) and 2)

and using the definition of concentration factor

we can obtain a formula relating seawater

requirement and product distillate capacity

$$\dot{m}_D = \dot{m}_{sw} \cdot \left(1 - \frac{1}{Cf_{bd}}\right)$$

- Note this formula is valid for all types of desalination processes including RO

Mass Balances relationships

But ….. Then why seawater consumption for SWRO technology is much lower than for thermal ?

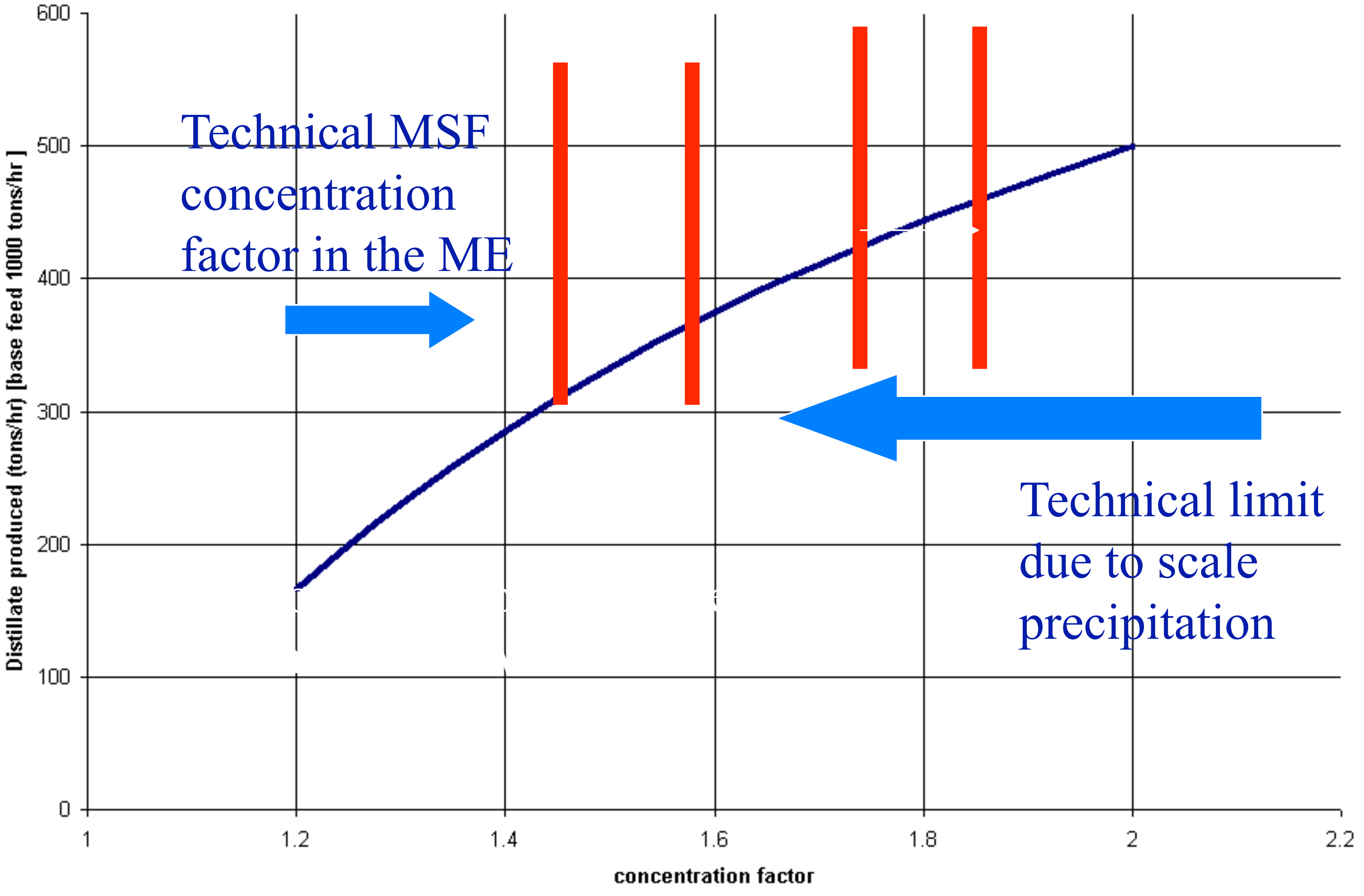
Mass Balances relationships

- Concentration factor – production ratio : theoretically it would be best to concentrate as much as possible
- However it is not possible to concentrate seawater – blowdown above a certain limit.
- The following constraints occur :
- scale precipitation in tube bundle are more frequent the more salt is concentrated

Concentration factor – production ratio

- Experience with all systems indicated need for scale control
- Hot brines easily reached saturation with inorganic species ($Mg(OH)_2$, $CaCO_3$, $CaSO_4$, etc.)
- Scale restricted flow paths, reduced heat transfer, caused outages

Concentration factor – production ratio



Concentration factor – production ratio

- A glance to ro technologies : Concentration factor – production ratio for RO system

- Typically the recovery rate for a SWRO is 38% to 45%

$$RR = 100\% \cdot \frac{\dot{m}_p}{\dot{m}_{SW}} = 100\% \frac{\dot{m}_p}{\left(\dot{m}_p + \dot{m}_{conc}\right)}$$

Concentration factor – production ratio

- A glance to other technologies : Concentration factor – production ratio for RO system

$$RR = \frac{TDS_{con} - TDS_{sw}}{TDS_{con} - TDS_{perm}}$$

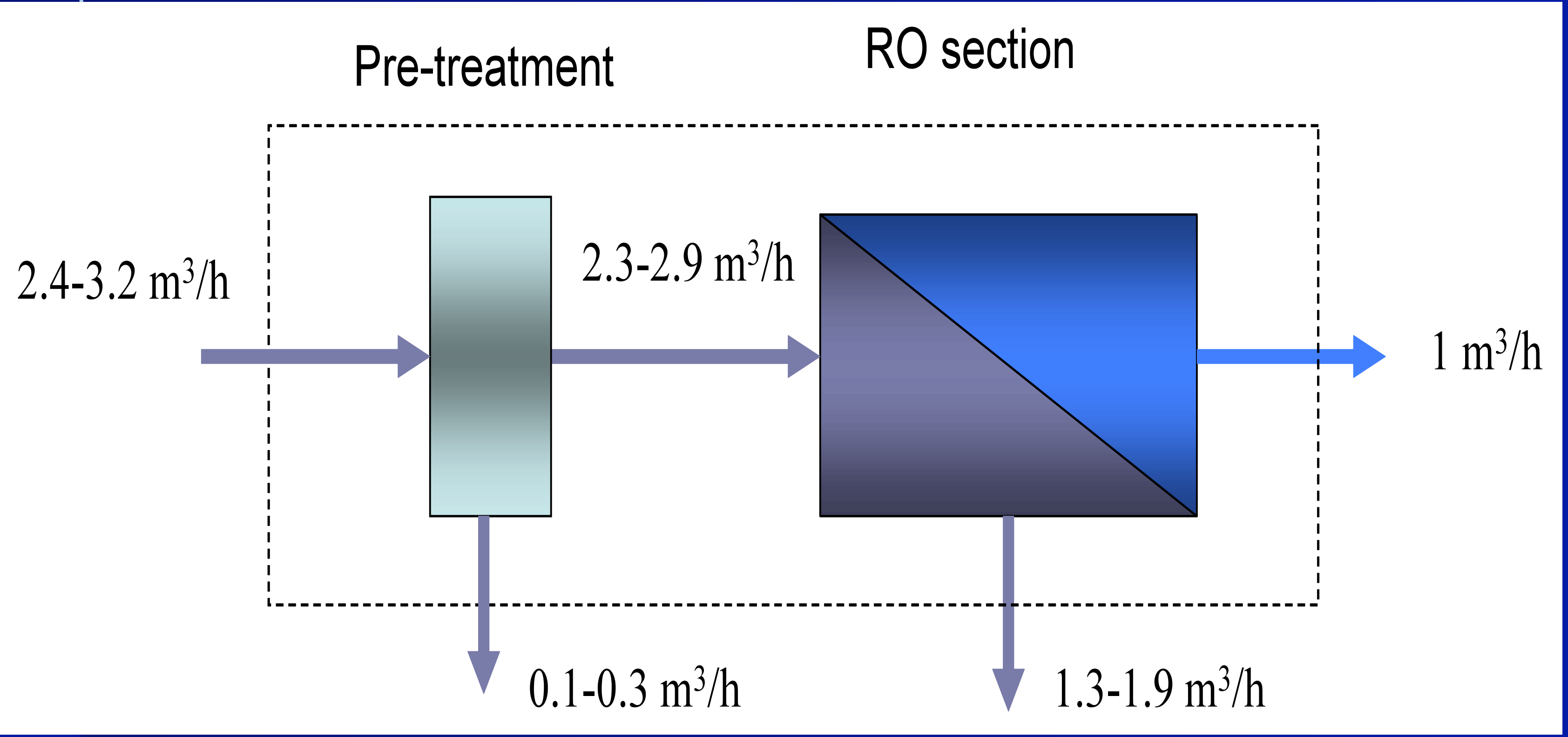
$$C_F = \frac{1}{1-RR} = \frac{1}{1-0.45} = 1.82$$

Concentration factor – production ratio

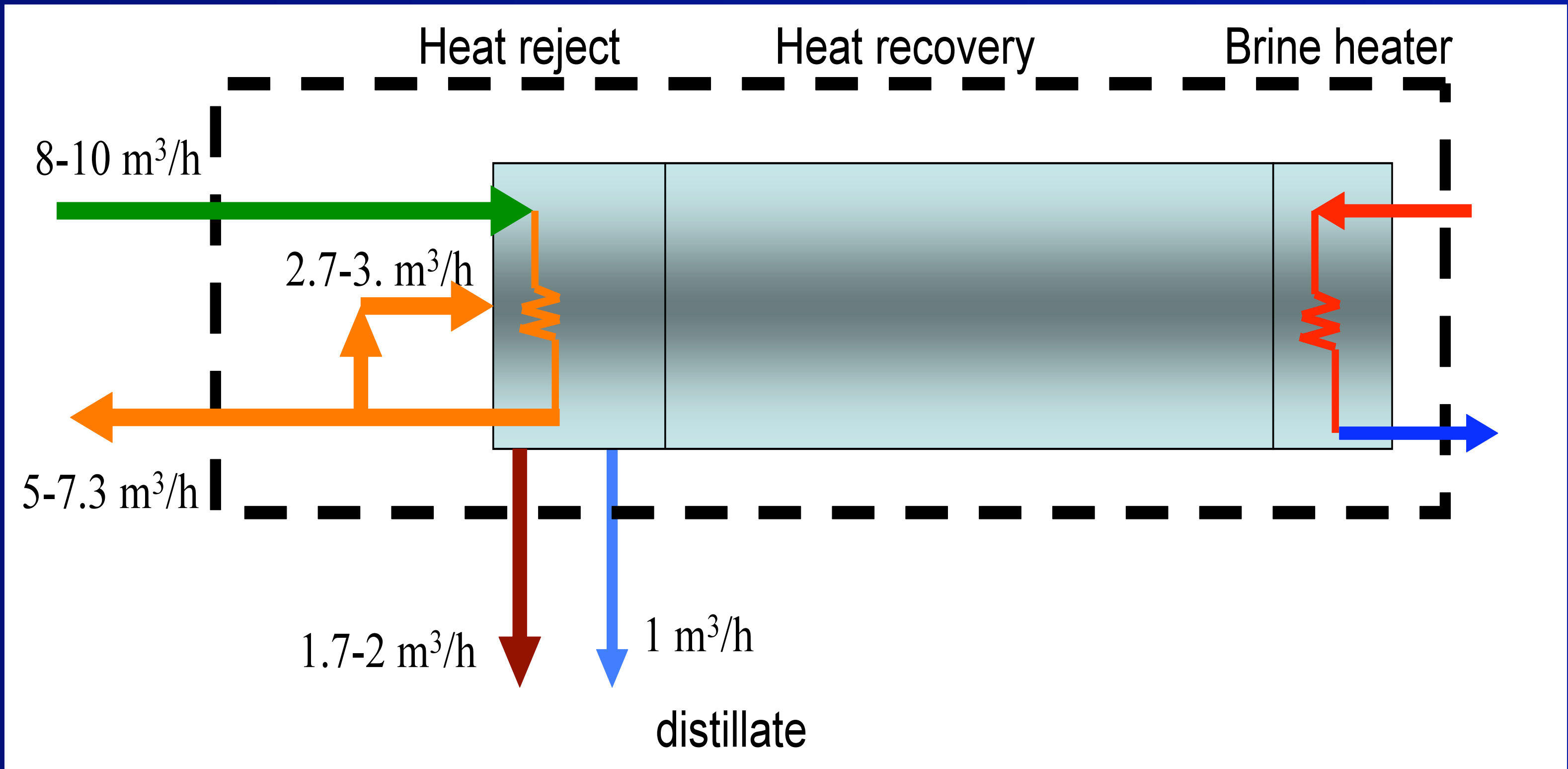
:seawater recovery ratio and concentration factors for each technology

	MSF	MED	MED-TVC	RO
Recovery ratio Y %	33%-37.5%	33%-37.5%	33%-37.5%	35%-43% (*)
Concentration factor 1/ (1-Y)	1.5-1.6	1.5-1.6	1.5-1.6	1.6-1.8

Seawater consumption difference between thermal and RO



Seawater consumption difference between thermal and RO



Seawater consumption difference between thermal and RO

	MSF	MED	MED-TVC	RO
Cooling water	8-10	2.3-5	2.3-5	0
Process water (make up-feed water)	2.7-3	2.7-3	2.7-3	2.3-2.9
Pre-treatment back washing losses	0	0	0	0.15-0.3
Brine discharge	1.7-2	1.7-2	1.7-2	1.3-1.9
Seawater discharge	5.-7.3		0.5-2	
Tonnes of seawater required per tonne of distillate water	**8-10**	**5-8**	**5-8**	**2.5-3.2**

Working example: classroom exercise

- Data available:
- Sea Water TDS = 45400 mg/l
- Desired distillate flow = 1200 tons/hr
- Brine blowdown
- max admissible TDS = 58000 mg/l
- Calculate :
- - brine blowdown flow rate
- - seawater make up requirement

Working example

- Step 1: Calculate blowdown concentration factor:

$$Cf_{bd} = \frac{58000}{45400} \cdot \frac{mg}{l} \cdot \frac{l}{mg} = 1.277$$

- Step 2 calculate seawater make flow rate:

$$1200 \cdot \frac{tons}{hr} = X \cdot \left(1 - \frac{1}{1.277}\right) = X \cdot 0.217$$

Working example

- Seawater make up flow rate:

$$X \cdot = \frac{1200}{0.217} \cdot \frac{tons}{hr} = 5530 \cdot \frac{tons}{hr}$$

- Calculate blowdown as the difference between make up and distillate

$$\dot{m}_{bd} = \dot{m}_{sw} - \dot{m}_{d} = (5530 - 1200) \cdot \frac{tons}{hr} = 4330 \cdot \frac{tons}{hr}$$

Association with power plant and Energy input classifications

Energy input classifications

Evaporative processes

Evaporative processes use thermal energy to produce distilled pure water from sea or brackish water.

Energy input classifications

Evaporative processes rely on a phase change from liquid (in this case brine) to the vapour phase.

In this process only the water molecules pass to the vapour phase leaving the other constituents behind in the liquid.

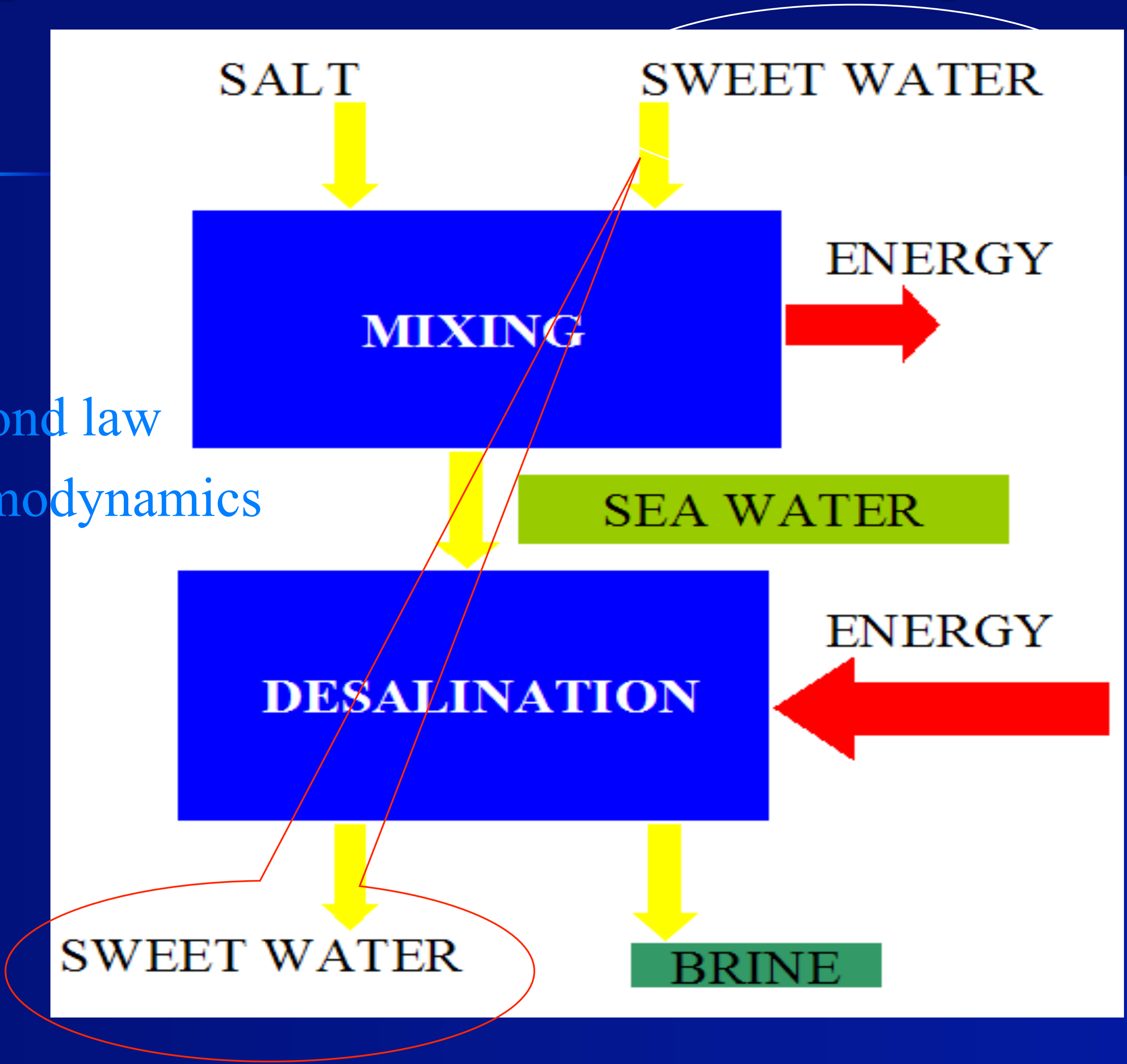
The two dominating systems that have evolved are Multi Stage Flash (MSF) and Multiple Effect Distillation(MED).

Energy input classifications

Membrane processes

In Membrane processes electric energy is used to pump seawater (or brackish water) through a series of semi permeable membranes to obtain a low salinity permeate as a product.

Energy balance in desalination processes :



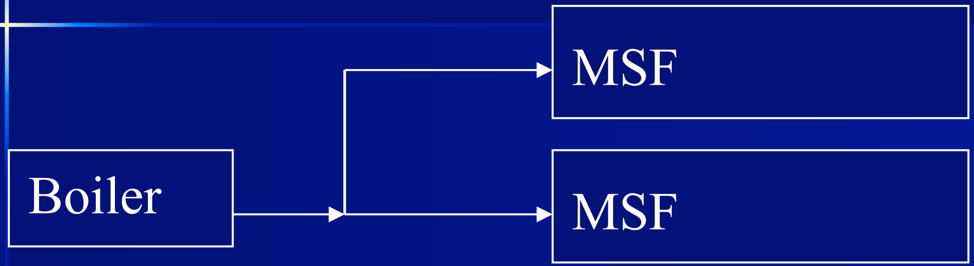
the second law
of thermodynamics

Energy input classifications

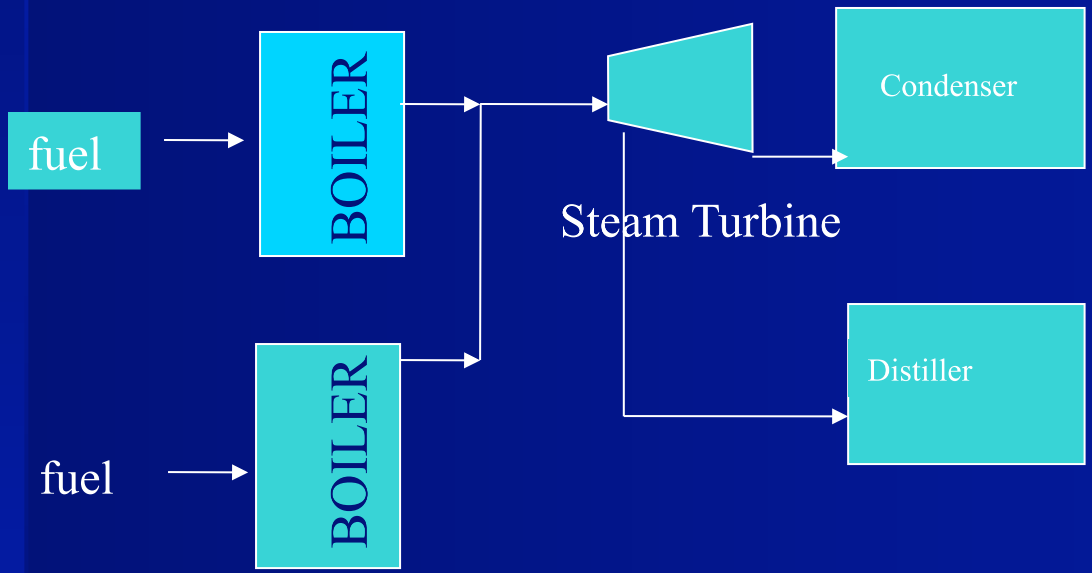
Membrane processes do not rely on a phase change but on the size and transport mobility of water molecules through a permeable membrane.

For the separation of fresh water from seawater or brackish water this process is known as Reverse Osmosis (RO).

Association with power plant



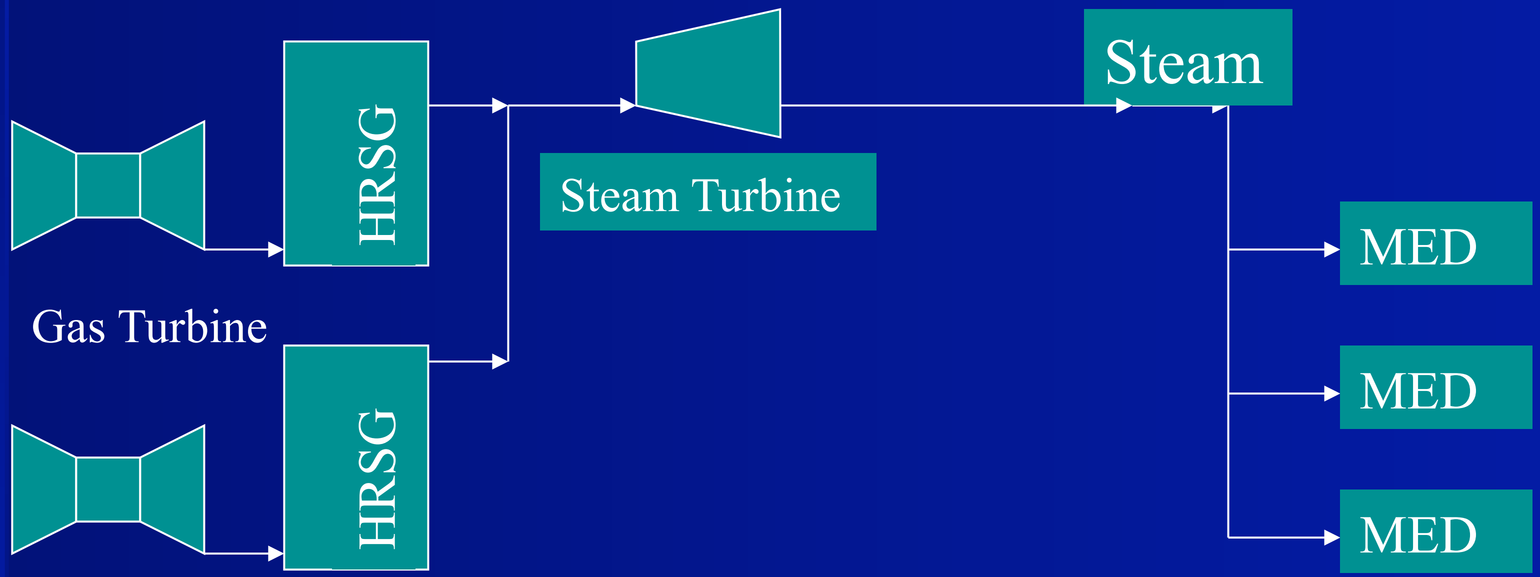
big kettle"



Cogeneration

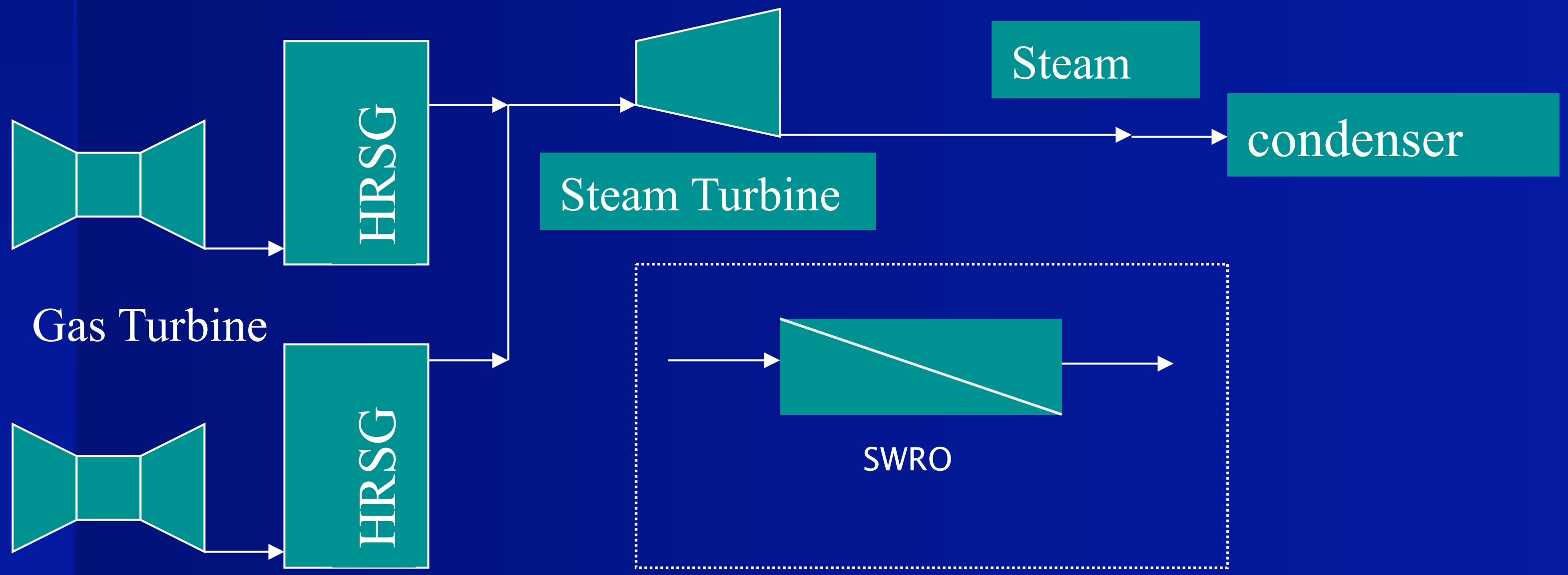
- Overview of desalination technologies

Power thermal desalination combinations



- Overview of desalination technologies

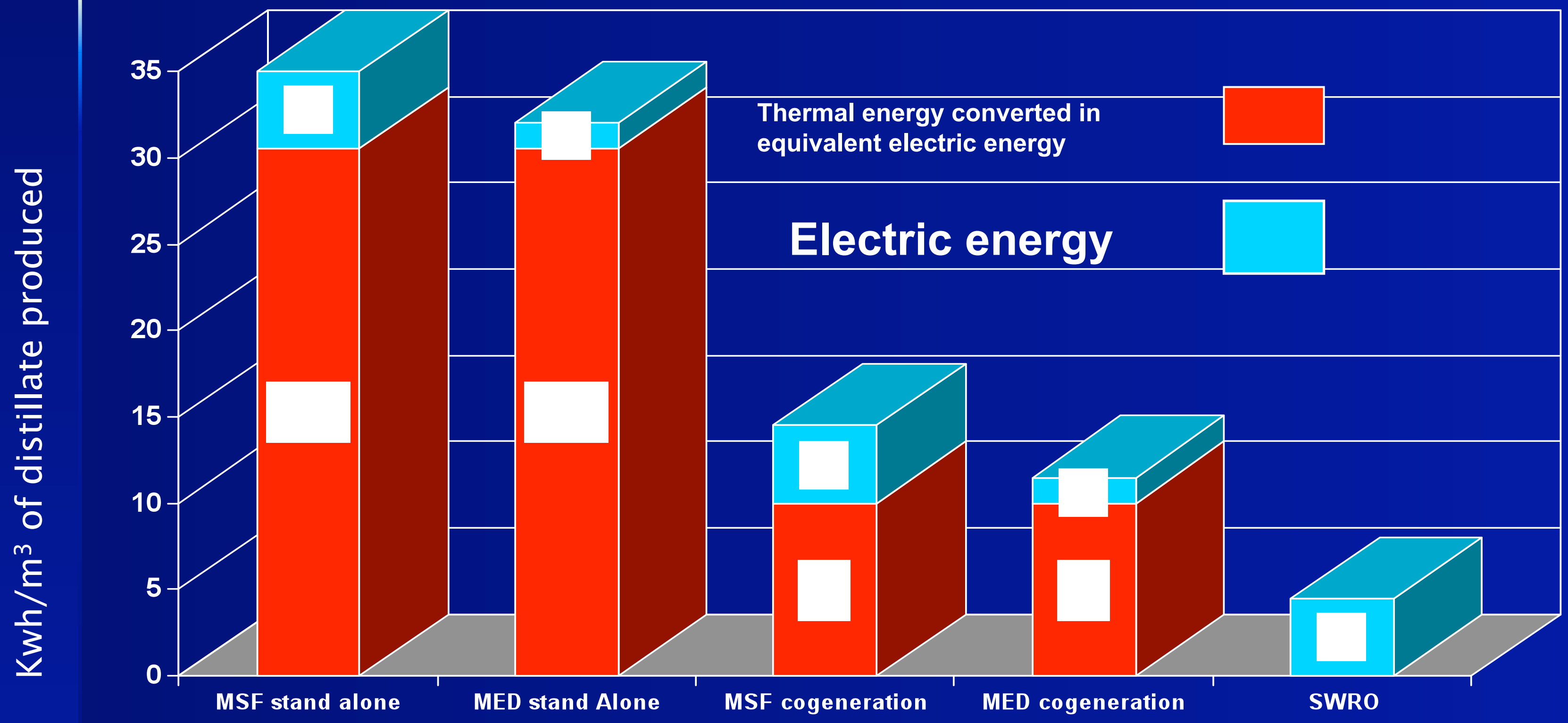
Power and SWRO plant combinations



Separate SWRO

- Overview of desalination technologies

The Energy Situation



Big kettle

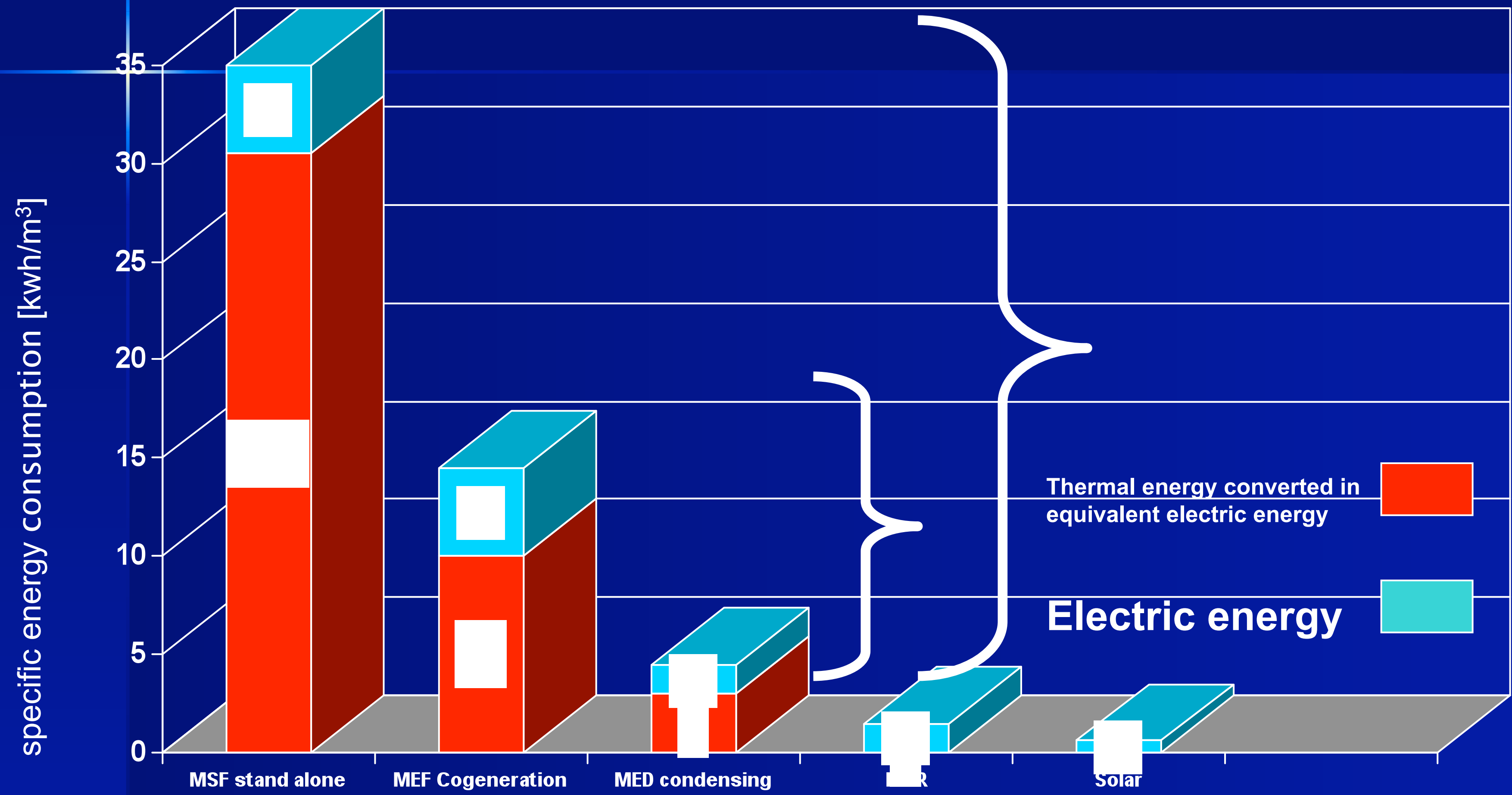
- Overview of desalination technologies

- Studies have been carried out showing that potable water with TDS lower than 500 mg/l could be obtained with less than 2.5 kwh/m3

- Minimum bottom threshold for power requirements for SWRO is 1.2-1.5 kwh/m3

Overview of desalination technologies

The Energy Situation



Energy consumption comparison MSF, MED and RO

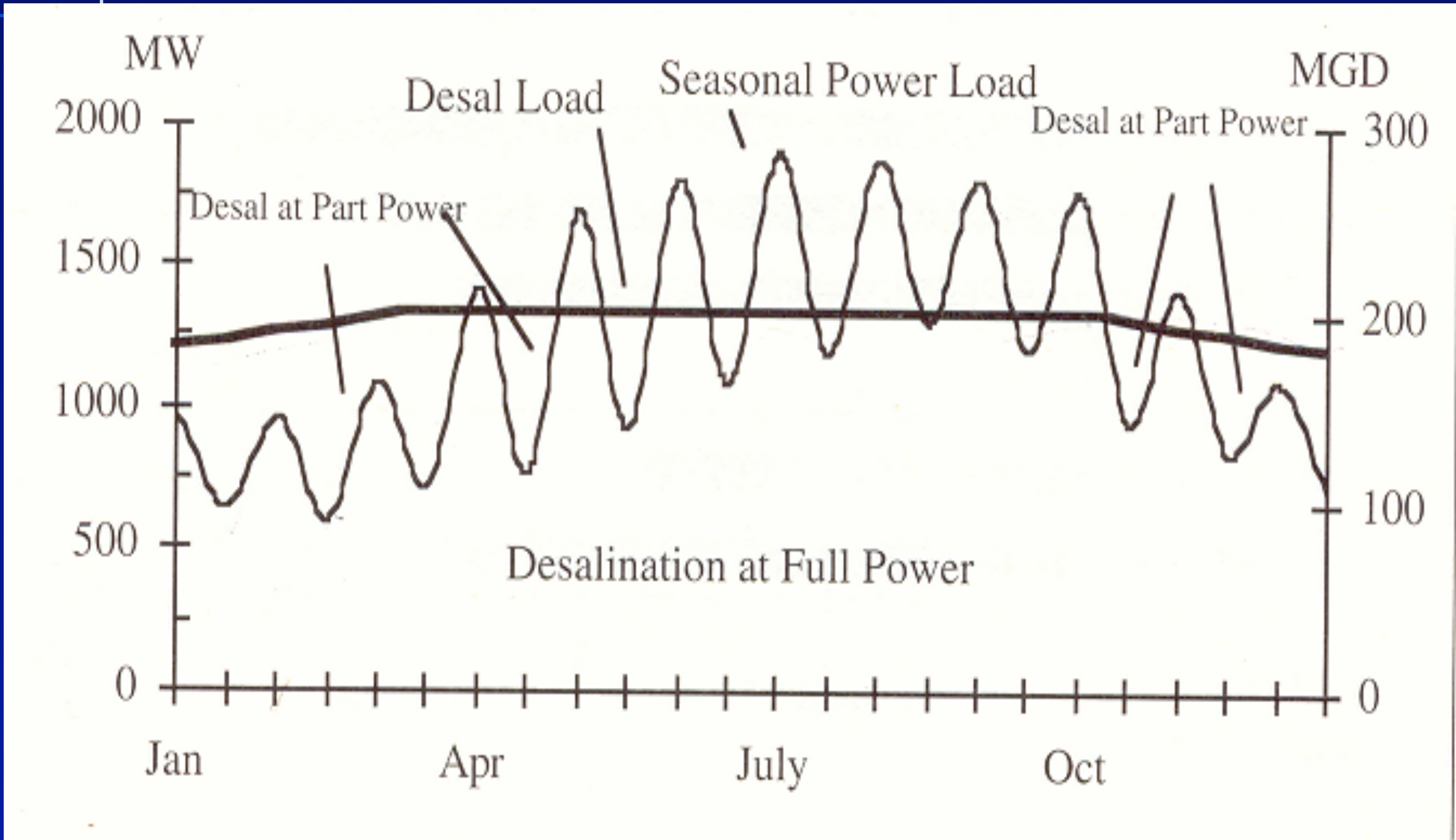
	Specific electric power	Specific heat consumption	Steam Extraction pressure	Thermal energy	Equivalent power loss	Total Energy requirements
	kwh/m³	kJ/kg	Bar abs	Thermal kwh/m³	Electric kwh/m³	kwh/m³
SWRO(Mediterranean Sea)	3.5	0	N.A.	0	0	3.5
SWRO (Gulf)	4.5	0	N.A.	0	0	4.5
MSF	4-5	287	2.5-2.2	78	10-20	14-25
MED-TVC	1.0-1.5	287	2.5-2.2	78	10-20	11-21.5
MED	1.0-1.5	250	0.35-0.5	69	3	4-4.5

Water and Power

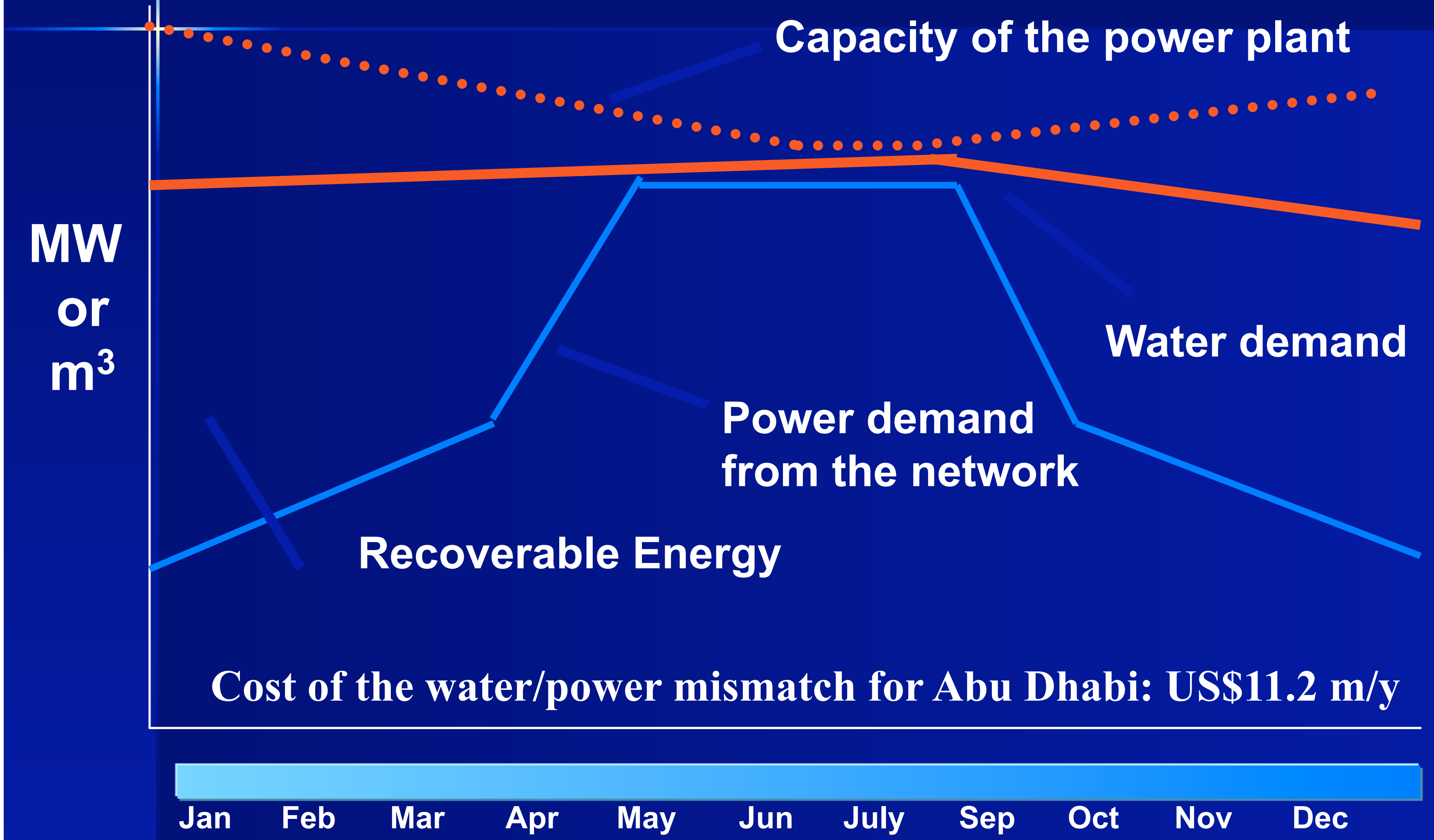
- Water and Power are essential simultaneously
- The variation of energy consumption (kWh/m3) is function of the site (rural or urban), of seasons (summer or winter). In the GCC, the electrical consumption in the winter represents only 30 - 40 % / summer
- Moreover, water needs are higher than electricity needs: in the GCC the growth rate of water consumption is 11 % per year and energy is only 4 % (*)

(*) Koussai Quteishat, Hydrorop 2001, Marseille

Seasonal variation of water and electricity needs in ABU DHABI



Seasonal mismatch between water & power generation capacities

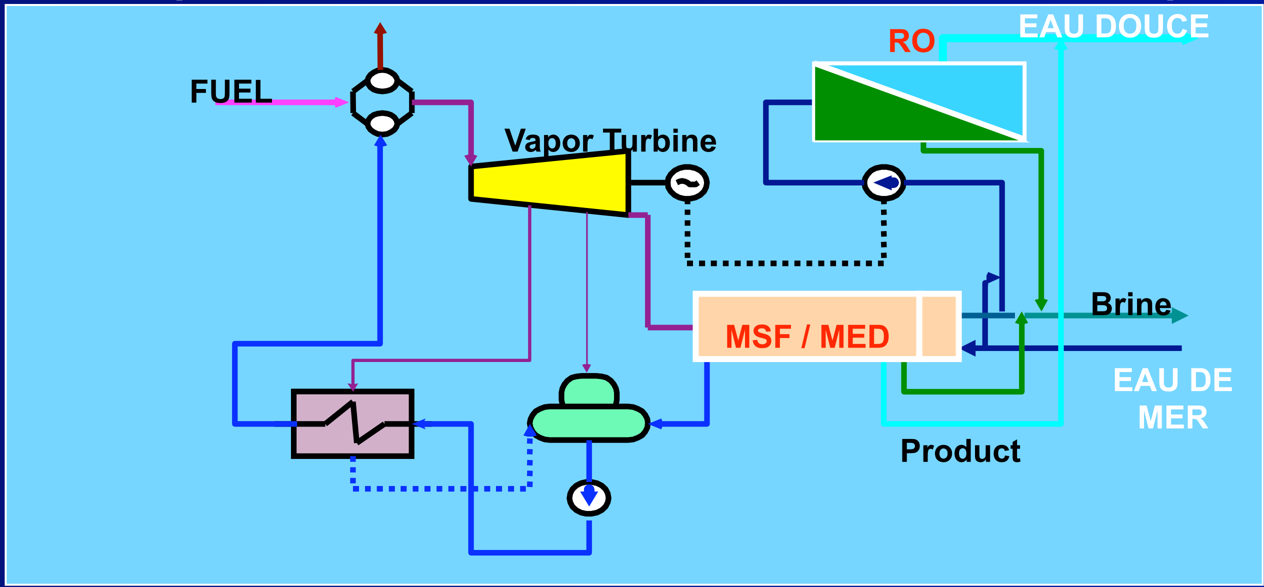


Source: SUEZ

Hybrid Systems

2 + different desalination processes are coupled with the power plant

- Mainly MSF or MED with RO or VC. This combination can better utilize fuel energy as well as the power produced
- For utilization of idle power to produce water via RO or MVC, the extra produced water can be stored in aquifers



Advantages & potential of hybrid systems

- A common intake, reduce pumping energy
- Blending products of RO and distillation plants
- Use of single stage RO thus lowers energy needs
- RO membrane life can be extended
- Feed water temperature to RO can be integrated and optimized with distillation and power plant
- Integrated pretreatment and post treatment can reduce energy and chemical consumption
- Possibility to increase the ratio water/electricity if the water consumption is preponderate

Fujairah Plant - UAE

- Seawater 40 g/l – T = 22 - 35 °C – Started in 2002
- Separate intake for MSF and RO
- Feed water for RO not heated by MSF
- 4 gas turbines of 109 MW + 3 generators of 380 t/h – 68 bar – 537 °C generates 500 MW_e net on the network + 662 MW for desalination

MSF	5x12,5 MIGD = 62,5 MIGD, 5 x 56.250 m^3/j = 281.250 m^3/j	
RO	15 x 2,5 MIGD = 37,5 MIGD, 15 x 11.250 m^3/j =168.750 m^3/j	
TOTAL	100,0 MIGD soit	450.000 m^3/j

MSF : Ratio = 8 TBT (Top Brine Temperature) = 107 - 109 °C

MULTISTAGE FLASH TECHNOLOGY (MSF)

Process description

Process thermodynamics

Stage simulation model

MSF what do we know ?

- Highly reliable operation
- Scalable up to very large sizes 18MIGD
- Readily coupled with steam turbine generating stations in “dual purpose plant” configuration
- Good water to power to power ratio

A big and well-deserved success since the 1960s

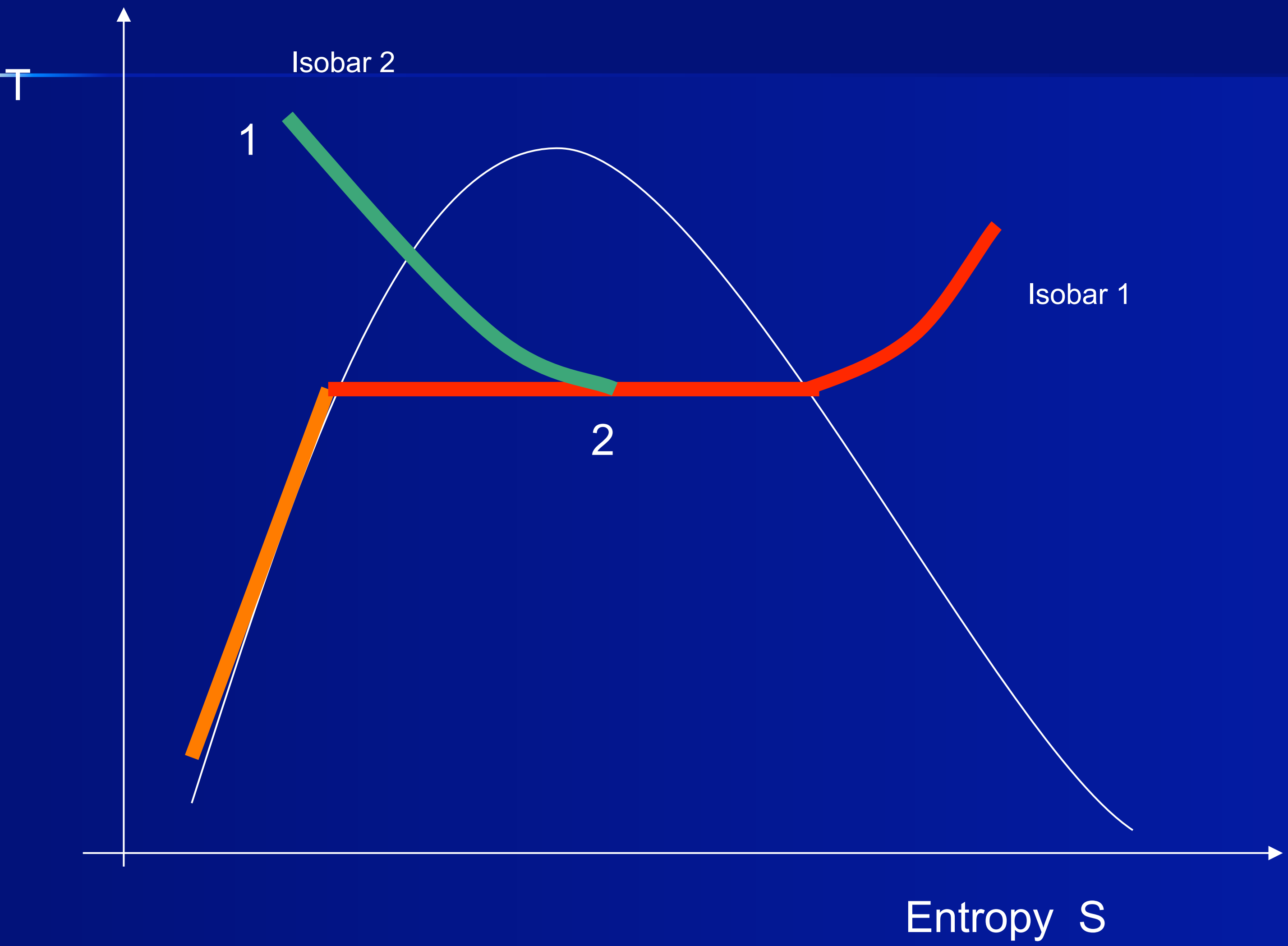
Process description: How did it begin?

- 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!

Flashing and boiling: the thermodynamic meaning

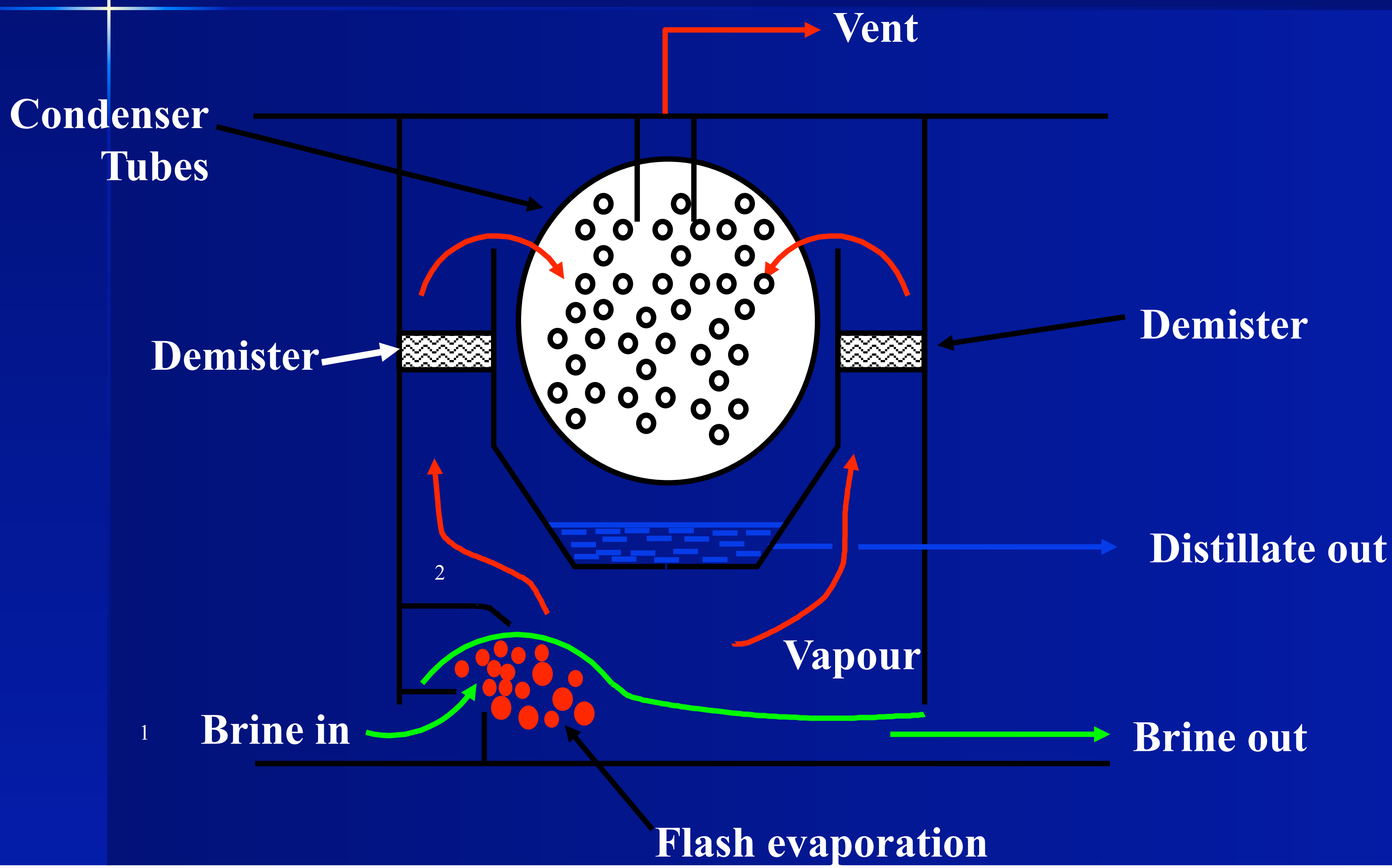


MSF development

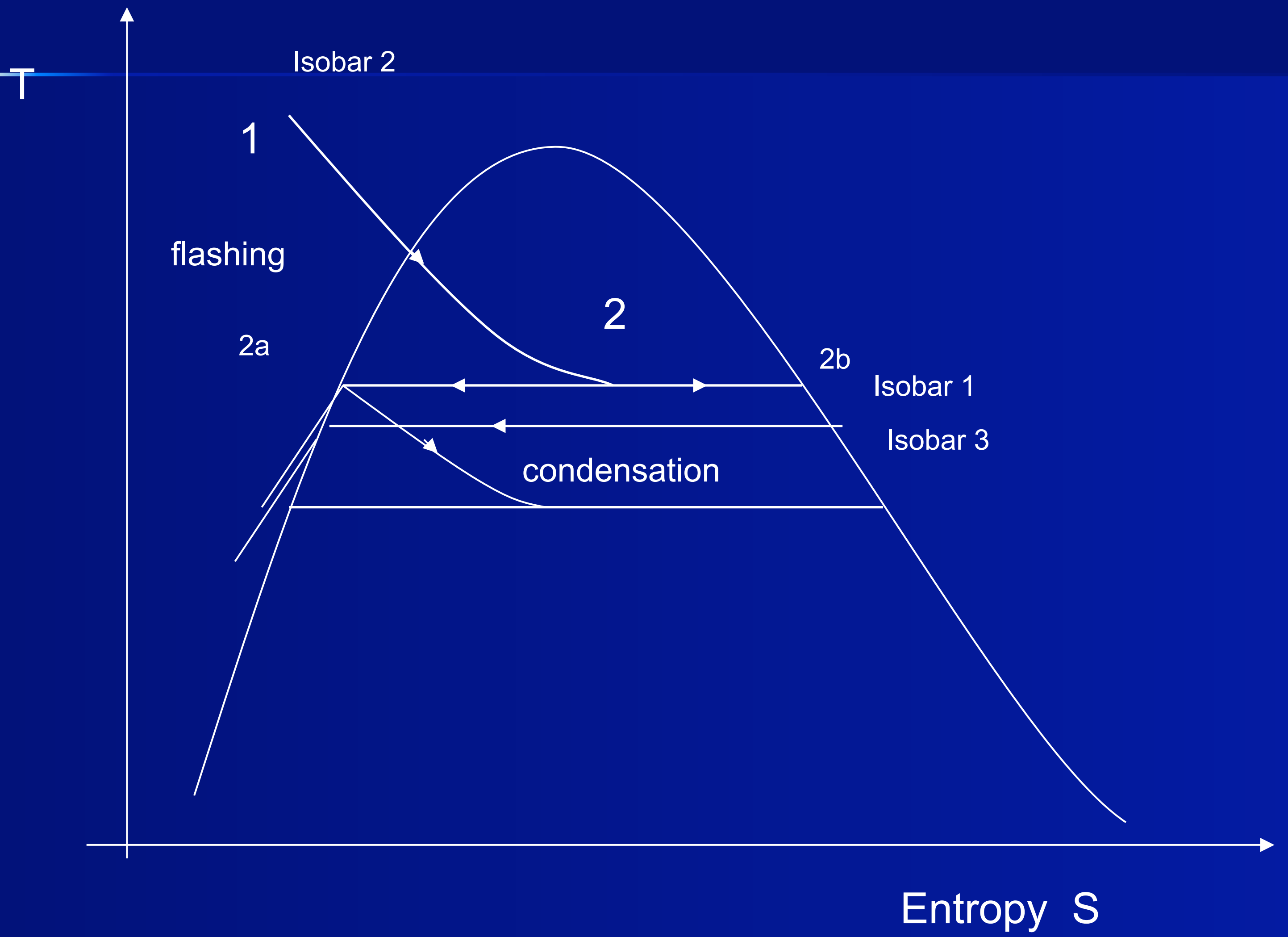
- Cross tube design - tube length limitations
- Long tube design
- Once through process
- Optimise structural design to reduce shell plate thickness and weight
- Solid stainless steel shell construction
- Thinner heat transfer tubes

MSF Desalination Plant

Typical stage arrangement of a large MSF plant



Stage modeling thermodynamic ideal case :



The influence of minor constituents of seawater and brackish waters

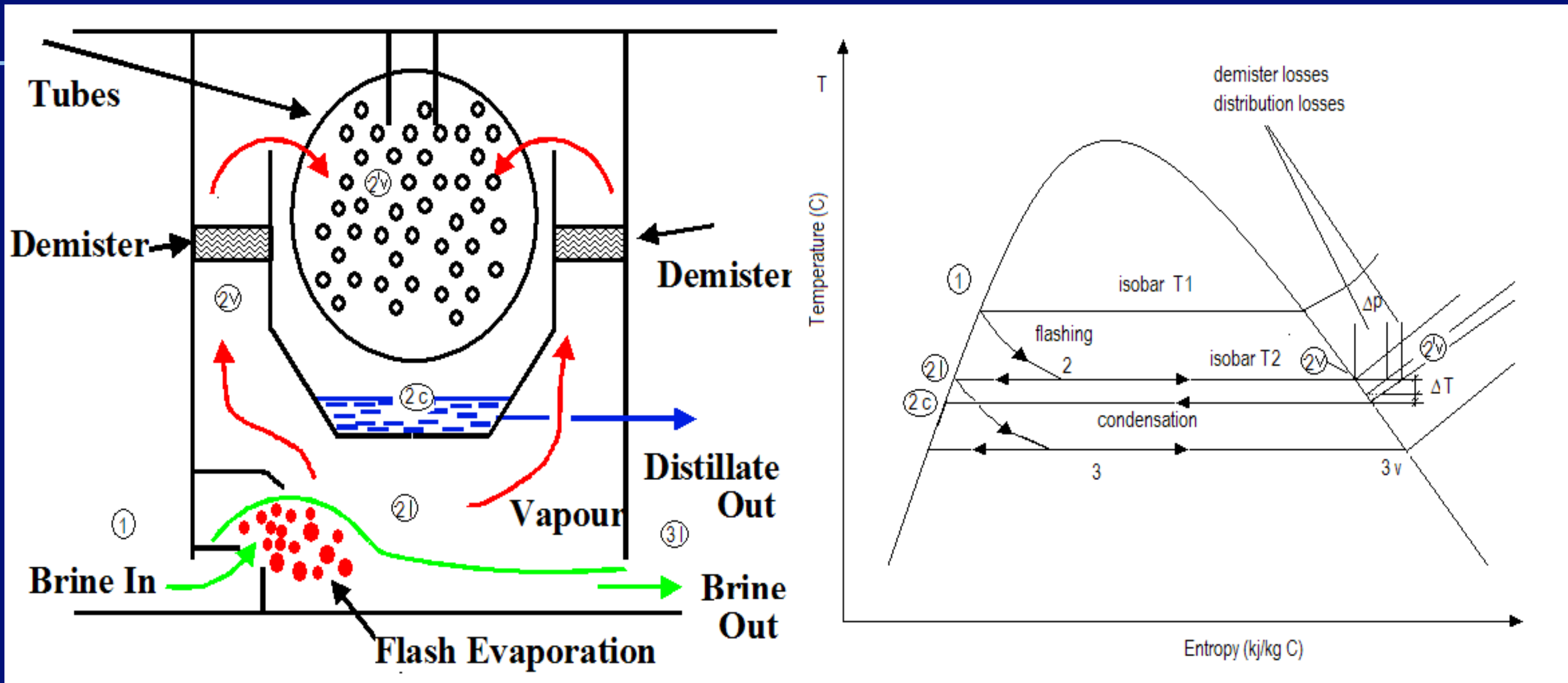
A. Dissolved inorganic

- If seawater consisted of only H_2O and NaCl, life would be simple
- But natural waters are often close to saturation in many inorganic compounds ($CaSO_4$, $Mg(OH)_2$, $Ca(HCO_3)_2$, etc.)
- What is worse, their solubility may be <u>inverse</u> functions of temperature

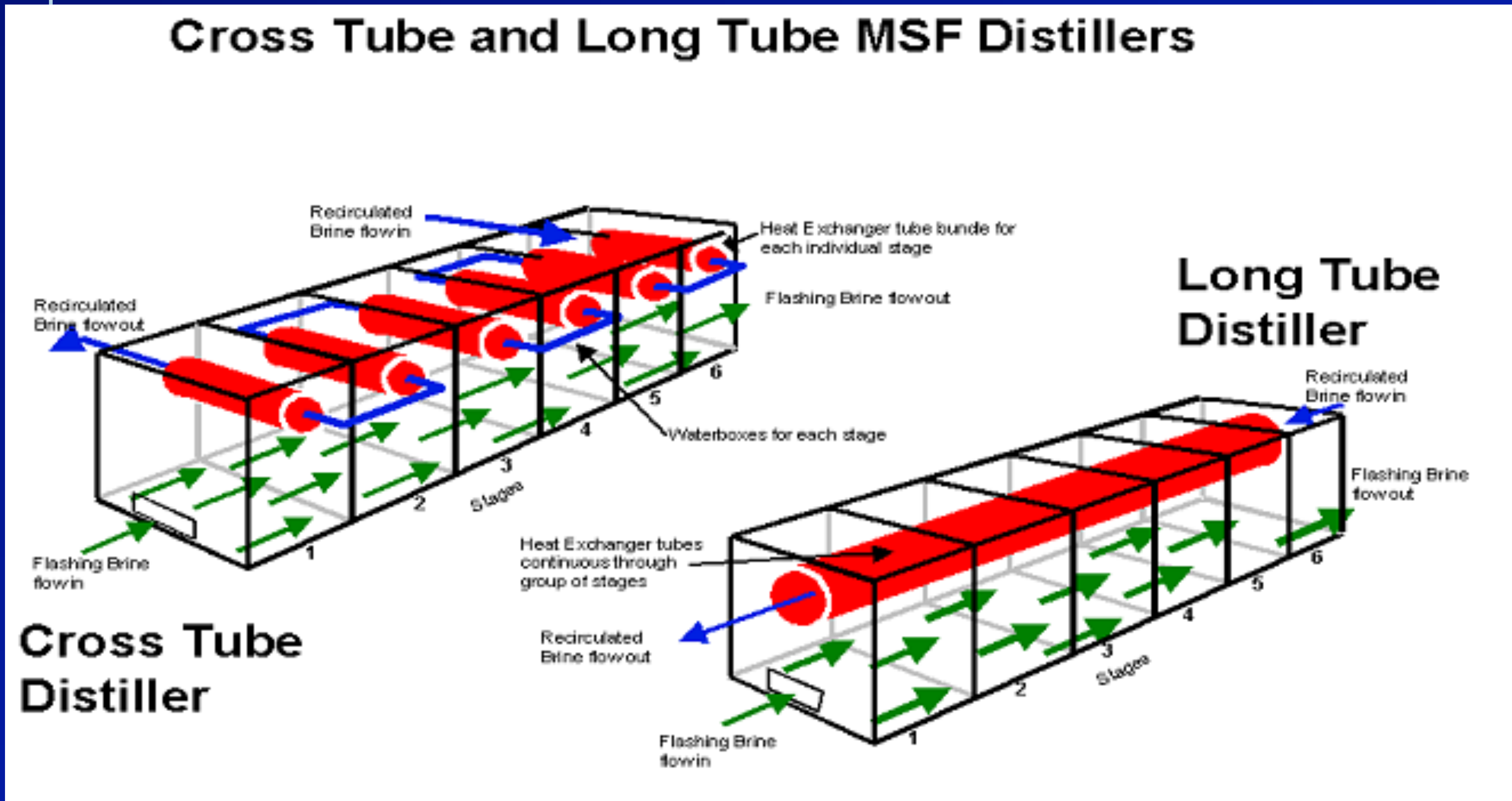
This involves the following aspects to be considered:

- scaling
- venting

Stage modeling thermodynamic real case :

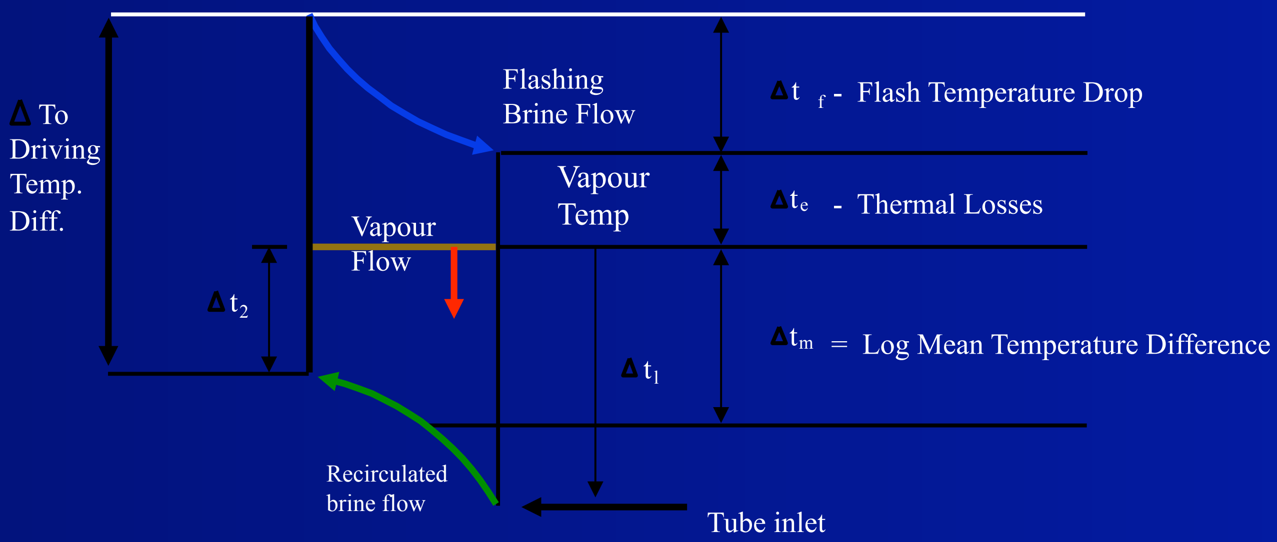


Multi stage flash



MSF Desalination Plant

Single stage temperature diagram



Δt_1 = Inlet temperature difference - Vapour to brine in

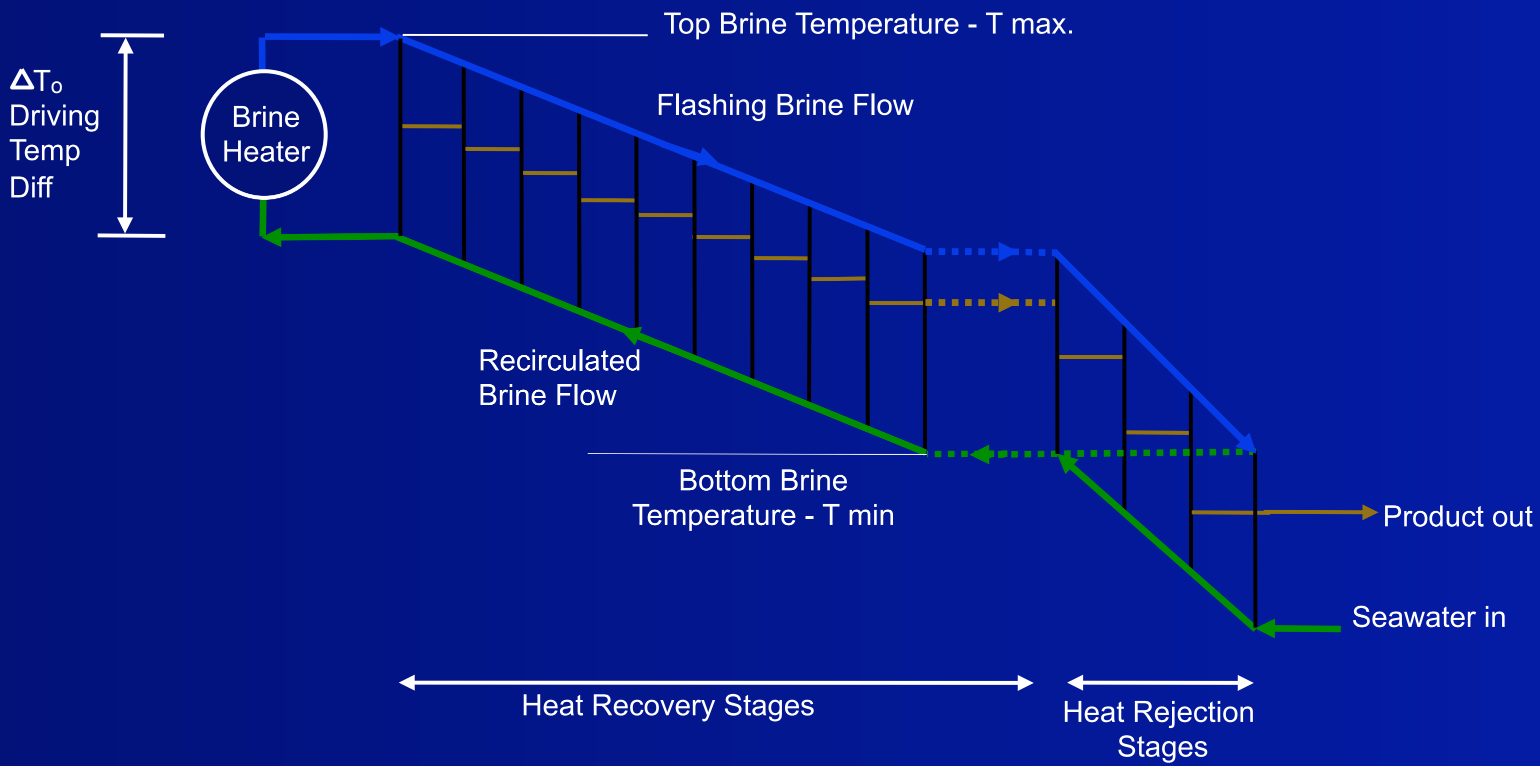
Δt_2 = Outlet temperature difference - Vapour to brine out

Δt_m = Log mean temperature difference (LMTD)

$$\Delta t_m = \frac{\Delta t_1 \quad \Delta t_2}{\mathrm{Log}\left(\Delta t_1 / \Delta t_2\right)}$$

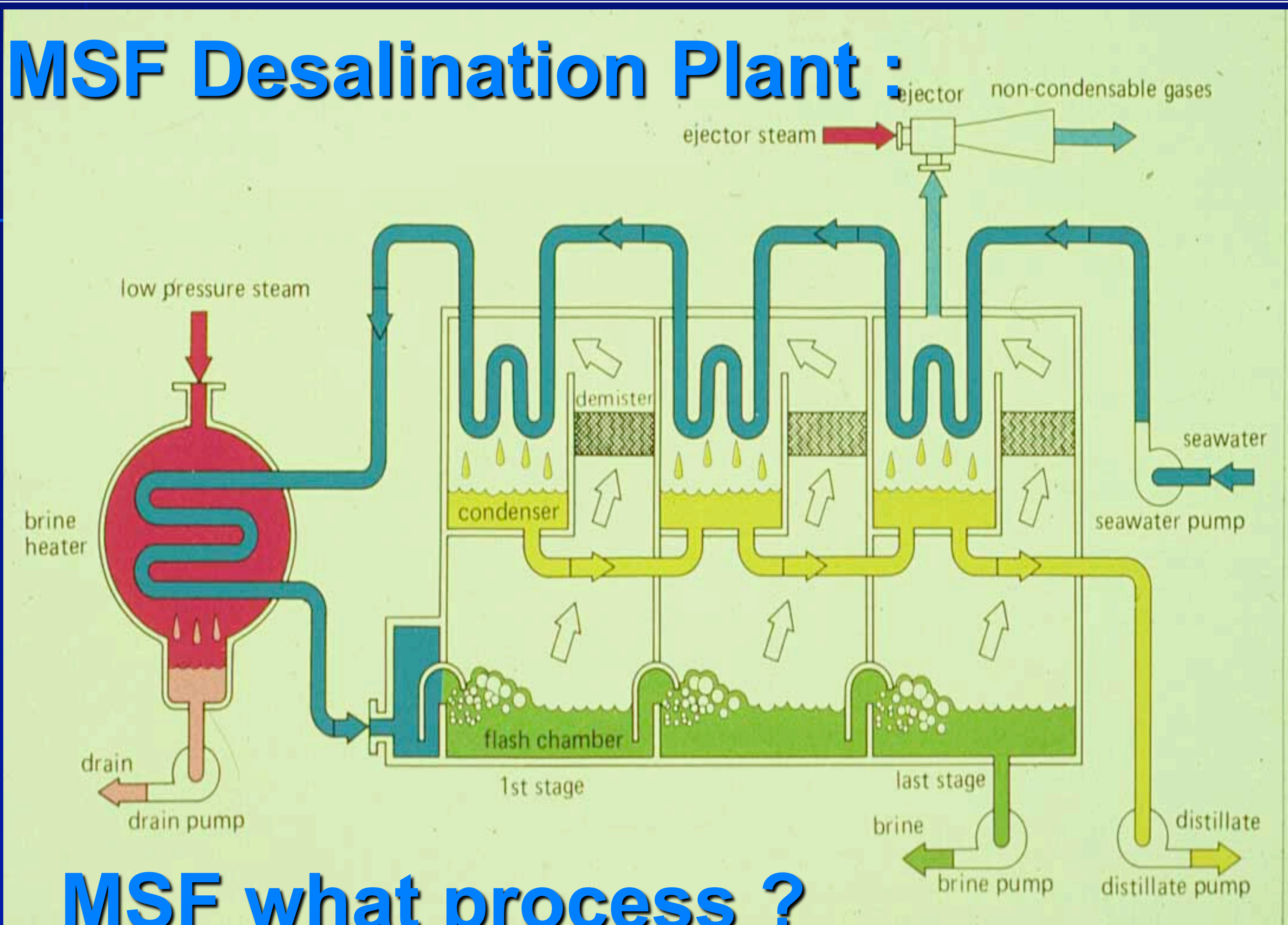
MSF Desalination Plant

Stage temperature diagram
Complete plant (brine recirculation type)



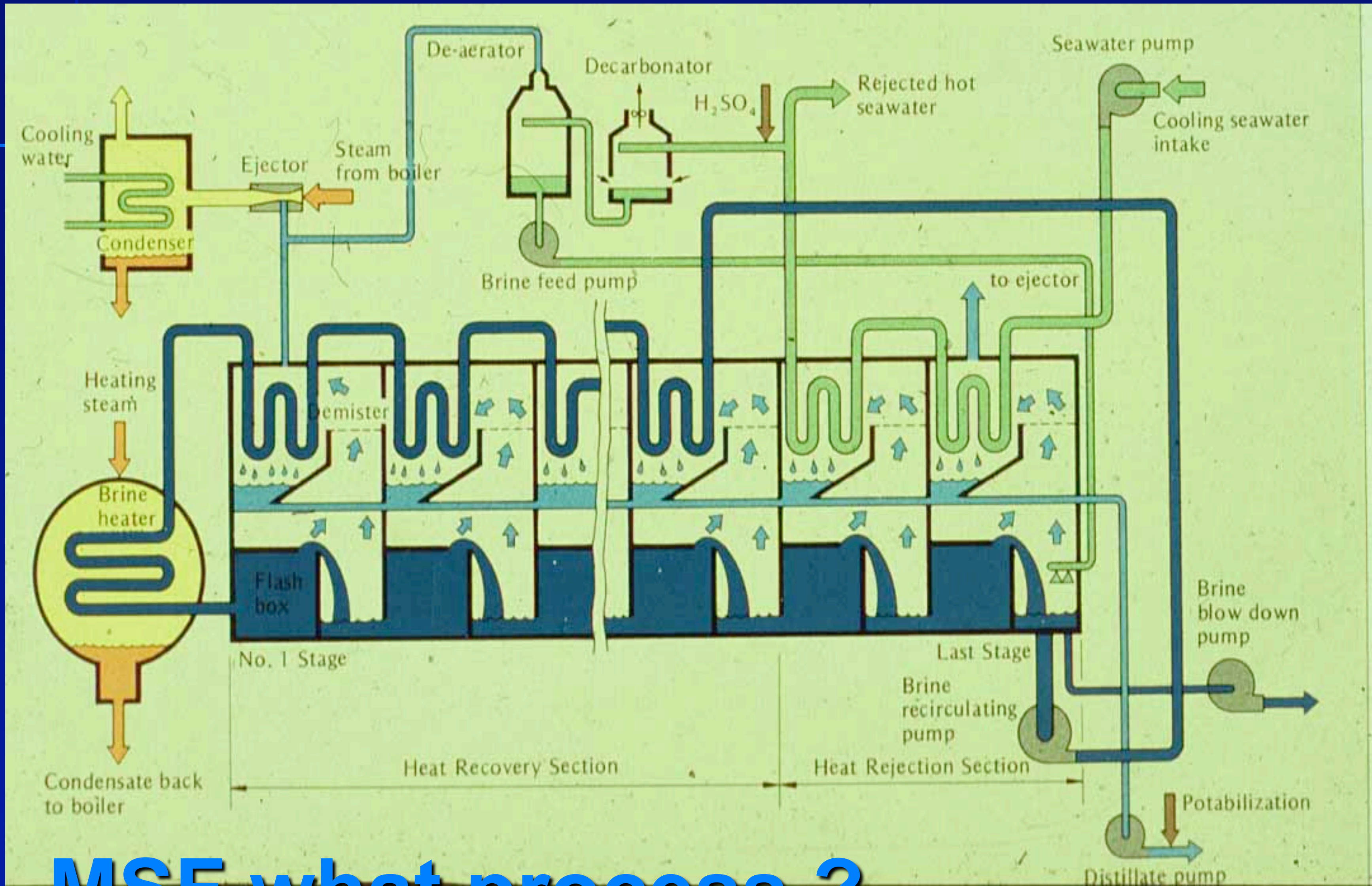
ΔTo = Driving Temperature Difference
(Practically constant through heat recovery stages)

MSF Desalination Plant :



MSF what process ?

MSF Desalination Plant



MSF what process ?

Flow sheets: cross flow brine

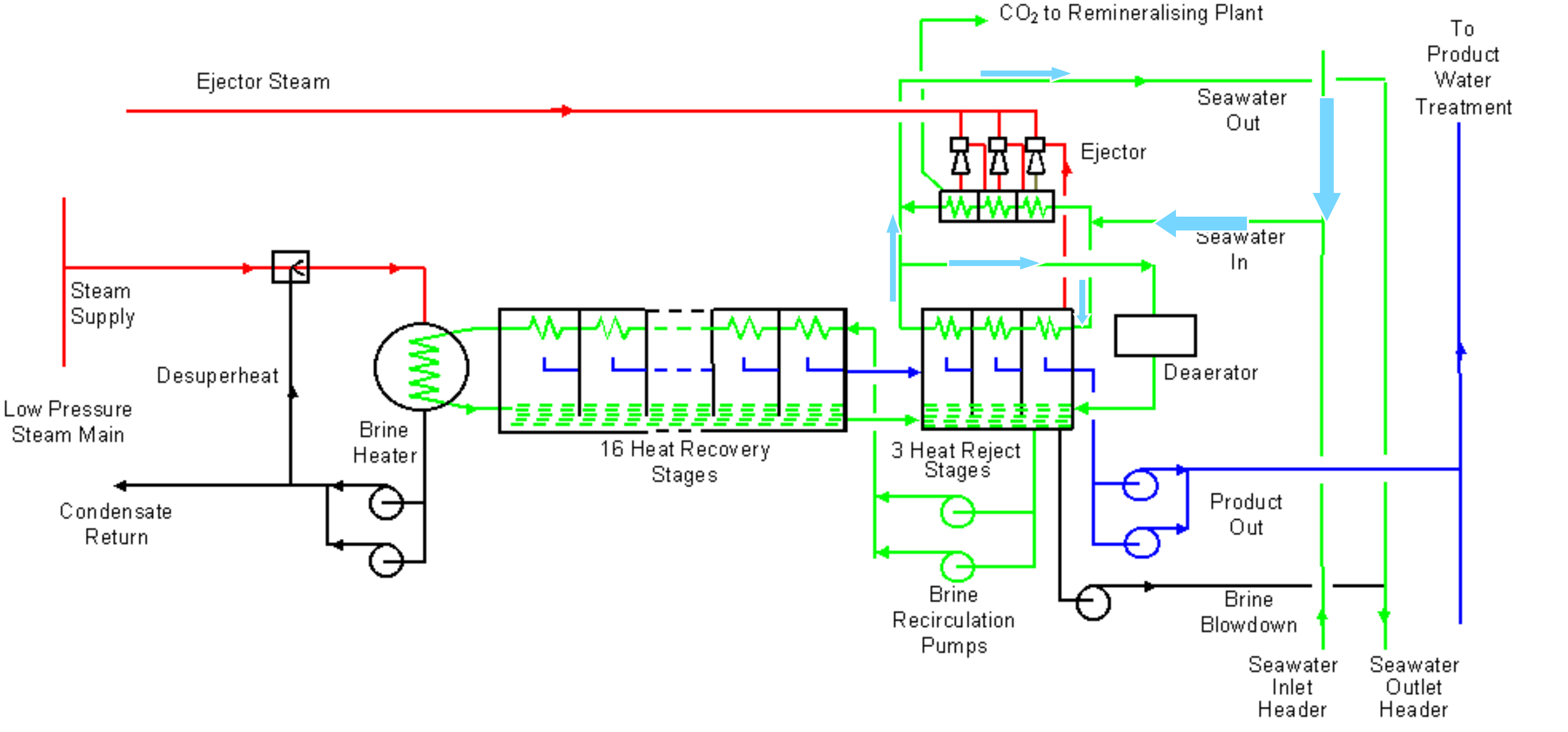
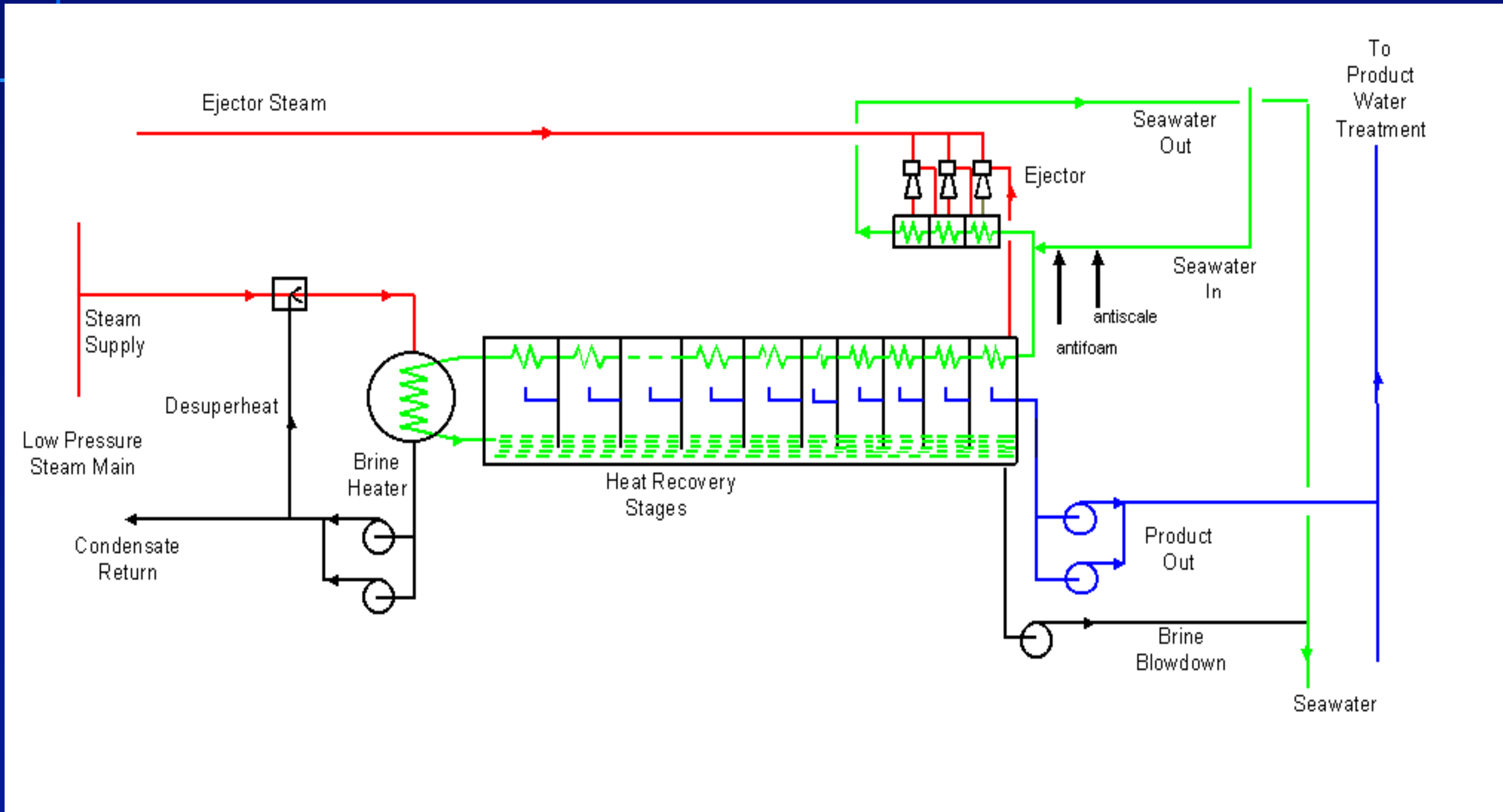
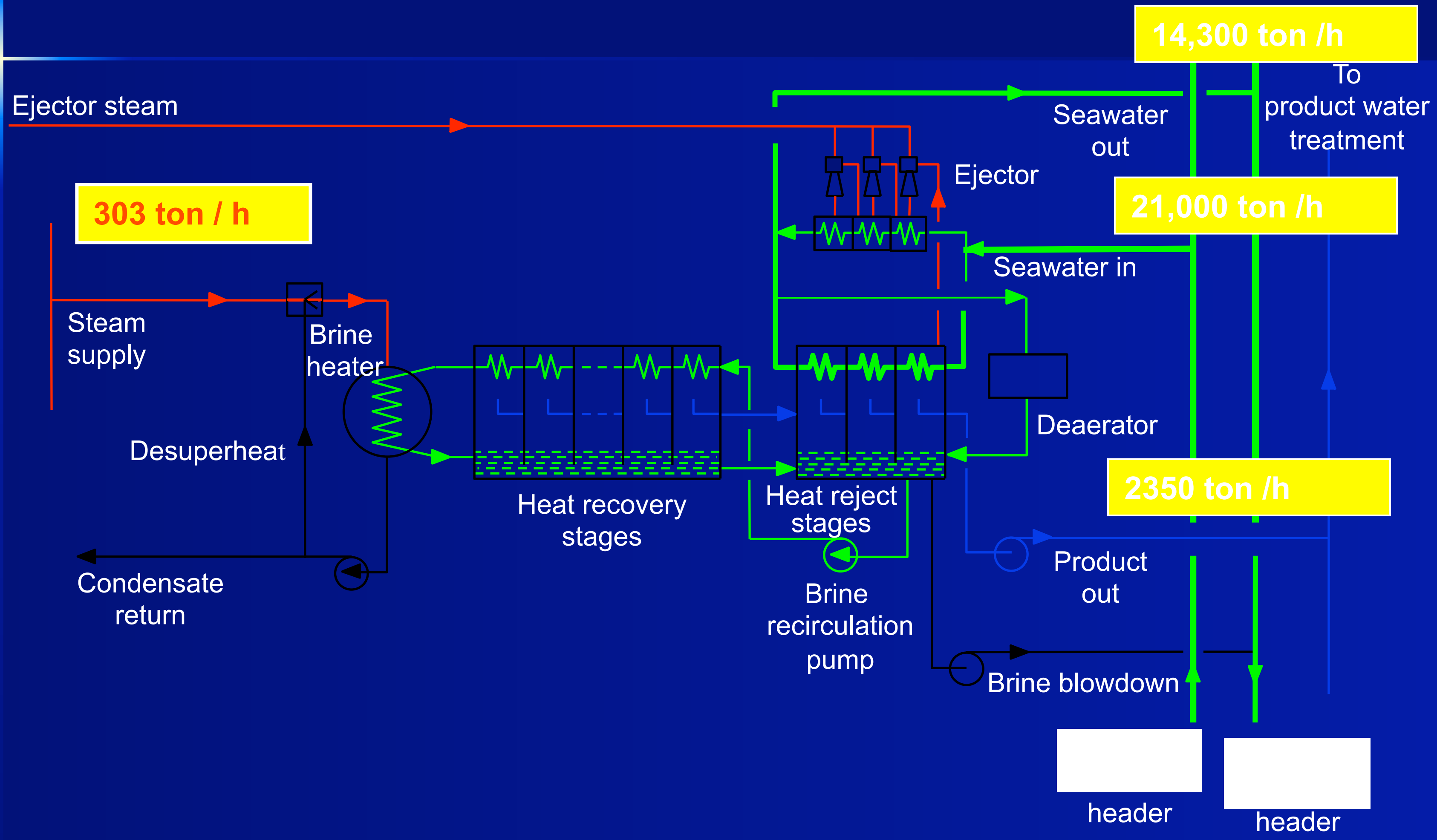


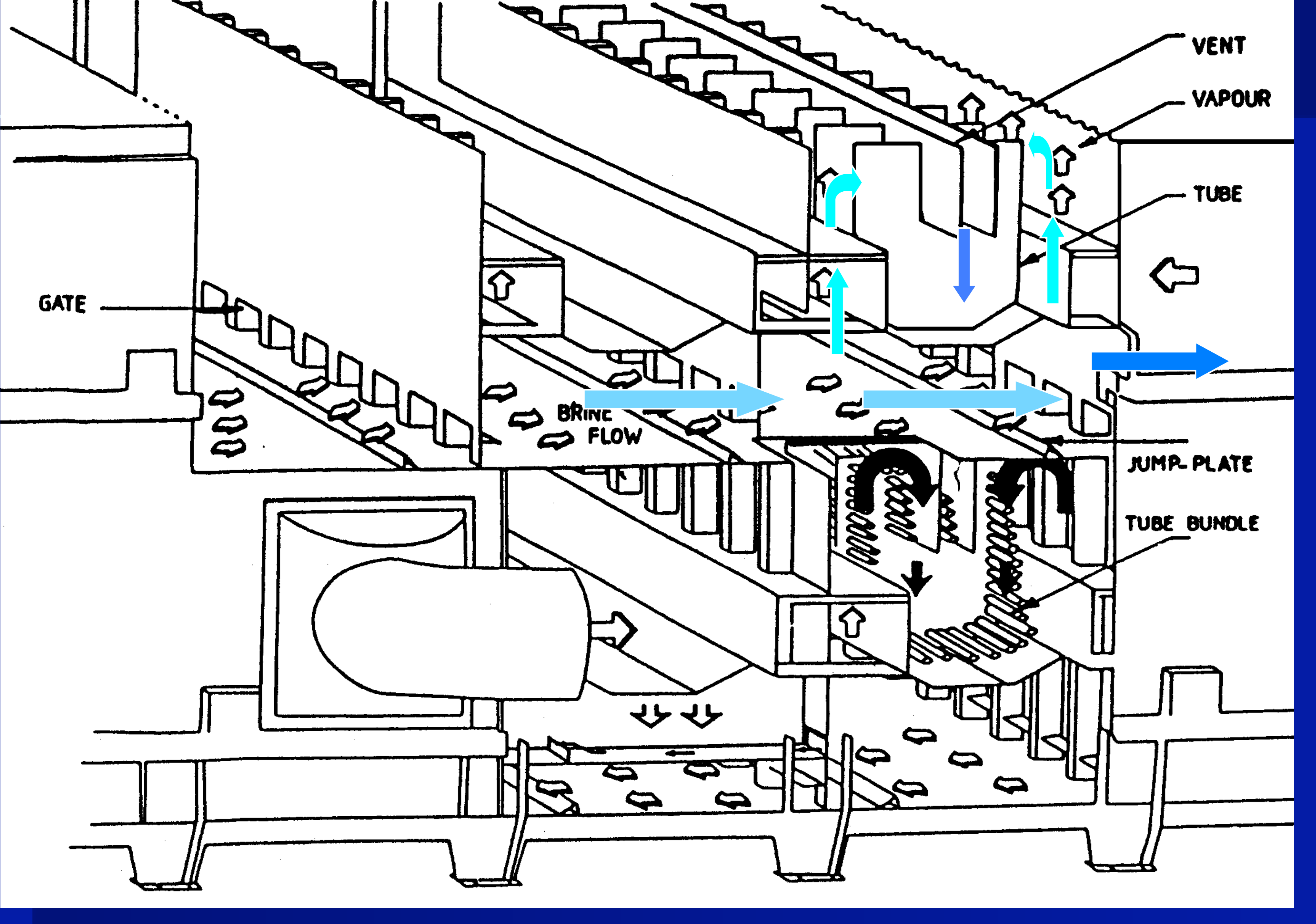
Figure 3

Flow sheets: once through



Main flow stream mass balance




VENT
VAPOUR
TUBE
GATE
BRINE
FLOW
JUMP PLATE
TUBE BUNDLE

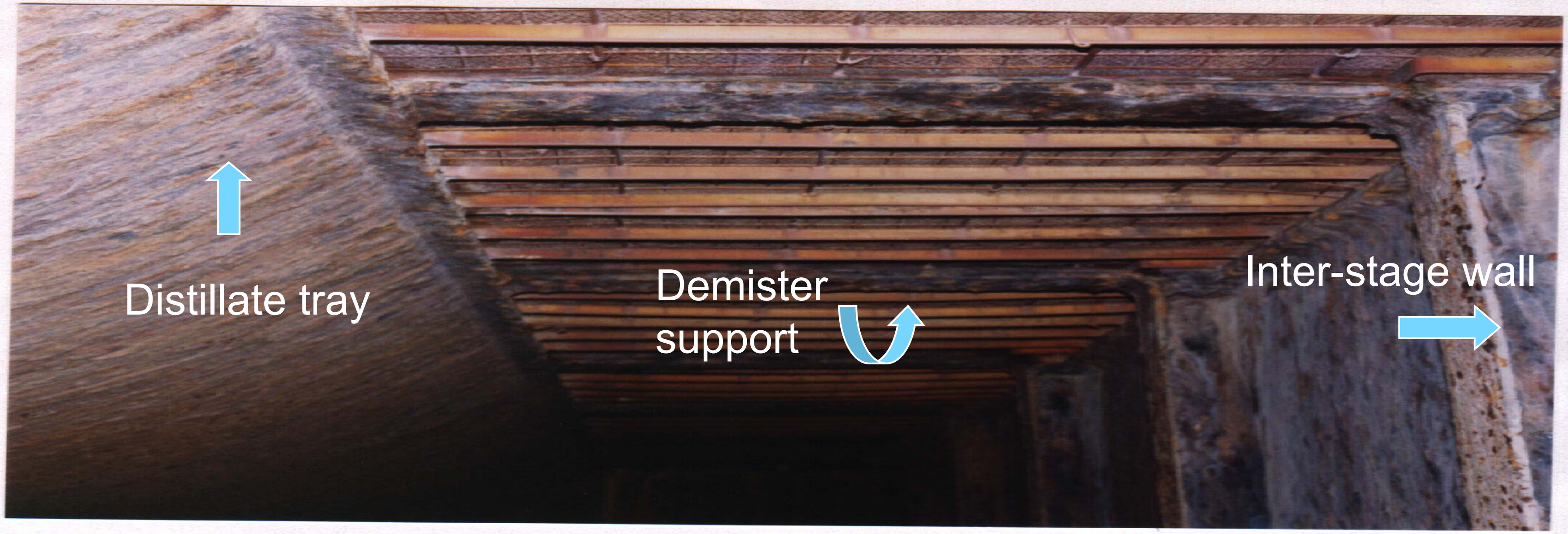
MSF cross flow plant internal layout: How it really looks like - low side flash chamber

MSF cross flow plant internal layout: how it really looks like - upper side

tube bundle tube supports roof plates and uncondensable extraction pipes

details of tube bundle and tube support

MSF cross flow plant internal layout



distillate tray, demister supports and interstage walls

corrosion in the distillate tray

Multiple Effect Desalination Technology

MED

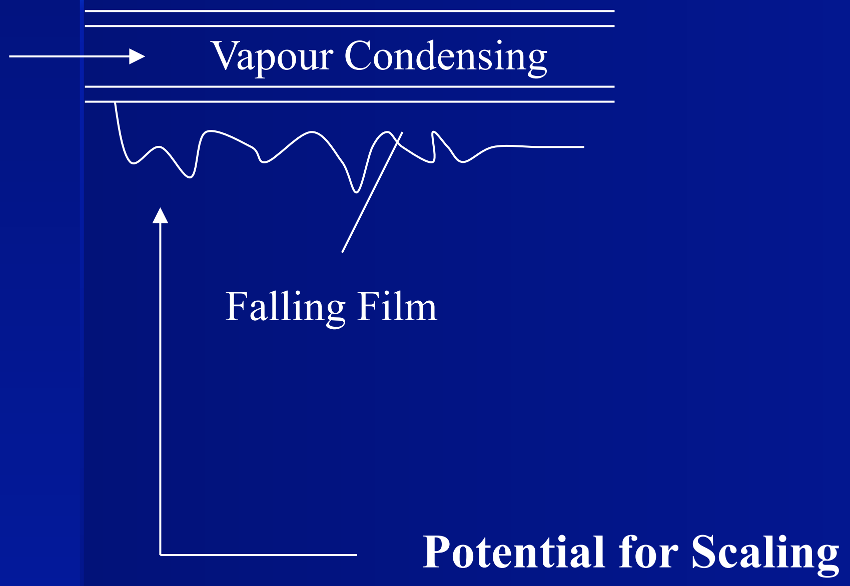
- process description

- process thermodynamics

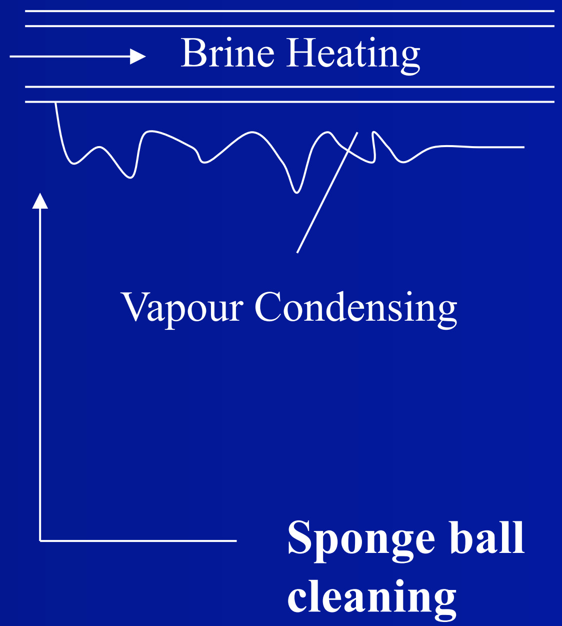
- stage simulation model

Evaporation Concept

MED



MSF



MED distillation

- Horizontal or vertical tube
- Falling film of seawater - high heat transfer coefficients
- Mostly horizontal tube, low temperature
- 1st effect 65^0 - 67^0 max temperature
- Performance ratio up to 9:1 with no TVC
- Up to 15:1 with TVC - thermal vapour compression and high steam pressure
- Steam isolation needed in dual purpose plants
- Lower power consumption than MSF and RO

MED distillation

- Unit size has increased from 1 to 5 MIGD (now 8 MIGD) in 8 years
- Potential for further increase?
- Improvements in thermal vapour compressors and plant configuration
- Reduce steam supply pressure
- Trade off between steam consumption and supply pressure
- Distiller performance v power plant output

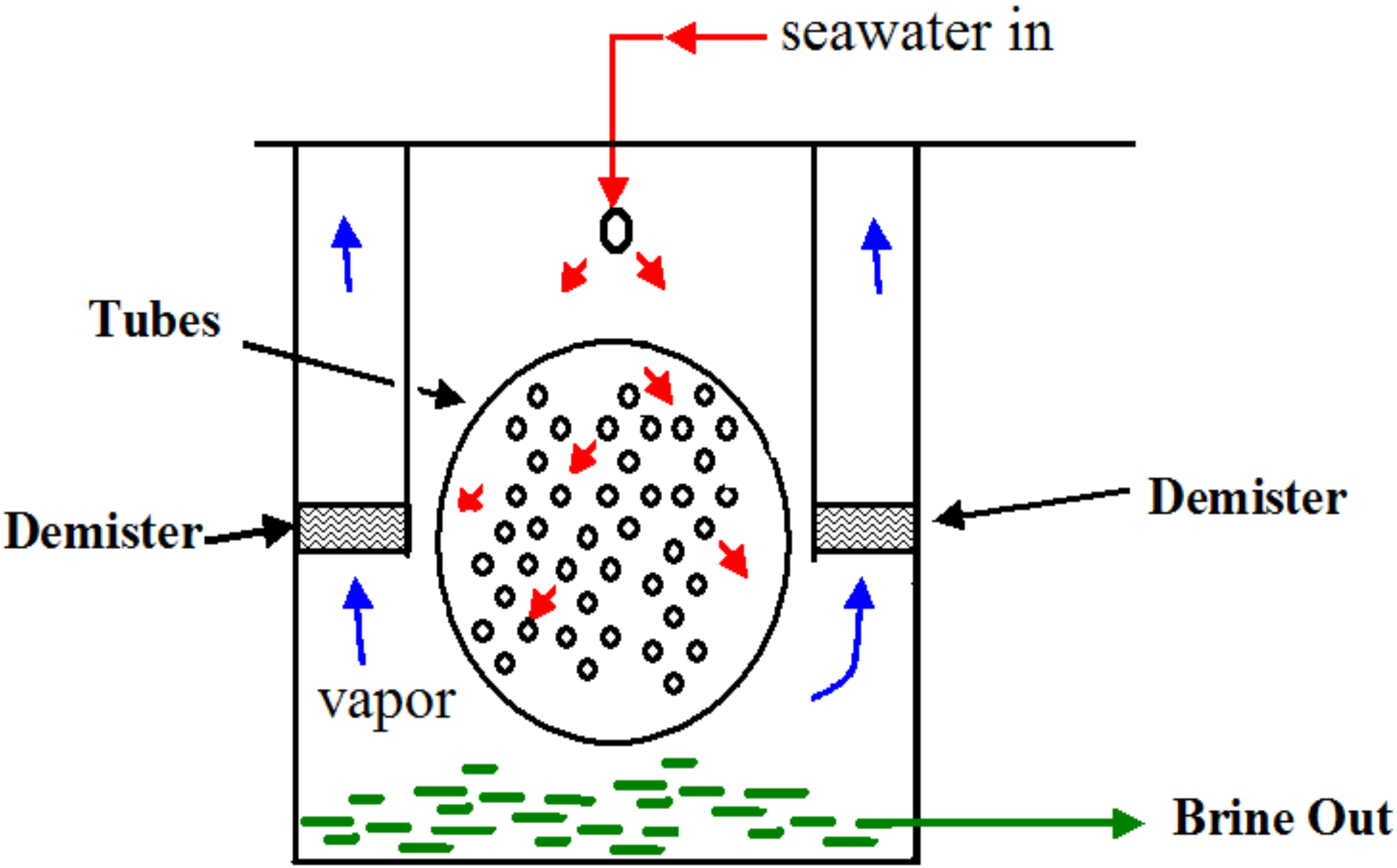
MED distillation

Typical parameters for large MED plant are:

Top Temperature of first stage 65 deg C
Performance Ratio 8 to 15
Distillate Output (*) 5-10 MIGD

MED Desalination Plant

Typical Stage Arrangement of a Large MSF Plant

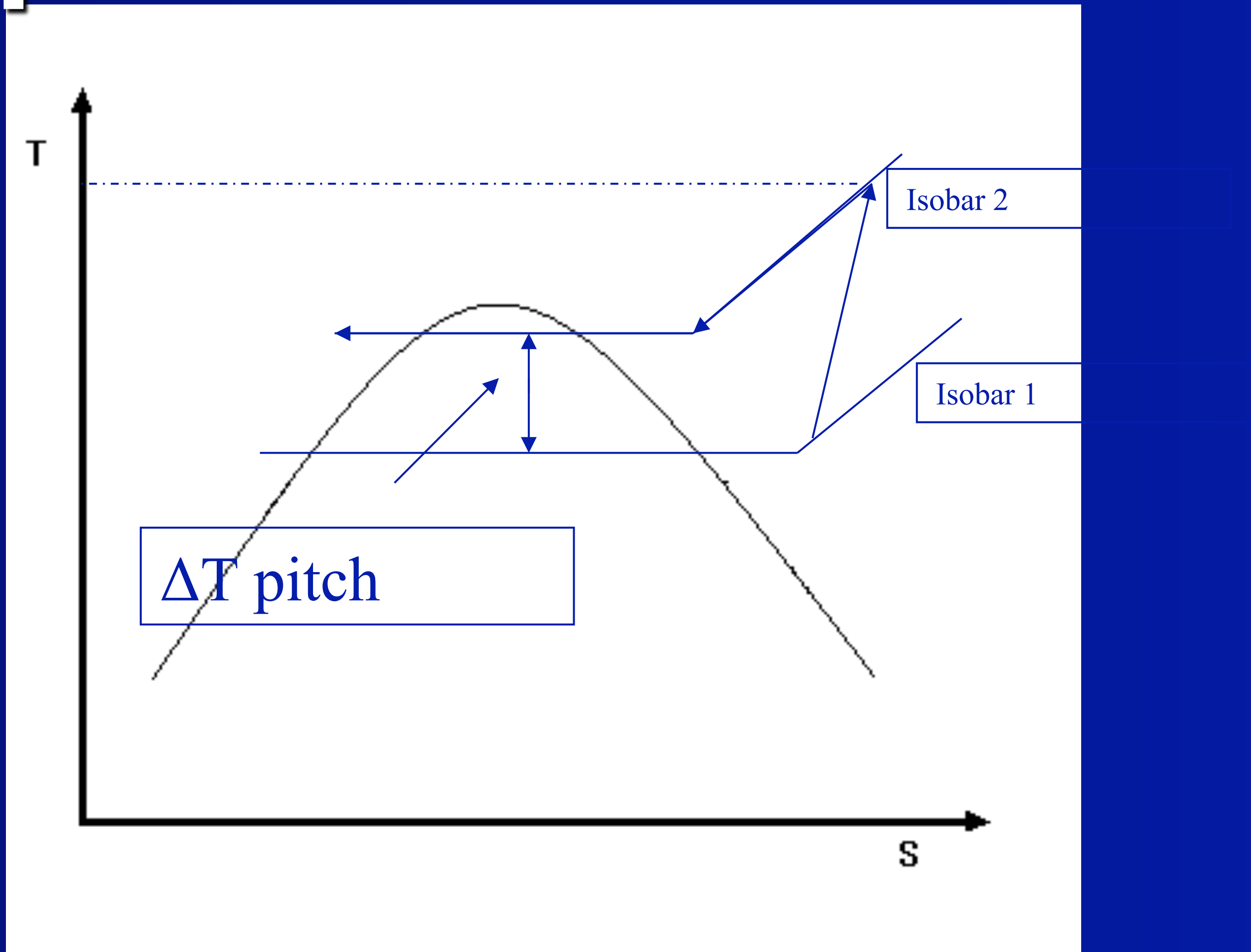


The concept of thermo compression

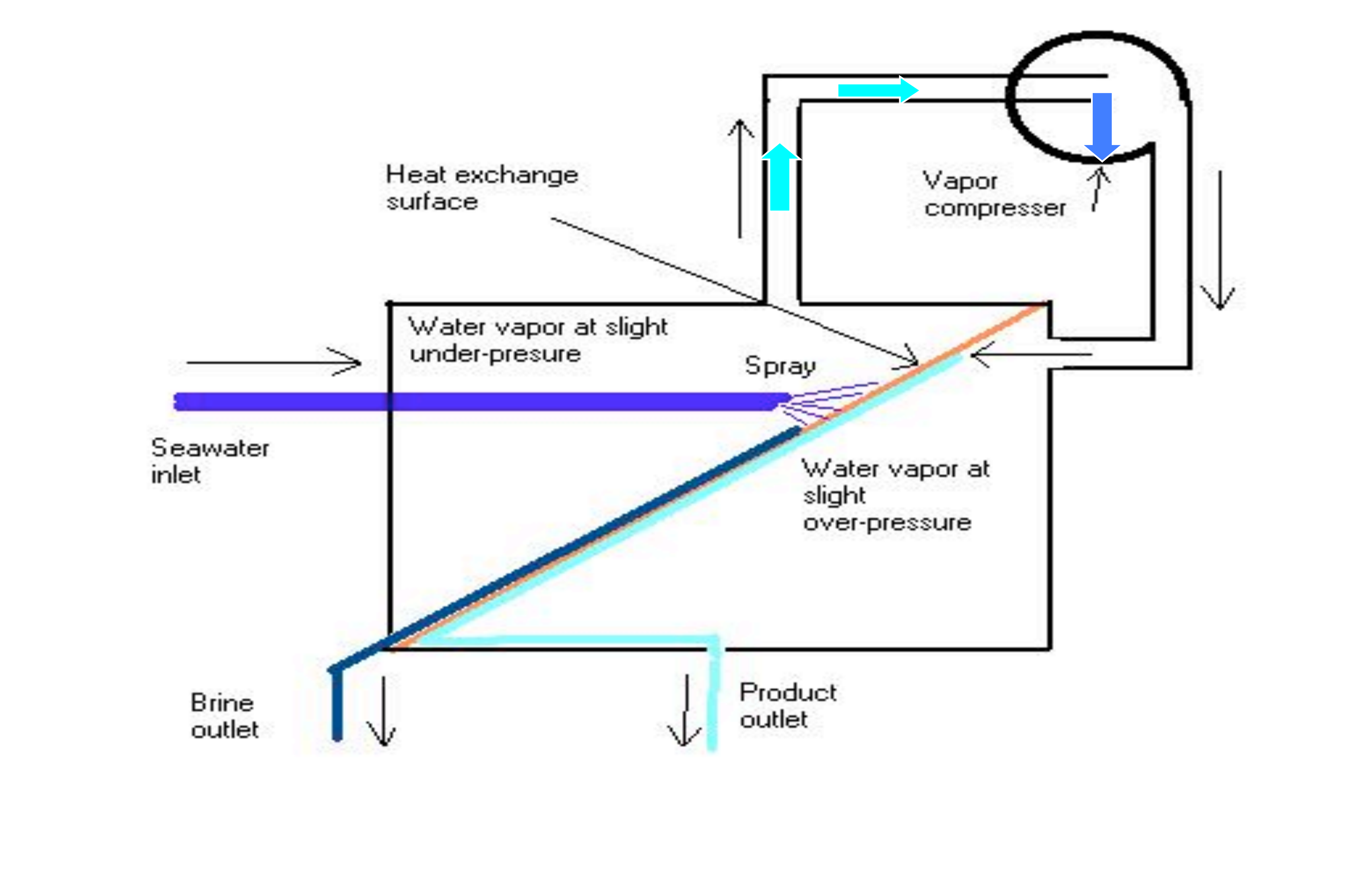
- If reduced pressure causes evaporation at a lower temperature, then compression should force condensation at a higher temperature

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

The concept of thermo compression



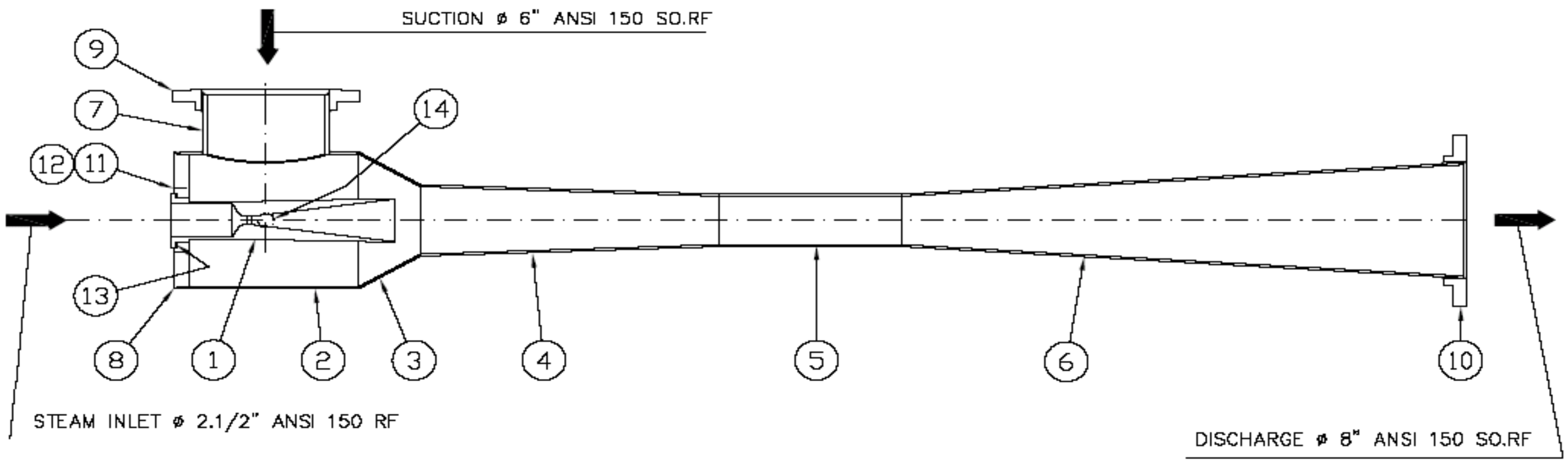
Mechanical Vapor Compression (MVC)



Mechanical Vapor Compression (MVC)

- Especially in their early development the mechanical compressors were unreliable
- They were replaced by a thermally-driven no-moving-parts substitute

A Simple Ejector-Compressor



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	ASTN 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	
Pos. Pos.	Q.ty Q.ta'	Description Denominazione	Material Materiale	Note Note

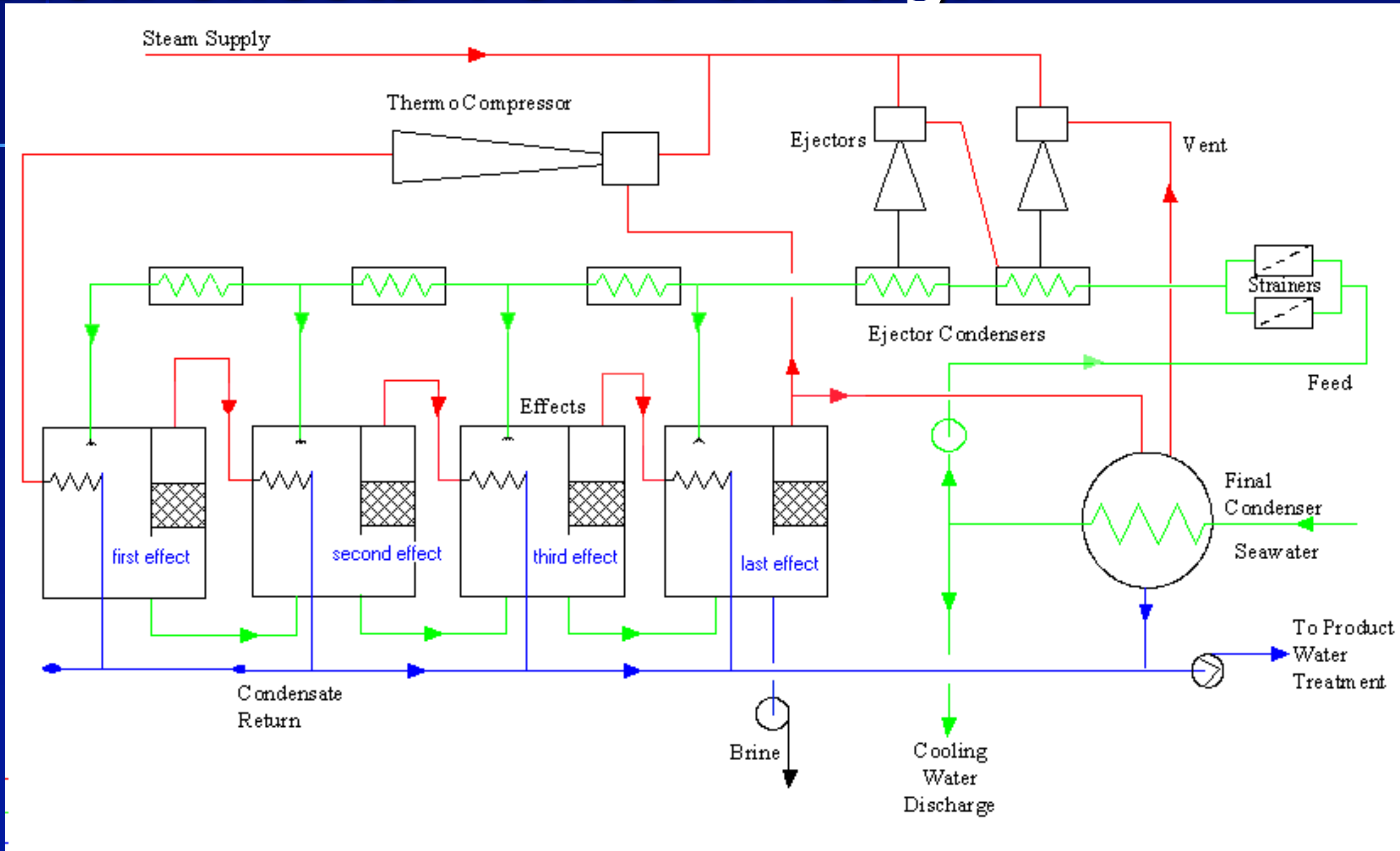
Fluid flowing in the pipeline (the "motive fluid") speeds up to pass through the restriction and in accordance with Bernoulli's equation creates vacuum in the restriction.

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

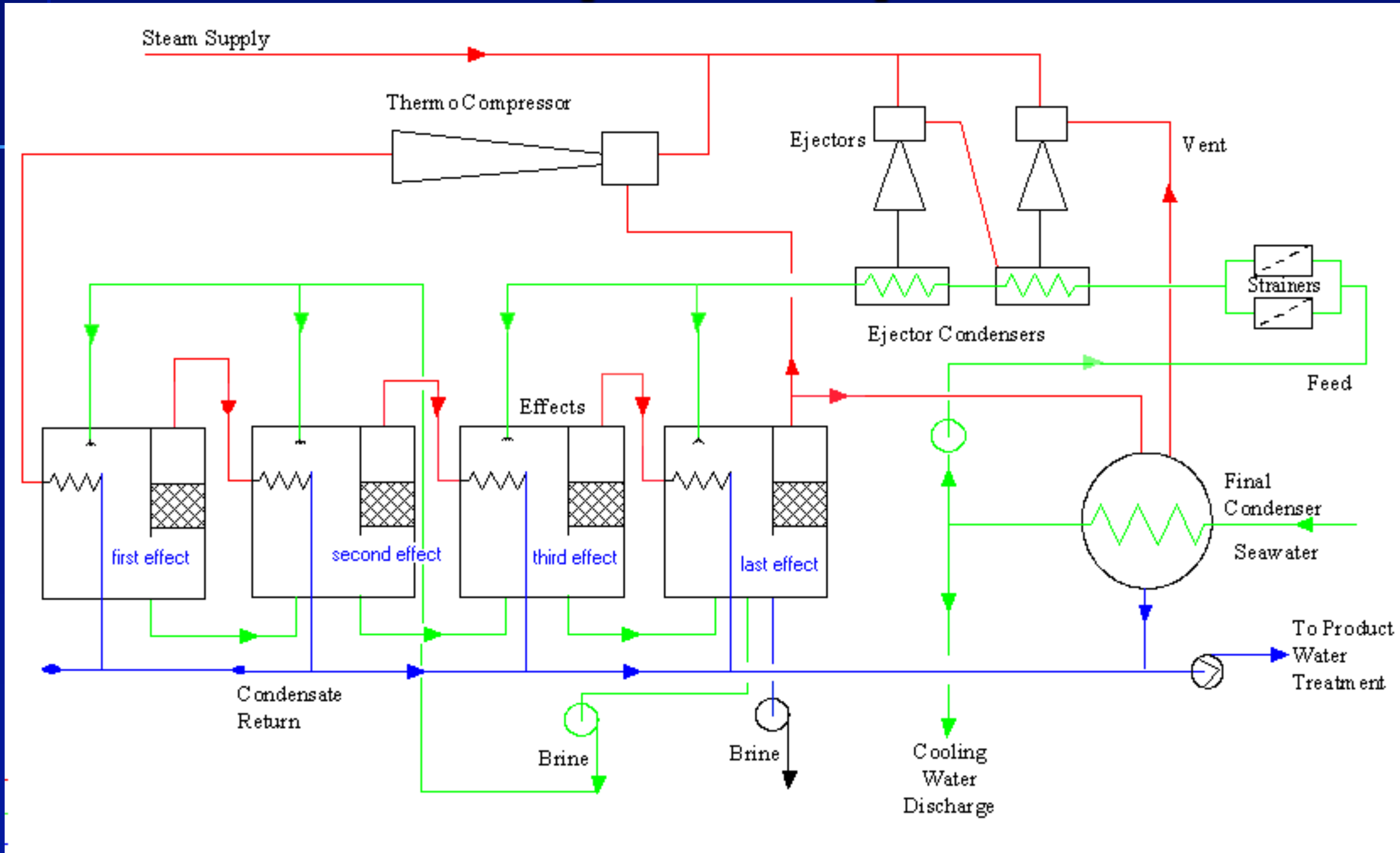
Turbulence downstream of the port entrains and mixes the ejected into the motive fluid.

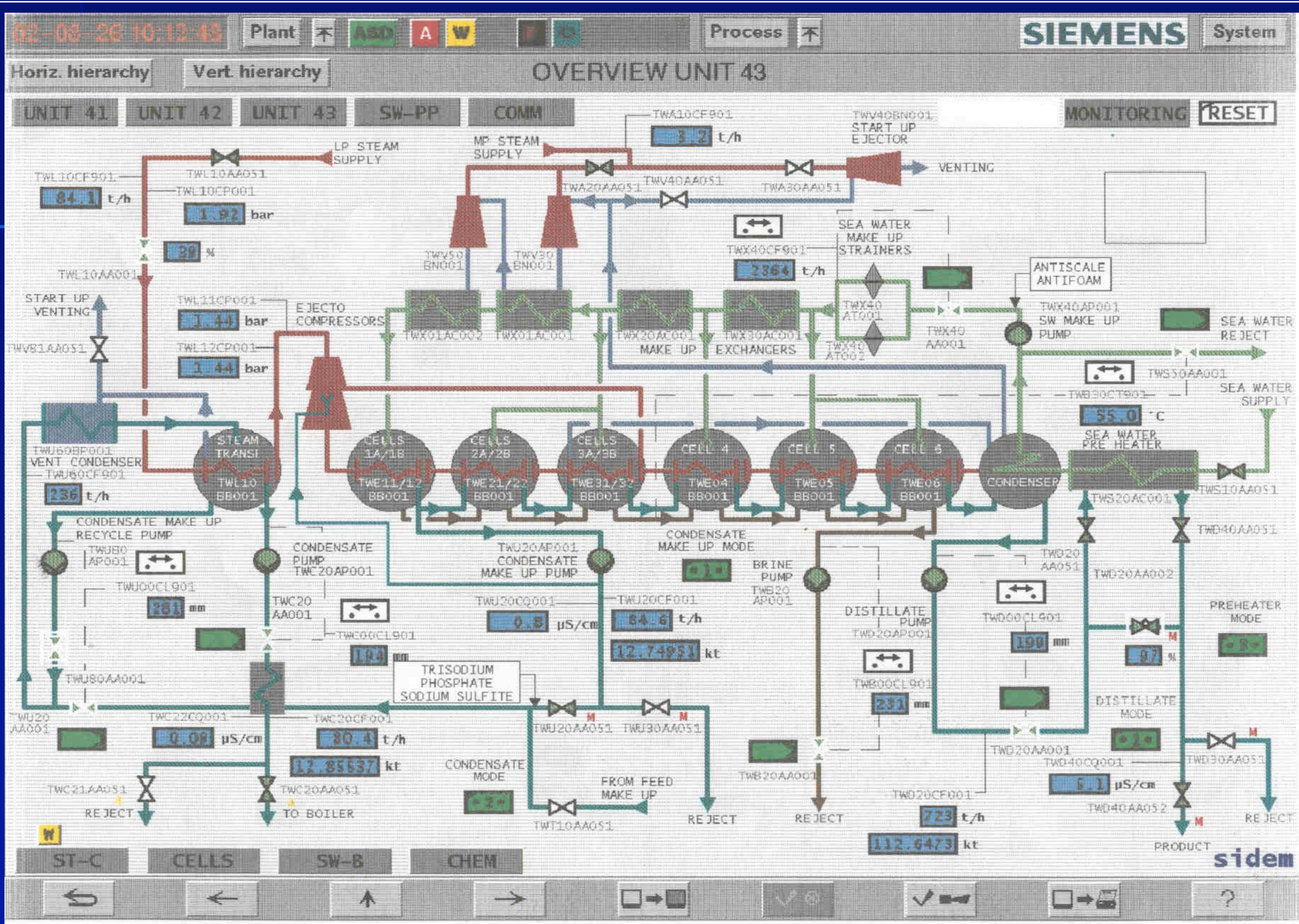
Process description

Flow sheets : once through



Flow sheets : vapor compression

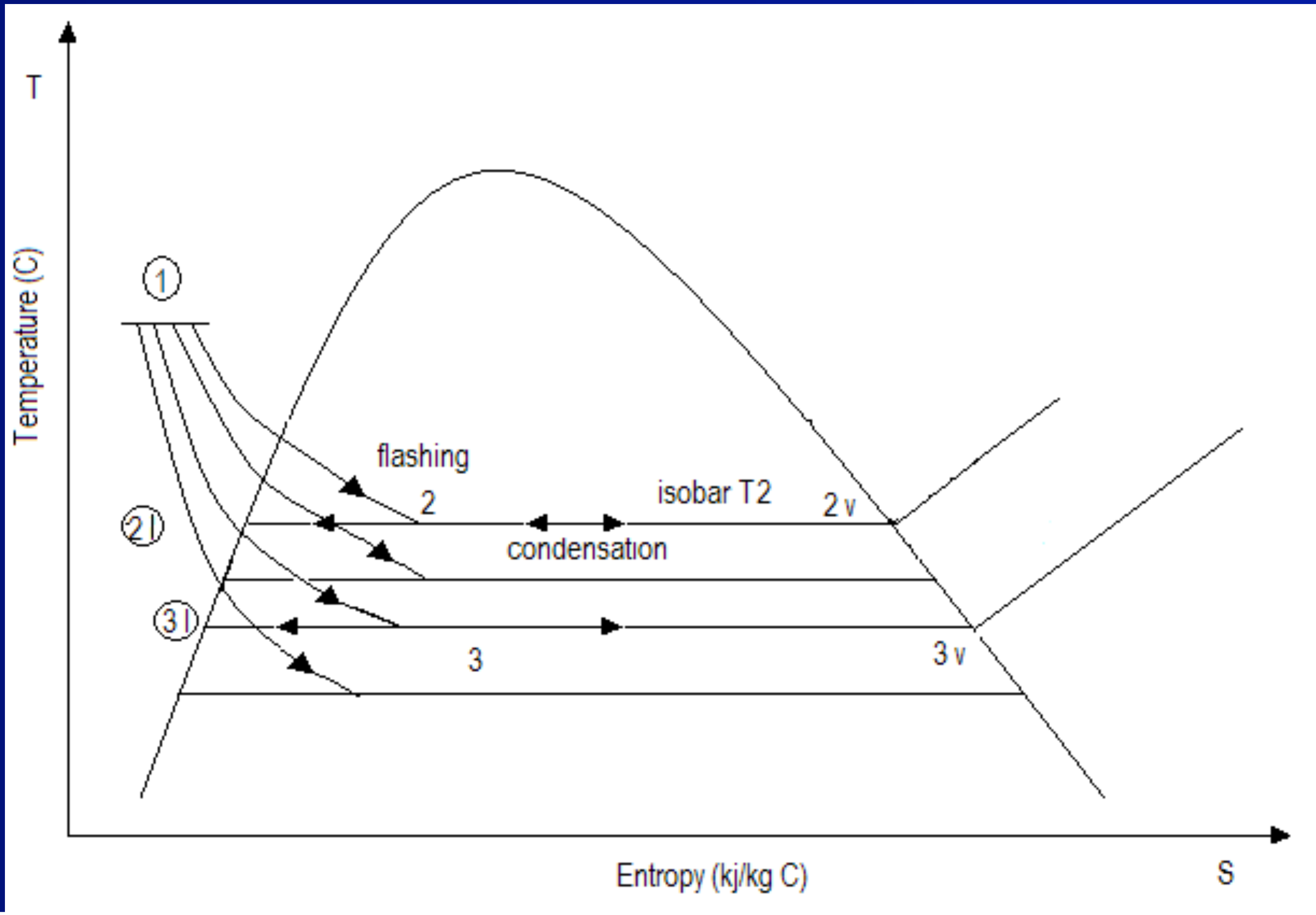




Plant
Process
SIEMENS
System
Horiz. hierarchy
Vert. hierarchy
OVERVIEW UNIT 43
UNIT 41
UNIT 42
UNIT 43
SW-PP
COMM
MONITORING
RESET
LP STEAM SUPPLY
MP STEAM SUPPLY
START UP EJECTOR
VENTING
START UP VENTING
EJECTO COMPRESSORS
SEA WATER MAKE UP STRAINERS
ANTISCALE ANTIFOAM
SW MAKE UP PUMP
SEA WATER REJECT
SEA WATER SUPPLY
MAKE UP EXCHANGERS
VENT CONDENSER
STEAM TRANSF
CELLS 1A/1B
CELLS 2A/2B
CELLS 3A/3B
CELL 4
CELL 5
CELL 6
CONDENSER
SEA WATER PRE HEATER
CONDENSATE MAKE UP RECYCLE PUMP
CONDENSATE PUMP
CONDENSATE MAKE UP PUMP
CONDENSATE MAKE UP MODE
BRINE PUMP
DISTILLATE PUMP
PREHEATER MODE
DISTILLATE MODE
TRISODIUM PHOSPHATE SODIUM SULFITE
CONDENSATE MODE
FROM FEED MAKE UP
REJECT
TO BOILER
PRODUCT
ST-C
CELLS
SW-B
CHEM
sidem

MED process phenomena :

thermodynamic path : the ideal case



MED cross flow plant internal layout