WATER ARABIA 2013

BASIC DESIGN OF DESALINATION PROCESS

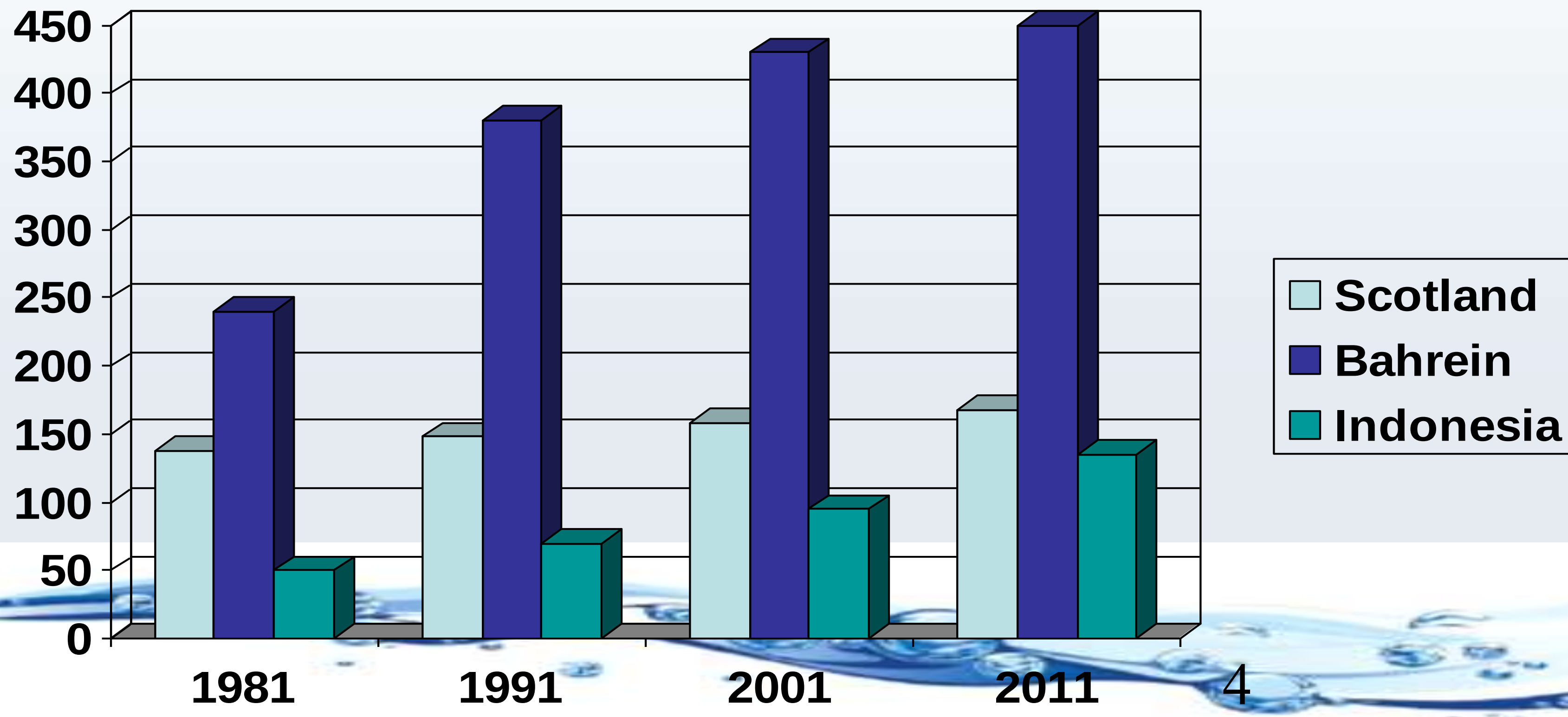
9.00 Introductions

9.15 Desalination Market

- General views of the desalination market

Rising standards of living –

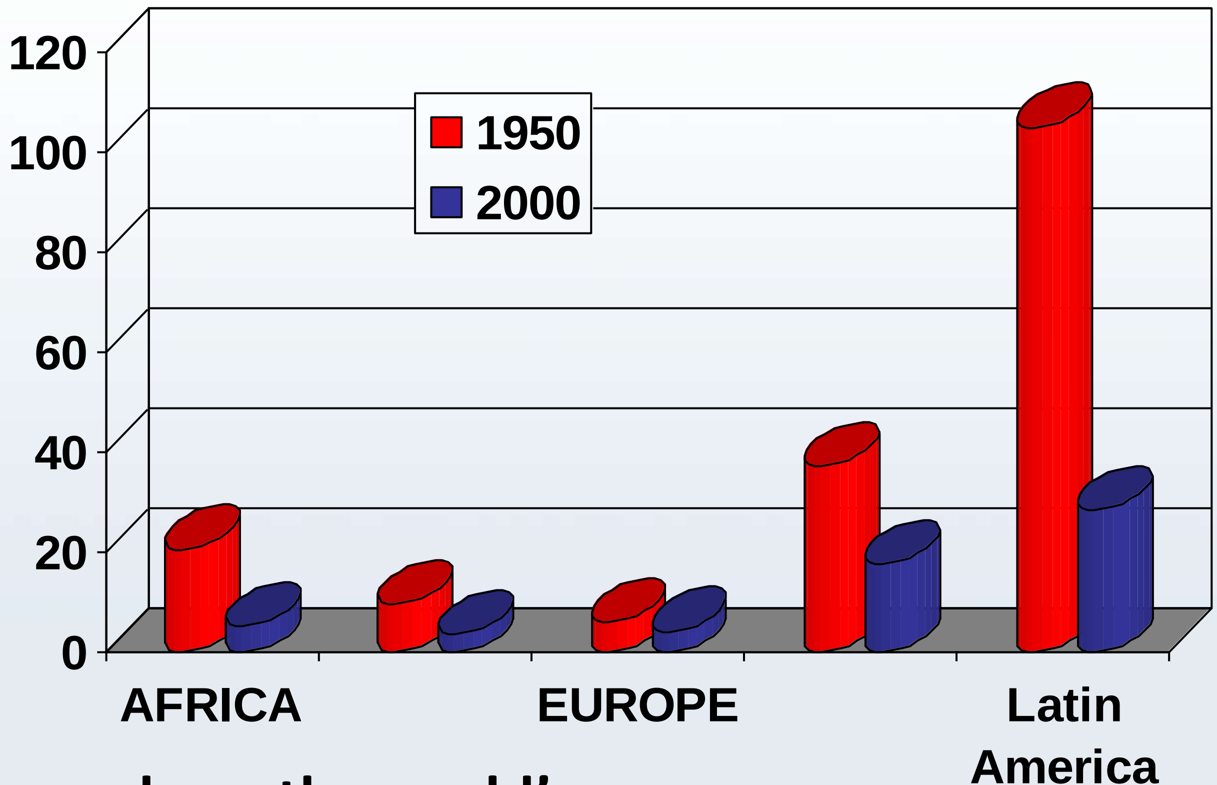
Liters of Water Per Person Per Day



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

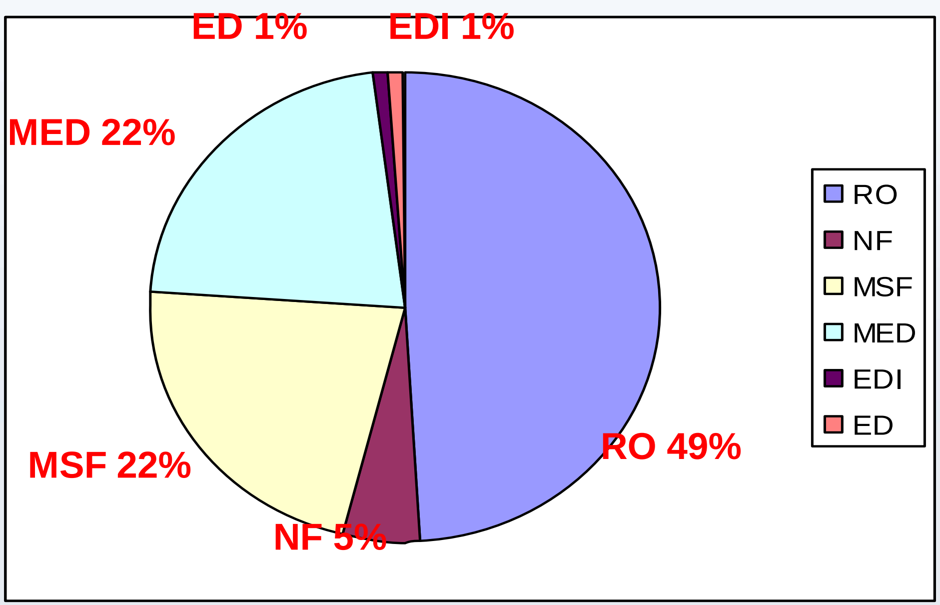
Increasing pressure on the environment

- 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.

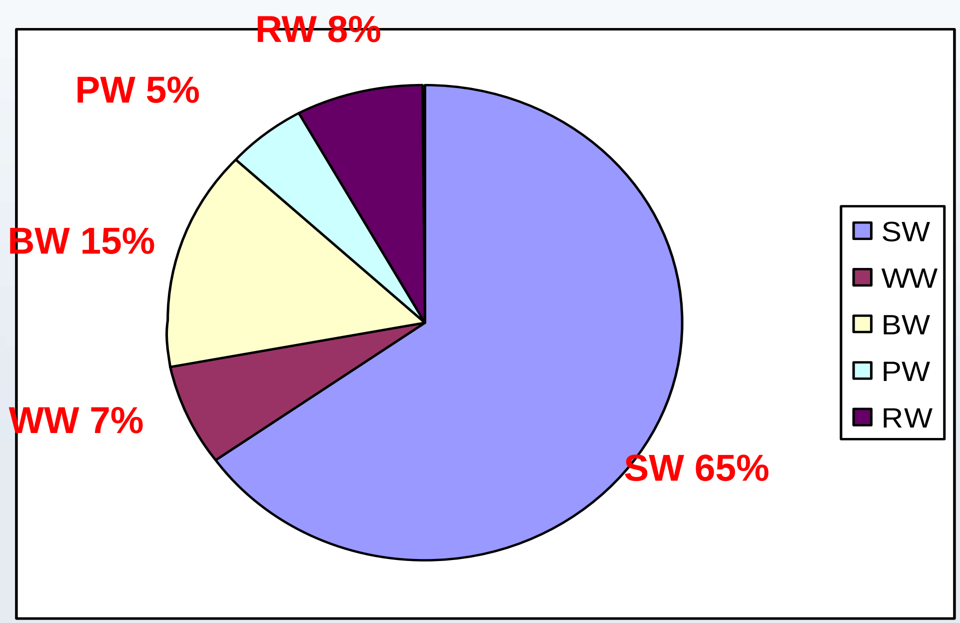
–General views of the desalination market

Global contracted capacity

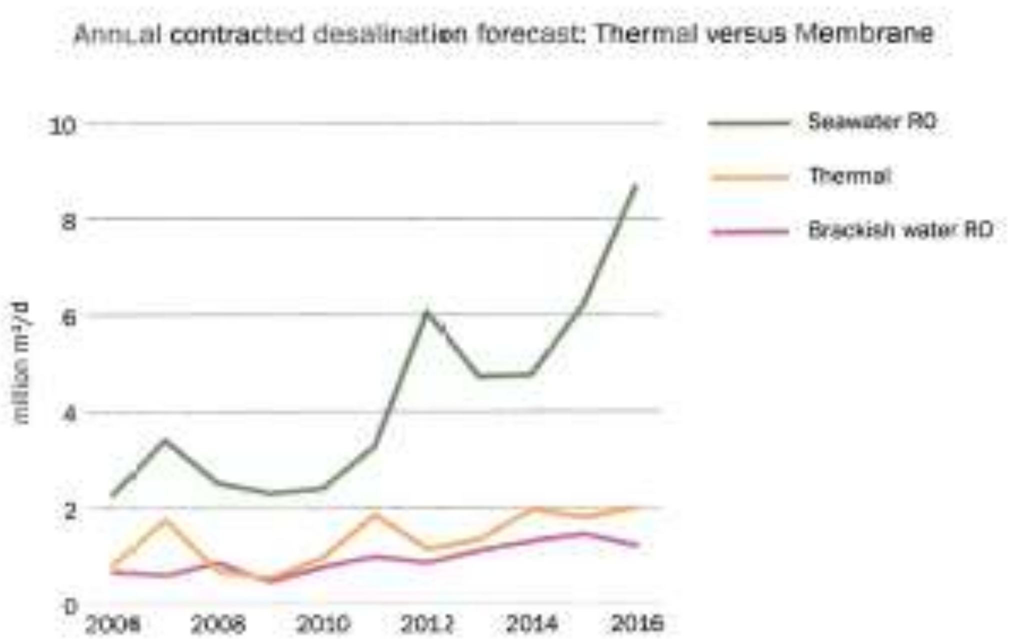
By technology

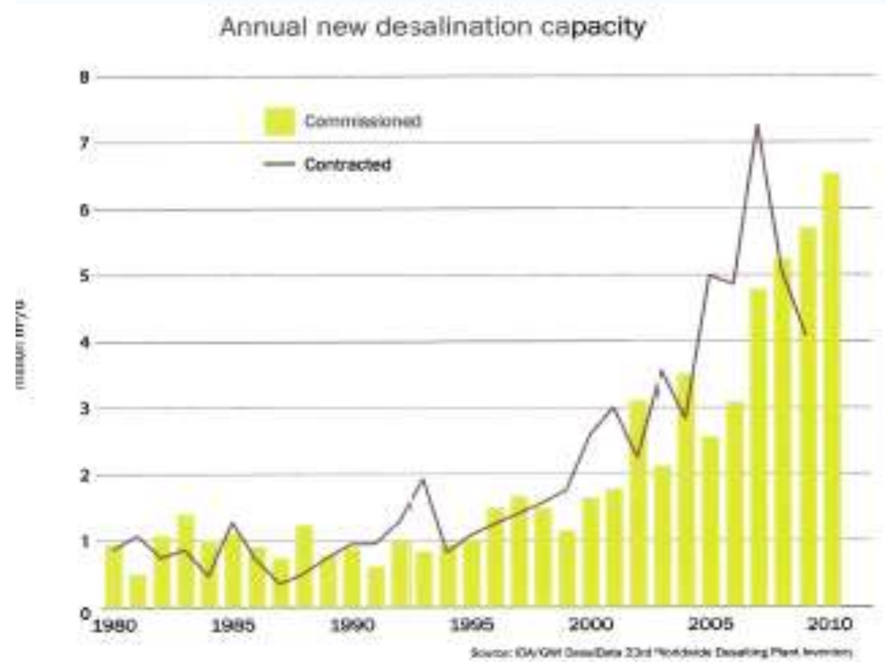


By water type



A growing market and a changing situation





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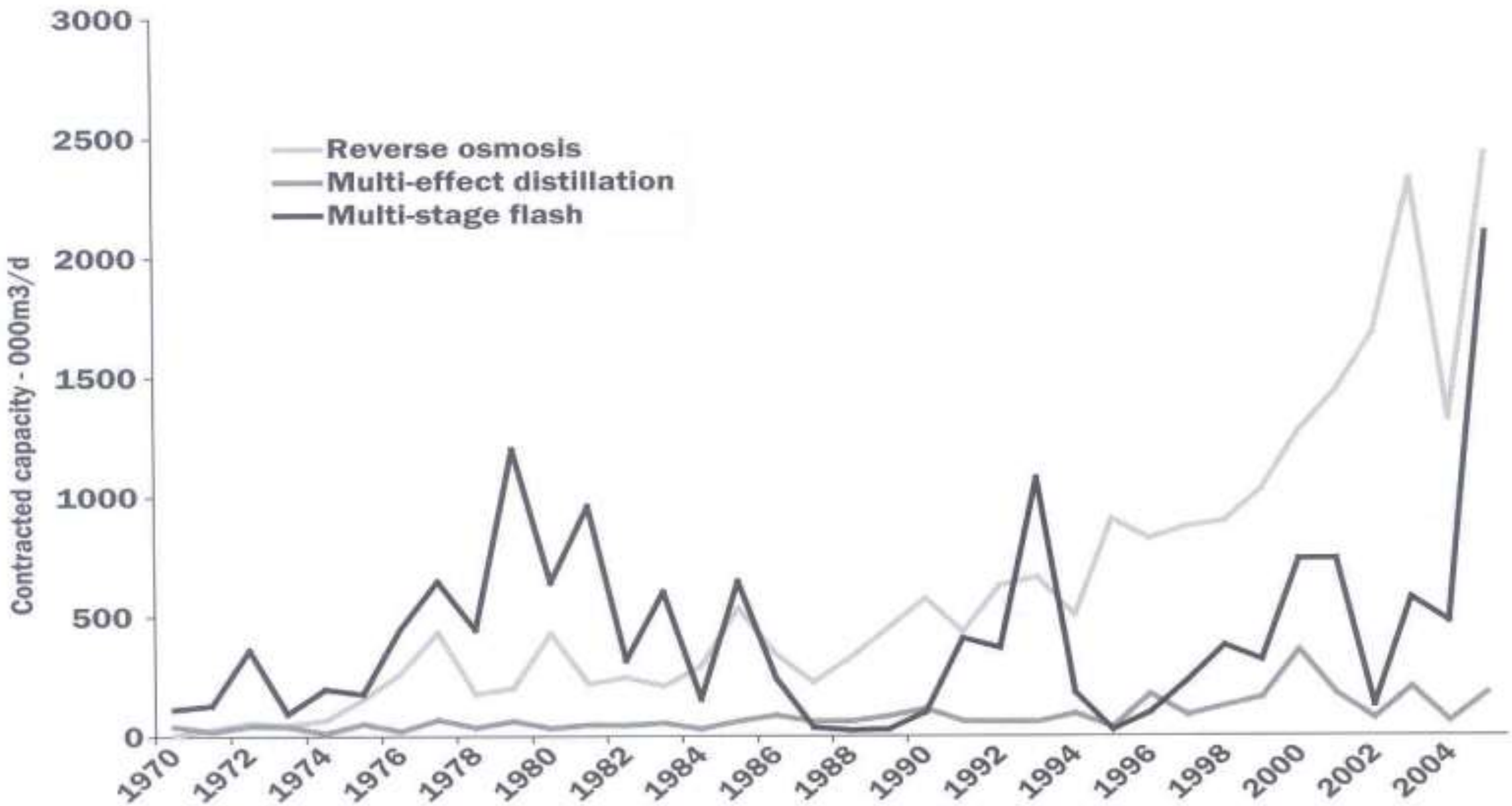
–General views of the desalination market

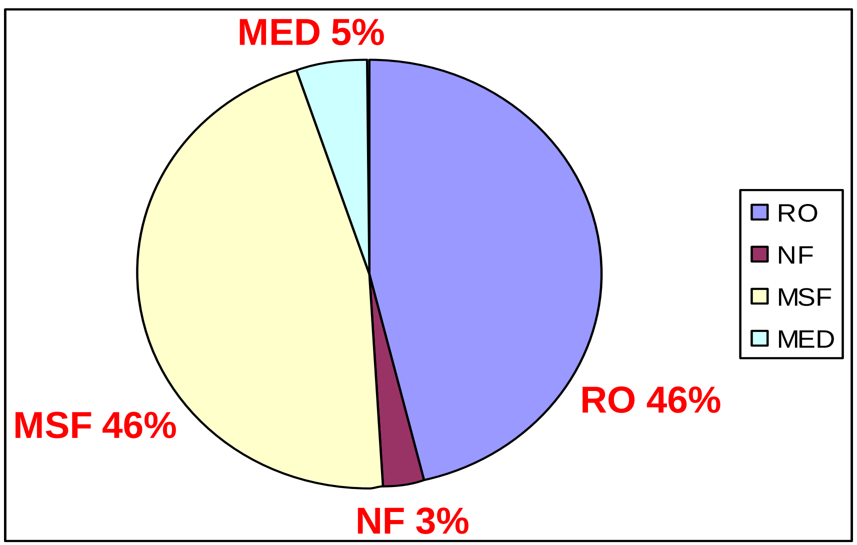
Technology trends 1970 -2004



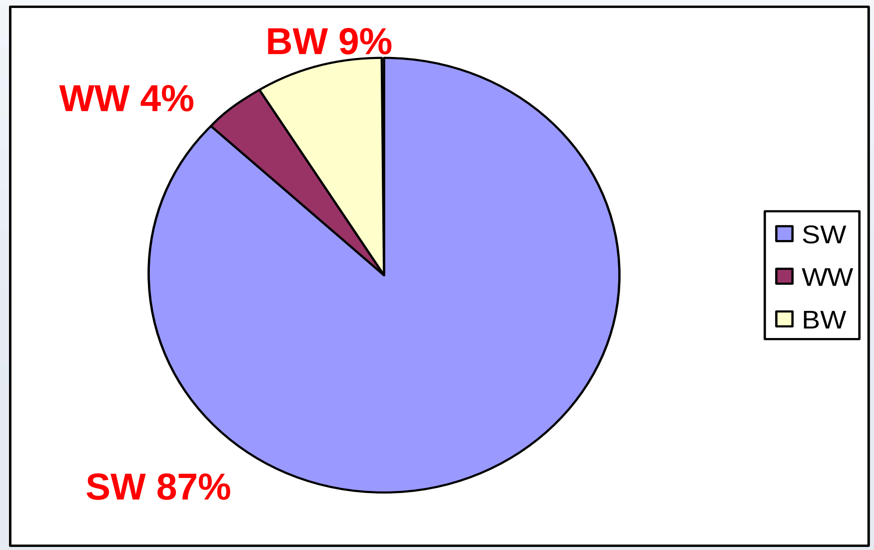
–General views of the desalination market

Contracted capacity in ME&A a couple of year ago

By technology



By water type



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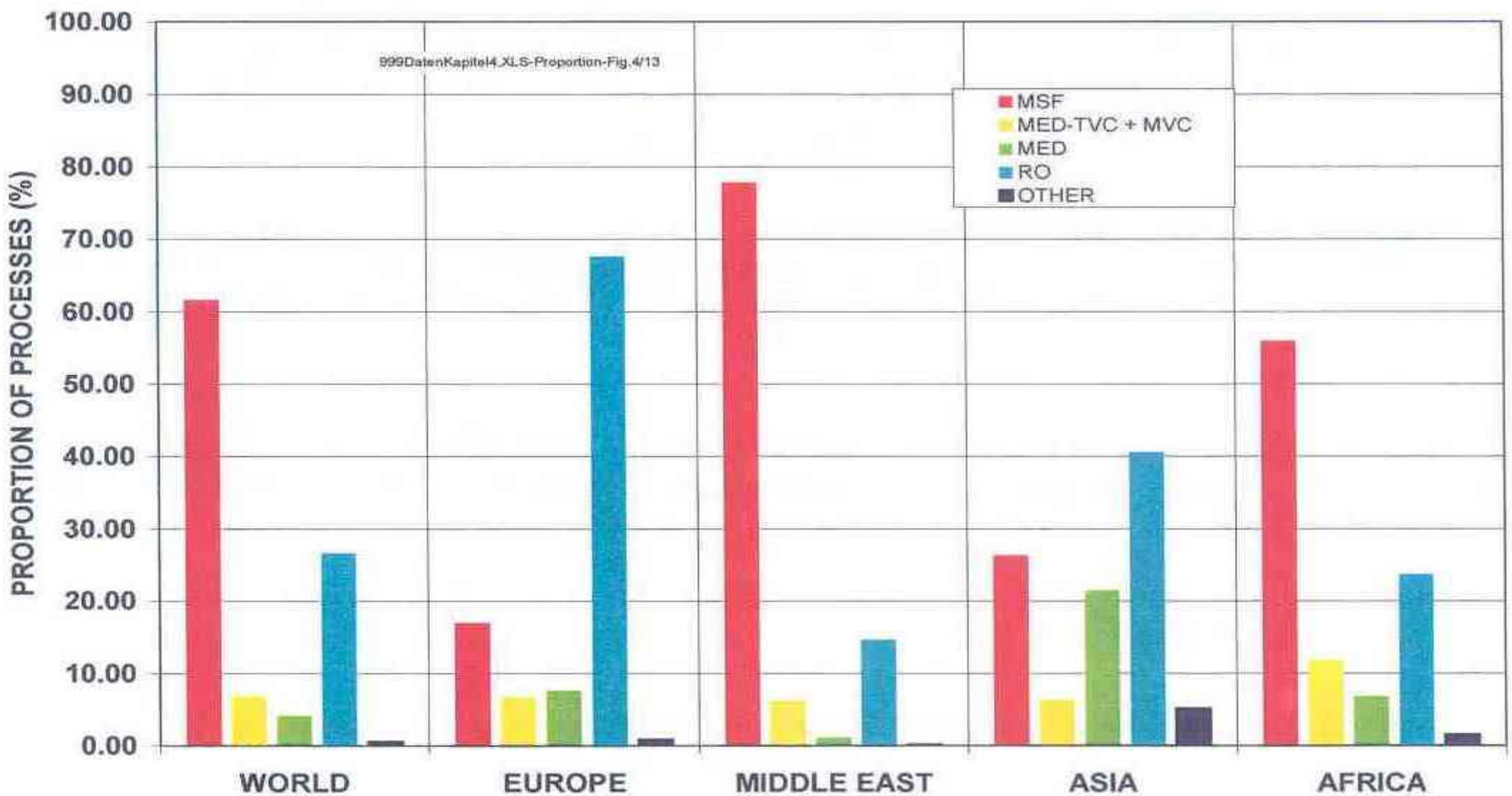
–General views of the desalination market

Proportions of the processes (seawater)



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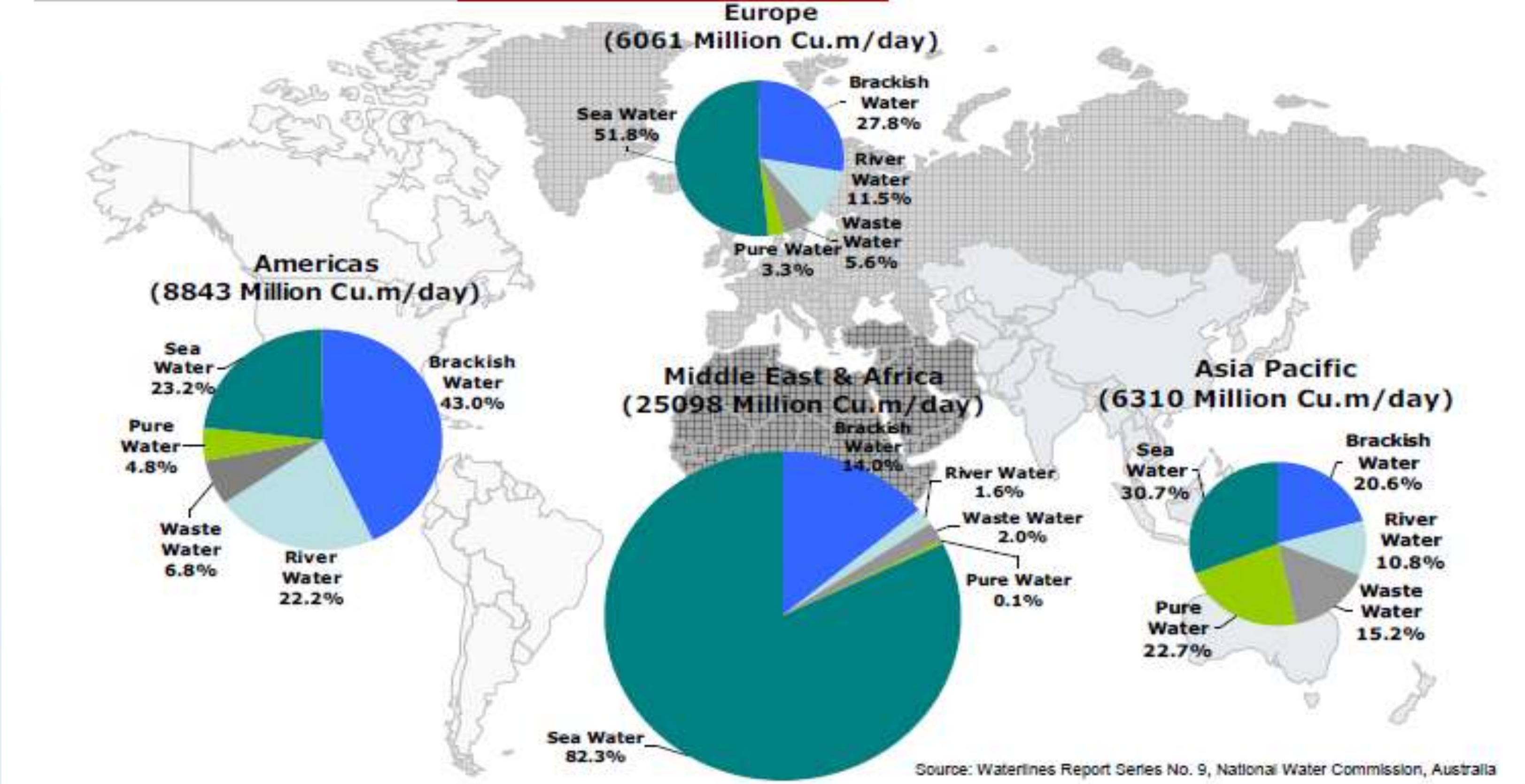
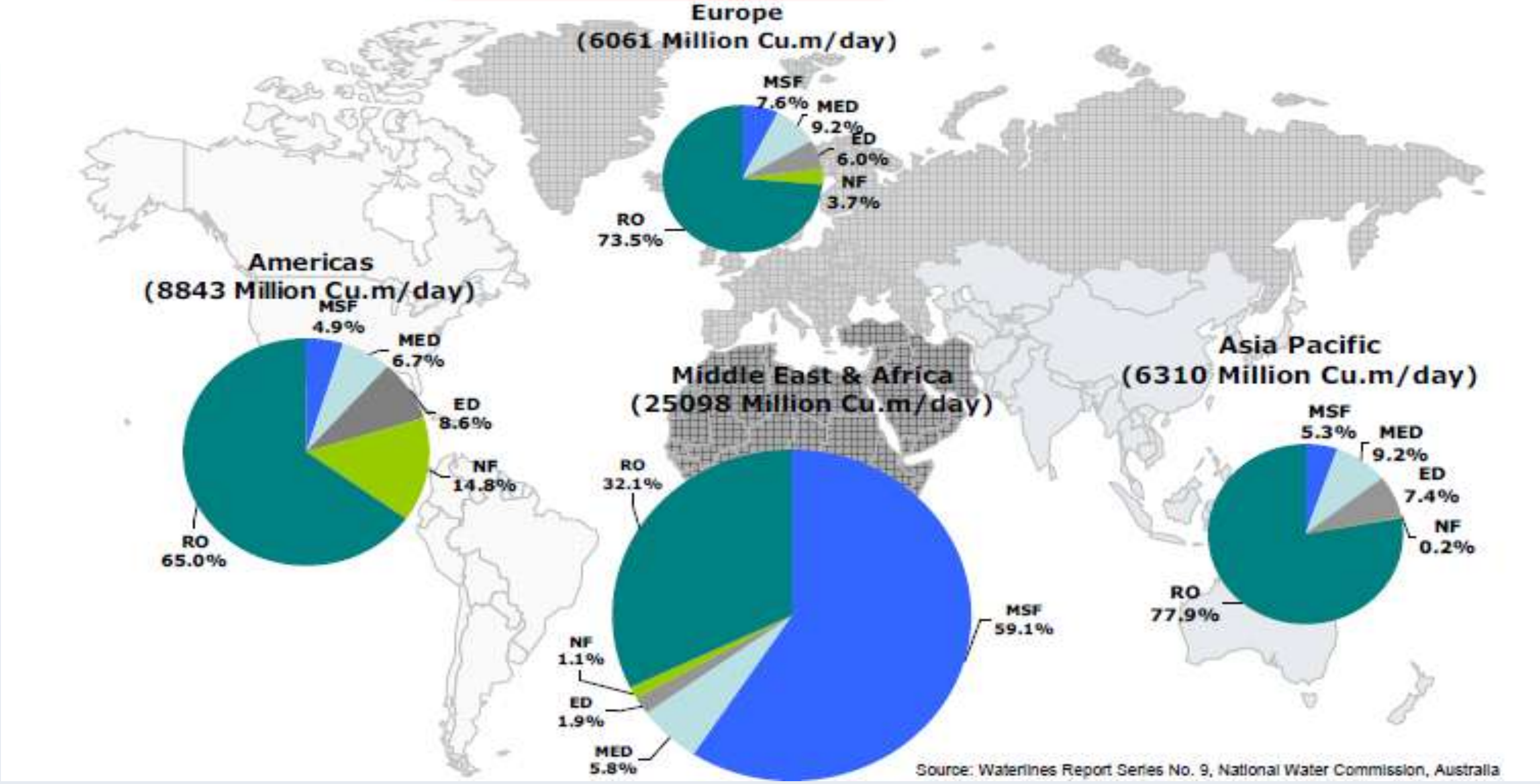
Trend by Desalination Source Water



Source: Waterlines Report Series No. 9, National Water Commission, Australia

Trend by Technology Type



Energy prices reverse desal trends

- Thermal processes are likely to continue to dominate the industry in the Gulf region over the next decade. thanks to MEGA project 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

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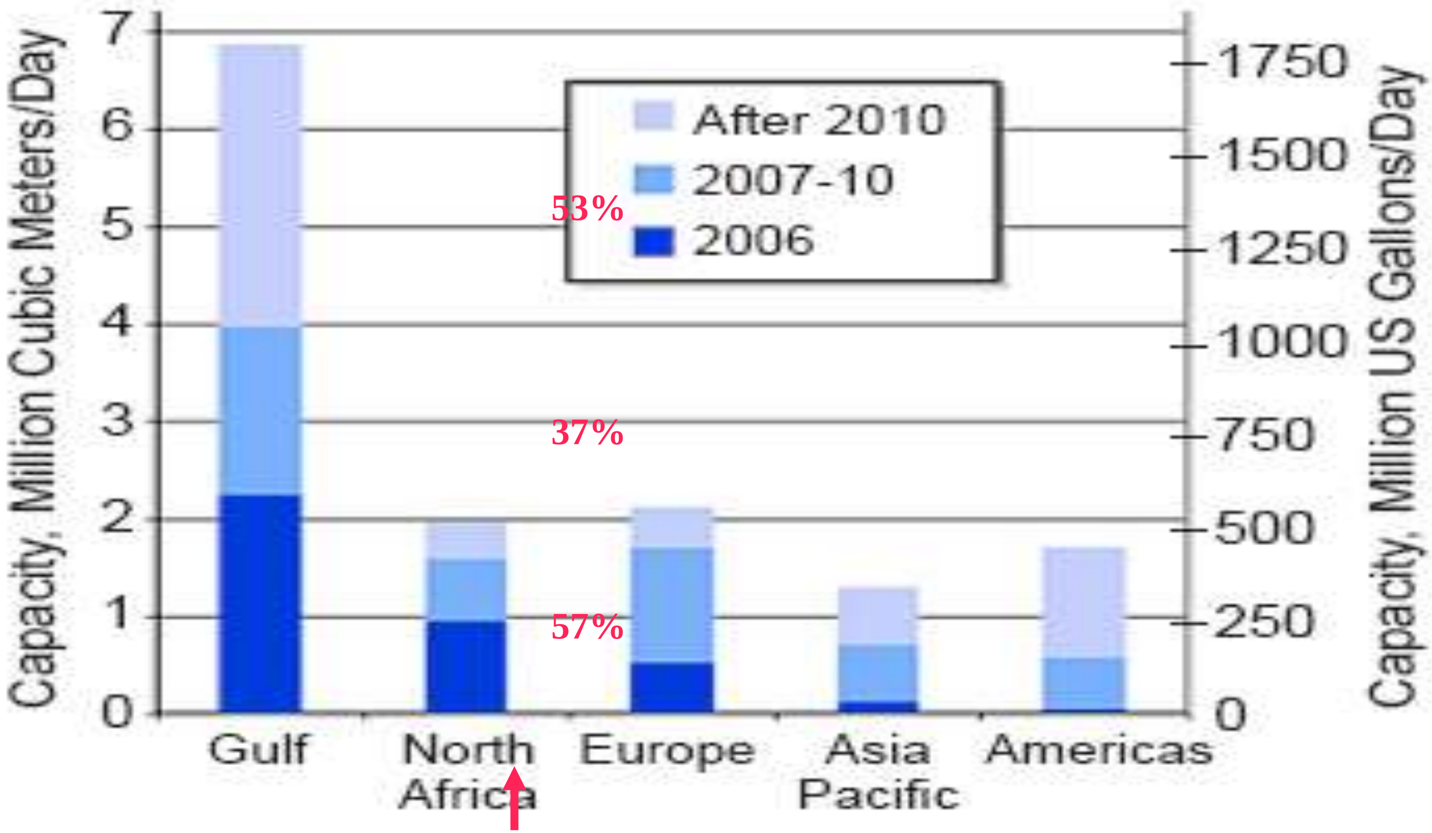
Forecast desalination capacity by region – future projects (2006-2010)*



* Water Desalination Report

Desalination plant Basic Mass Balances

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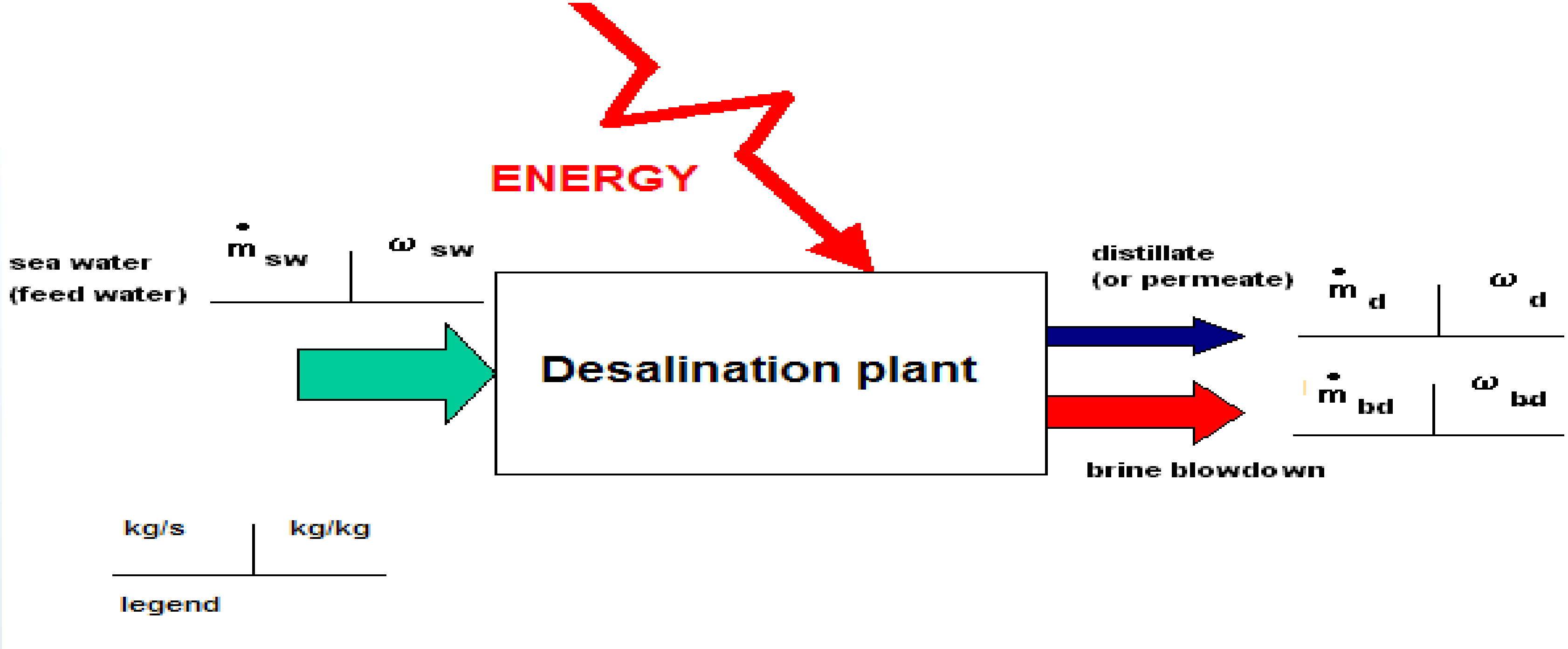
Desalination plant Basic Mass Balances



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

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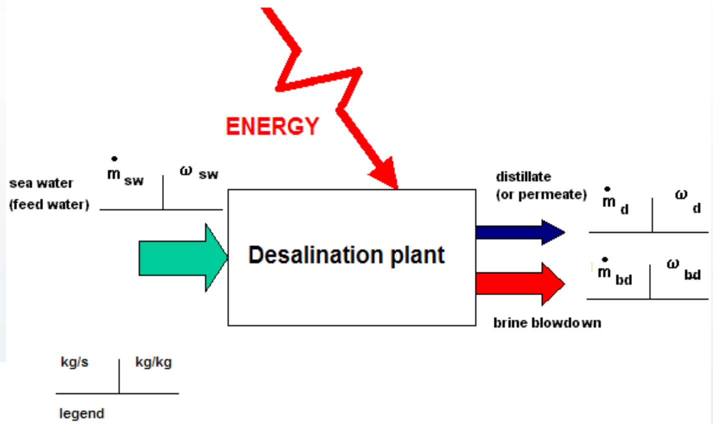
Mass Balances relationships

1) mass conservation (overall mass balance)

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



2) 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

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Recovery ratio and concentration factor

$$RR = \frac{Q_F - Q_C}{Q_F}$$

$$Q_F * TDS_F = Q_C * TDS_C + Q_P * TDS_P \rightarrow Q_F = Q_C \frac{TDS_C}{TDS_F}$$

$$RR = \frac{Q_C \frac{TDS_C}{TDS_F} - Q_C}{Q_C \frac{TDS_C}{TDS_F}}$$

$$RR = \frac{TDS_C - TDS_F}{TDS_C}$$

Concentration factor – production ratio

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

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

Concentration factor

Comparison of concentration factor CF (seawater) for different processes

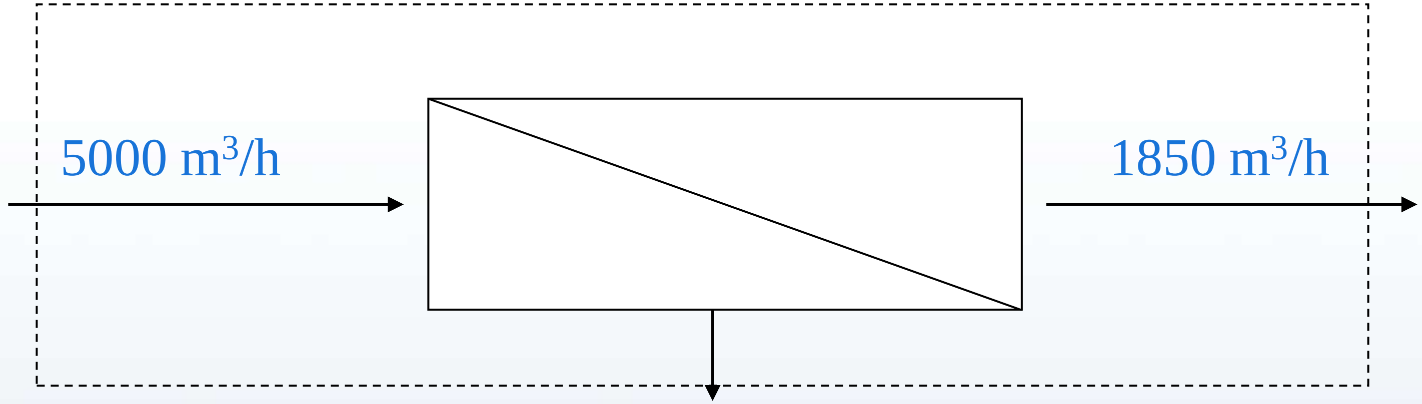
	MSF	MED	VC	RO
Recovery (Y%)	30 – 5	40 – 50	40 – 50	35 - 45
$CF \# \frac{1}{1 - Y}$	1,4 – 2	1,6 – 2	1,6 - 2	1,5 - 1,8

Mass Balances relationships

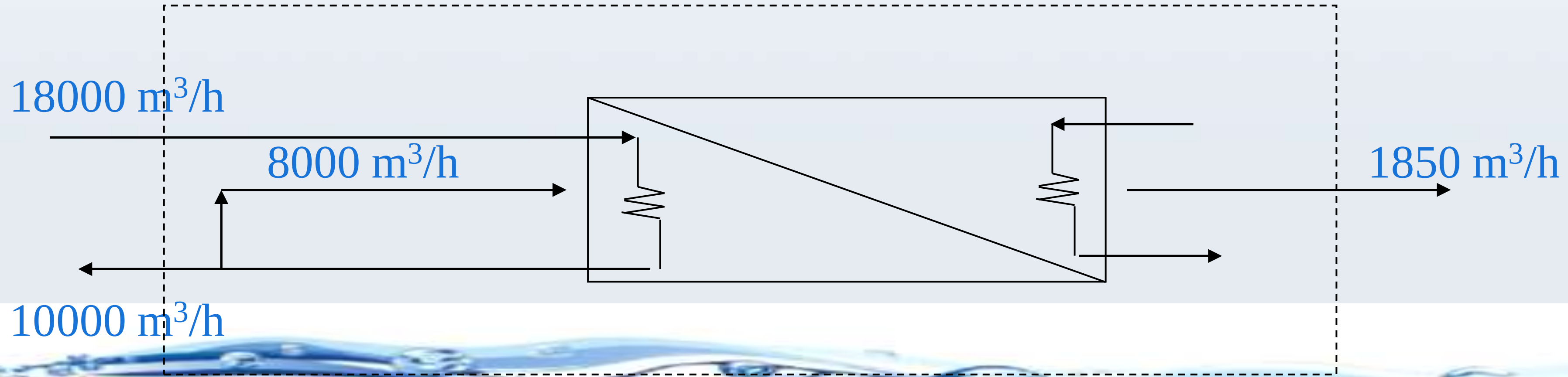
But ….. Then why seawater consumption for SWRO technology is much lower than for thermal ?

Mass Balances relationships

10 MIGD SWRO vs THERMAL



Distinguish between overall SW flow rate to thermal plant and make up flow rate



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Seawater requirement

Quantity of seawater needed to produce 1 m^3 product water by different processes

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

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

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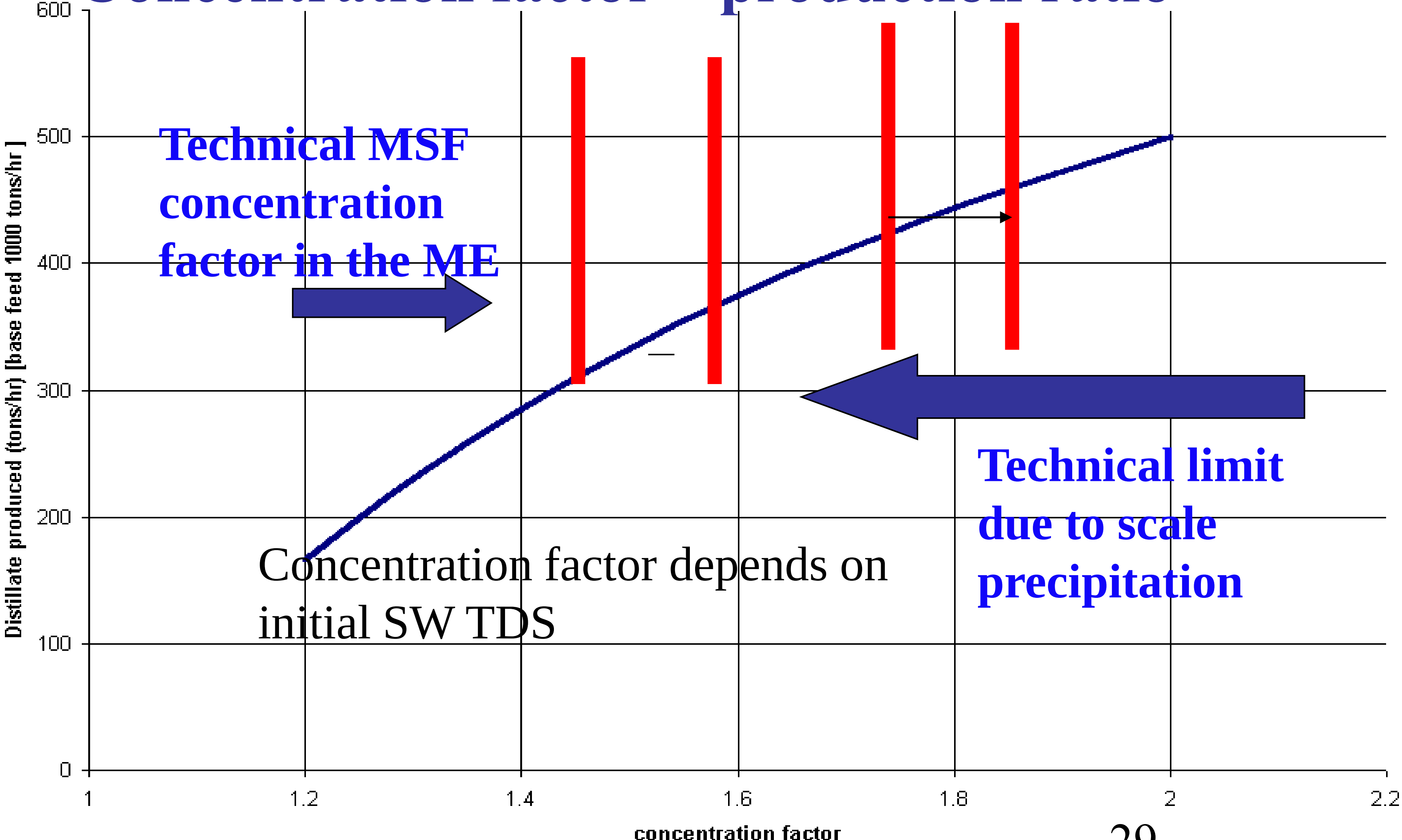
Concentration factor – production ratio



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%

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

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Concentration factor – production ratio

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

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

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

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 blow down as the difference between make up and distillate

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

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.

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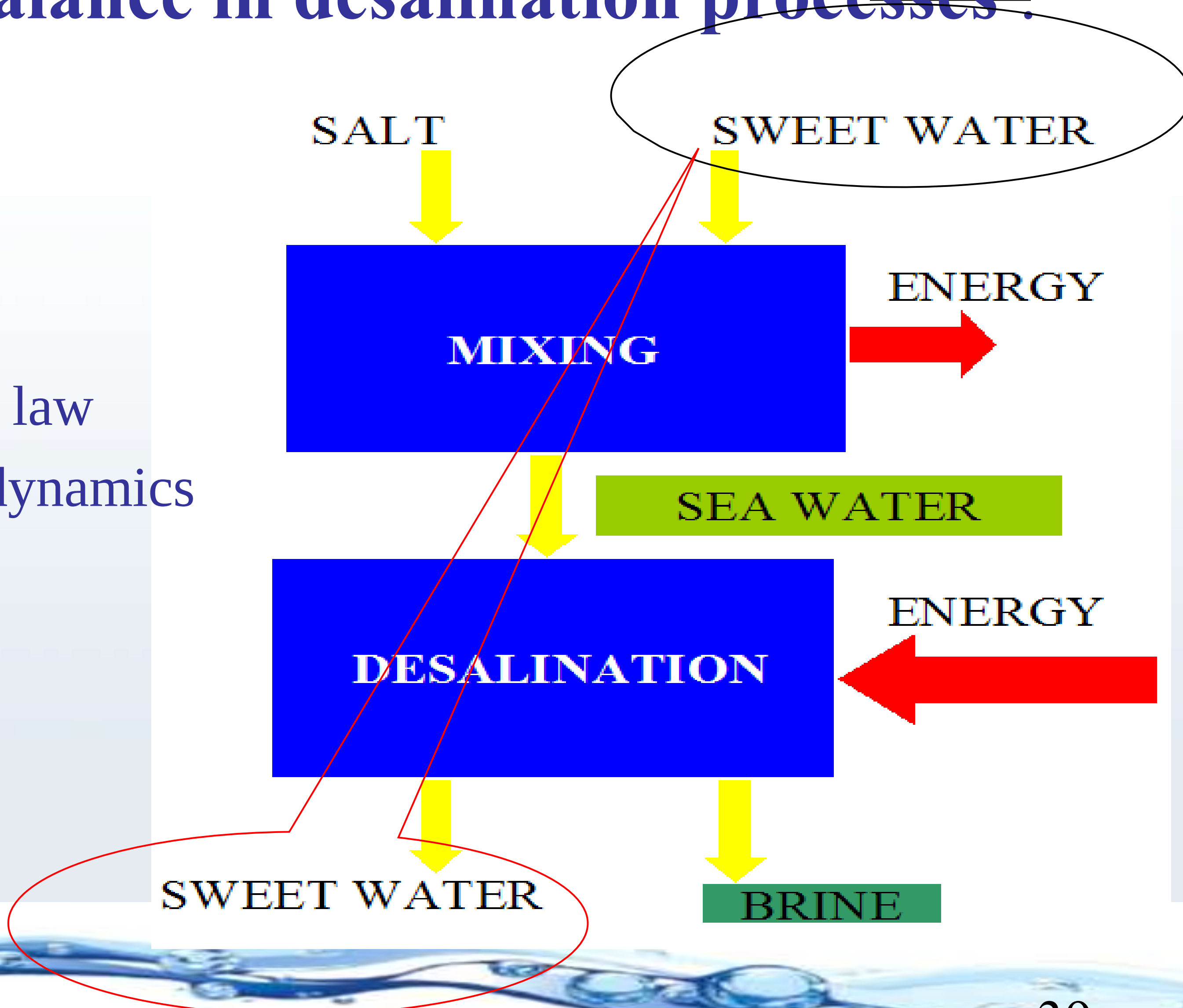
Energy balance in desalination processes :

the second law

of thermodynamics

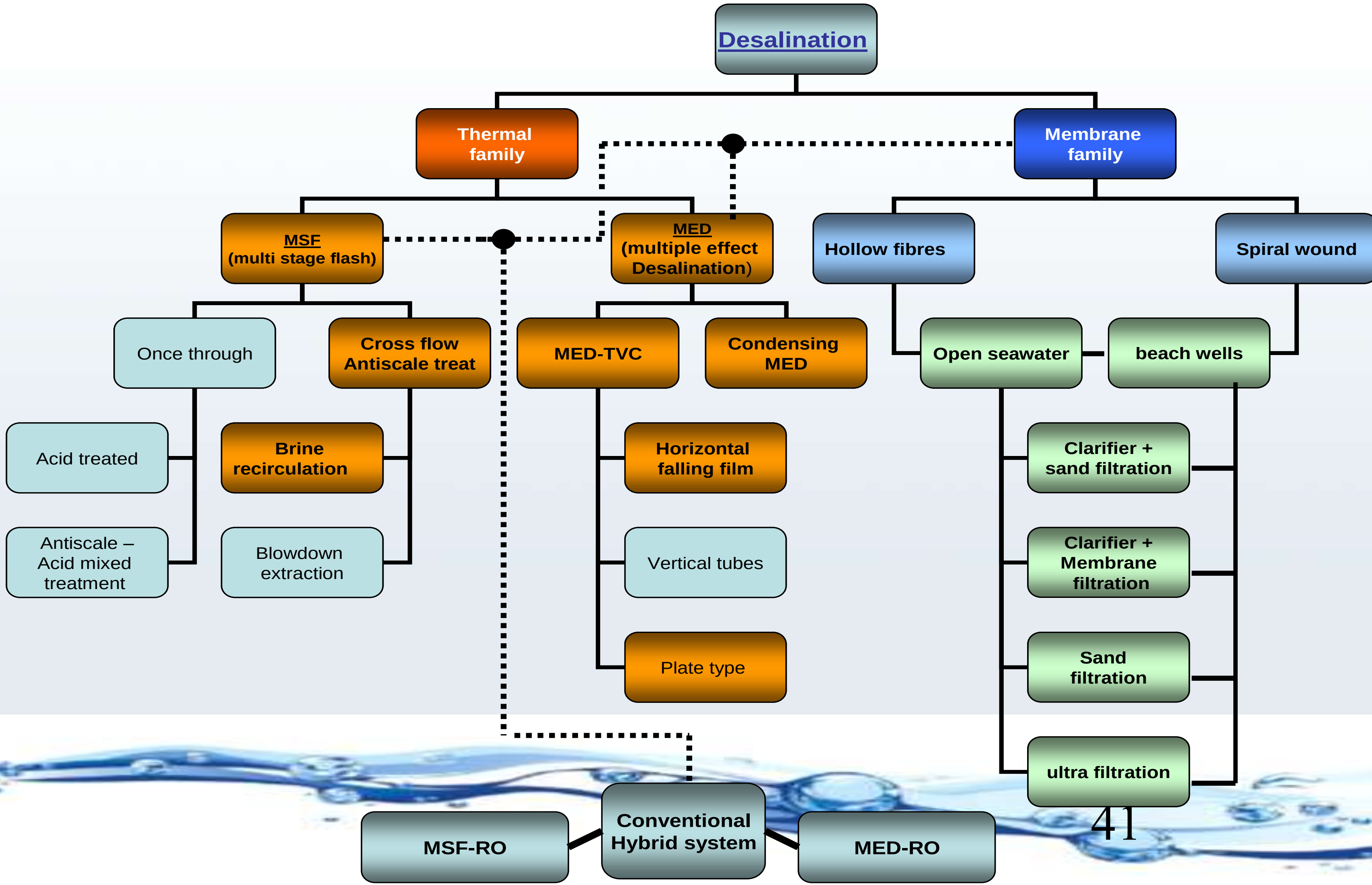


Energy input classifications

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).

Energy input : Desalination processes



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

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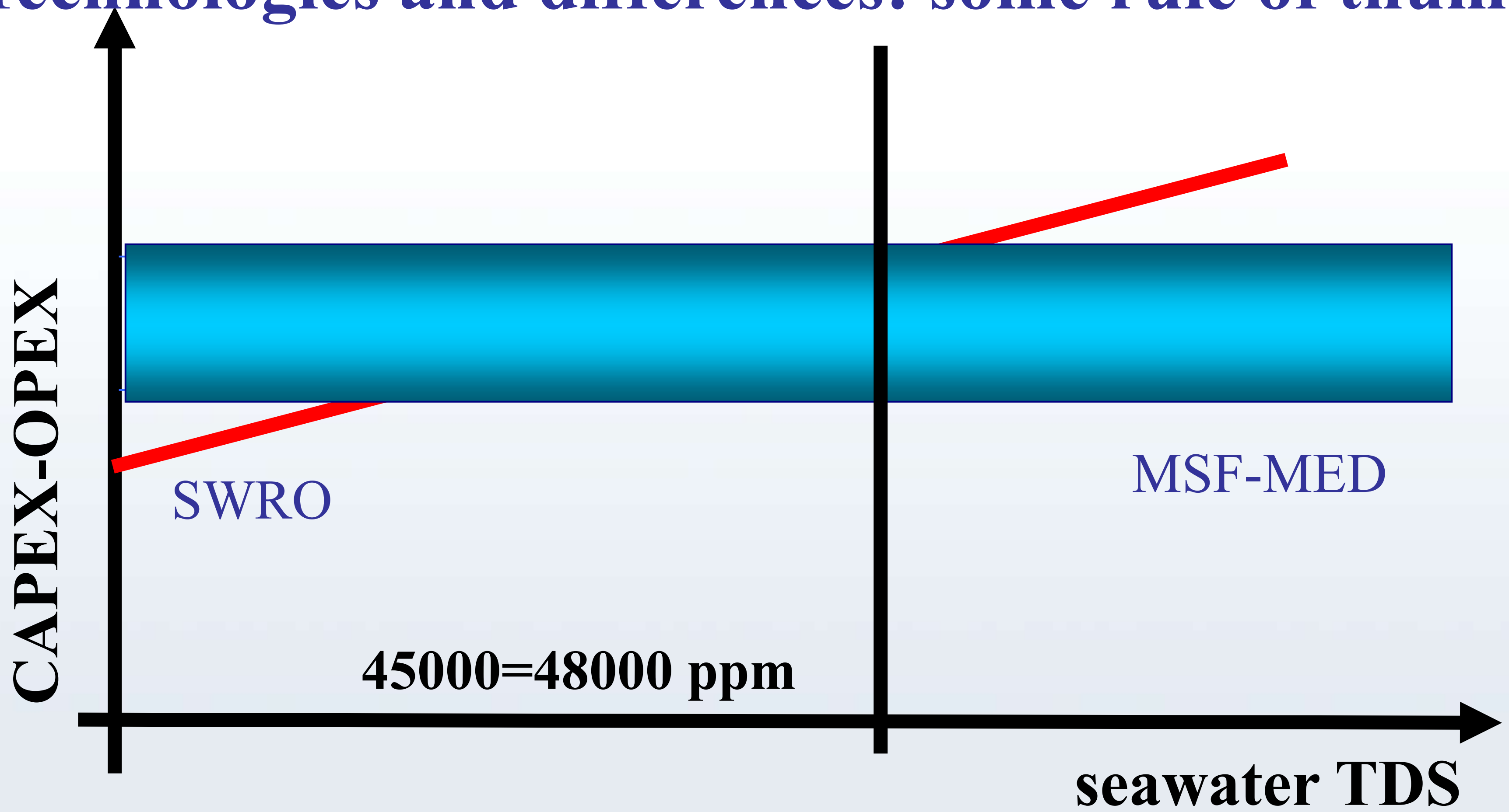
Technologies and differences: some rule of thumb

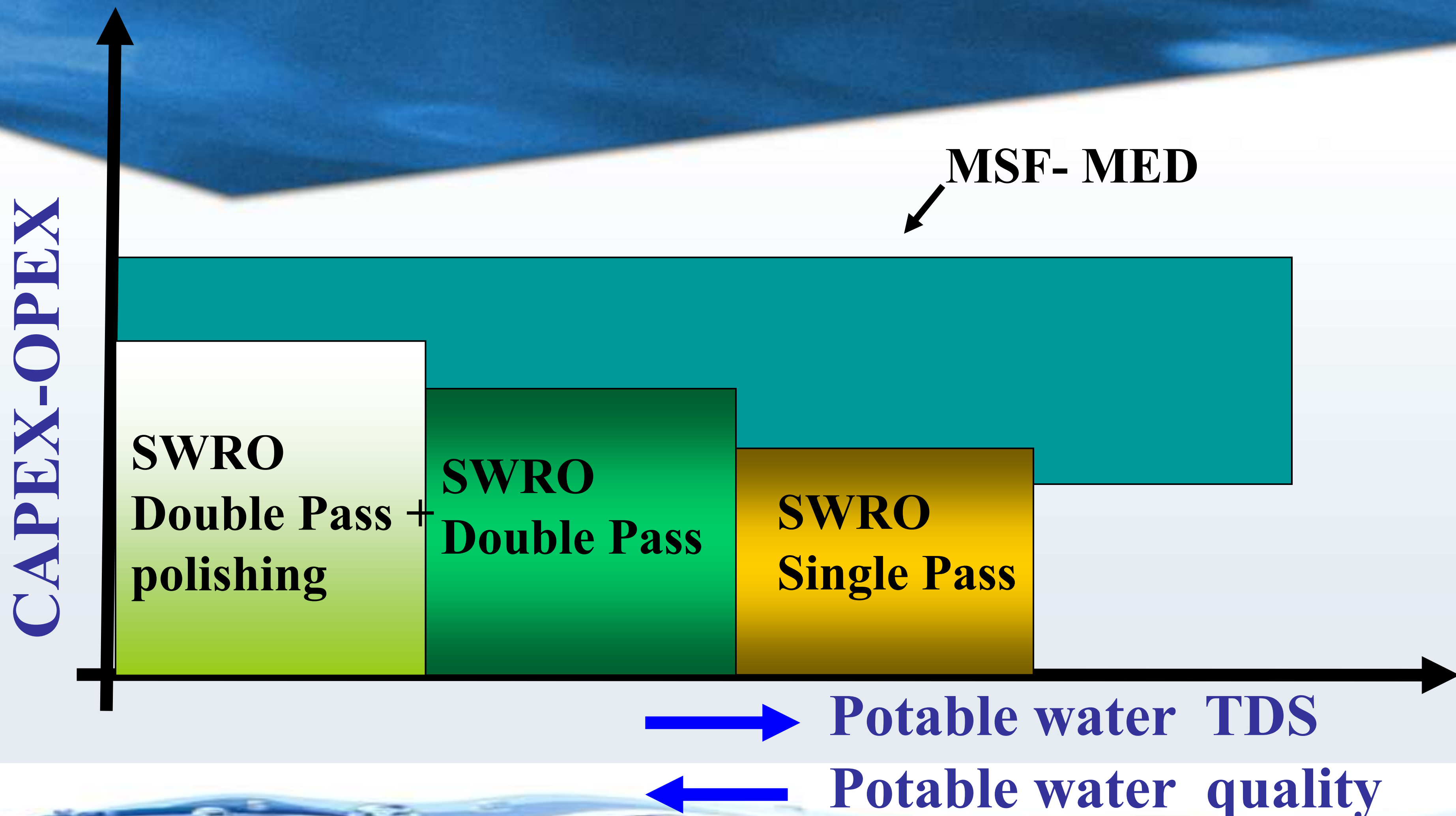


RR α 1/TDS

SW → 5000 — RR → 75%-85%

TDS → 45000 — RR → 40-45%

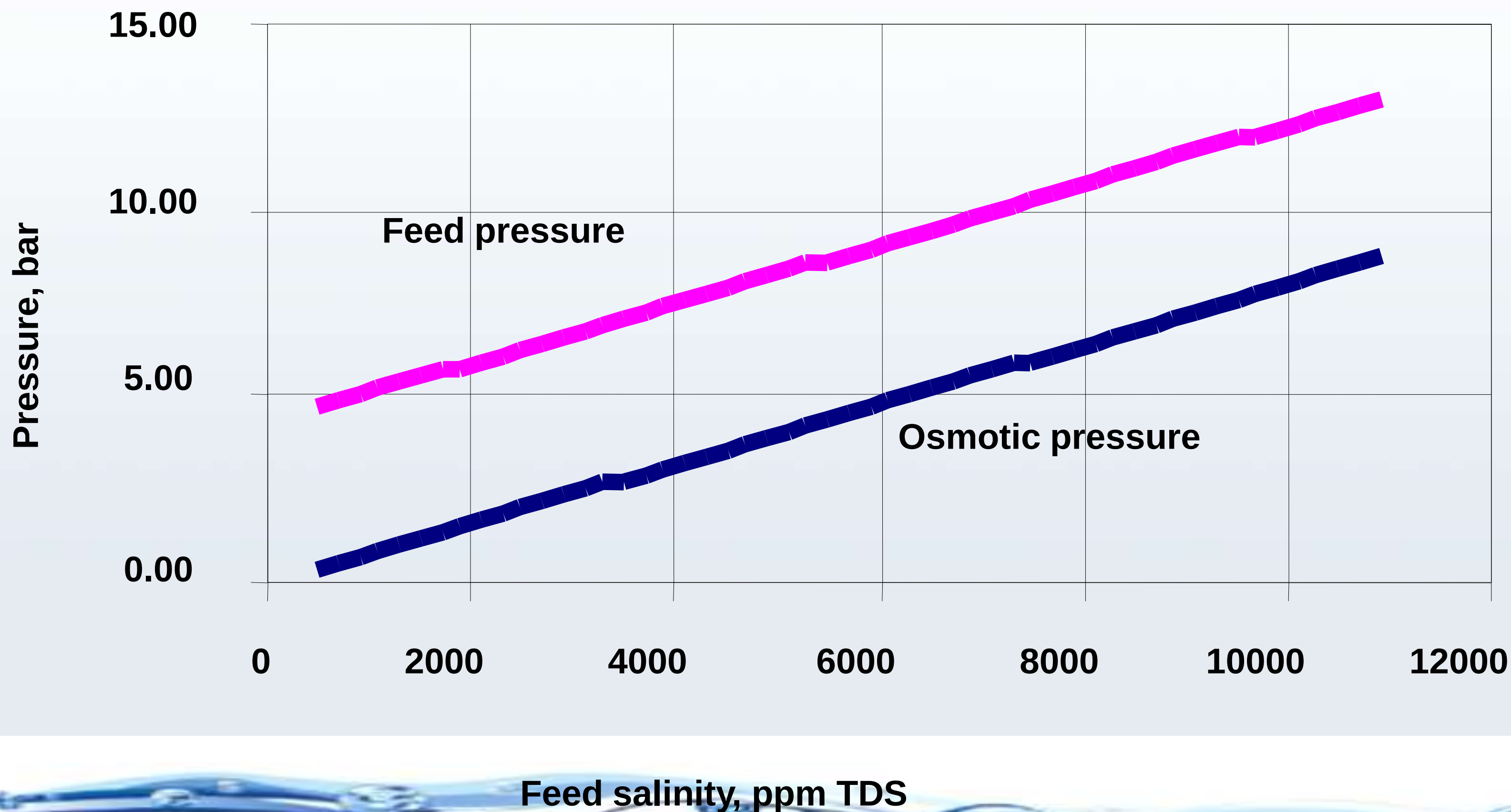
Technologies and differences: some rule of thumb



Technologies and differences: some rule of thumb

Energy consumption of status of art desalination projects

The main problem is that specific energy consumption for SWRO is directly proportional to the seawater salinity



Effect of feed salinity on osmotic pressure and required feed pressure in RO unit

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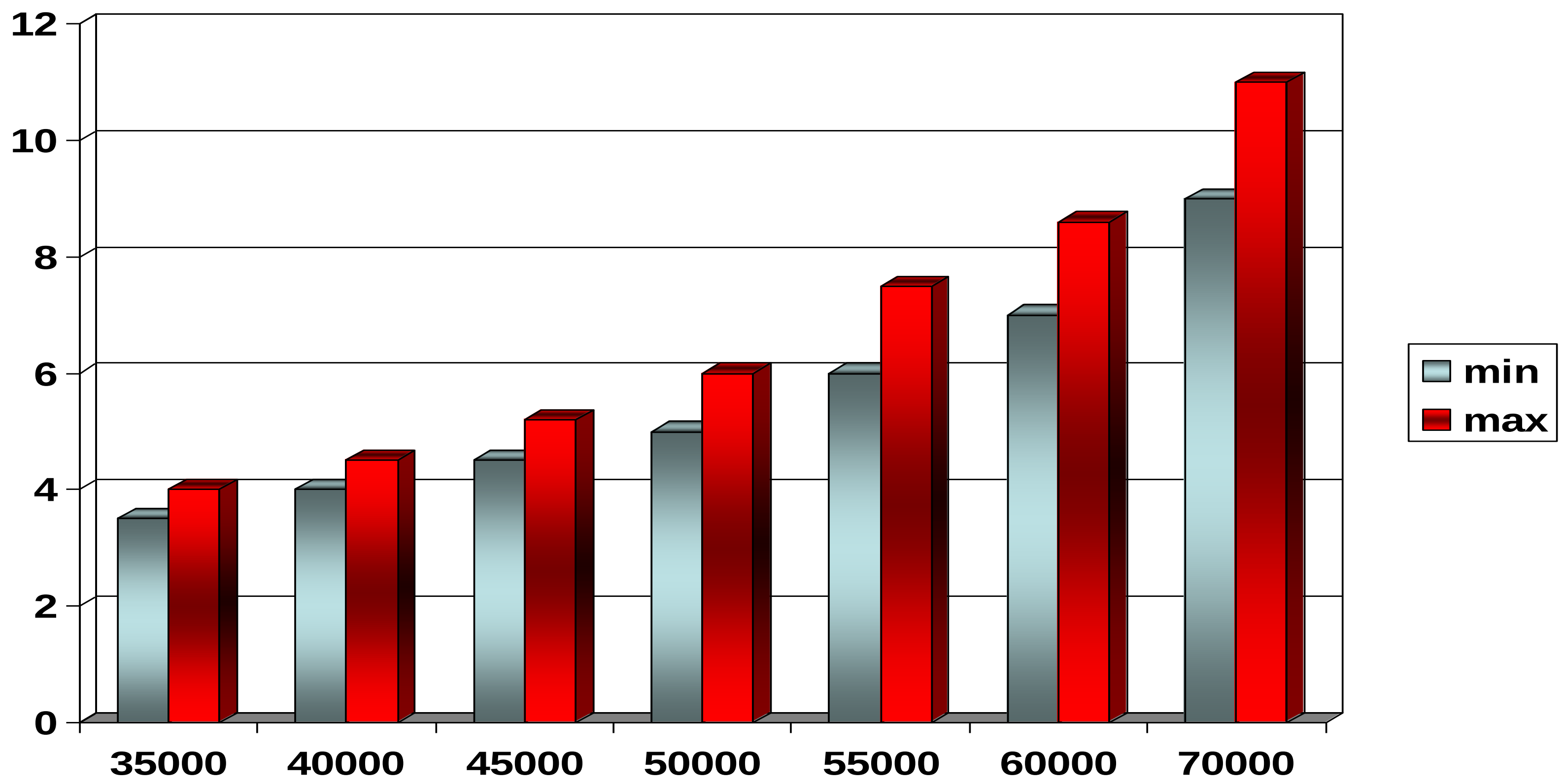
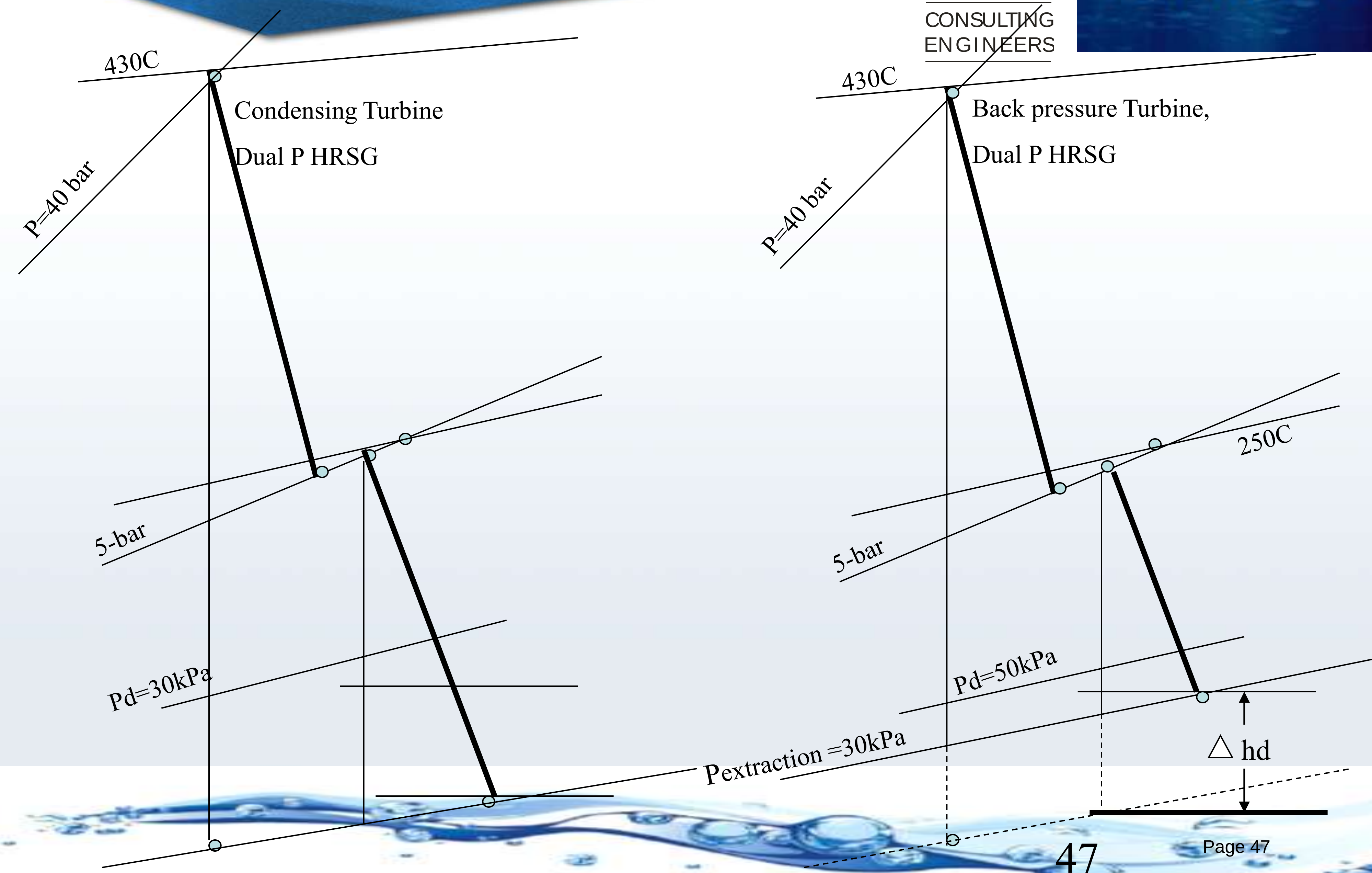
Technologies and differences: some rule of thumb

Energy consumption of status of art desalination projects

The main problem is that specific energy consumption for SWRO is directly proportional to the seawater salinity, therefore it is not a suitable solution with high salinity seawaters



Effect of feed salinity on specific power consumption in RO unit


430C
Condensing Turbine
Dual P HRSG
P=40 bar
5-bar
Pd=30kPa
Pextraction =30kPa
430C
Back pressure Turbine,
Dual P HRSG
P=40 bar
250C
5-bar
Pd=50kPa
△ hd

Desalination technologies energy consumption thermal and electric power cogeneration

	Specific electric power	Specific heat consumption	Steam Extraction pressure	Thermal energy	Equivalent power loss	Total Energy requirements
	Kwh/m^3	kJ/kg	Bar abs	Thermal kwh/m^3	Electric kwh/m^3	kwh/m^3
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

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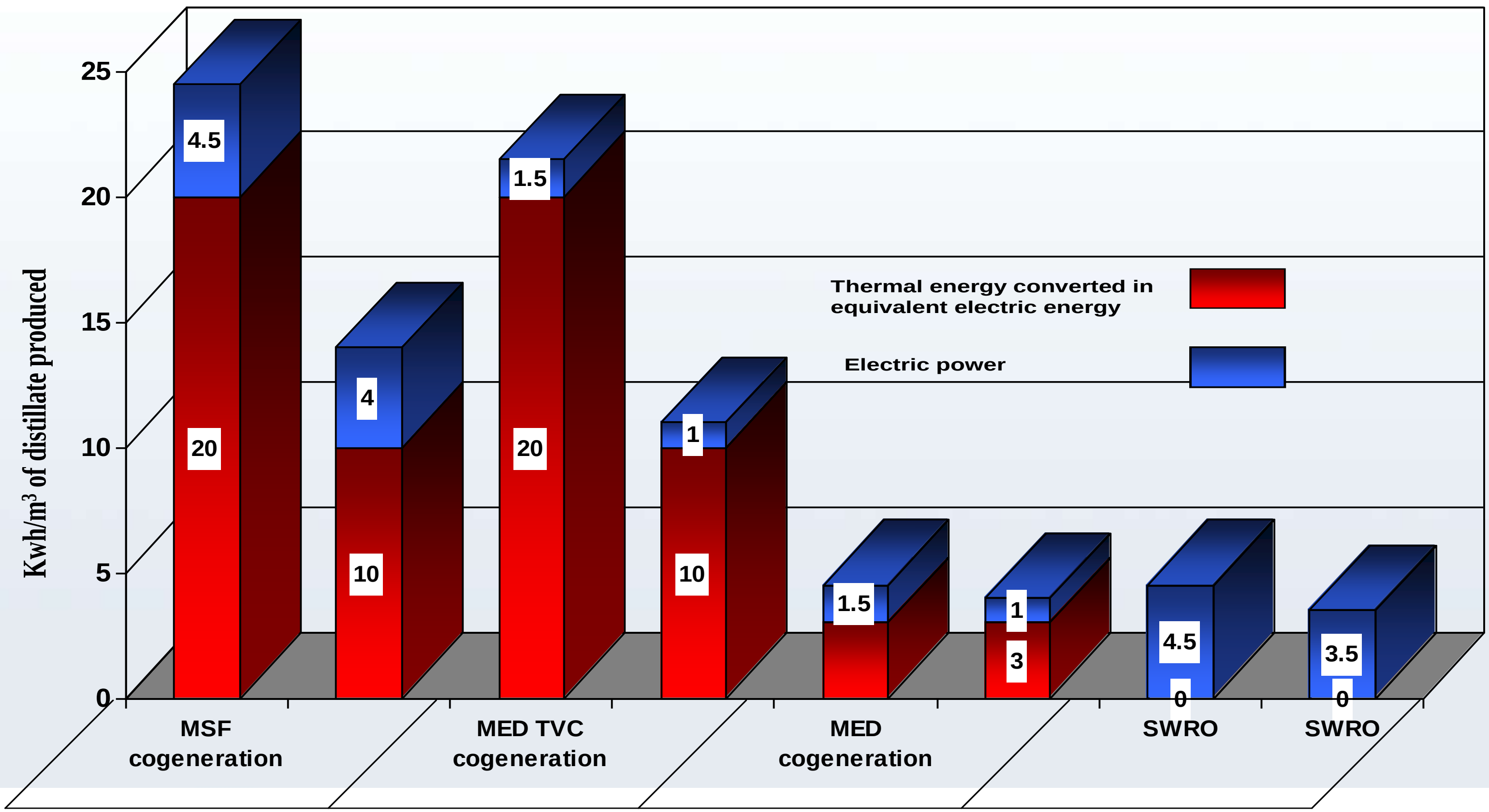
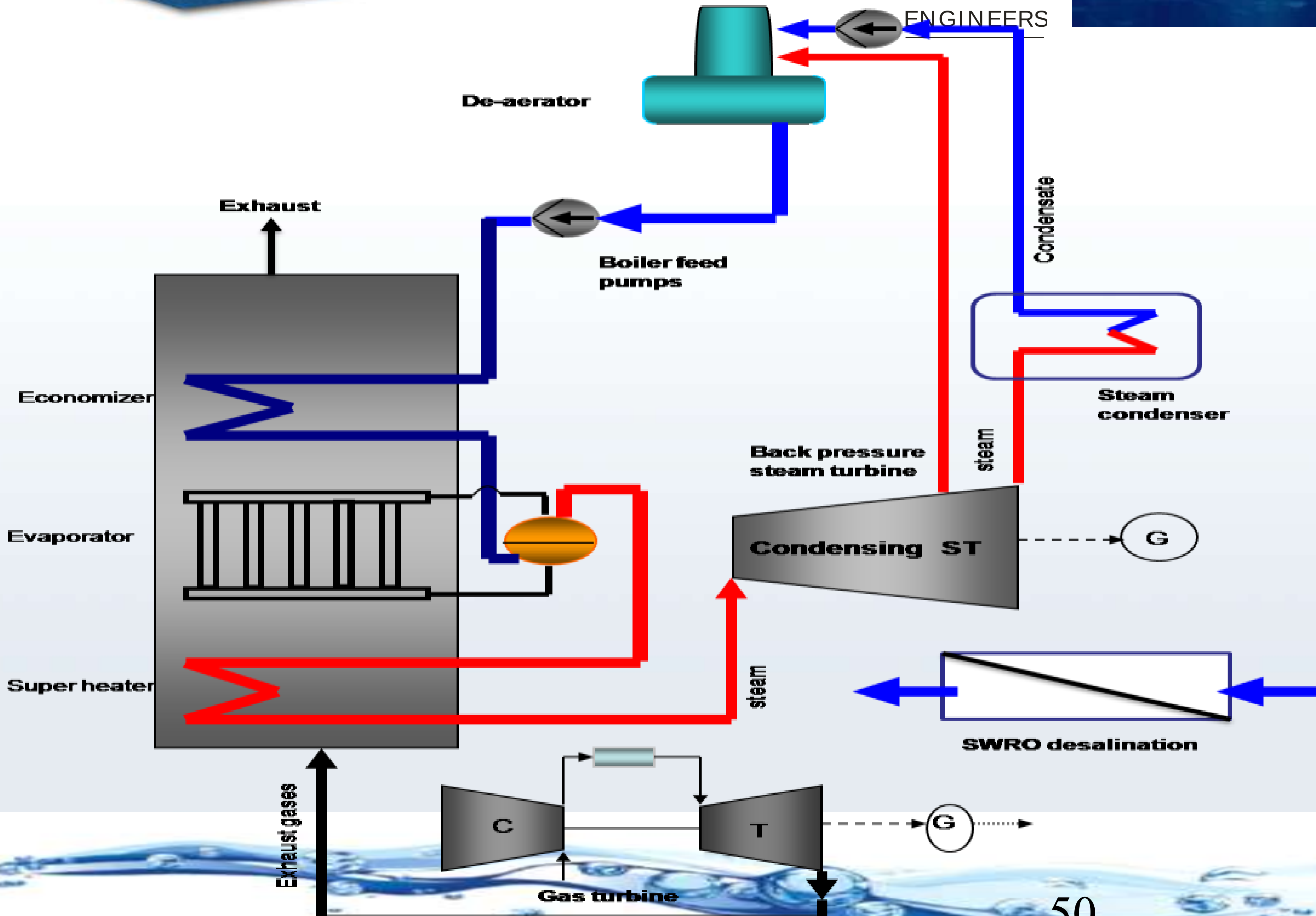
Energy consumption of status of art desalination projects

Desalination plants are very energy intensive processes !!!





De-aerator
Exhaust
Boiler feed pumps
Condensate
Economizer
Steam condenser
Back pressure steam turbine
steam
Evaporator
Condensing ST
G
Super heater
steam
SWRO desalination
Exhaust gases
C
T
G
Gas turbine

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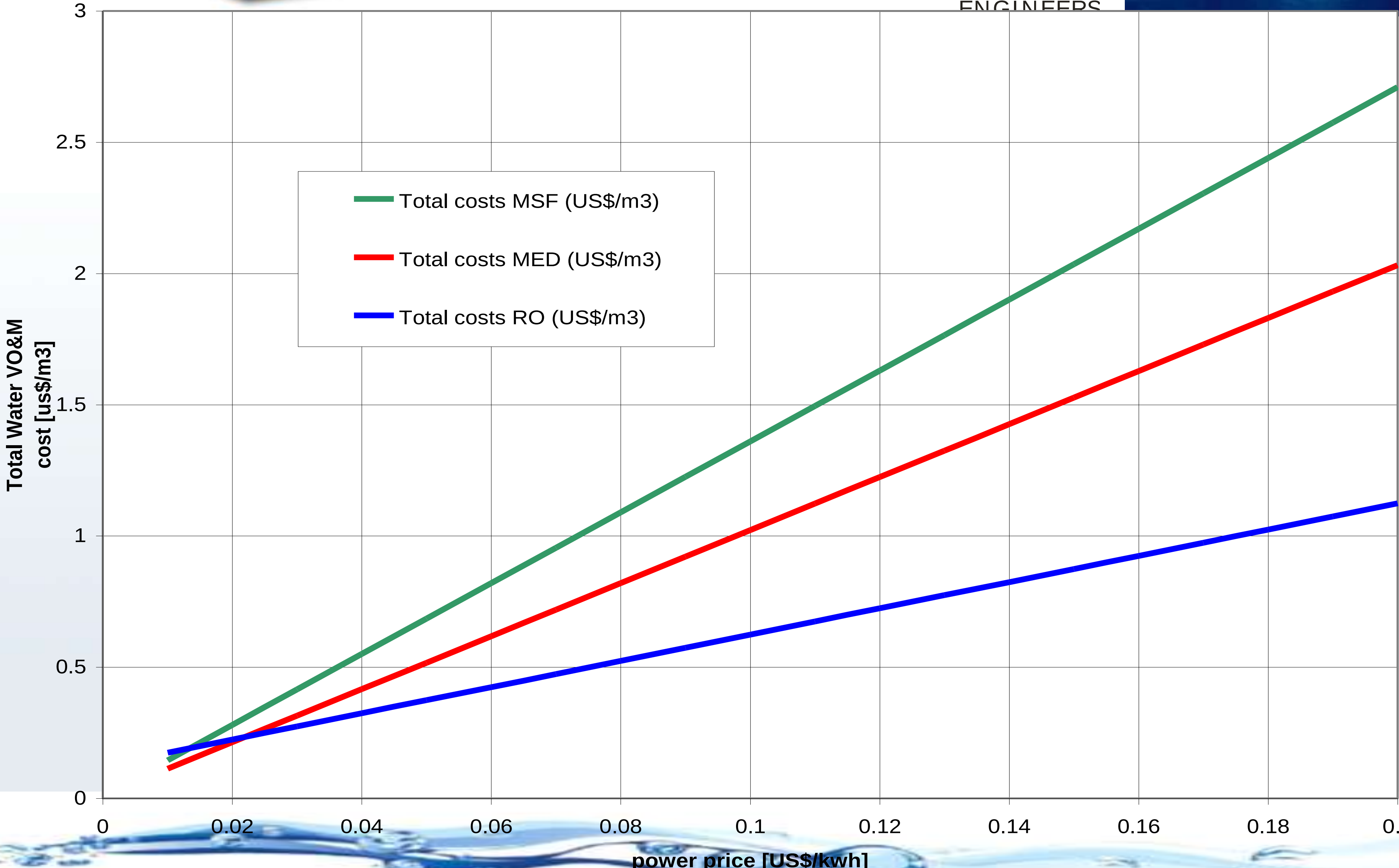

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Clean technologies with renewable energy

For thermal desalination the steam extraction conditions are extremely important for the energy associated to the steam value…. The lower the pressure and temperature the better for efficiency purpose

Clean technologies with renewable energy

The problem is ....

$$\Delta H = K_t \cdot A \cdot \Delta T_{ml}$$

ΔH = energy exchanged kJ/sec

K_t = overall heat transfer coefficient kJ/m^2° C

A= overall heat transfer area m^2

ΔT_{ml} = Delta Temperature (media logarithmic) between the streams ° C

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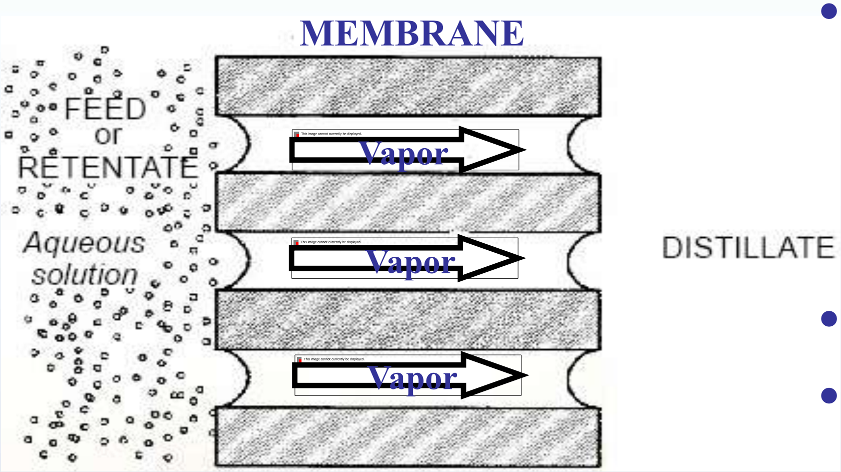
Clean technologies with renewable energy

Membrane Distillation (MD) is a separation technique which joints a thermally driven distillation process with a membrane process.



The membrane should be:

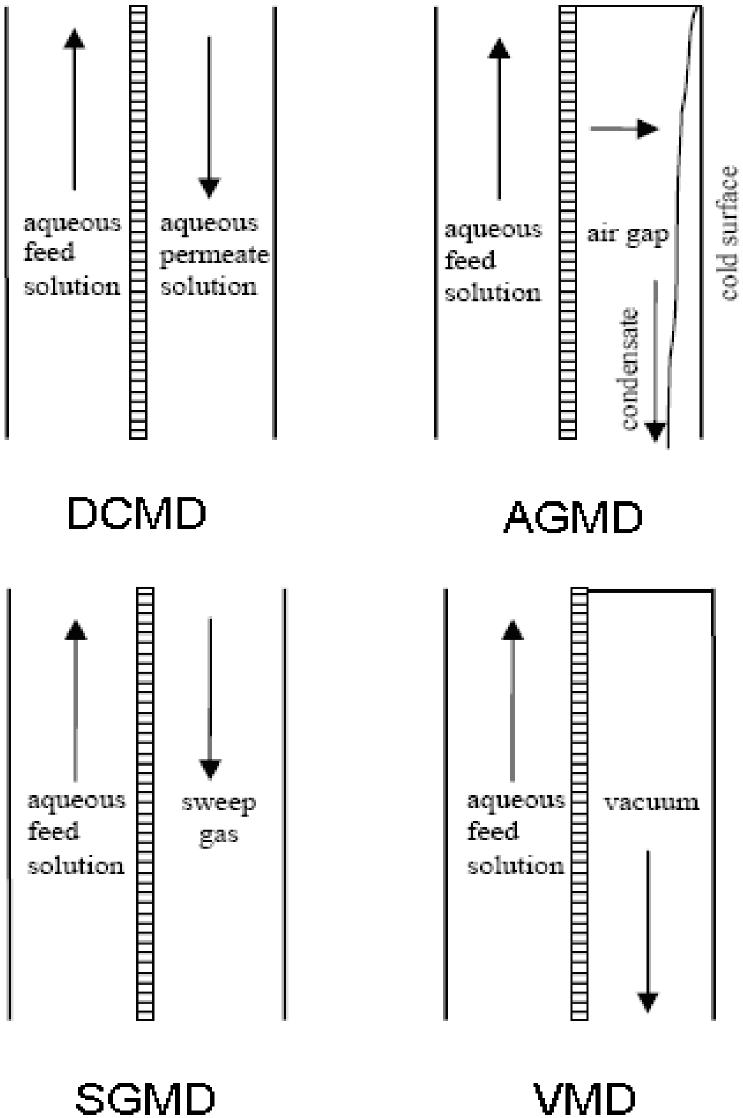
- porous
  - no capillary condensation takes place inside the pores
  - only vapor pass through the membrane
  - the membrane must not alter vapor equilibrium
- not be wetted by process liquid
- hydrophobic material (PP – PTFE)

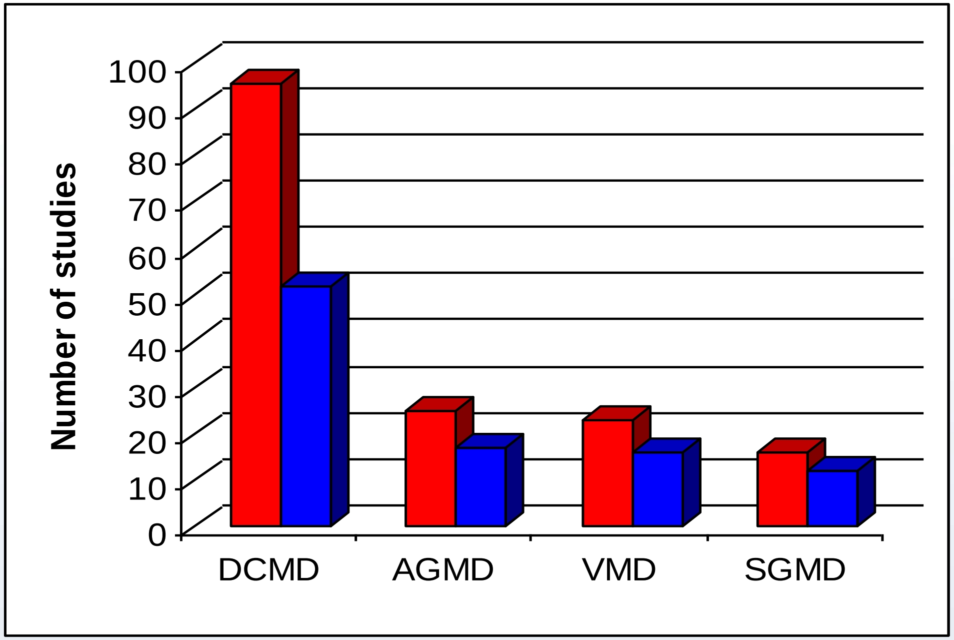
- The driving force is a vapor pressure difference

$$J = f(\Delta p^{\circ}) \Rightarrow J = f(\Delta T)$$

- Membrane pore supports the vapor-liquid interface
- The thermal energy is used for phase changing

Membrane Distillation (MD) system





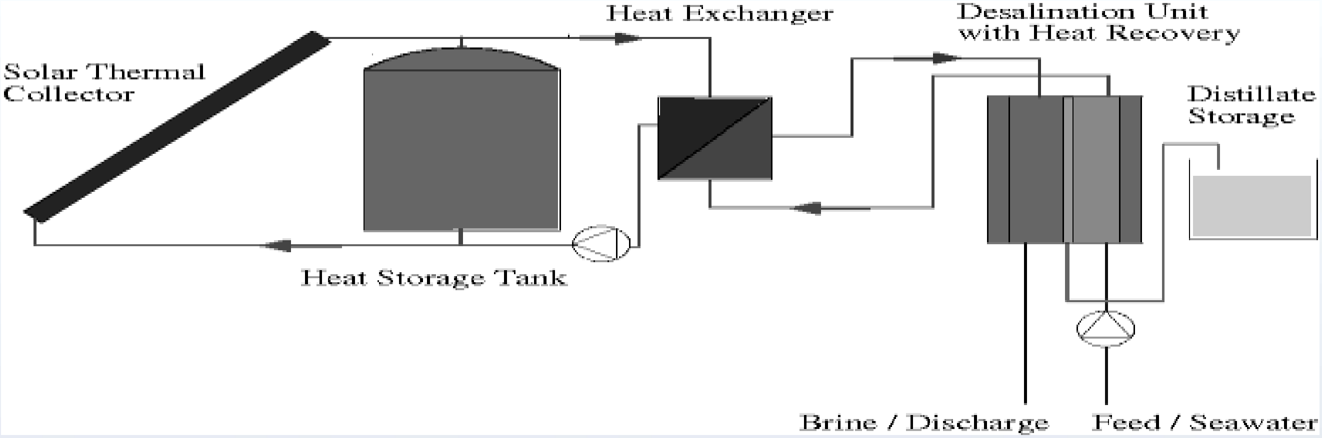
- Direct Contact Membrane Distillation (DCMD)
- Air Gap Membrane Distillation (AGMD)
- Sweeping Gas Membrane Distillation (SGMD)

Clean technologies with renewable energy

Membrane Distillation (MD) system

Solar Desalination coupled with Membrane distillation

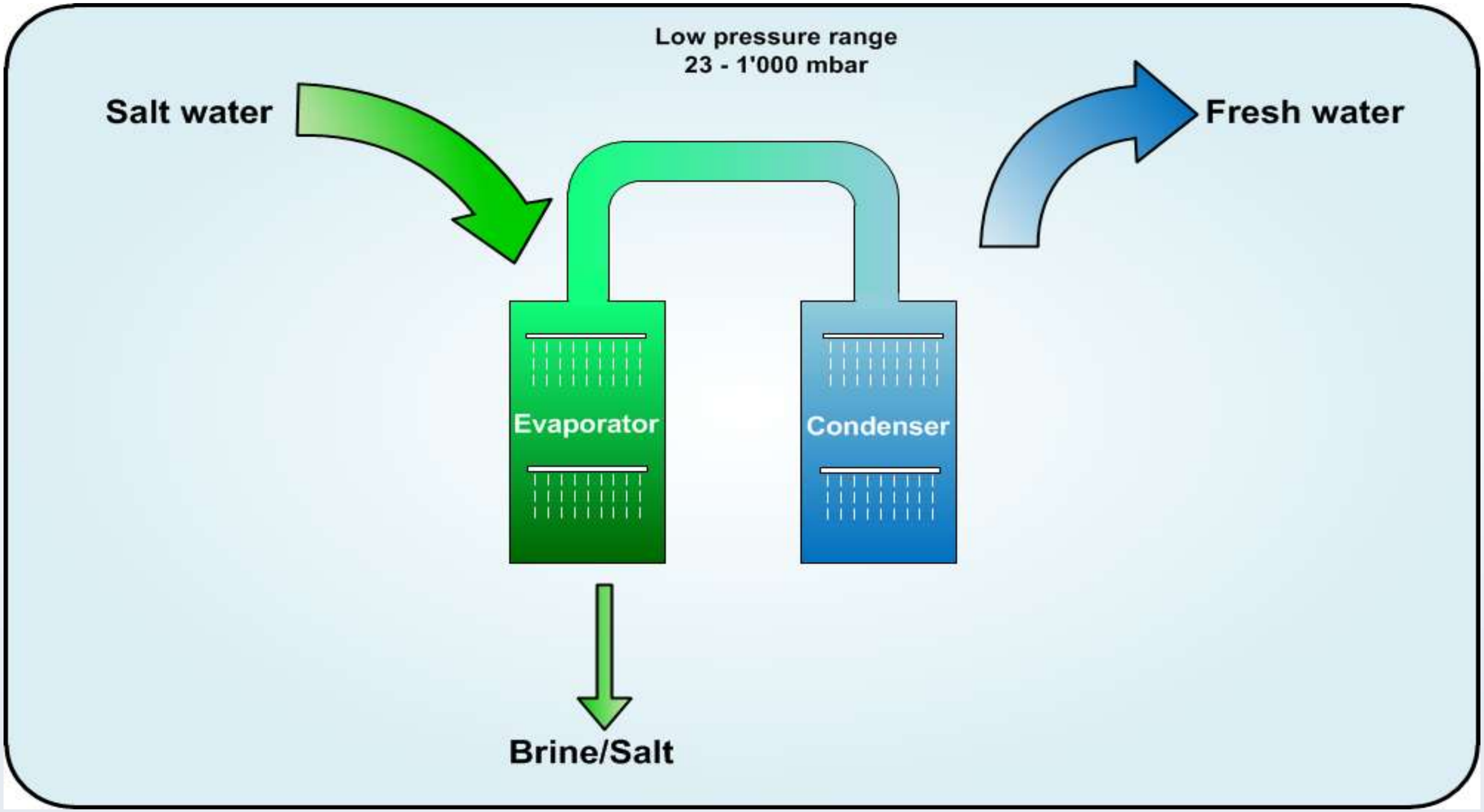
- The operating temperature of the MD process is in a range (60 ÷ 80 °C) where thermal flat plate collectors have a sufficient efficiency
- Various solar pilot MD plants have been designed and proposed.



	Aqaba, Red Sea, Jordan	Gran Canary, Spain
Design capacity [l/day]	700 -900	1000-1500
Collector area [m²]	72	90
PV area [kWp]	1.44	1.92

Clean technologies with renewable energy

Low temperature Distillation (LTD) system



Clean technologies with renewable energy

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Low temperature Distillation (LTD) system

Pilot plant in El Gouna

Clean technologies with renewable energy

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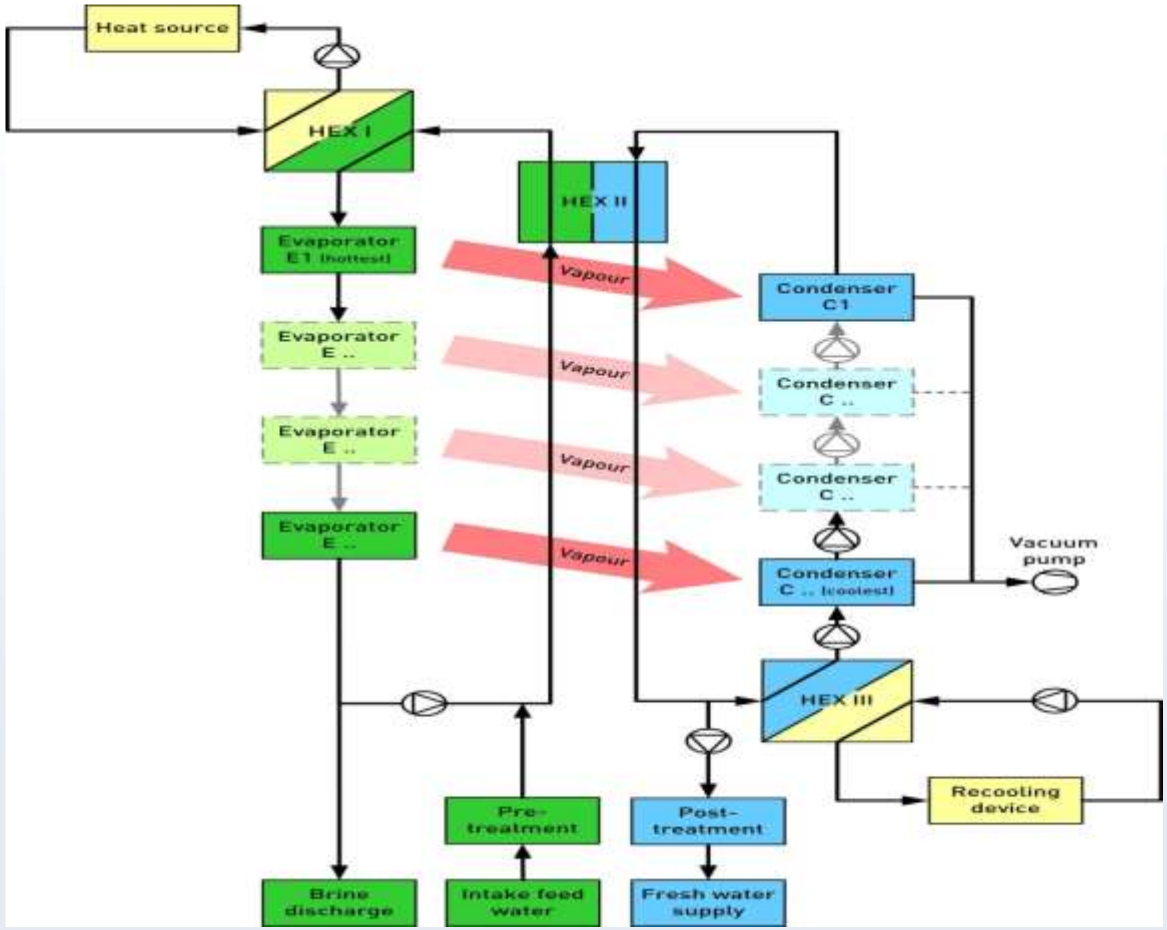
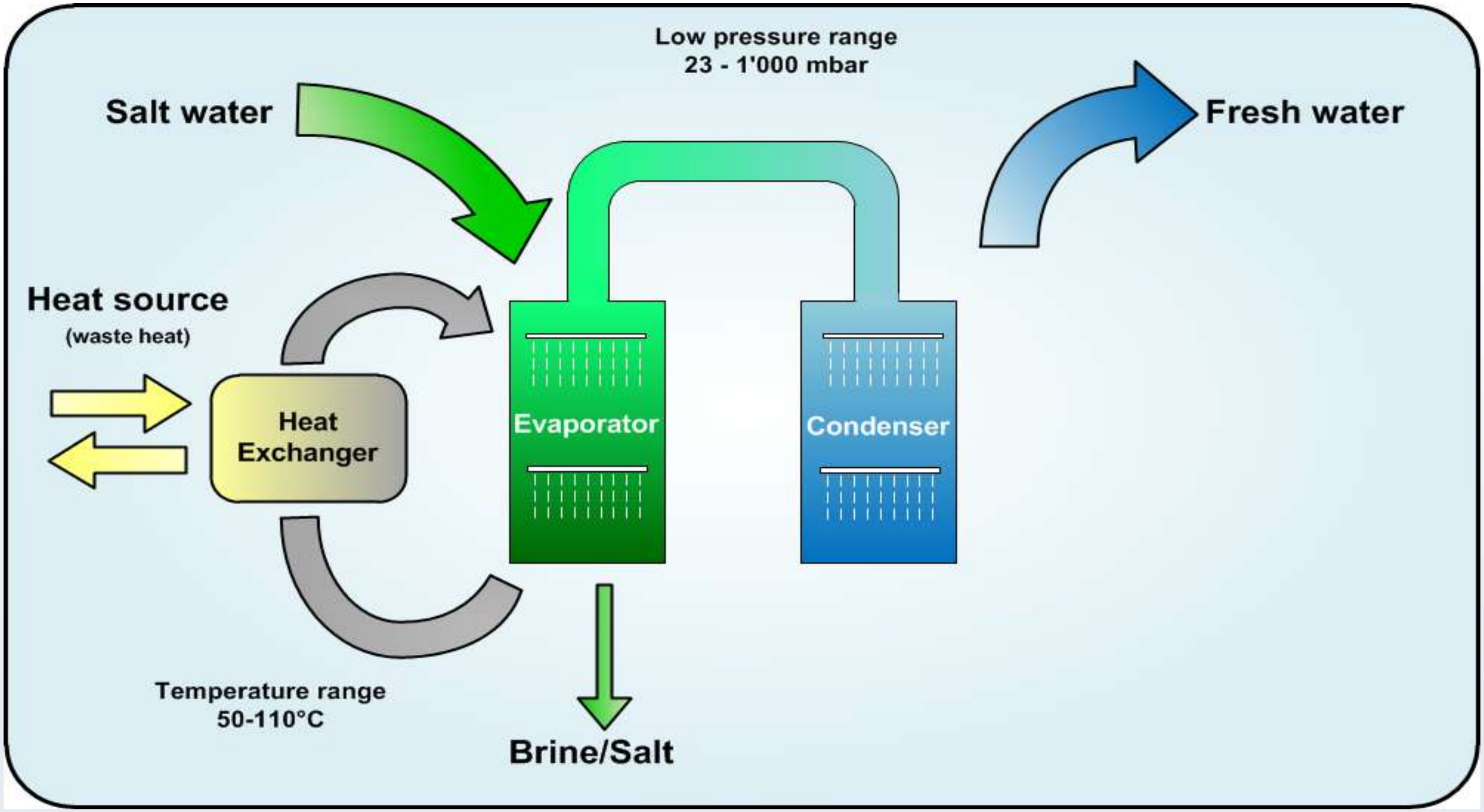
> WS LTD Flow Sheet



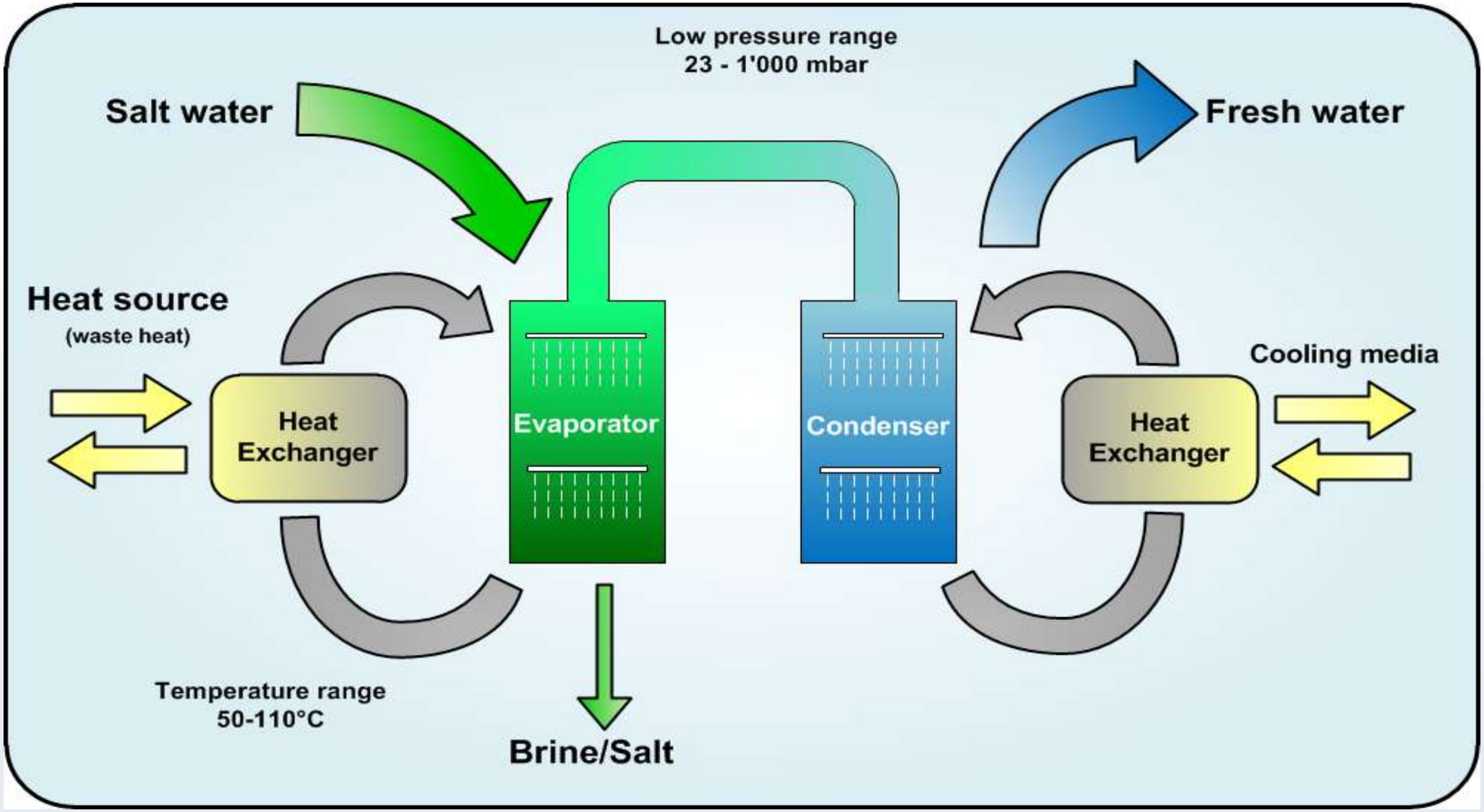
Clean technologies with renewable energy

> WS LTD Process



> WS LTD Process

Clean technologies with renewable energy



Clean technologies with renewable energy

> WS LTD Process

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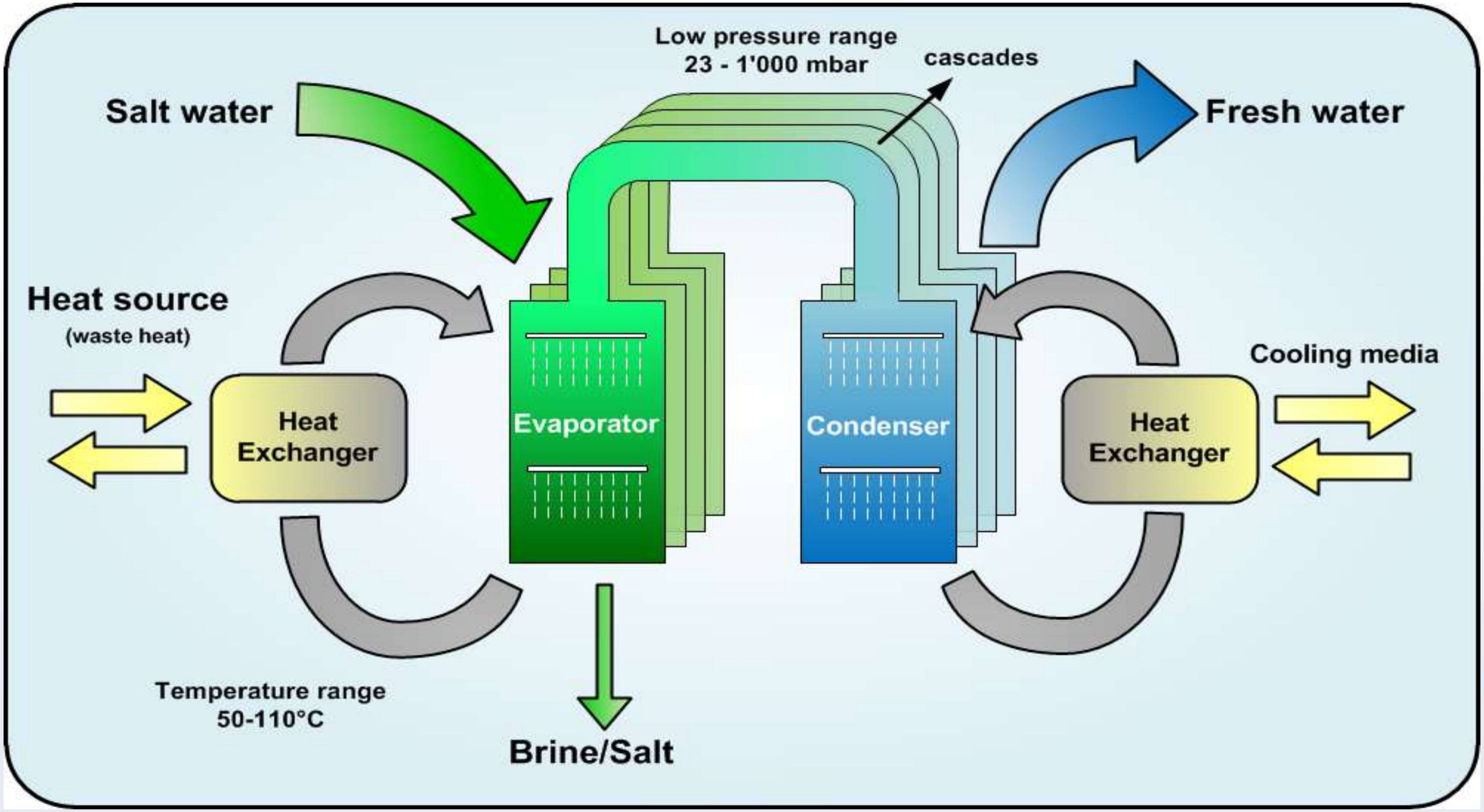
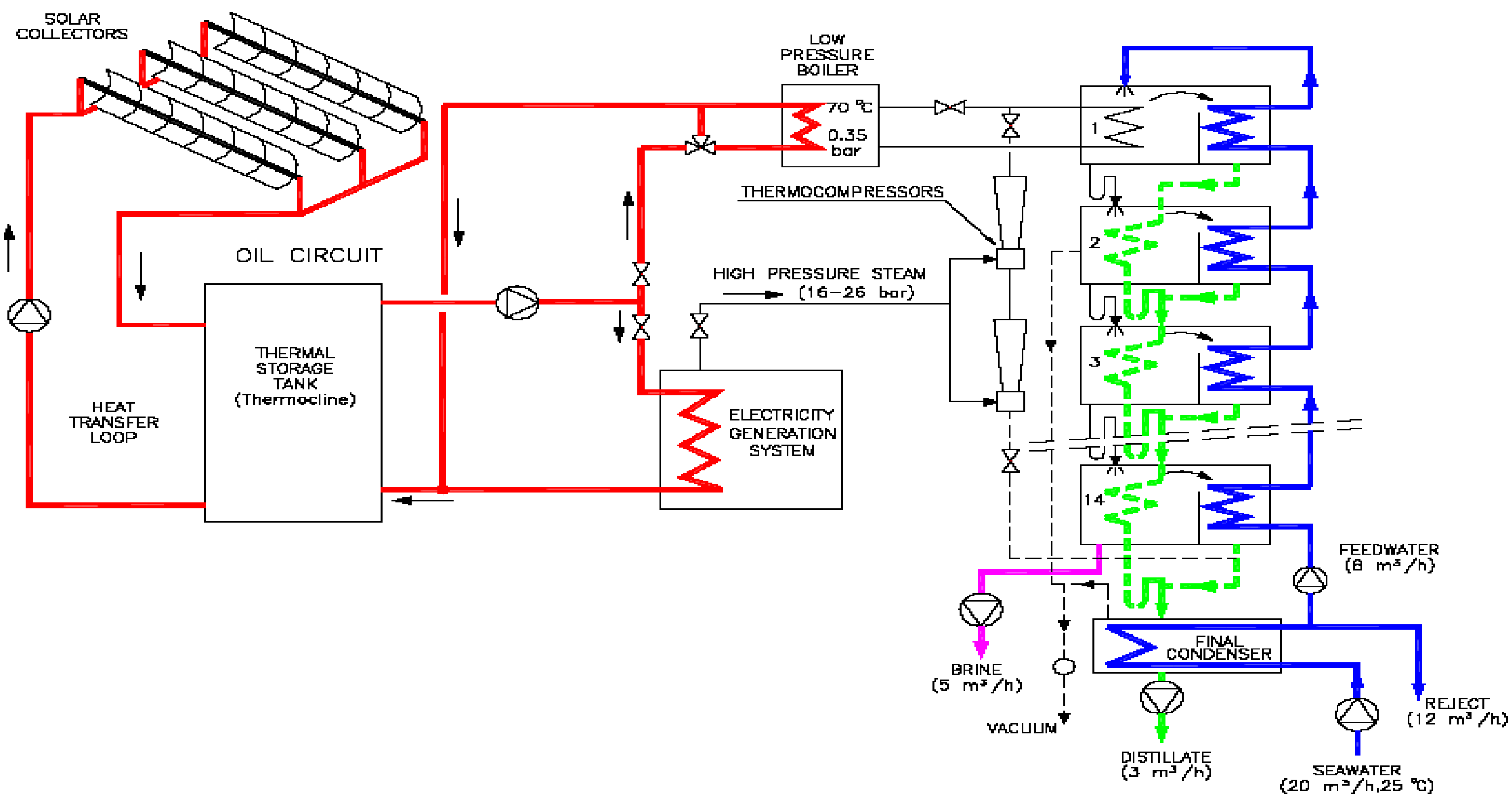


Clean technologies with renewable energy

■A small plant in Almeria totally solar



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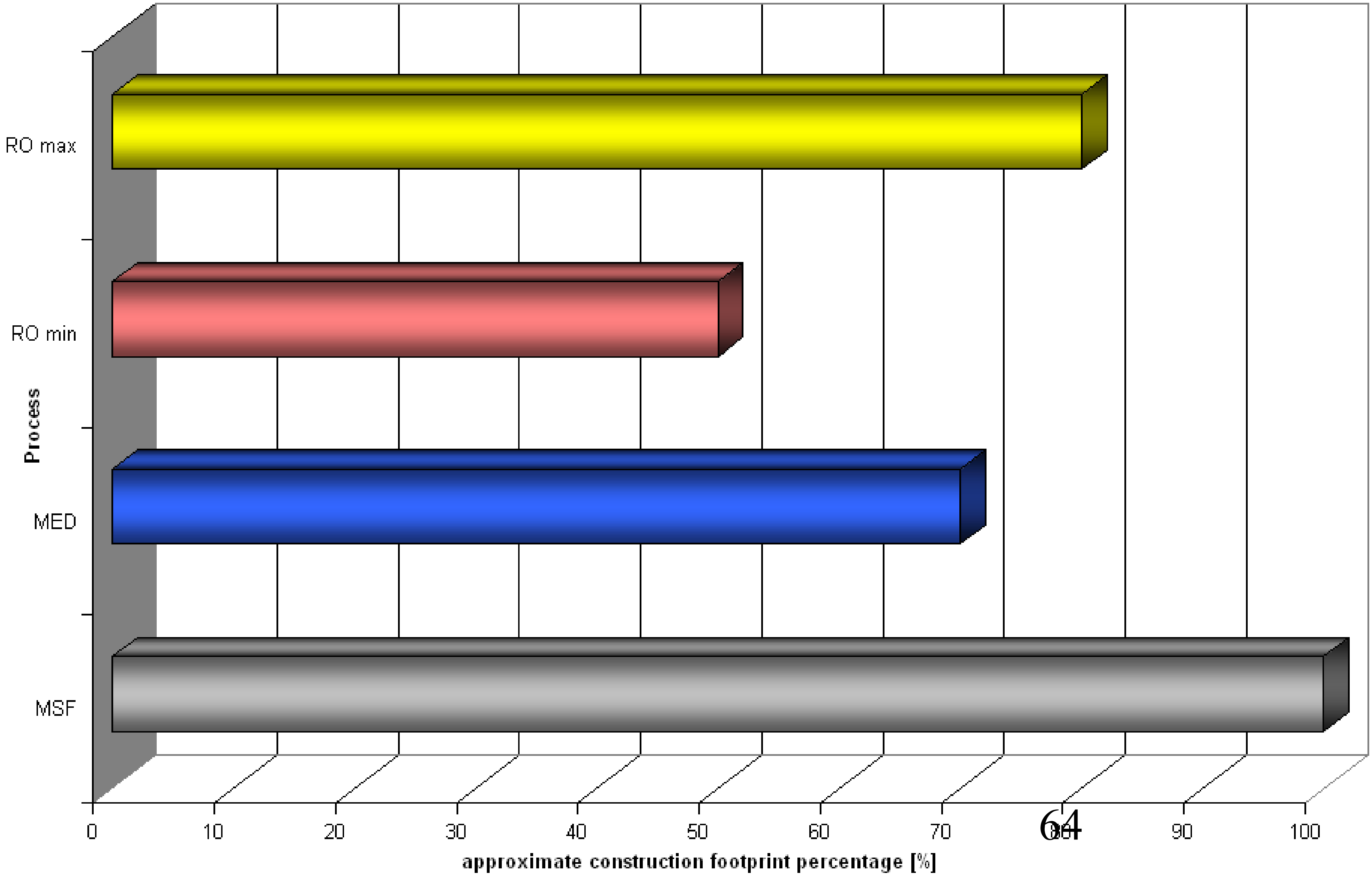

Technologies and differences: some rule of thumb potable water quality

	MSF	MED	RO 1st pass	RO 2nd pass	RO 2nd pass + polishing
TDS [ppm]	5-30	5-50	100-500 (*)	25-100	< 20 ppm
Possibility of High purity extractions	Yes	Yes	n.a	n.a	n.a
By products	No	No	boron		

Overview of Desalination Driven Technologies

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 :
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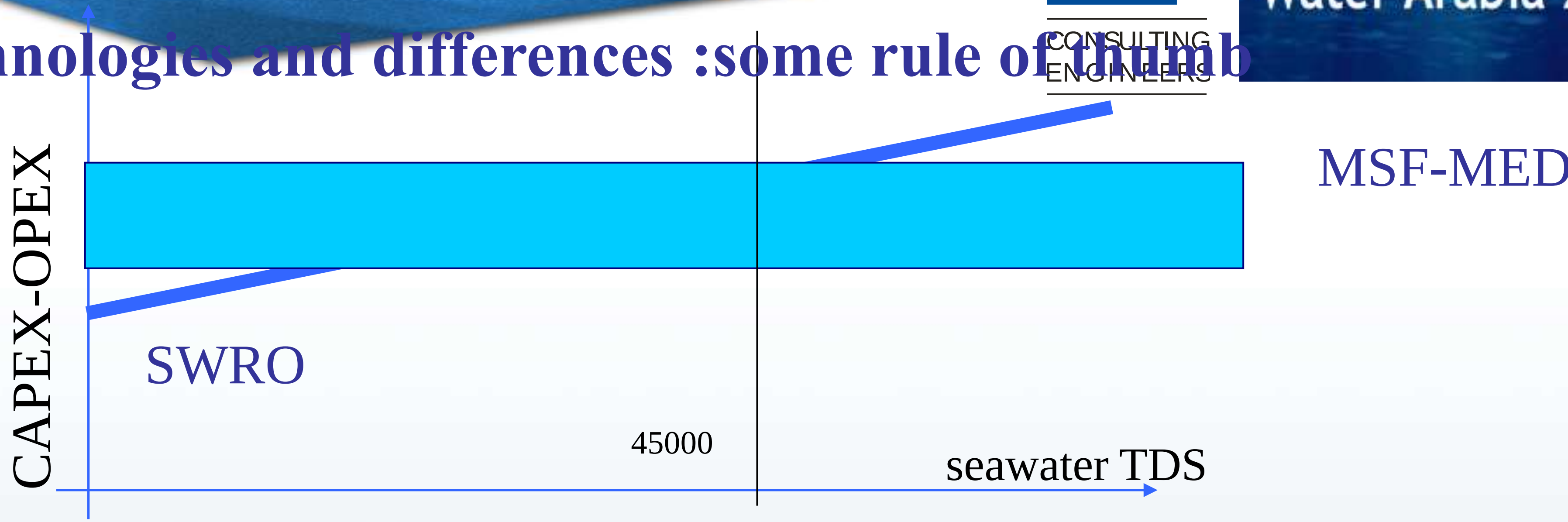
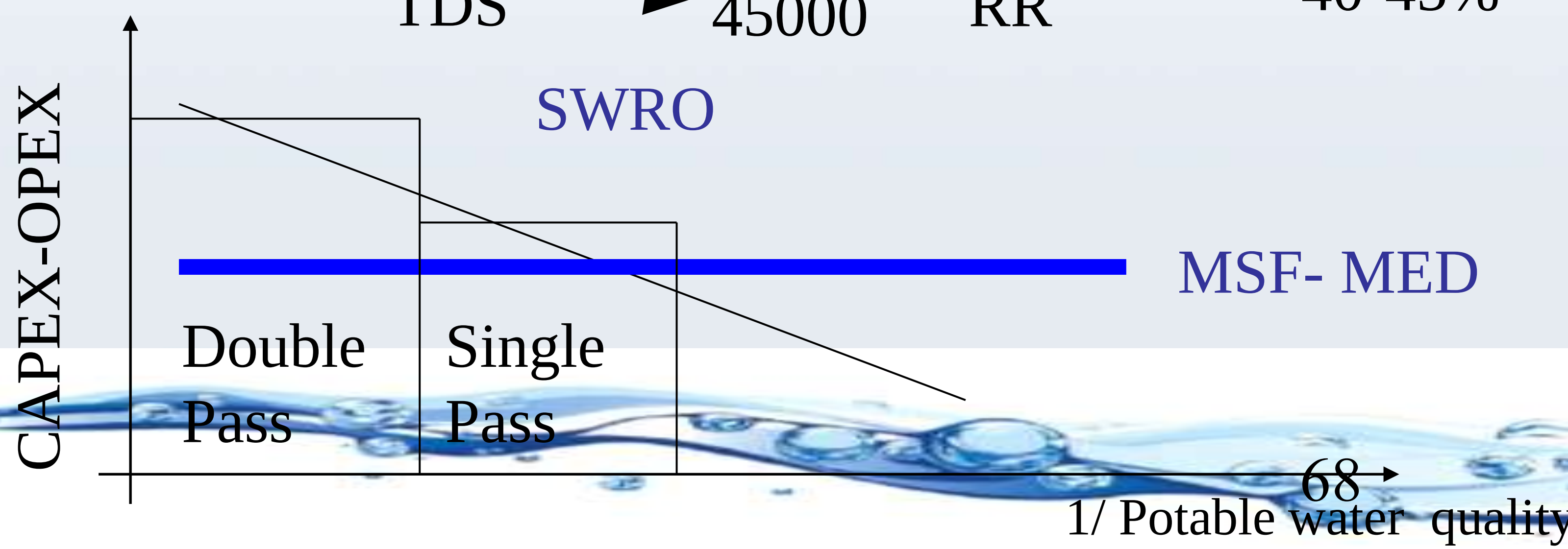
Technologies and differences :some rule of thumb



RR α 1/TDS

SW TDS → 5000 RR → 75%-85%

SW TDS → 45000 RR → 40-45%



Overview of thermally driven technologies

Multi stage flash
Dominant technology world-wide

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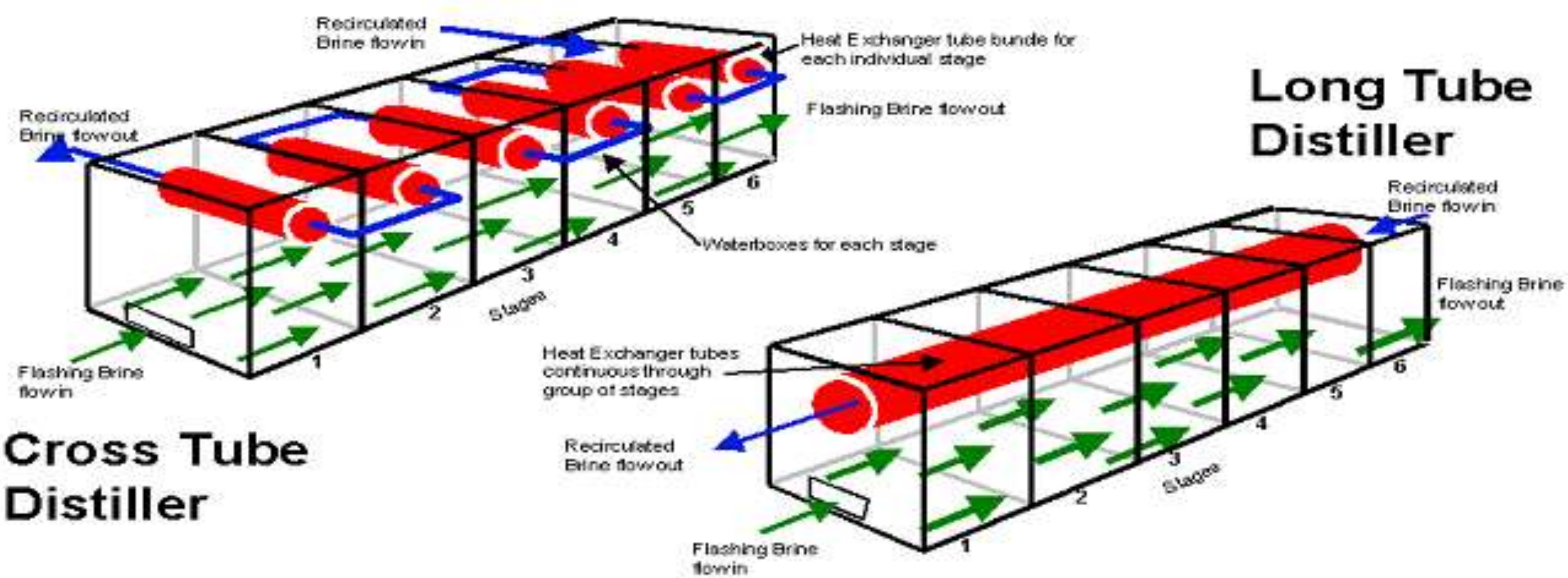
Overview of thermally driven technologies

Multi stage flash

Cross Tube and Long Tube MSF Distillers



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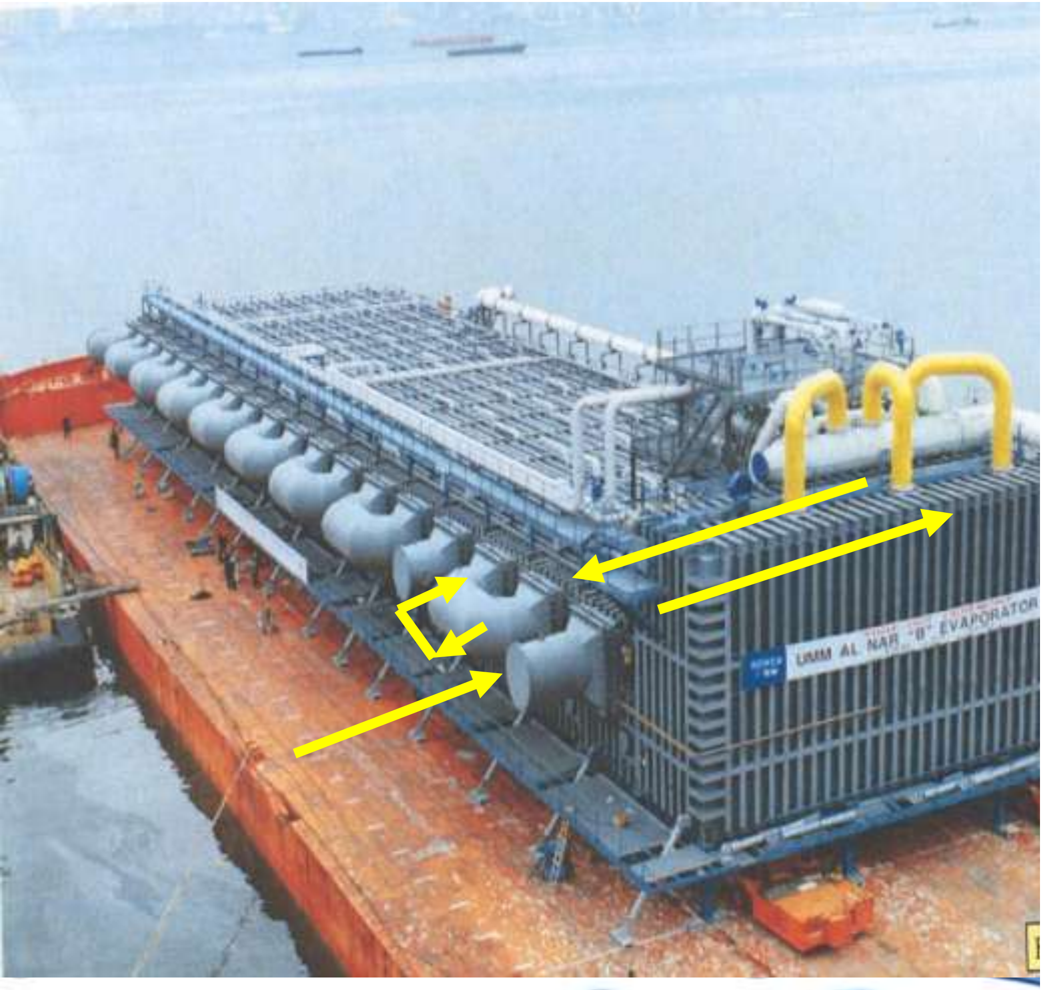
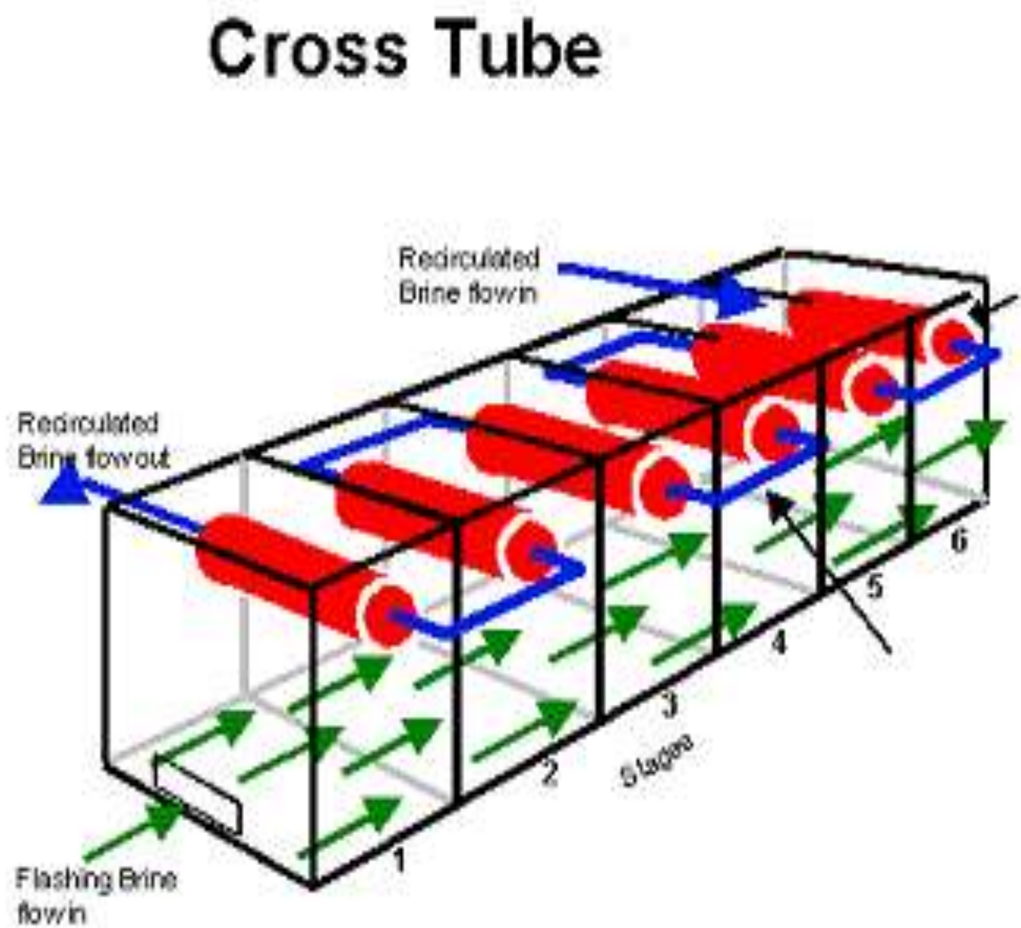
Overview of thermally driven technologies

Multi stage flash





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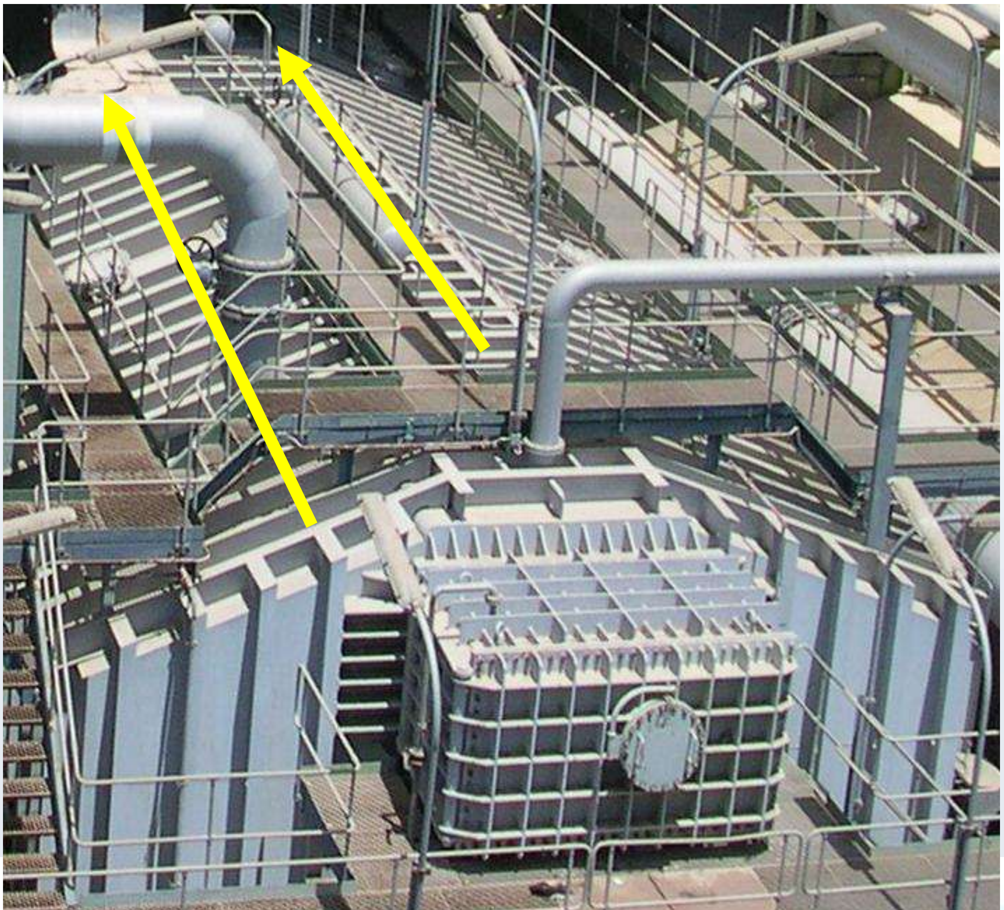
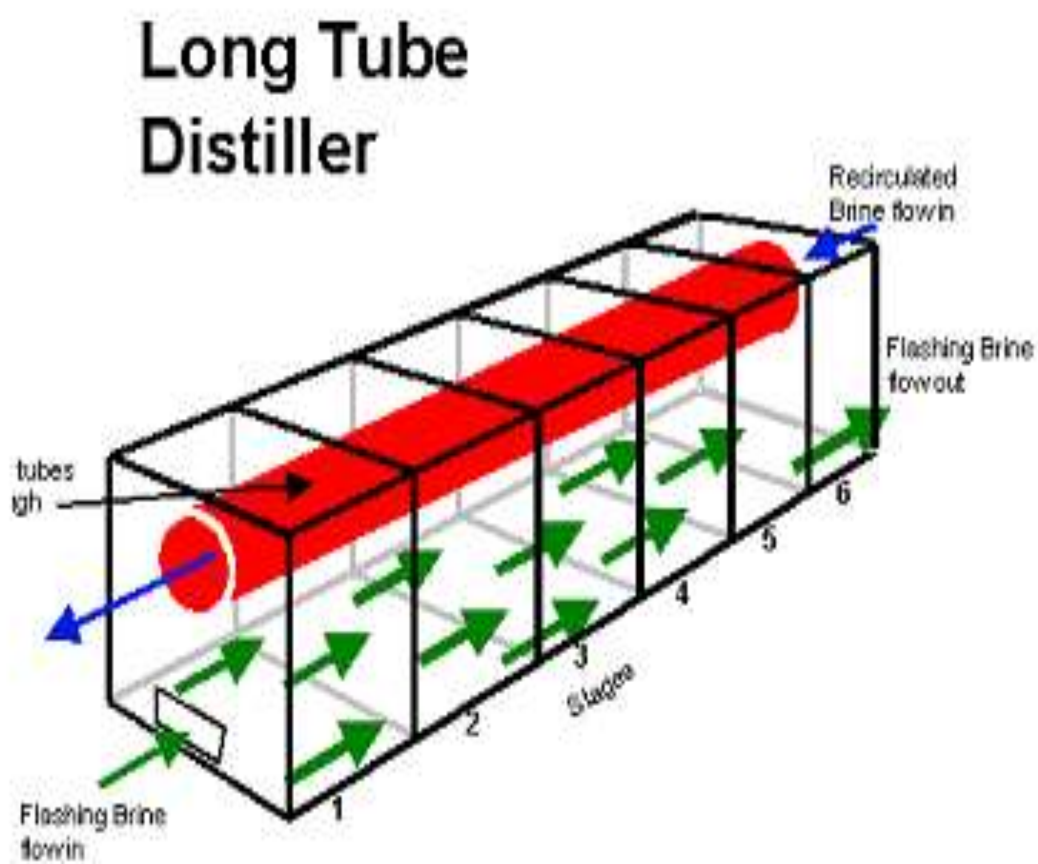
Overview of thermally driven technologies
Multi stage flash





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Overview of thermally driven technologies

Multiple effect desalination

Evolved from small installation

To relatively large unit size

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Overview of thermally driven technologies

Multiple effect desalination With Thermo compression

Condensing

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- Overview of desalination technologies

Reverse osmosis

Dominant technology when power plant is not associated to desalination

Condensing

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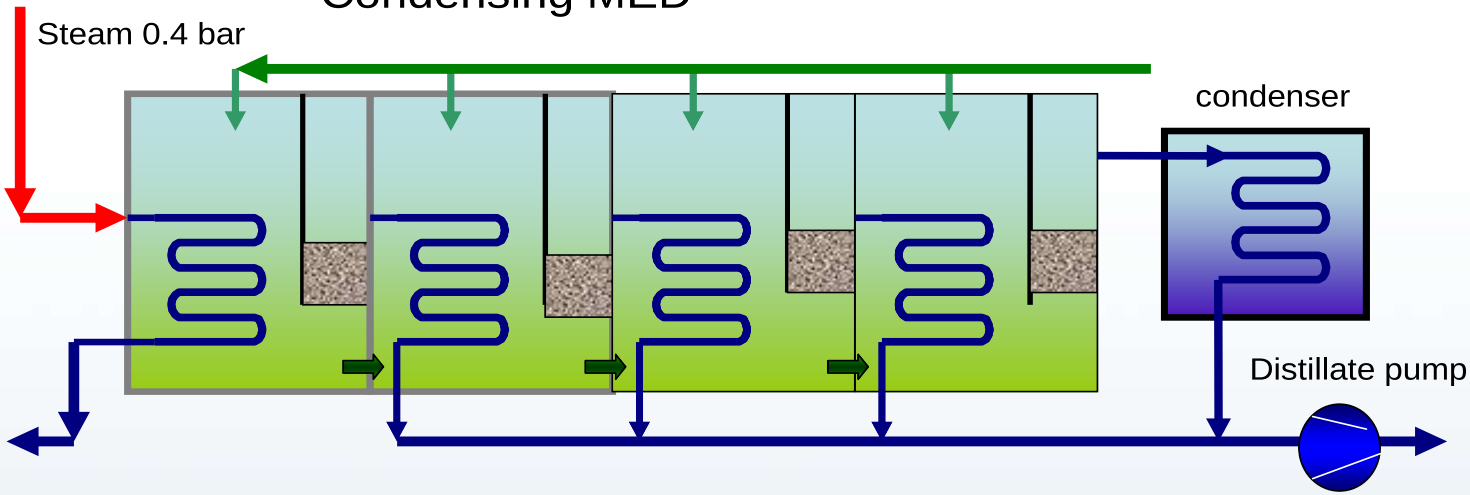
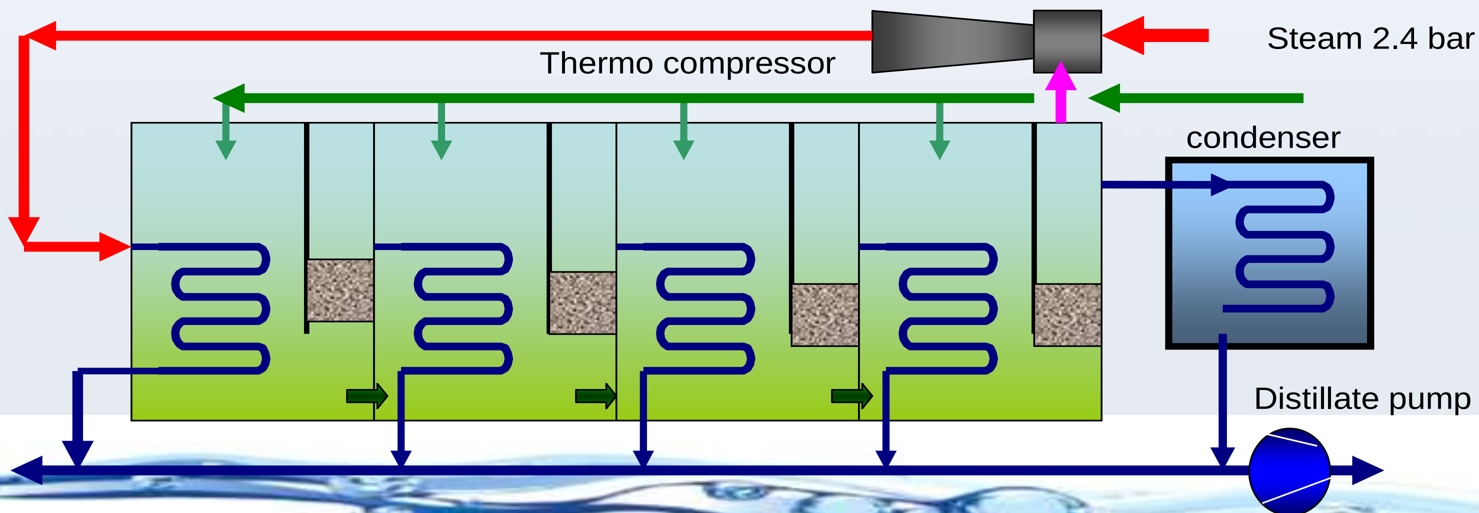
Condensing MED



MED TVC



Energy effect

In fact as it can be seen from the enclosed energy flow diagram 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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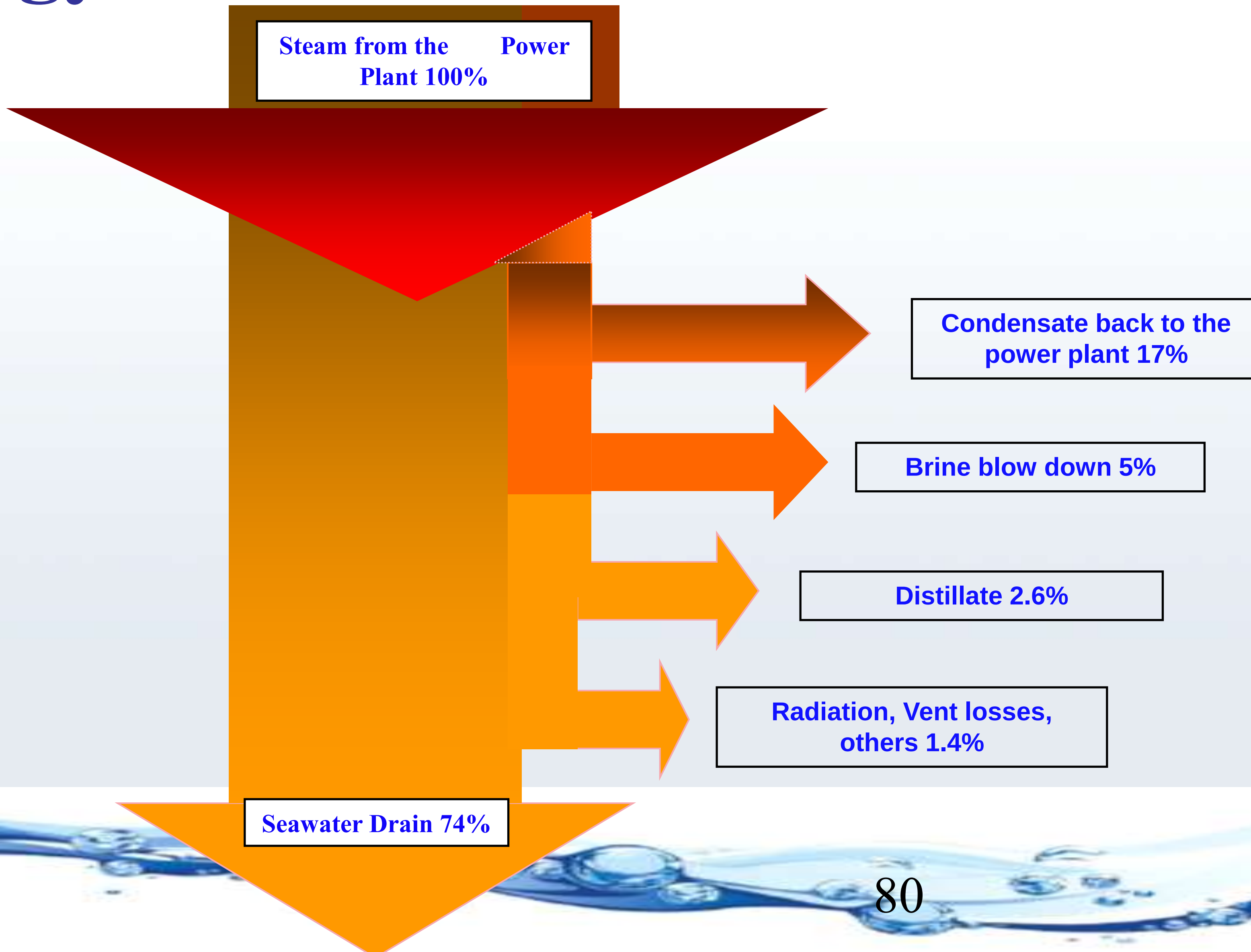
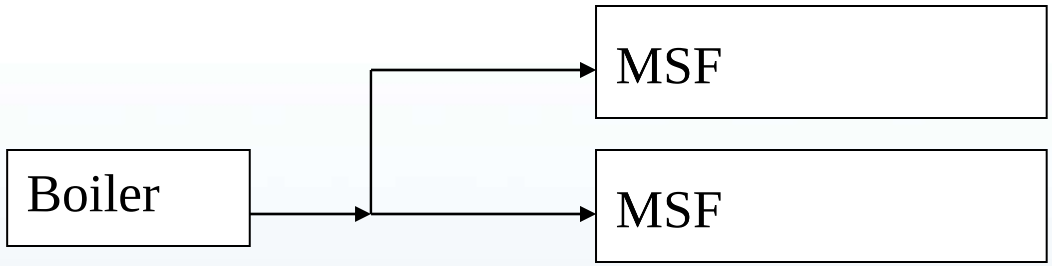
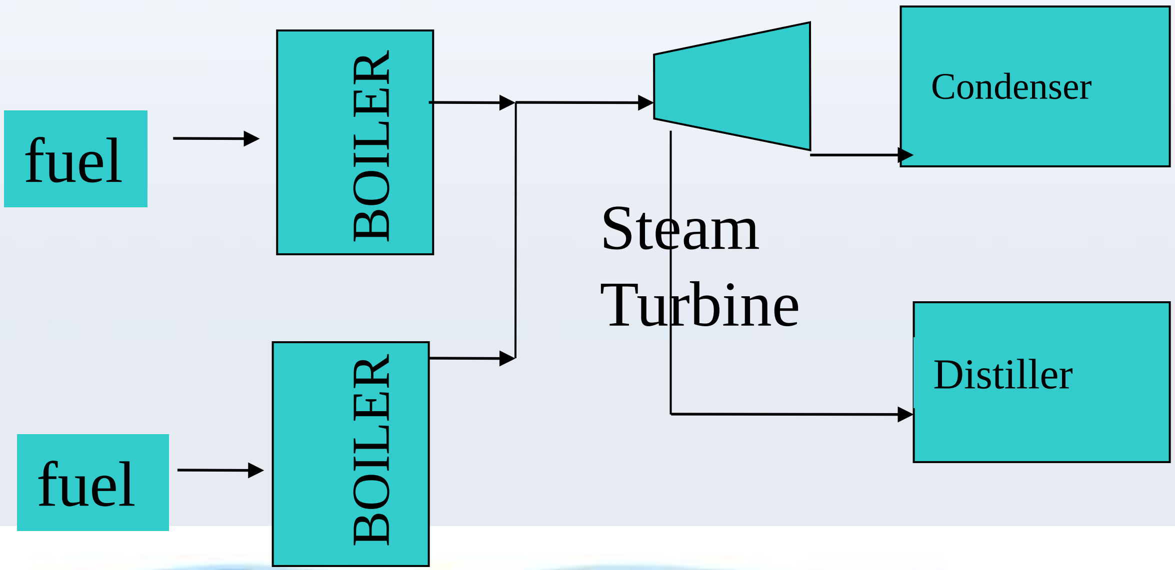
Energy effect



Association with power plant



big
kettle"



Cogeneration

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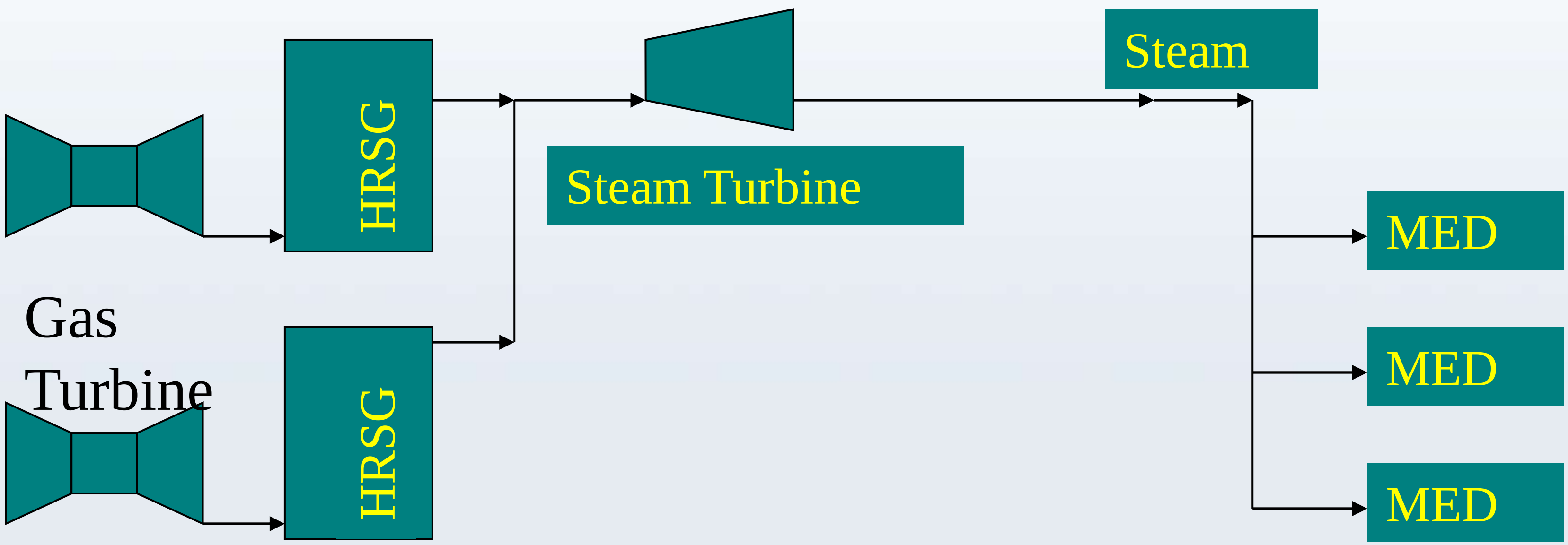
- Overview of desalination technologies

Power thermal desalination combinations



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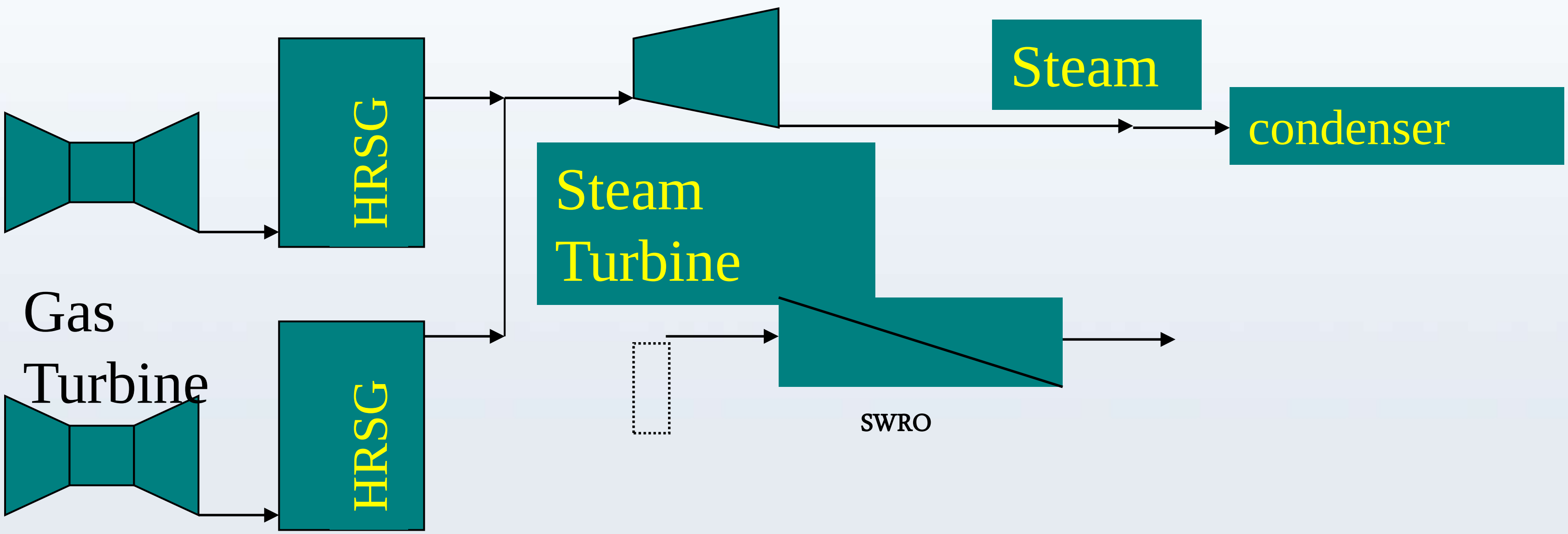
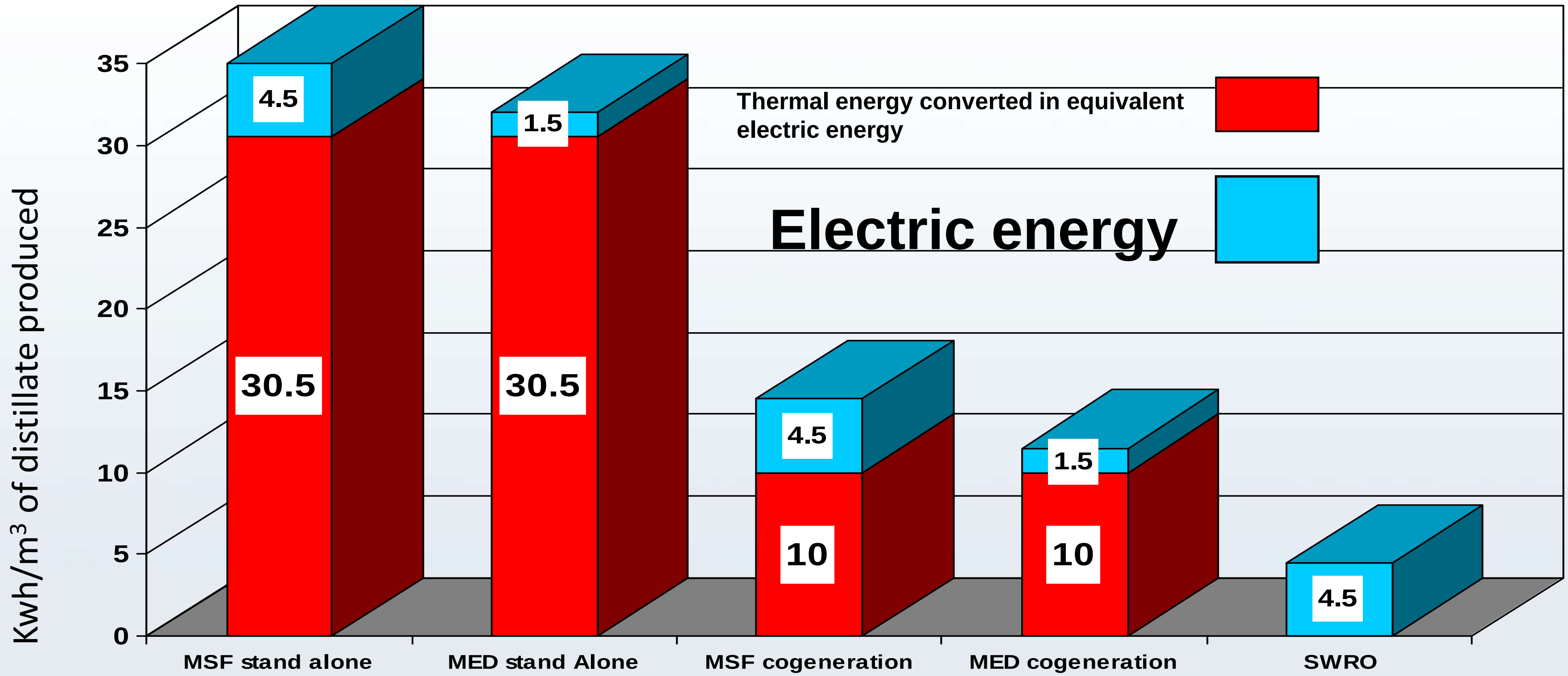
- Overview of desalination technologies

Power and SWRO plant combinations



- Overview of desalination technologies

The Energy Situation



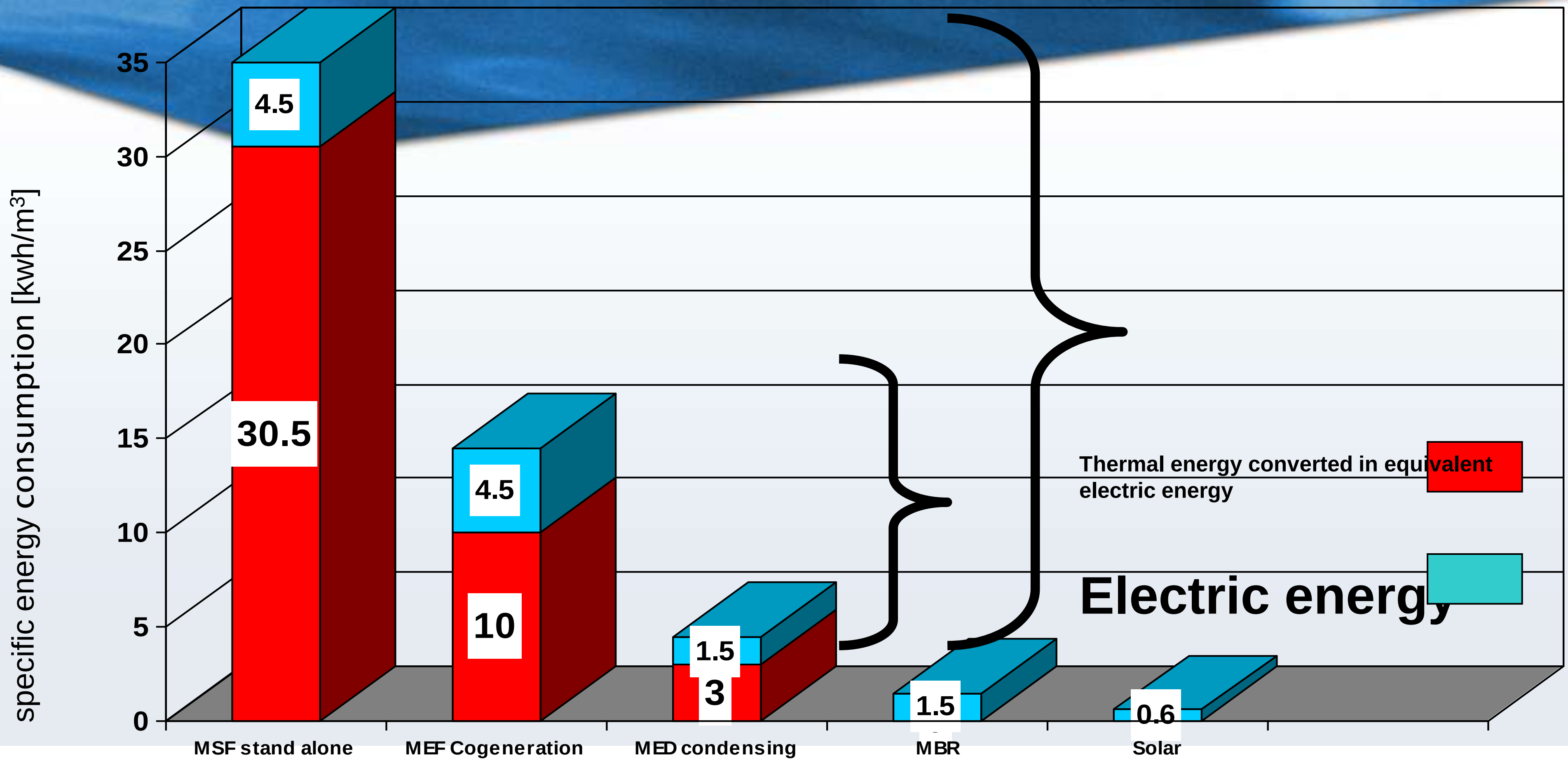
{ Big kettle }

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

The Energy Situation



Water and Power

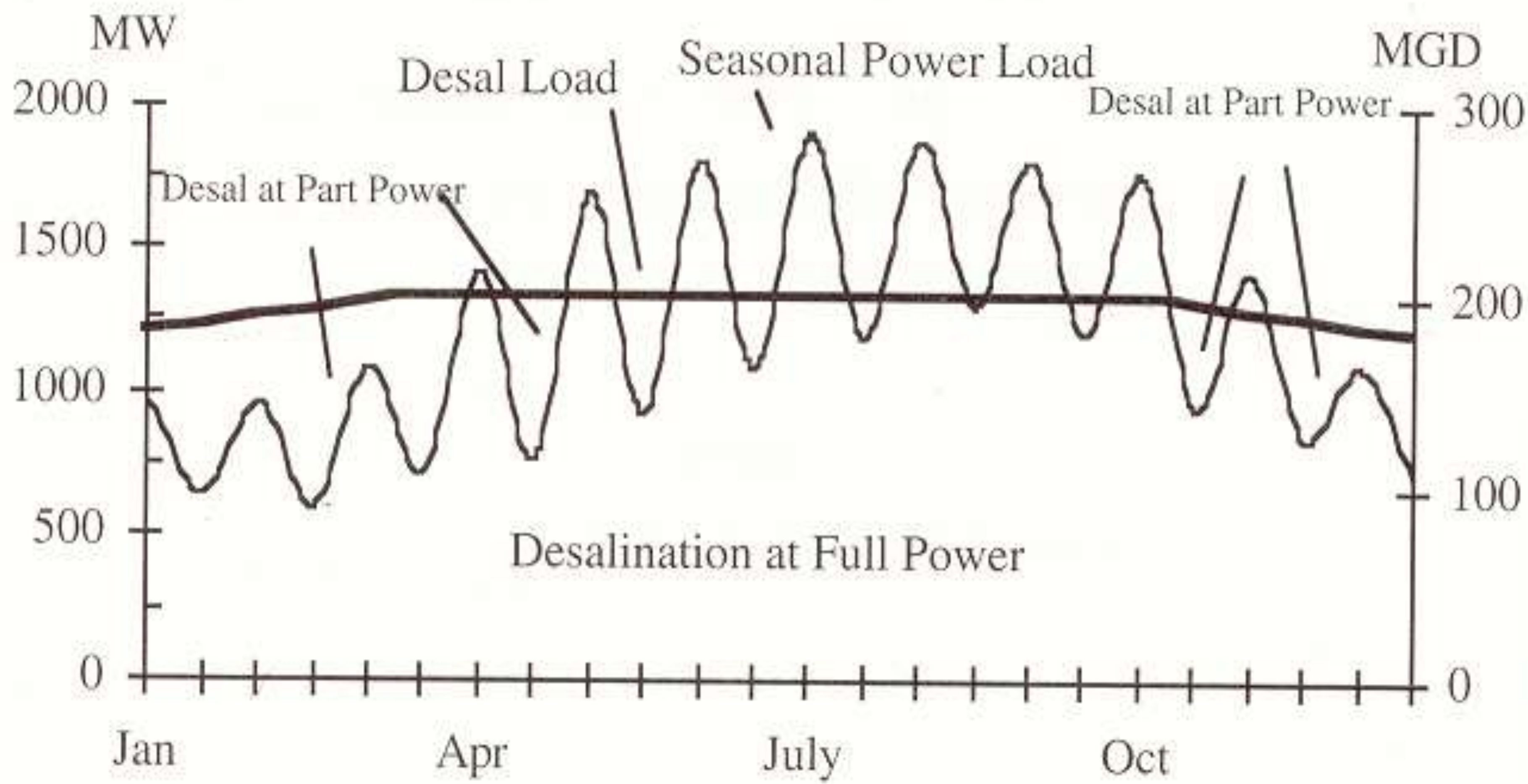
- Water and Power are essential simultaneously

- 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

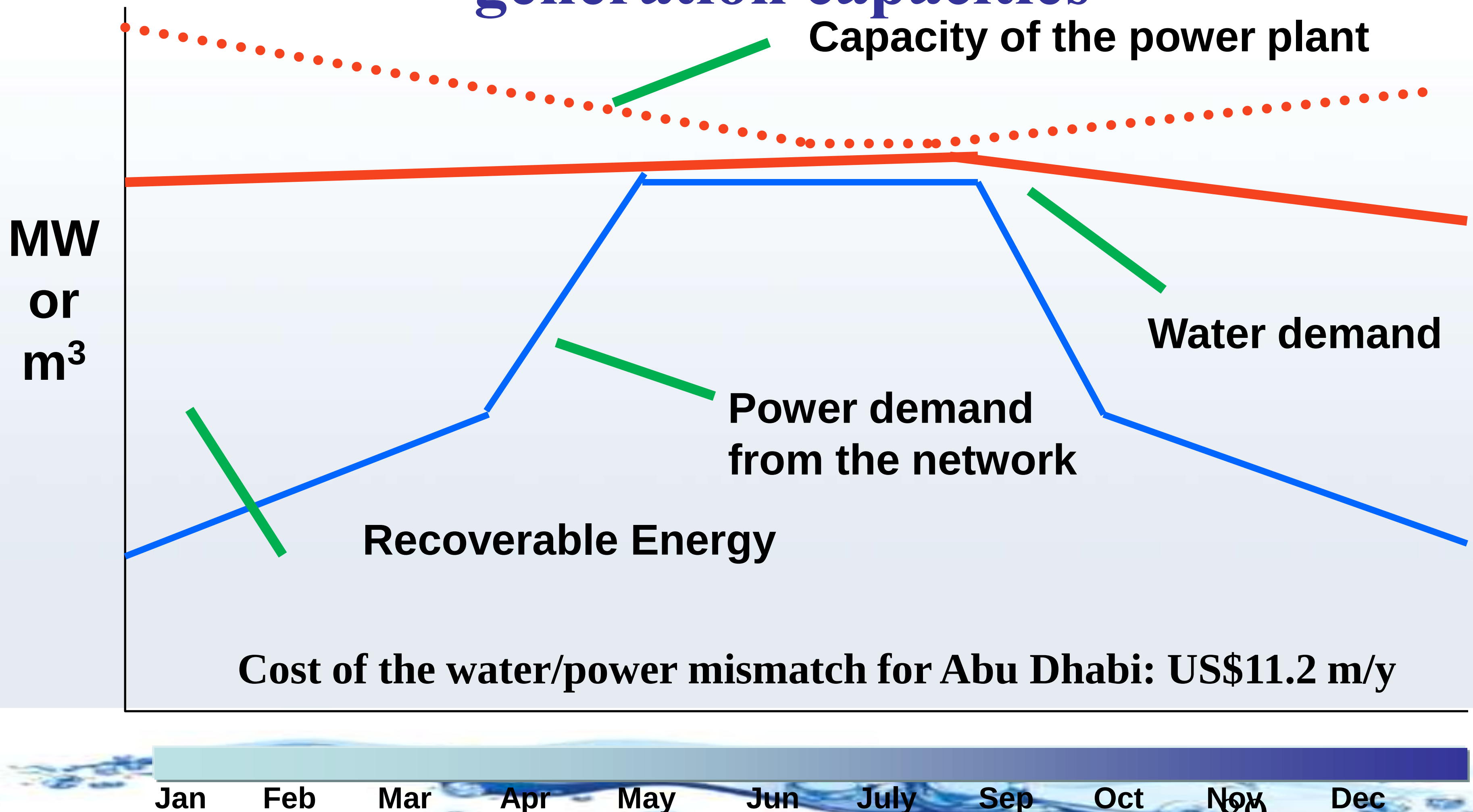
- Moreover, water needs are higher than electricity needs: in the GCC the growth rate of water consumption is 11 % per year and energy is only 4 % (*)

(*) Koussai Quteishat, Hydrorop 2001, Marseille

Seasonal variation of water and electricity needs in ABU DHABI



Seasonal mismatch between water & power generation capacities



Cost of the water/power mismatch for Abu Dhabi: US$11.2 m/y

Source: SUEZ

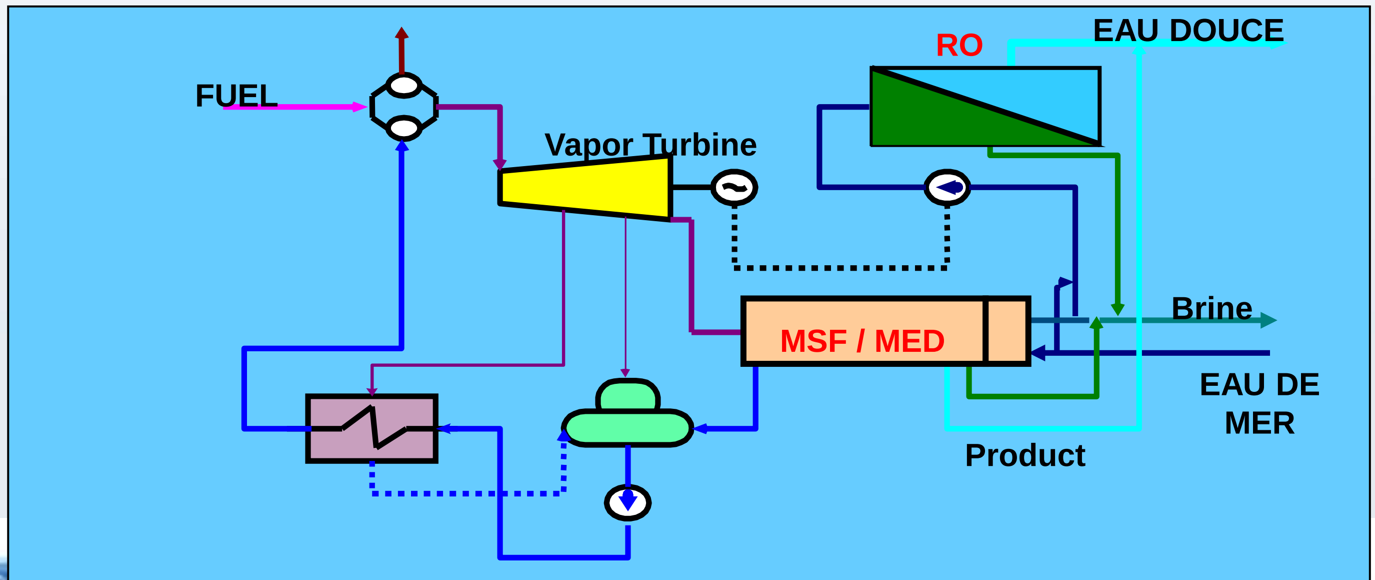
Advantages of thermal process in ME

- Suitability in Dual process (power/water) plants
- Gulf water has high salinity. Peculiarity of seawater, polluted sites, foulants (very simple pretreatment)
- Availability of very low energy cost (waste energy). MED becomes more viable than RO
- More reliable and mature (MSF)
- Produces pure water TDS < 25mg/L
- Large scale size units
- Integrates water and power demands

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:

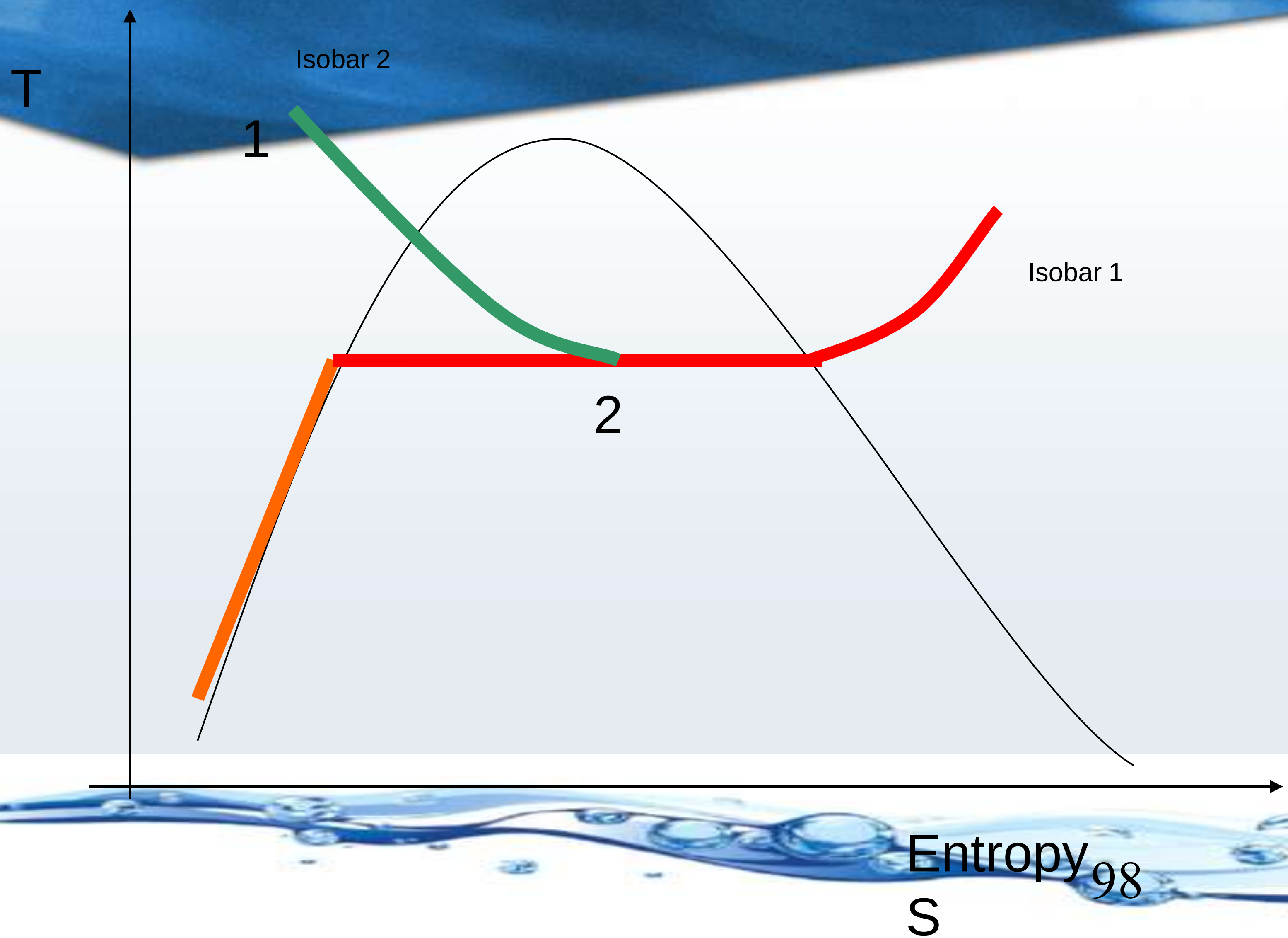
How did it begin?

- 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

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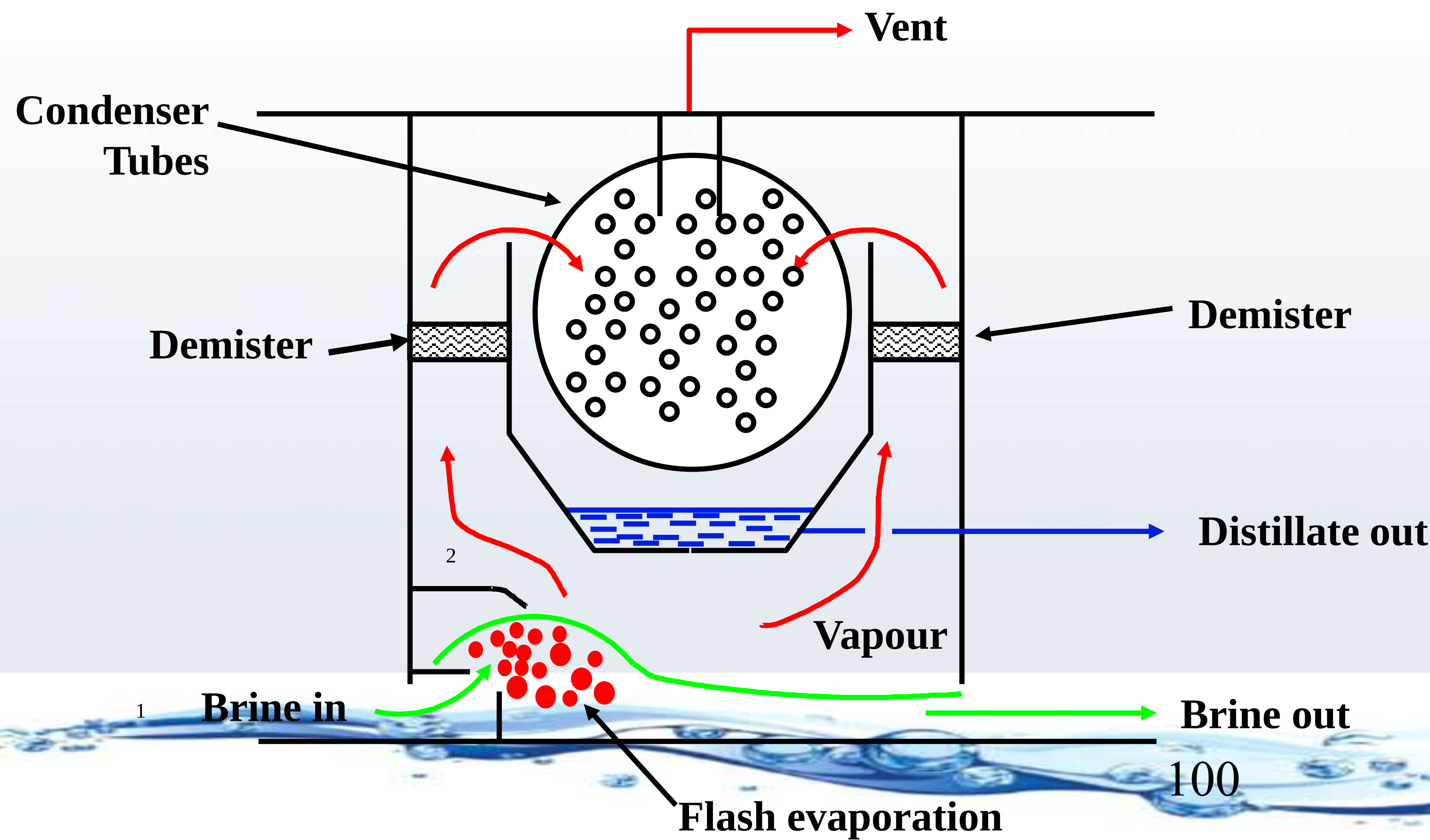
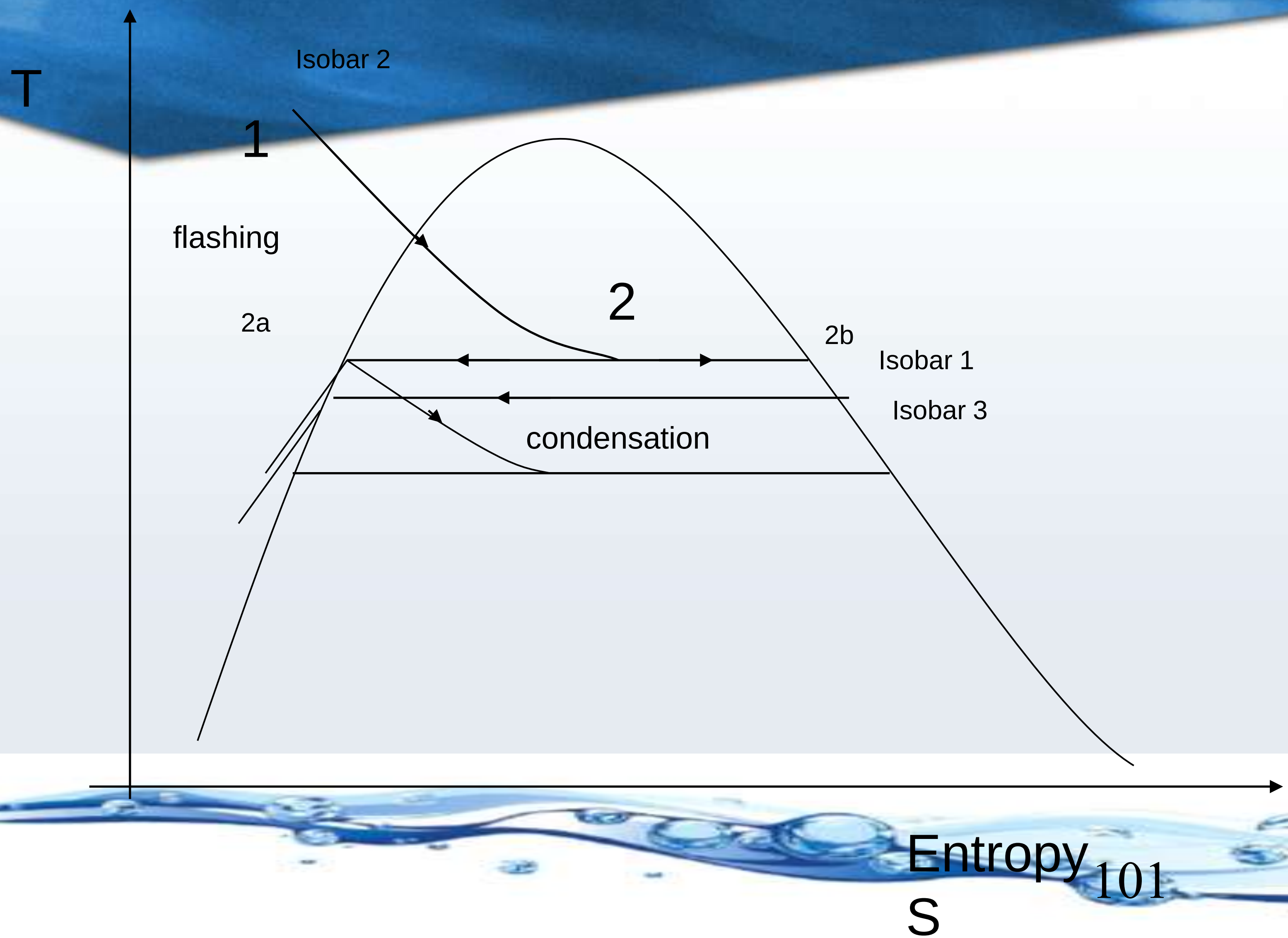
MSF Desalination Plant

Typical stage arrangement of a large MSF plant



Stage modeling thermodynamic ideal case :



The influence of minor constituents of seawater and brackish waters

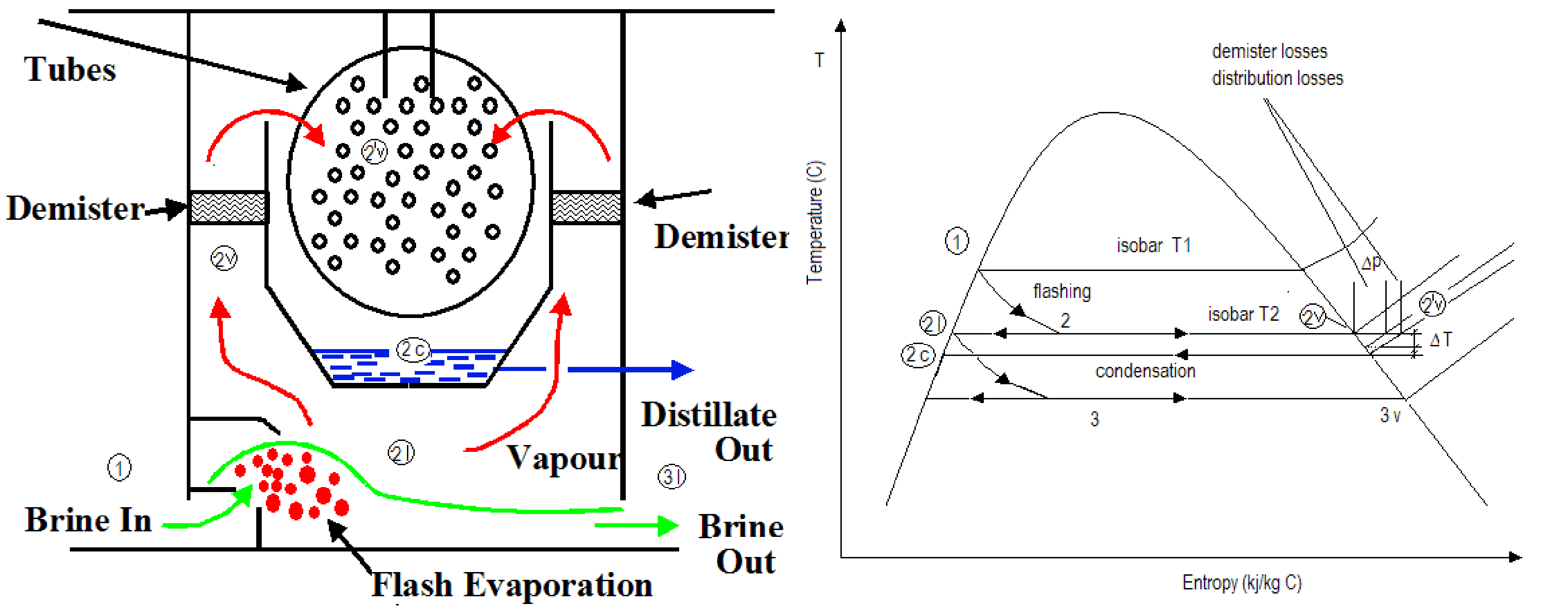
A. Dissolved inorganic

- 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 inverse functions of temperature

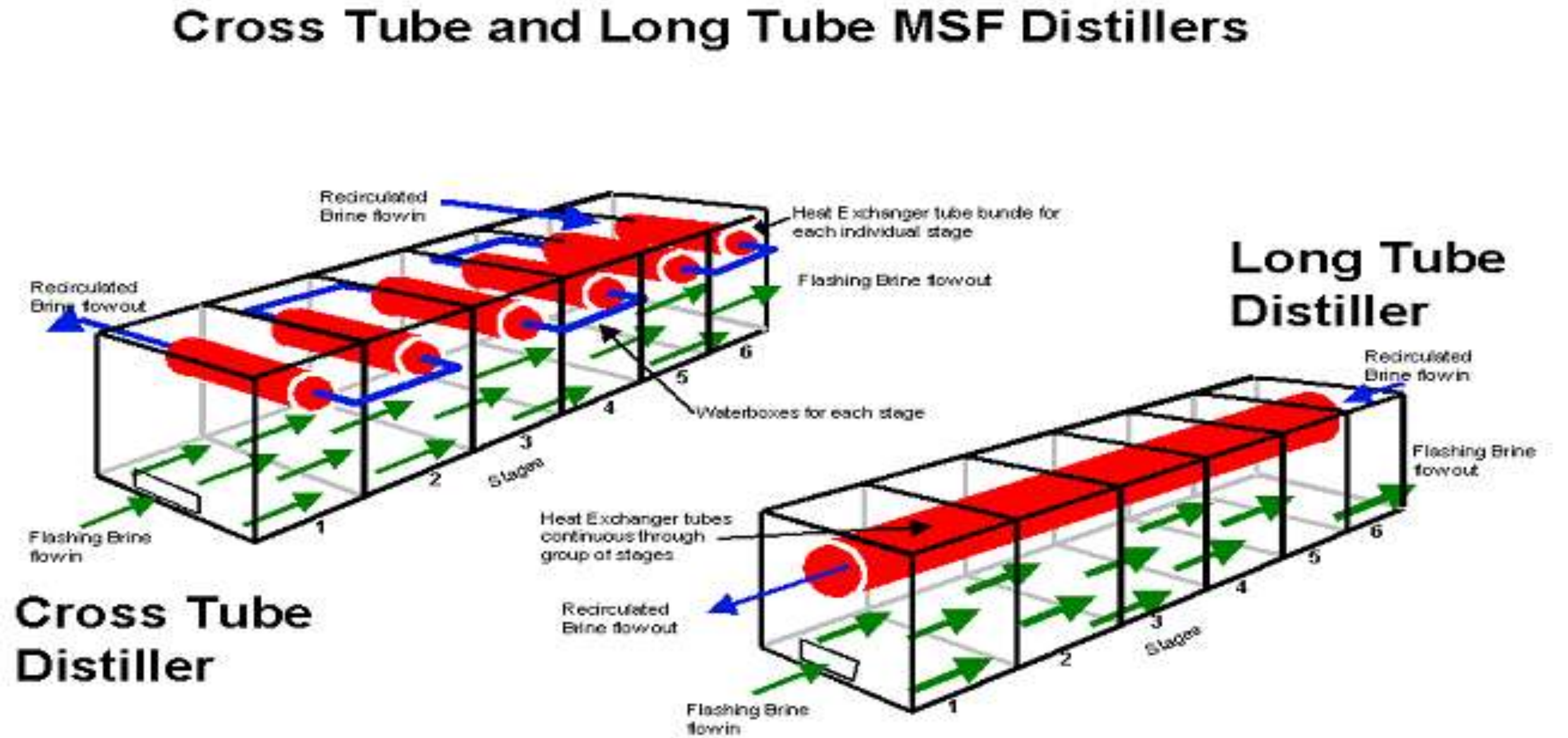
This involves the following aspects to be considered:

- scaling
- venting

Stage modeling thermodynamic real case :



Multi stage flash



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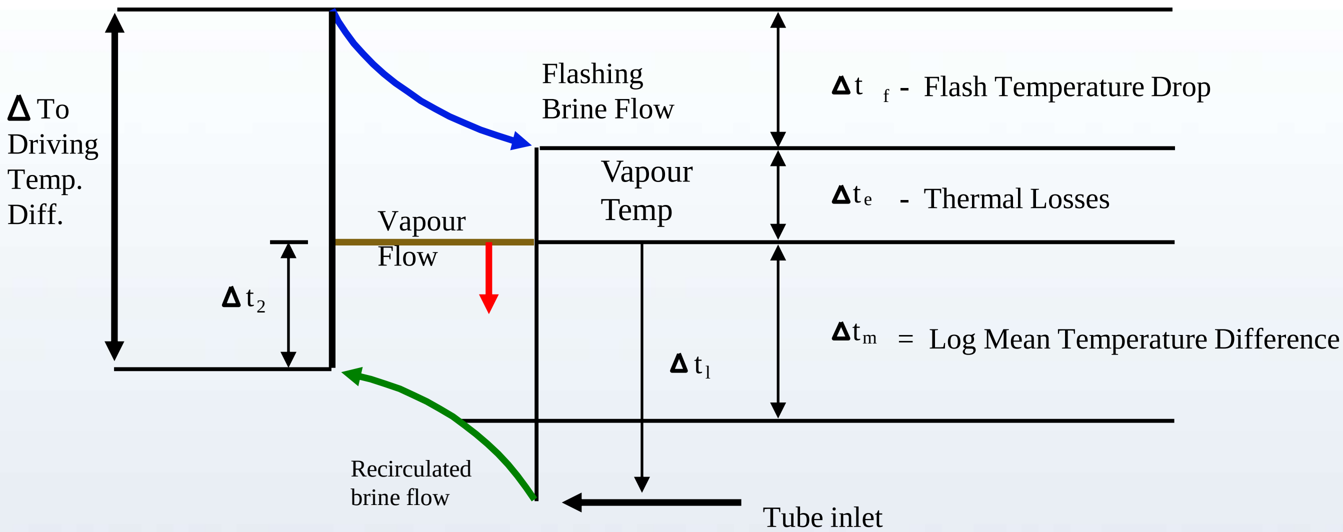
MSF Desalination Plant

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)

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

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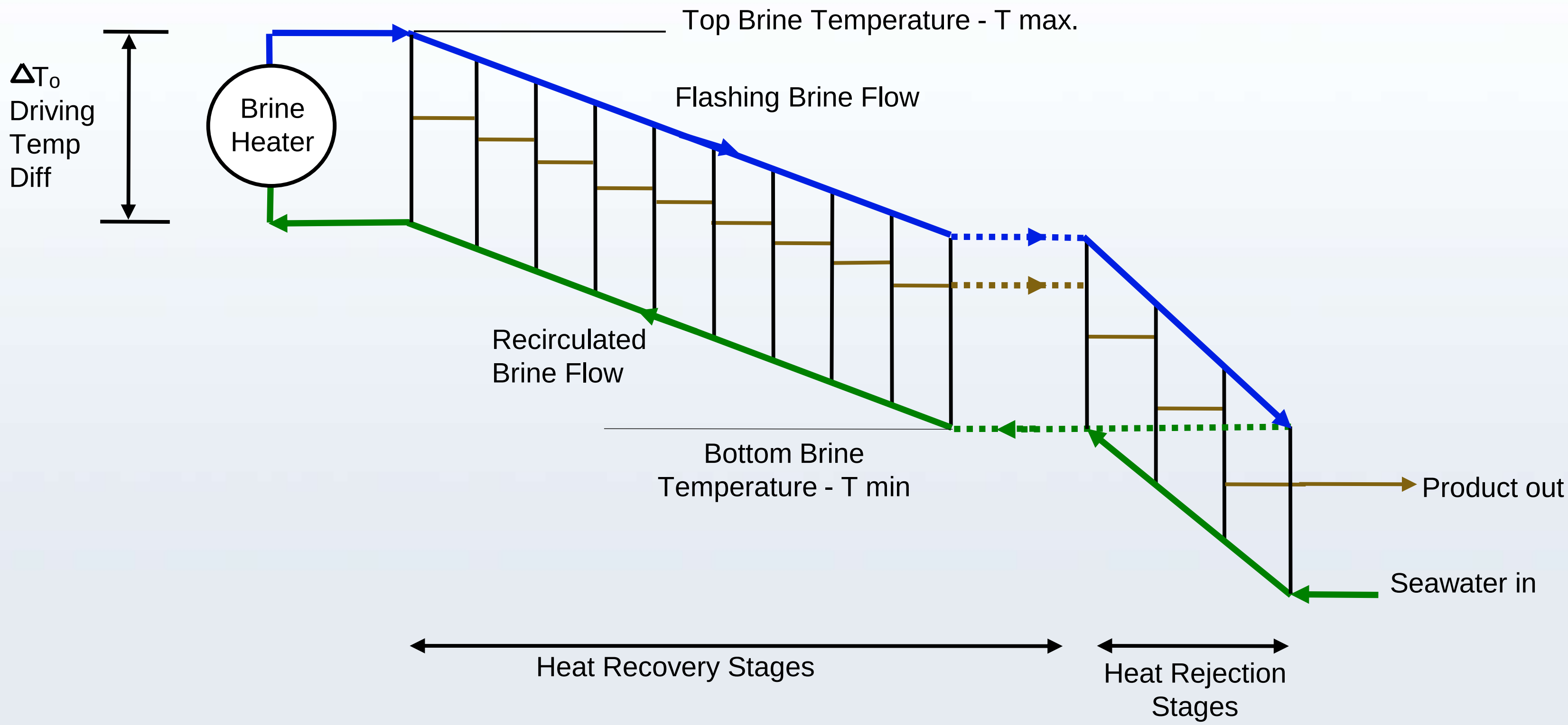
MSF Desalination Plant

Stage temperature diagram
Complete plant (brine recirculation type)



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

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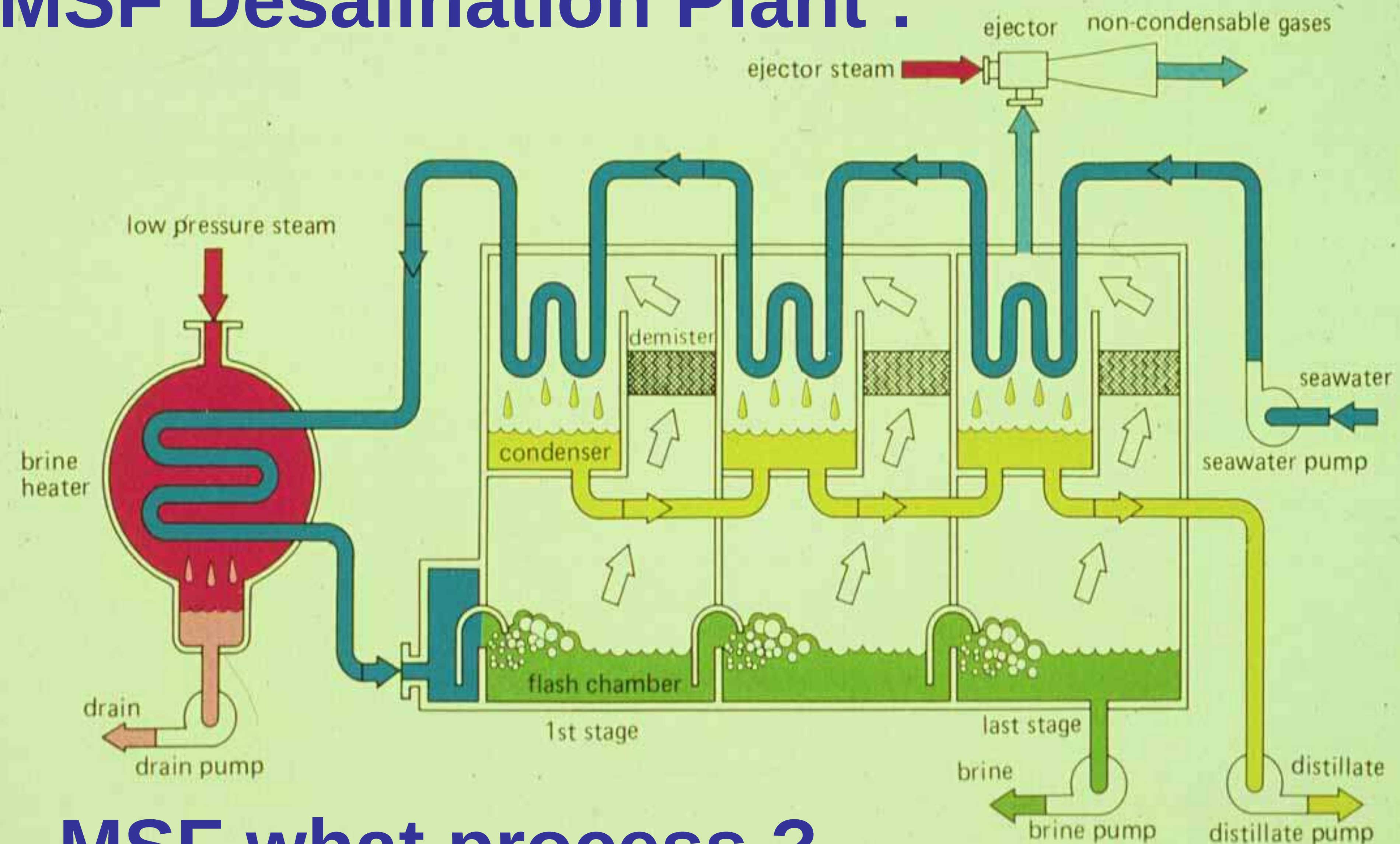
MSF Desalination Plant :



MSF what process ?

MSF Desalination Plant

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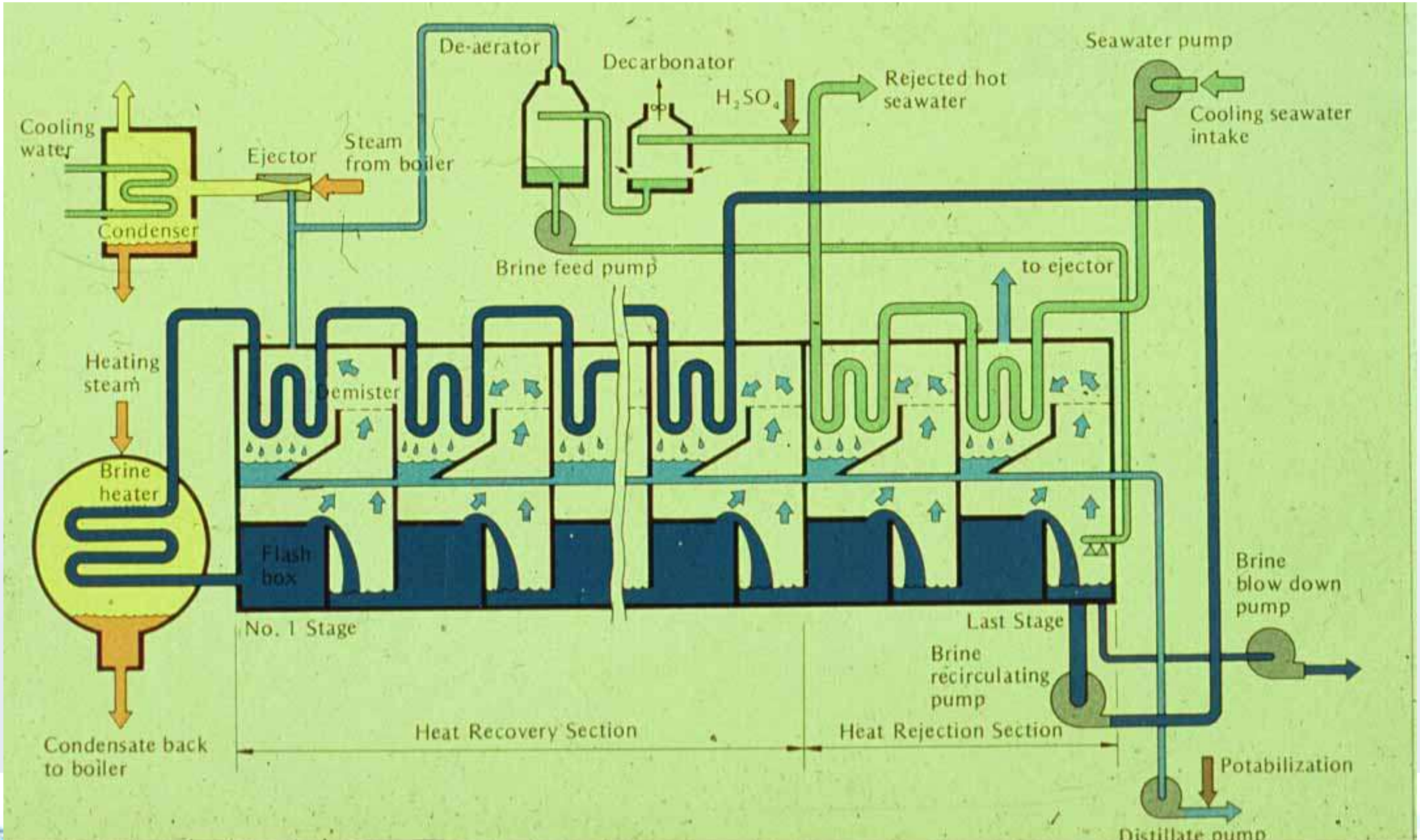

MSF what process ?

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Flow sheets: cross flow brine recirculation

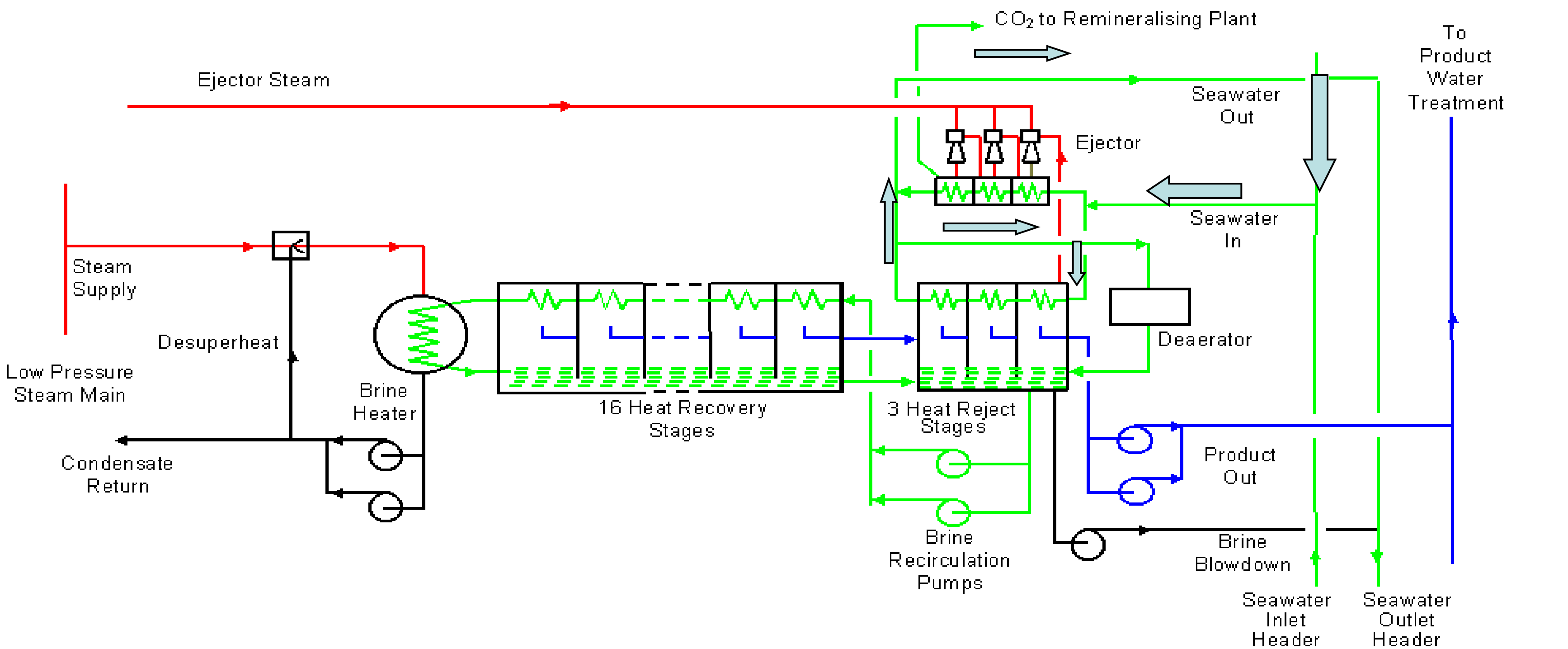
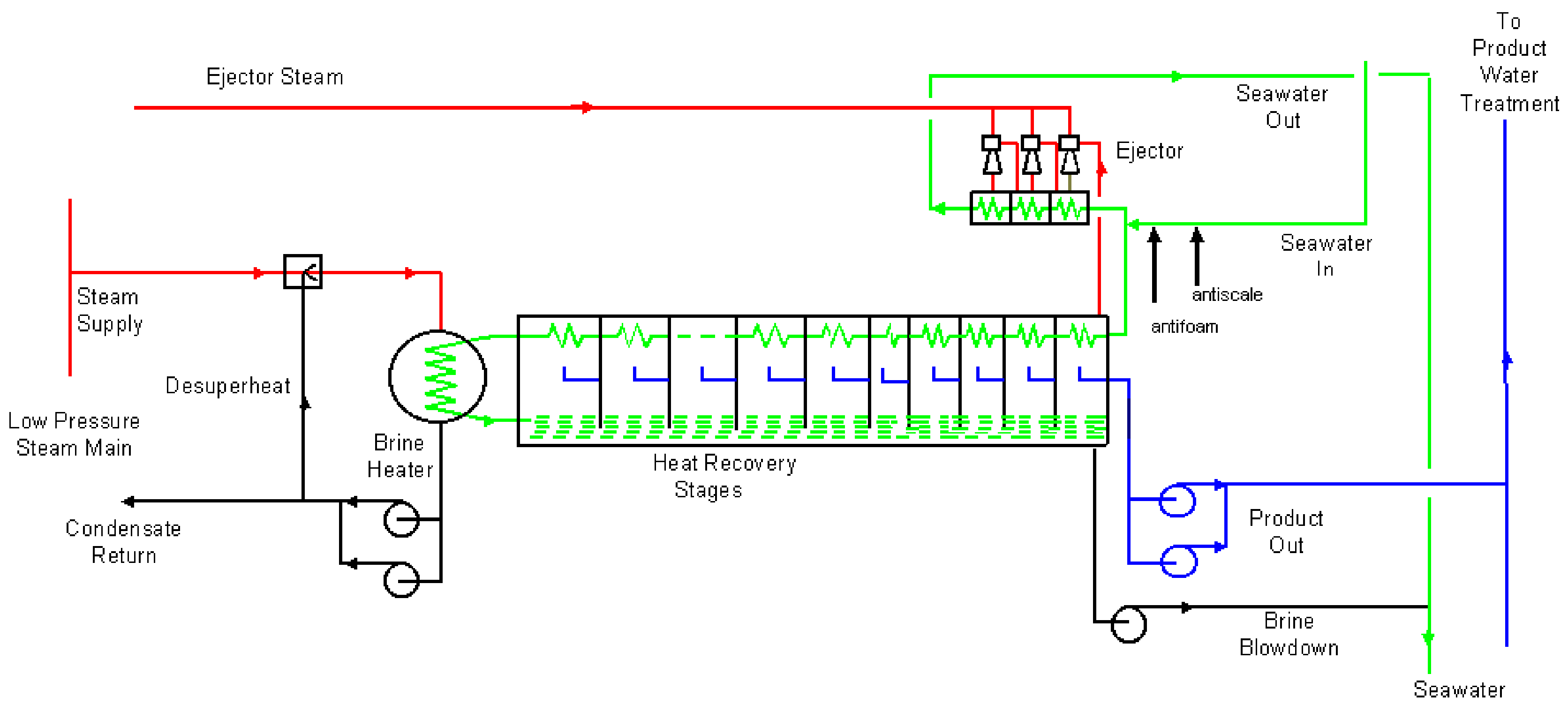


Figure 3

Flow sheets: once through



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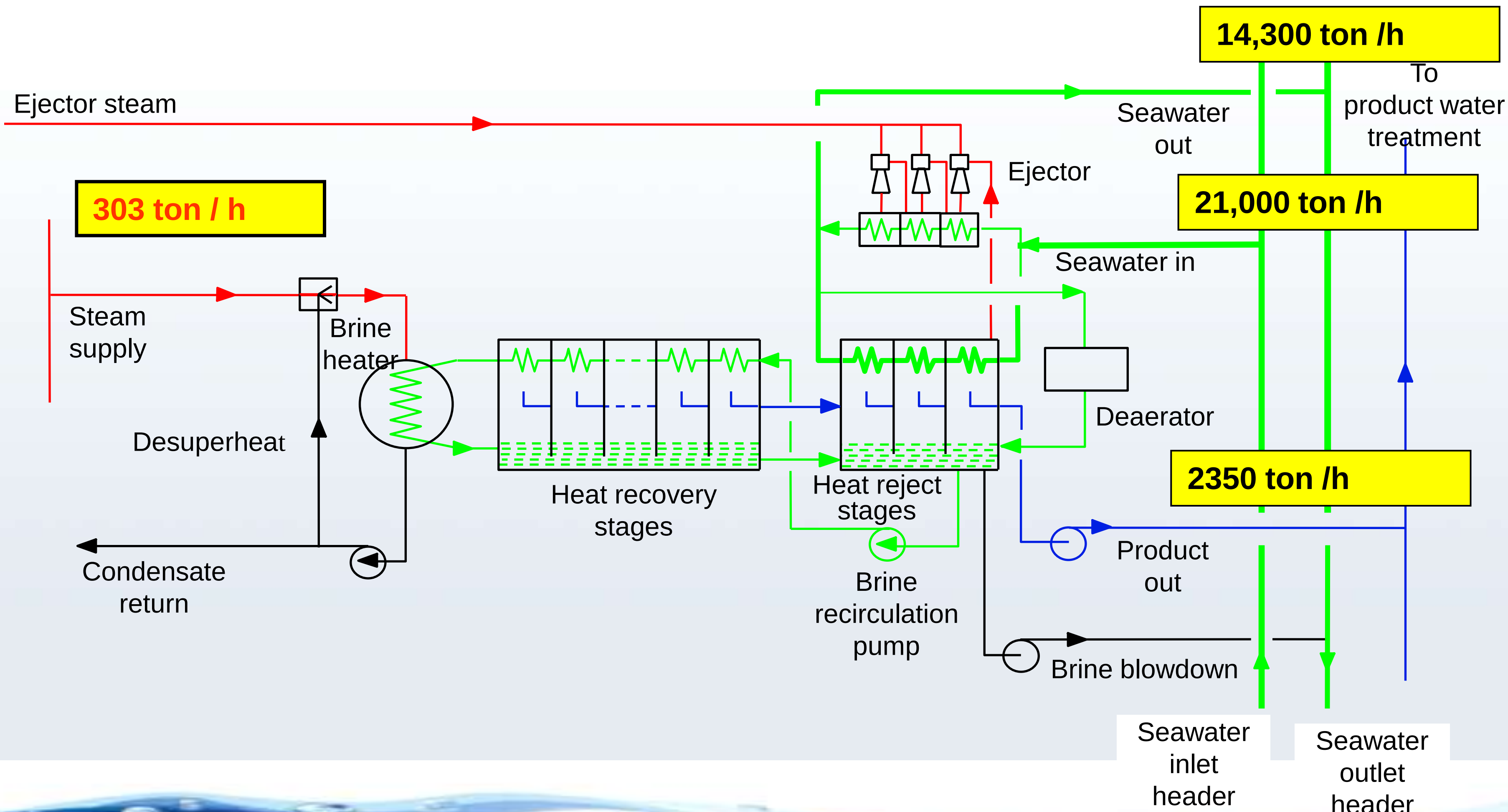
Main flow stream mass balance



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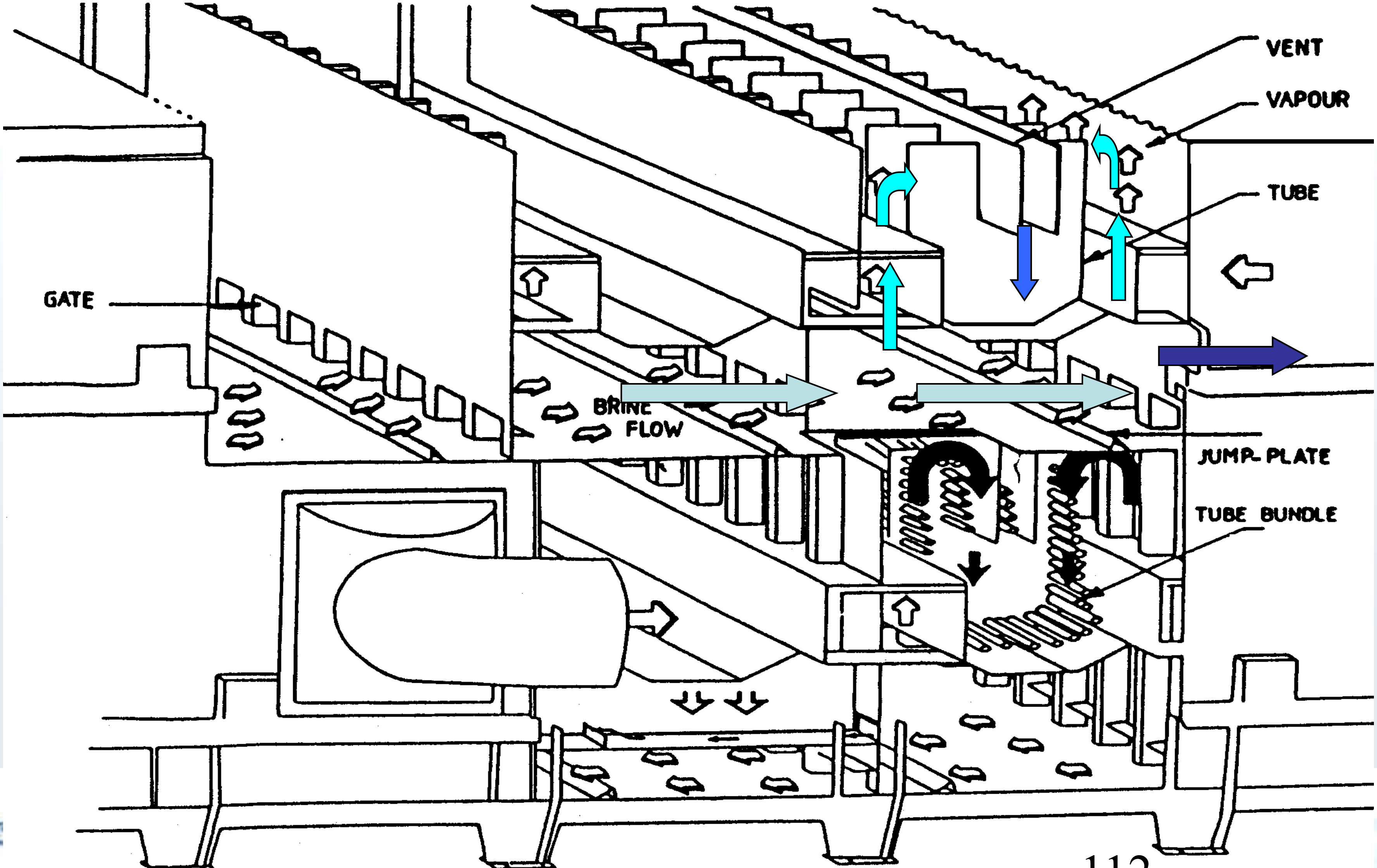

MSF cross flow plant internal layout:
How it really looks like – low side flash chamber

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

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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

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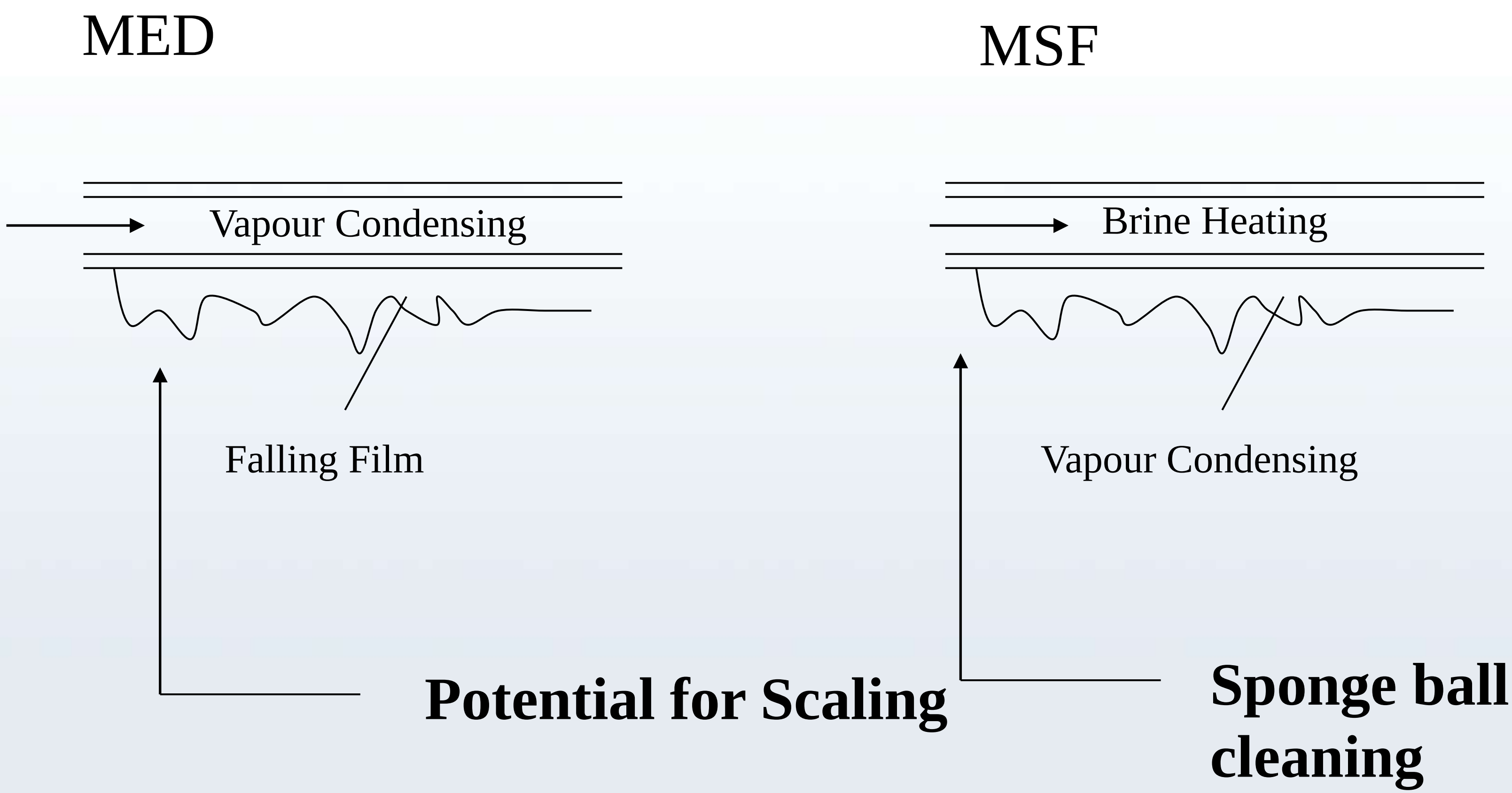
Evaporation Concept



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

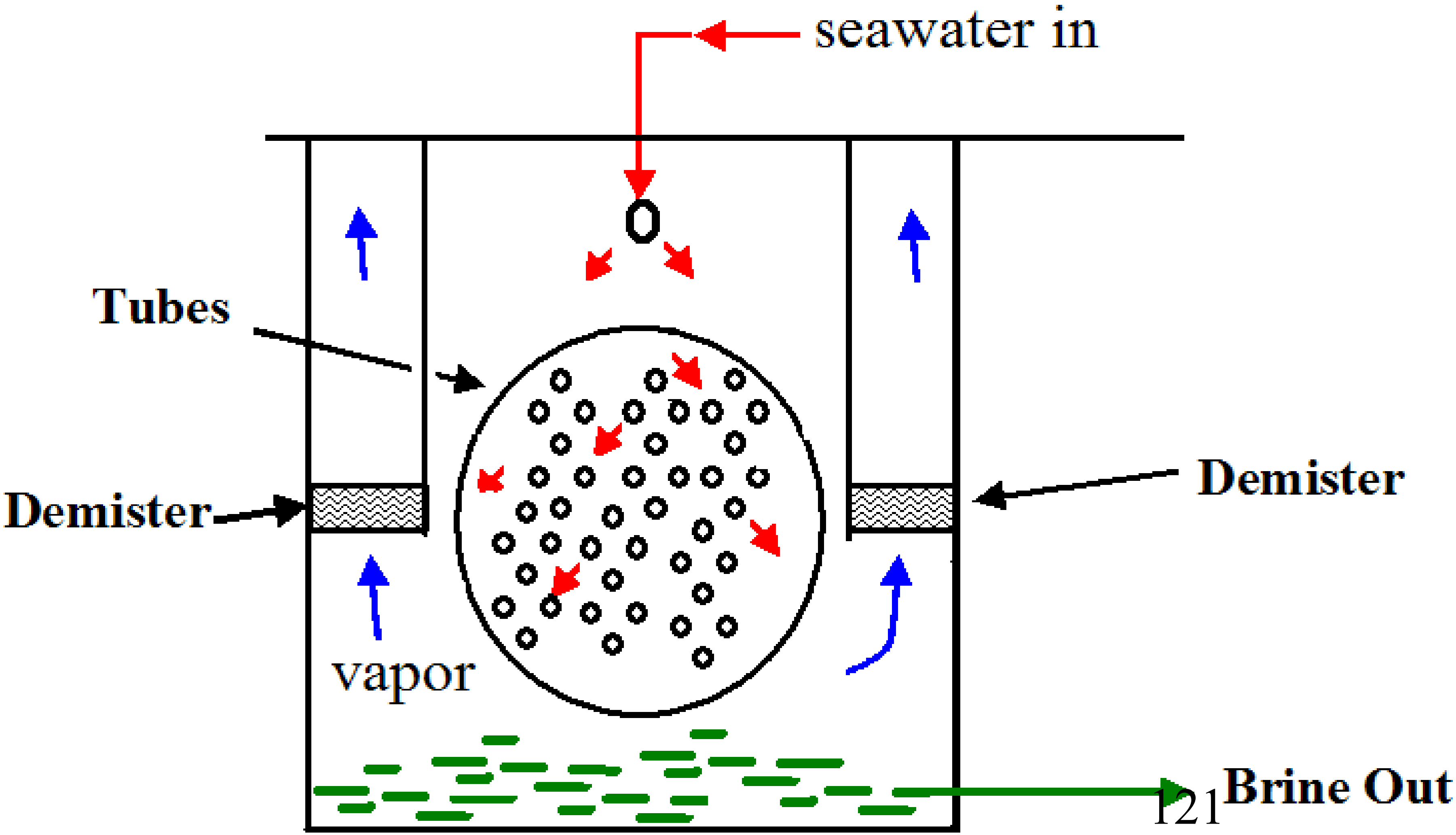
MED distillation

Typical parameters for large MED plant are:

Top Temperature of first stage	65 deg C
Performance Ratio	8 to 15
Distillate Output (*)	3.5-5 MIGD

MED Desalination Plant

Typical Stage Arrangement of a Large MSF Plant

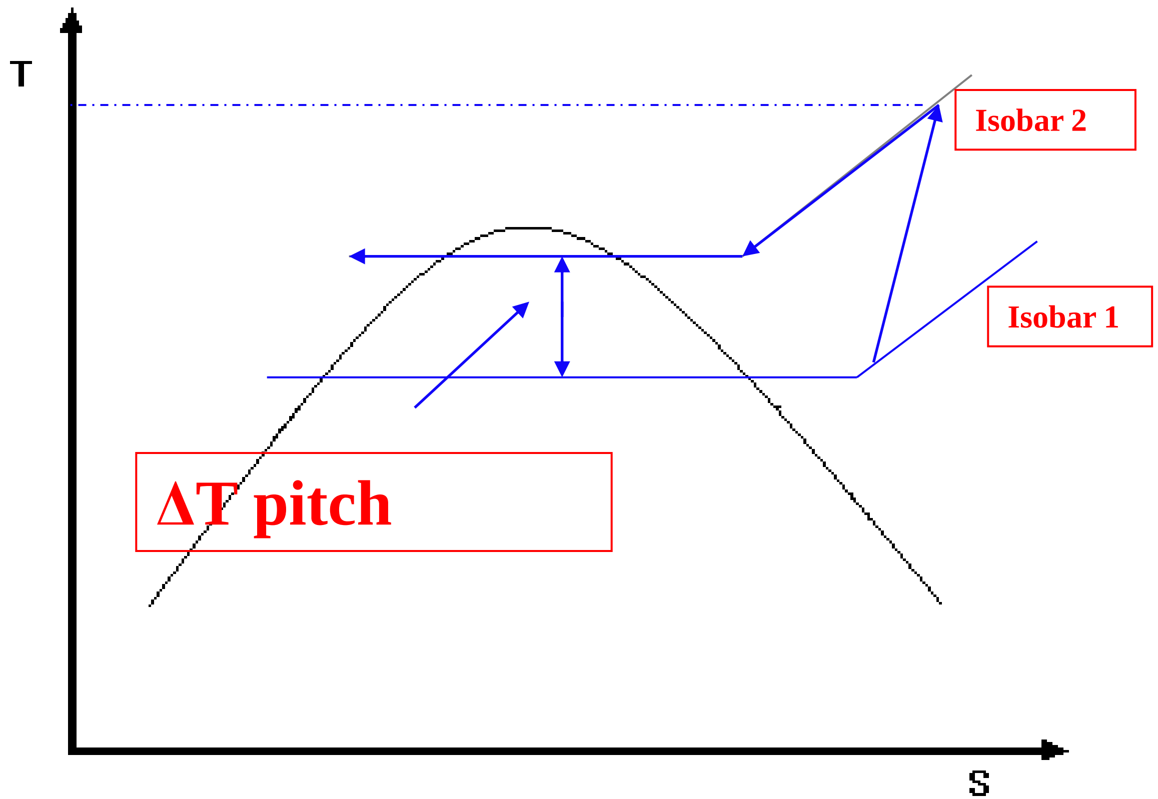


The concept of thermo compression

- 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



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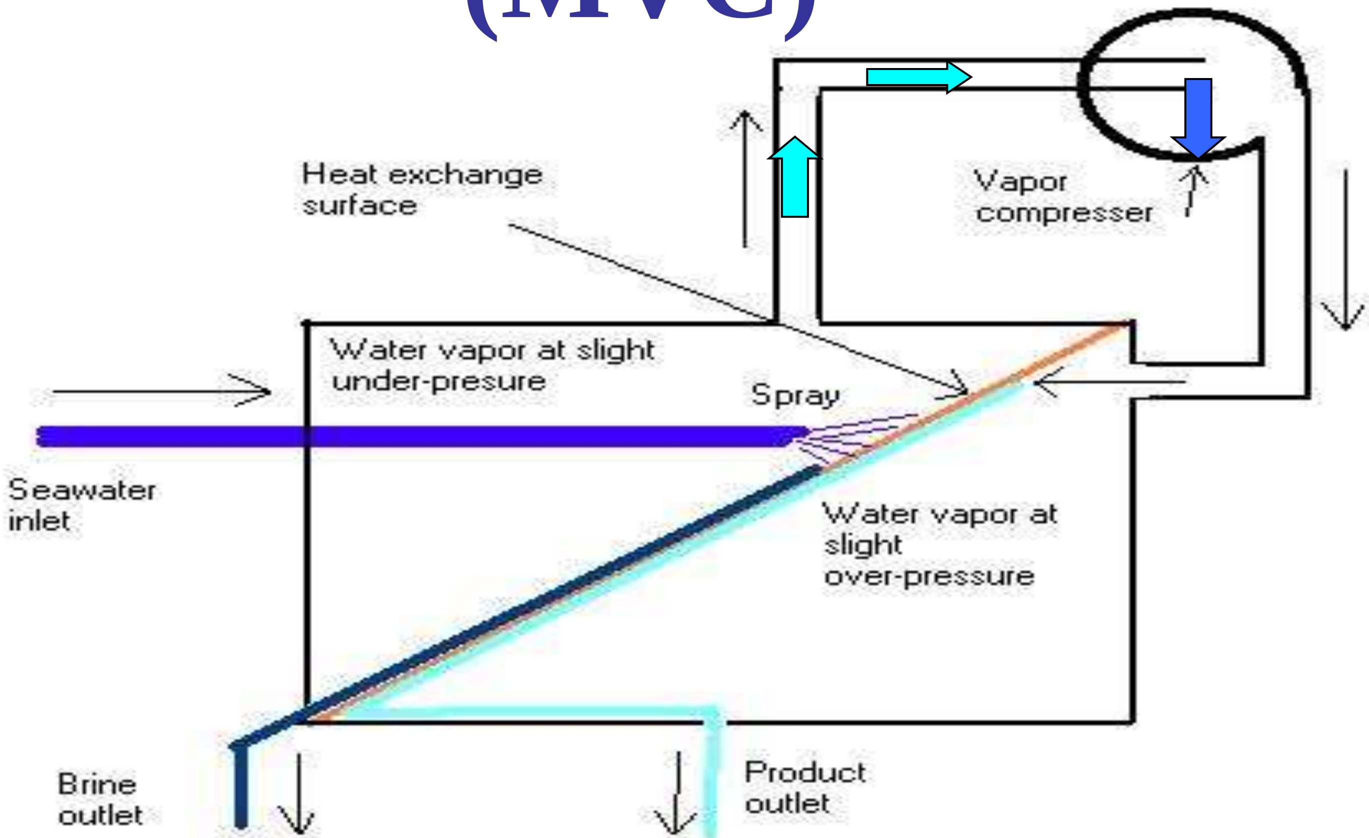
Mechanical Vapor Compression (MVC)



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

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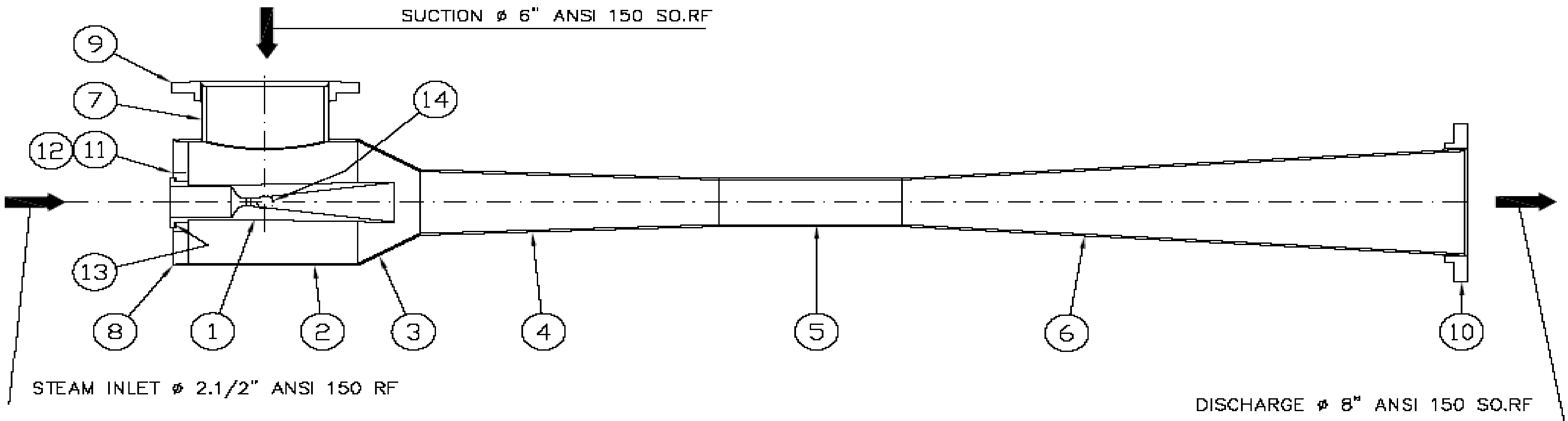
A Simple Ejector-Compressor



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	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	
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

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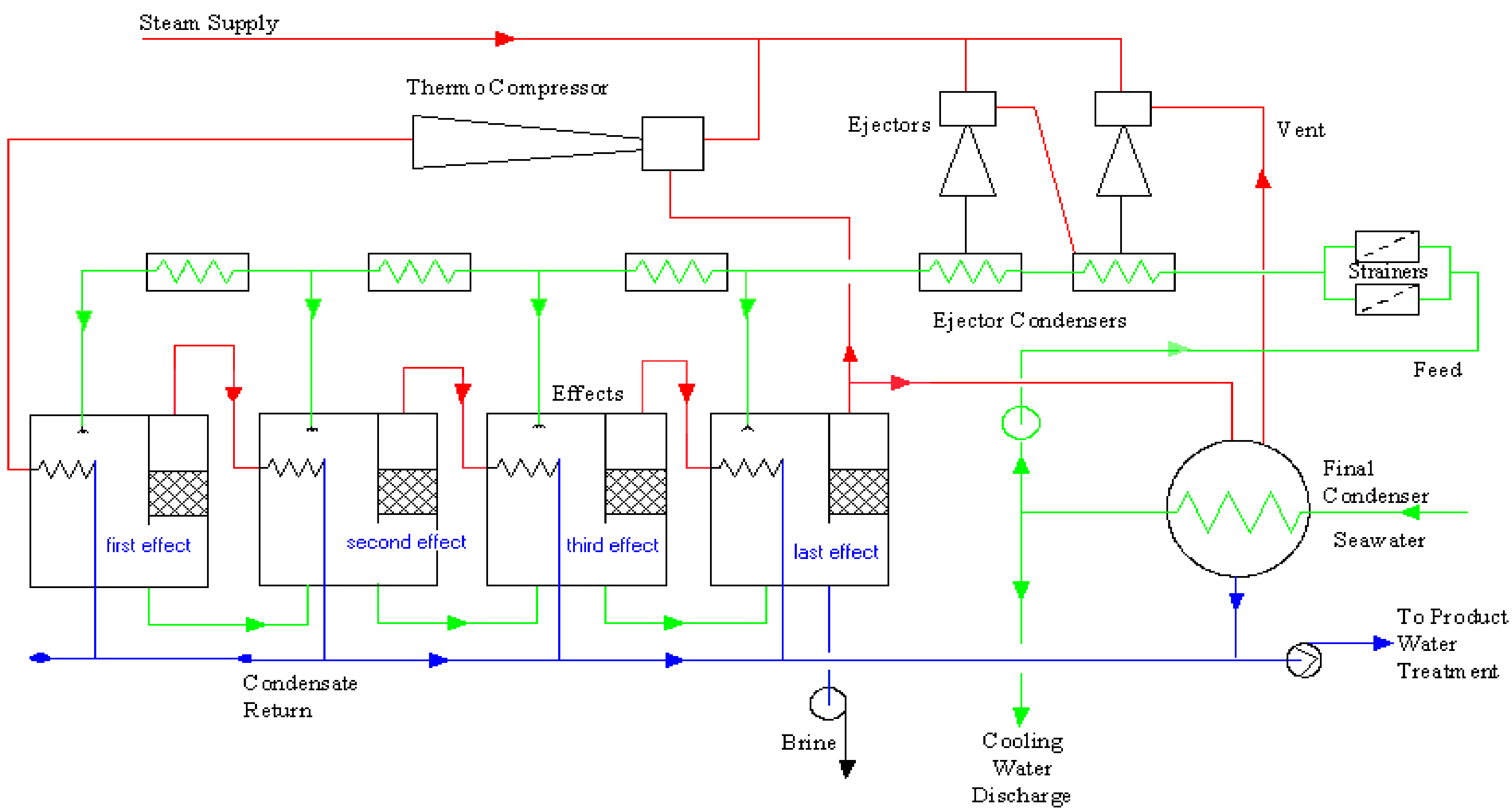
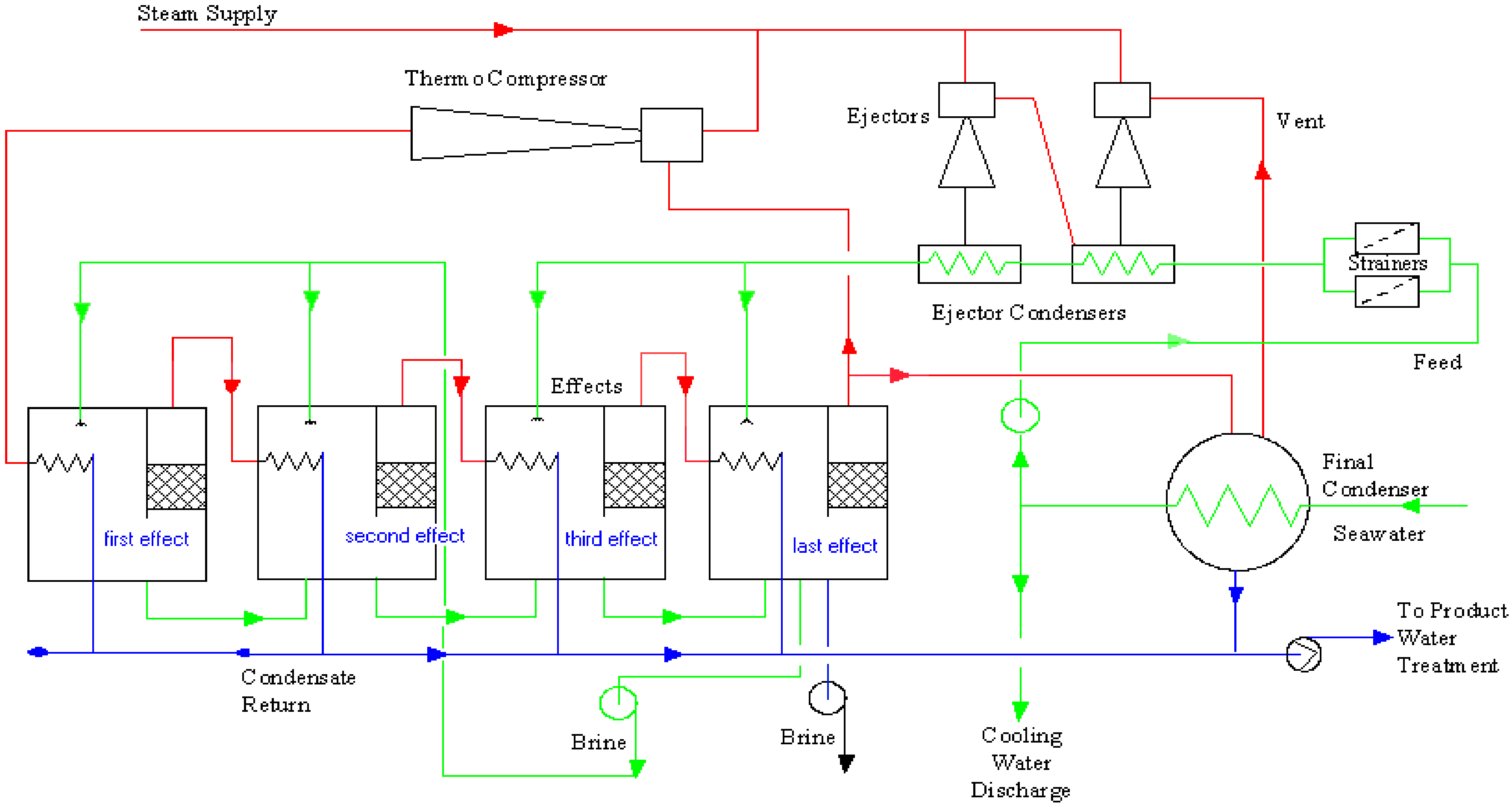
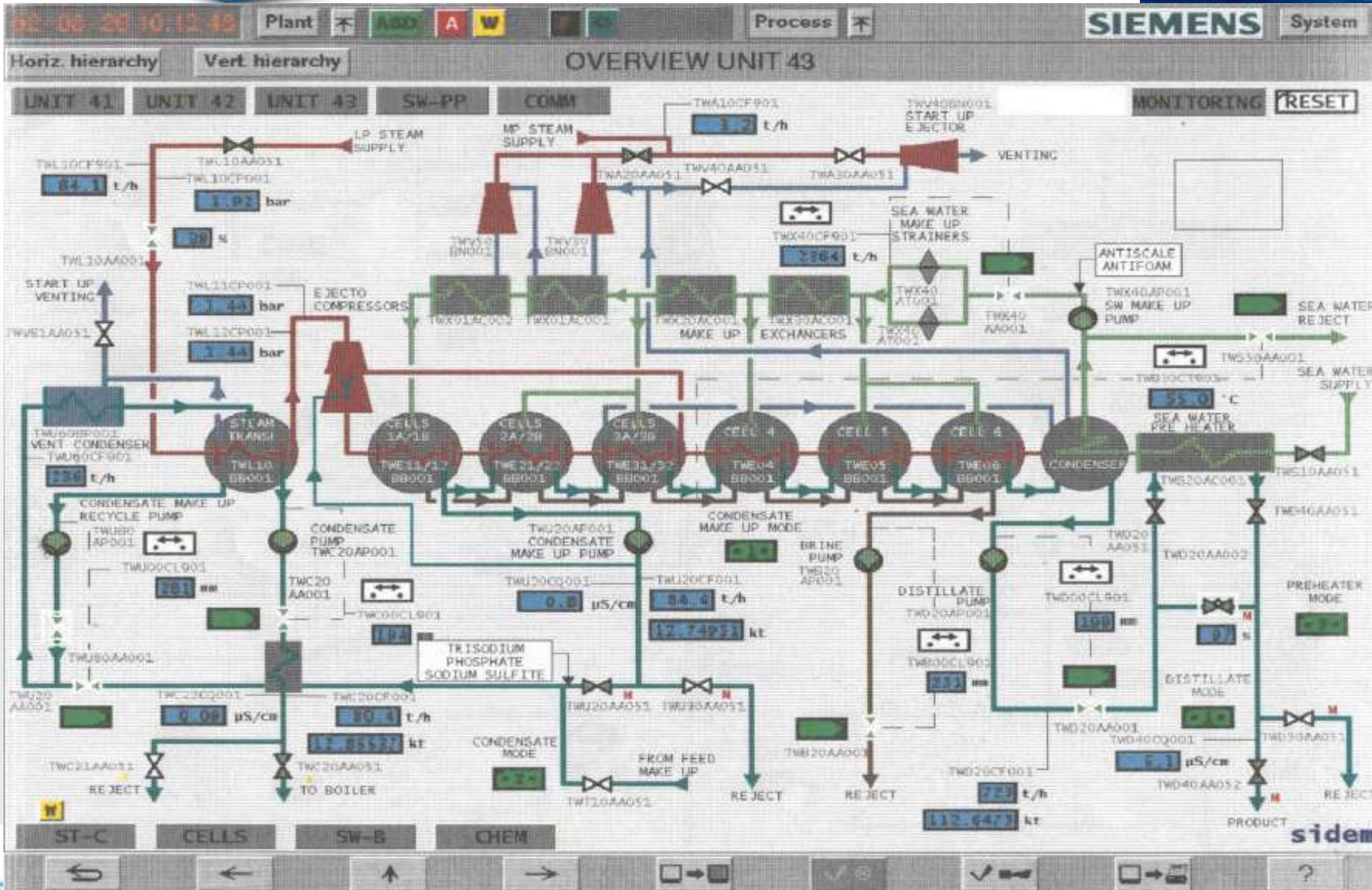
Flow sheets : once through



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
MAKE UP
EXCHANGERS
SEA WATER SUPPLY
SEA WATER PRE HEATER
VENT CONDENSER
STEAM TRANSF
CELLS 1A/1B
CELLS 2A/2B
CELLS 3A/3B
CELL 4
CELL 5
CELL 6
CONDENSER
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

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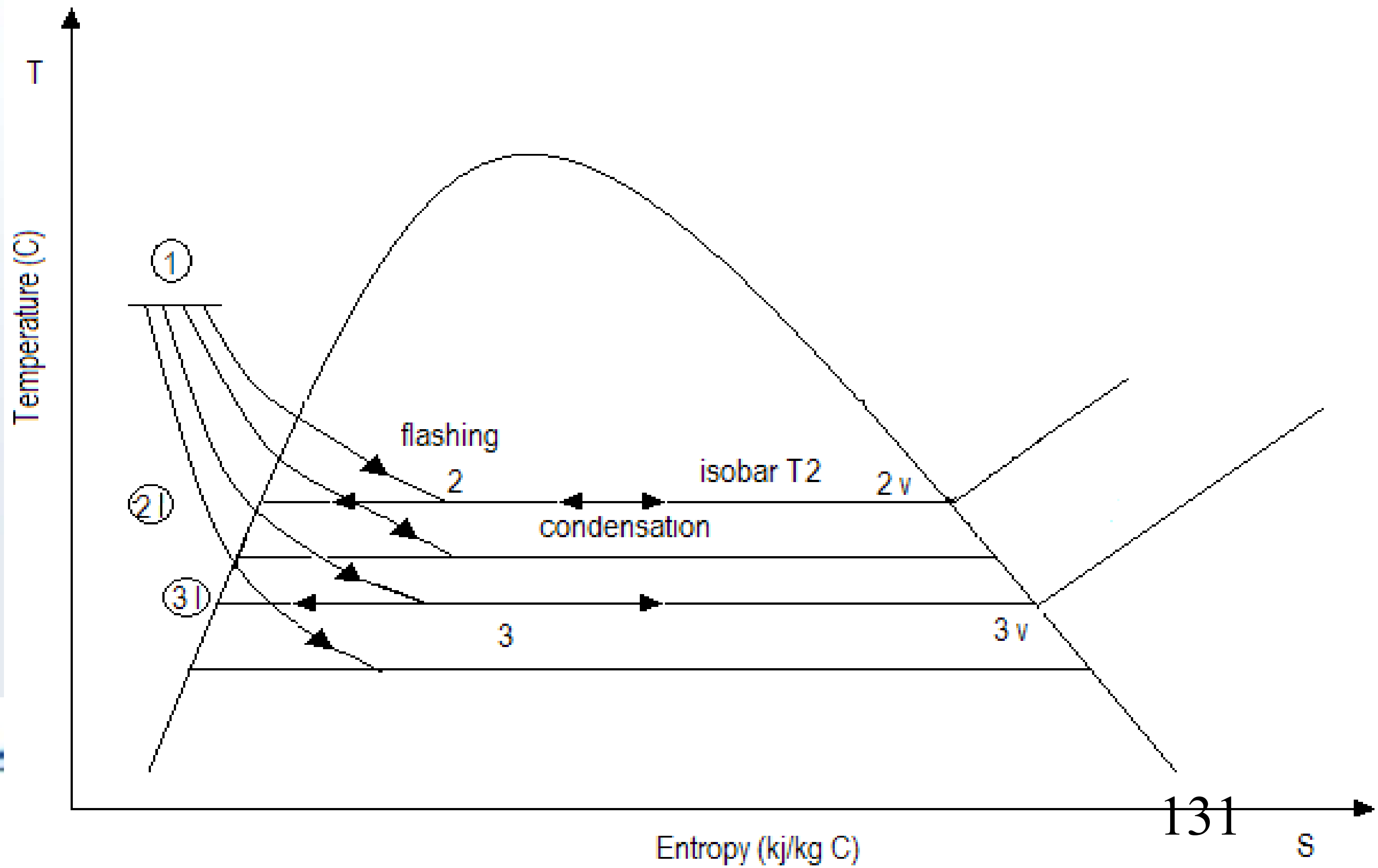
MED process phenomena :

thermodynamic path : the ideal case



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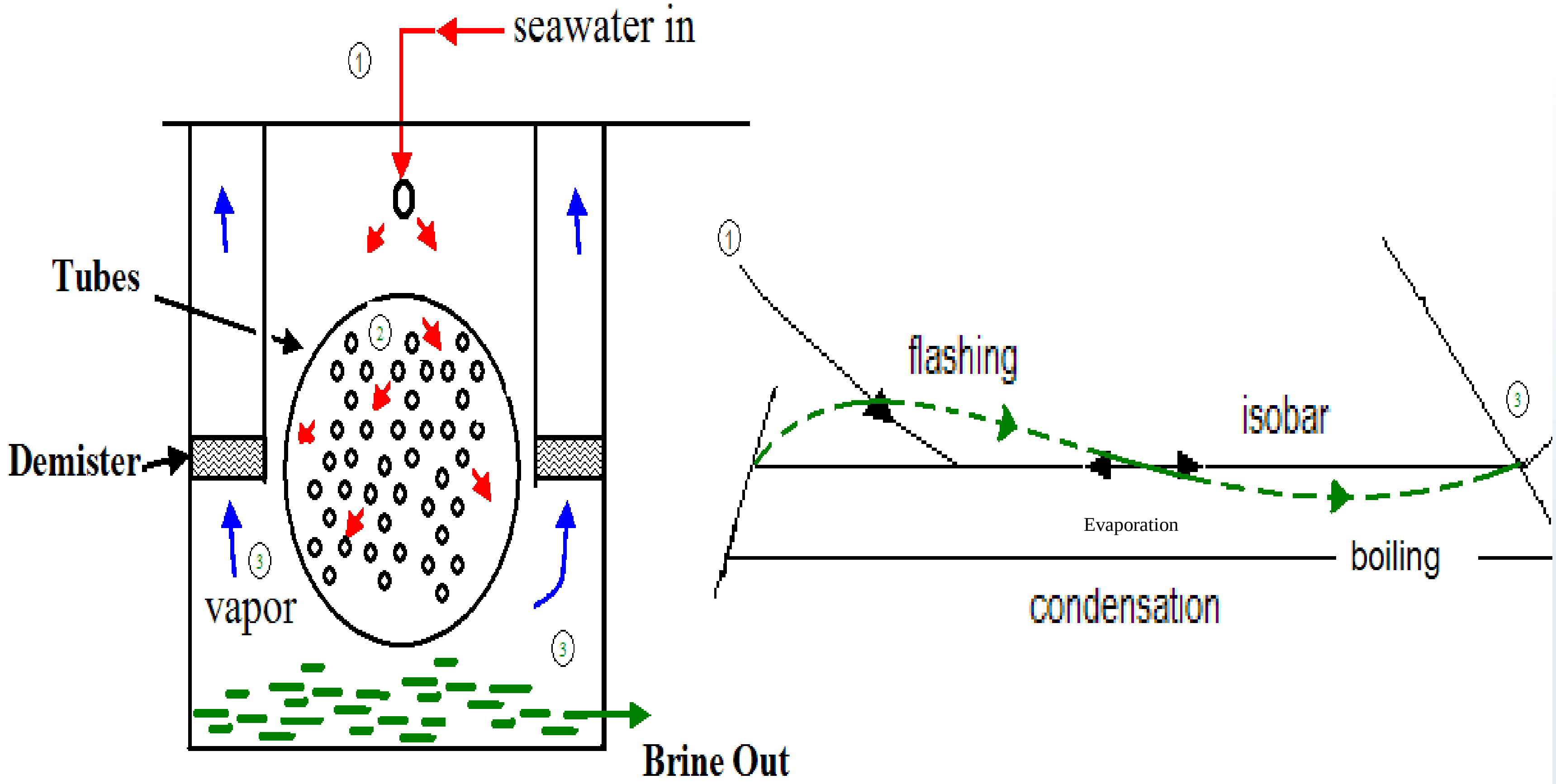
MED process phenomena :

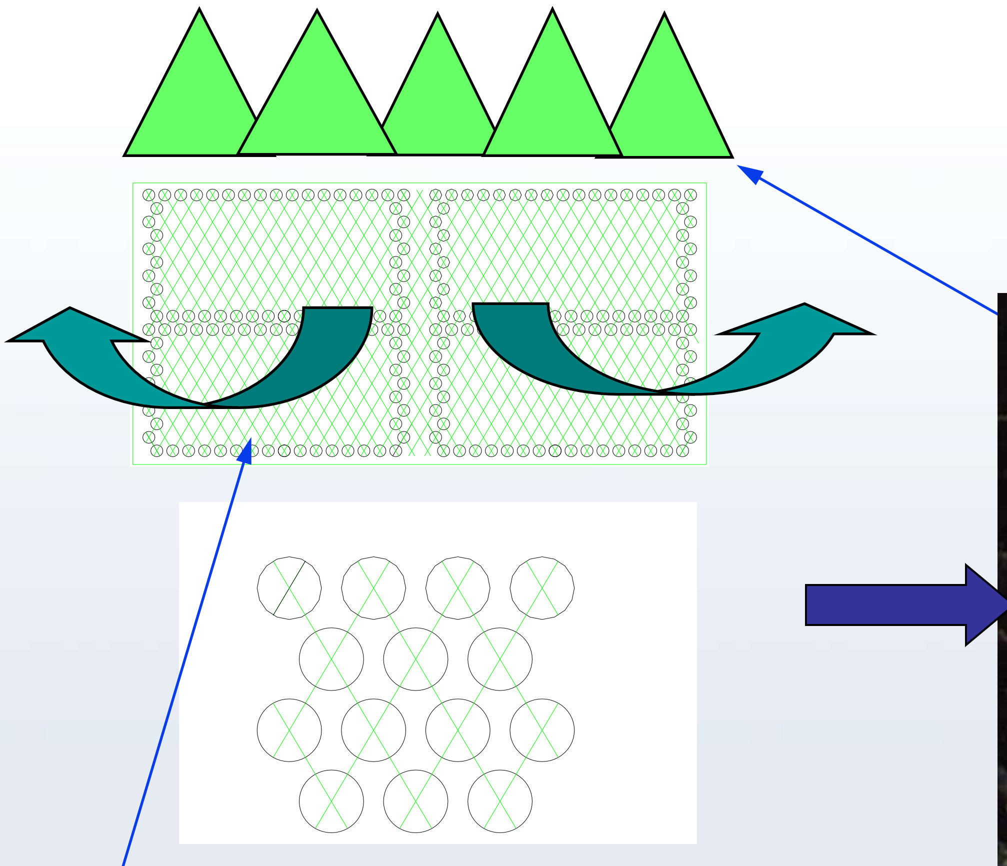
thermodynamic path : the ideal case

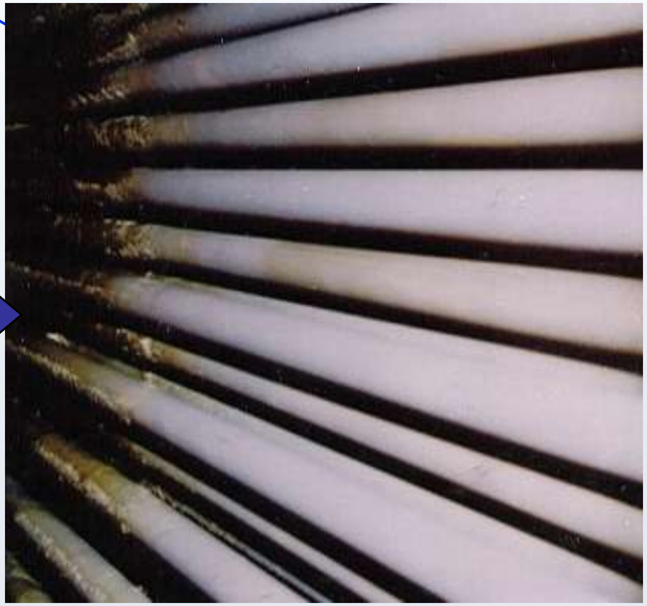


MED the importance of the wetting rate

Spray nozzles

Large wetting ensures complete wetting of tubes. Complete wetting is a prime contributor to avoid scale build-up on heat transfer tubes.





The feed can be sprayed in parallel over all effects wetting rate = 100 l/m/hr

The feed can be sprayed over the first effects and then with brine recirculation over the remaining = 400 l/m/hr

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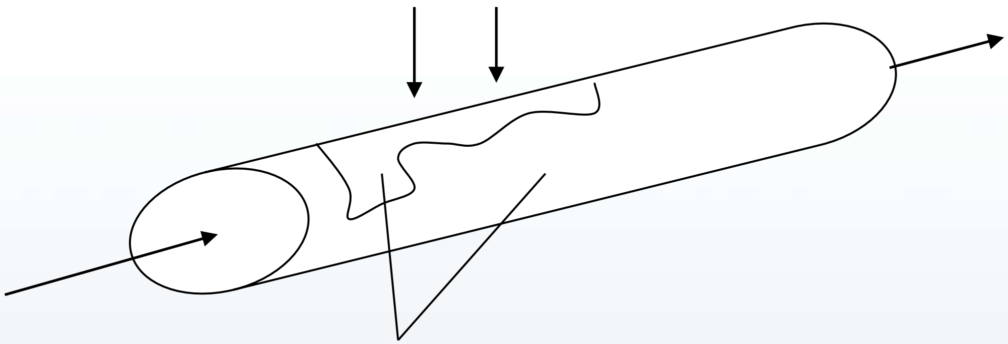
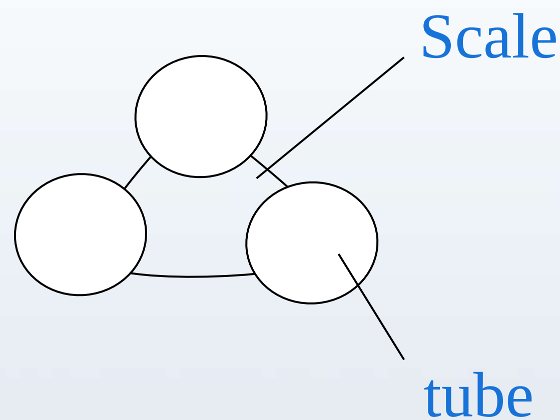
MED: Wetting Rate



All heat transfer surface must contribute to the brine boiling



Danger of tube scale bridging

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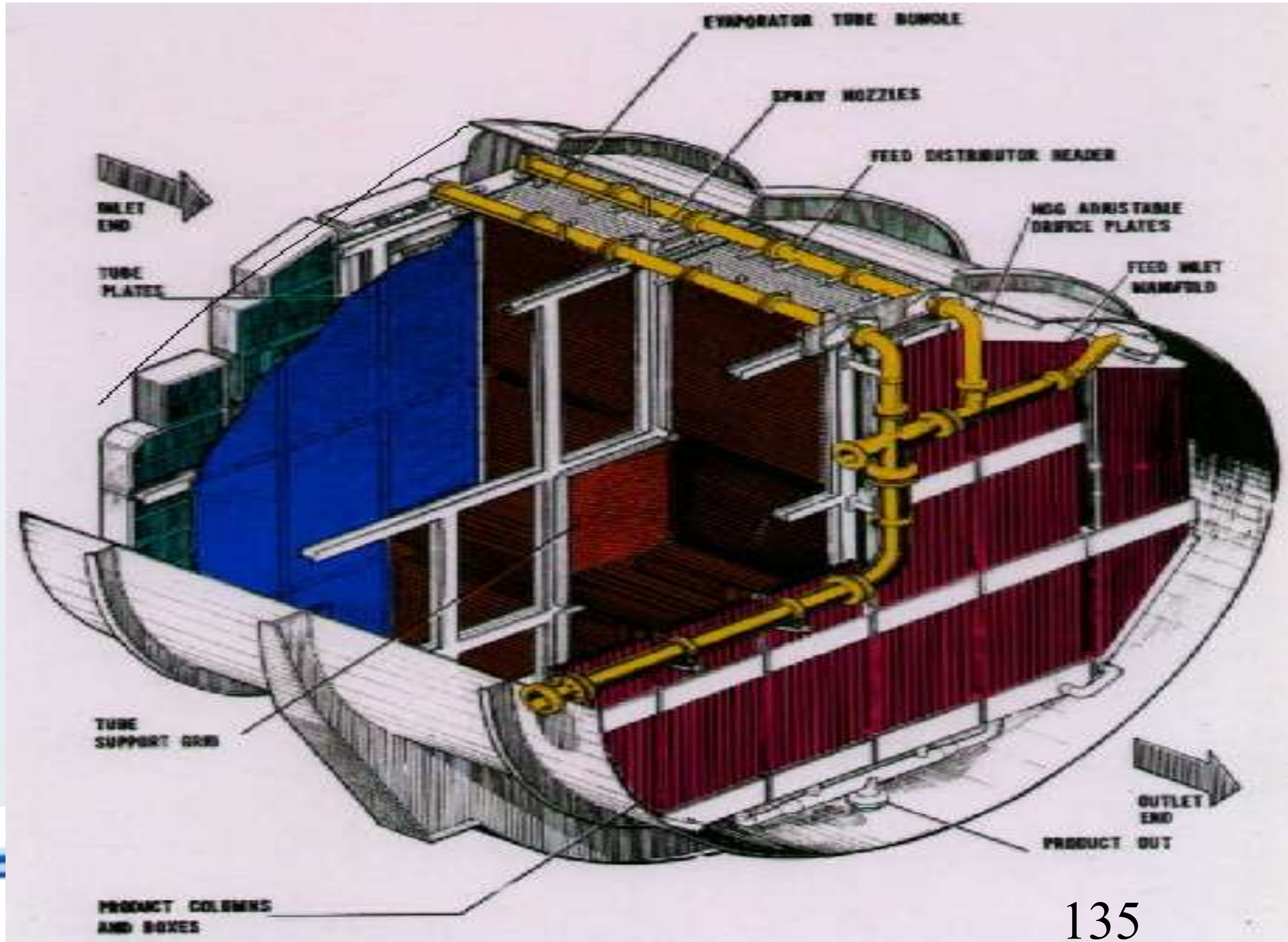
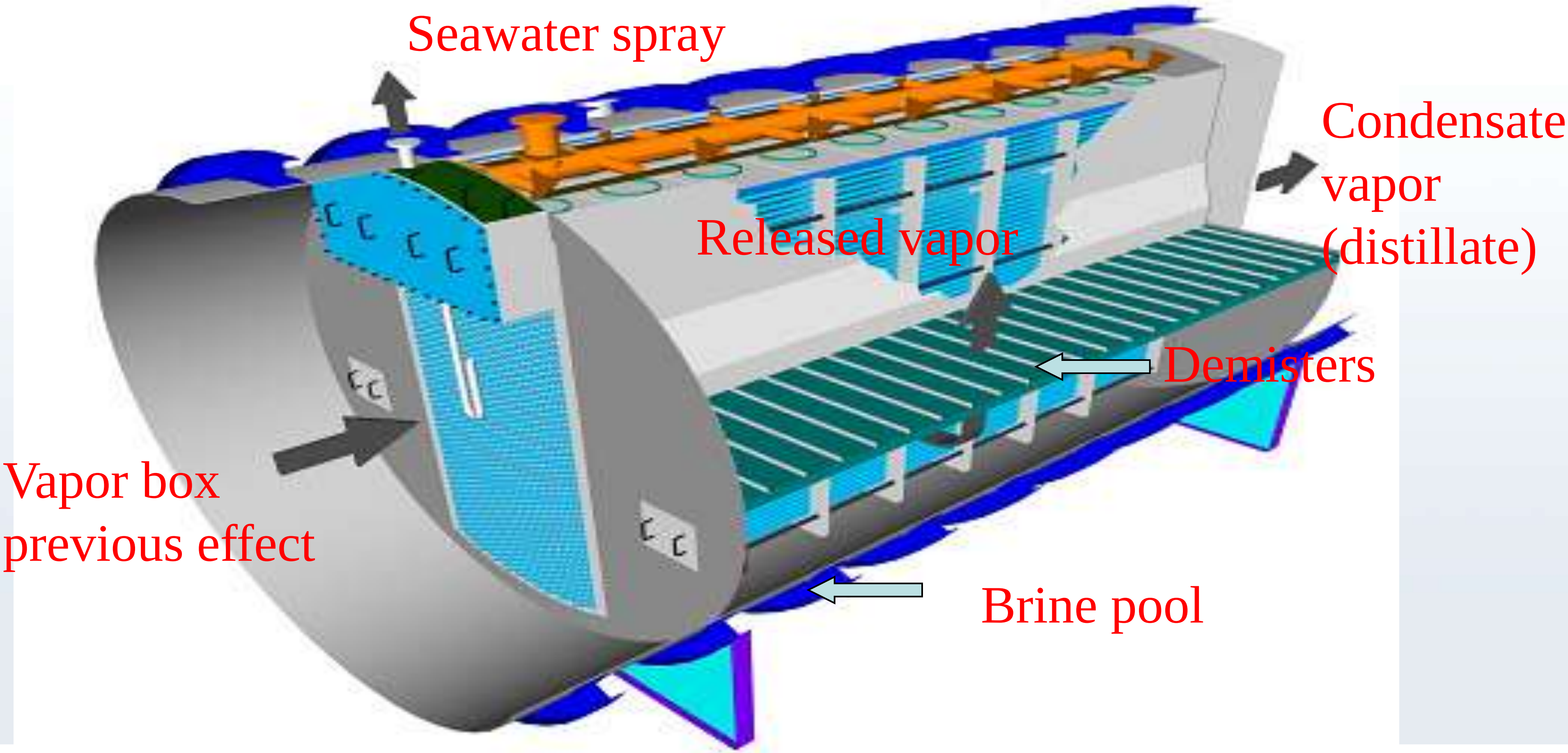
MED cross flow plant internal layout

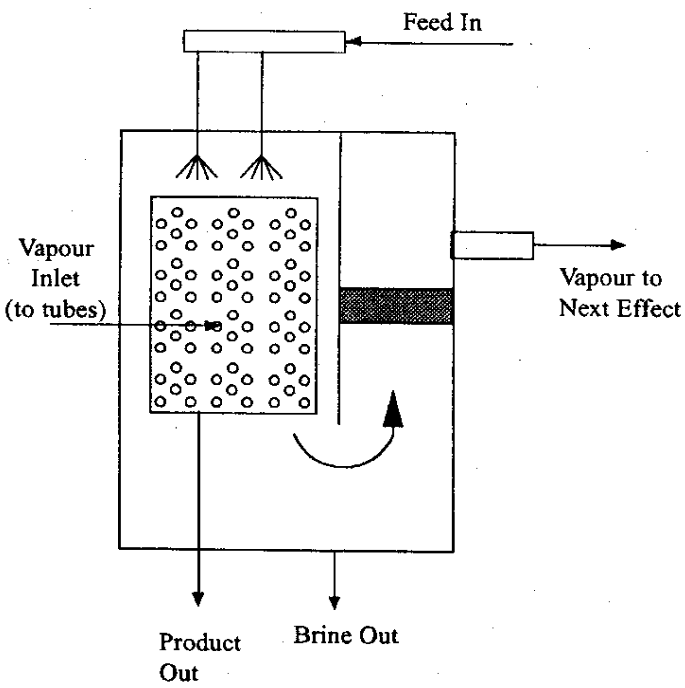


MED cross flow plant internal layout

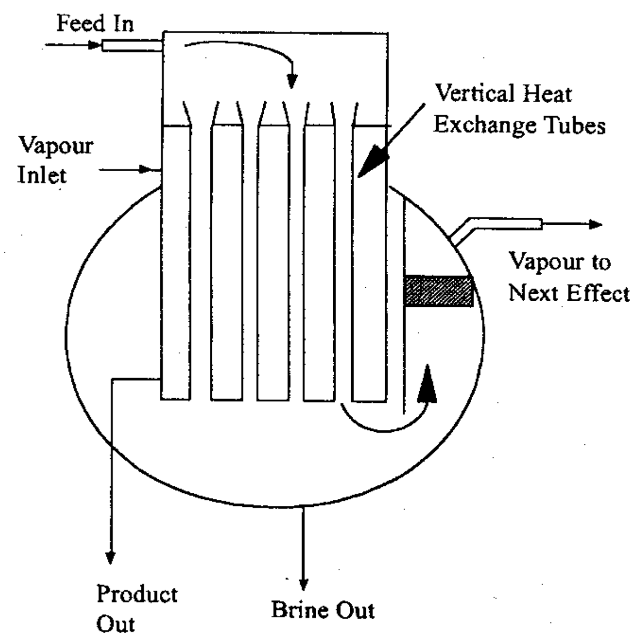


MED arrangements

TYPICAL HTE ARRANGEMENT



TYPICAL VTE ARRANGEMENT



1143/3003/EPB/01

FIG. 3

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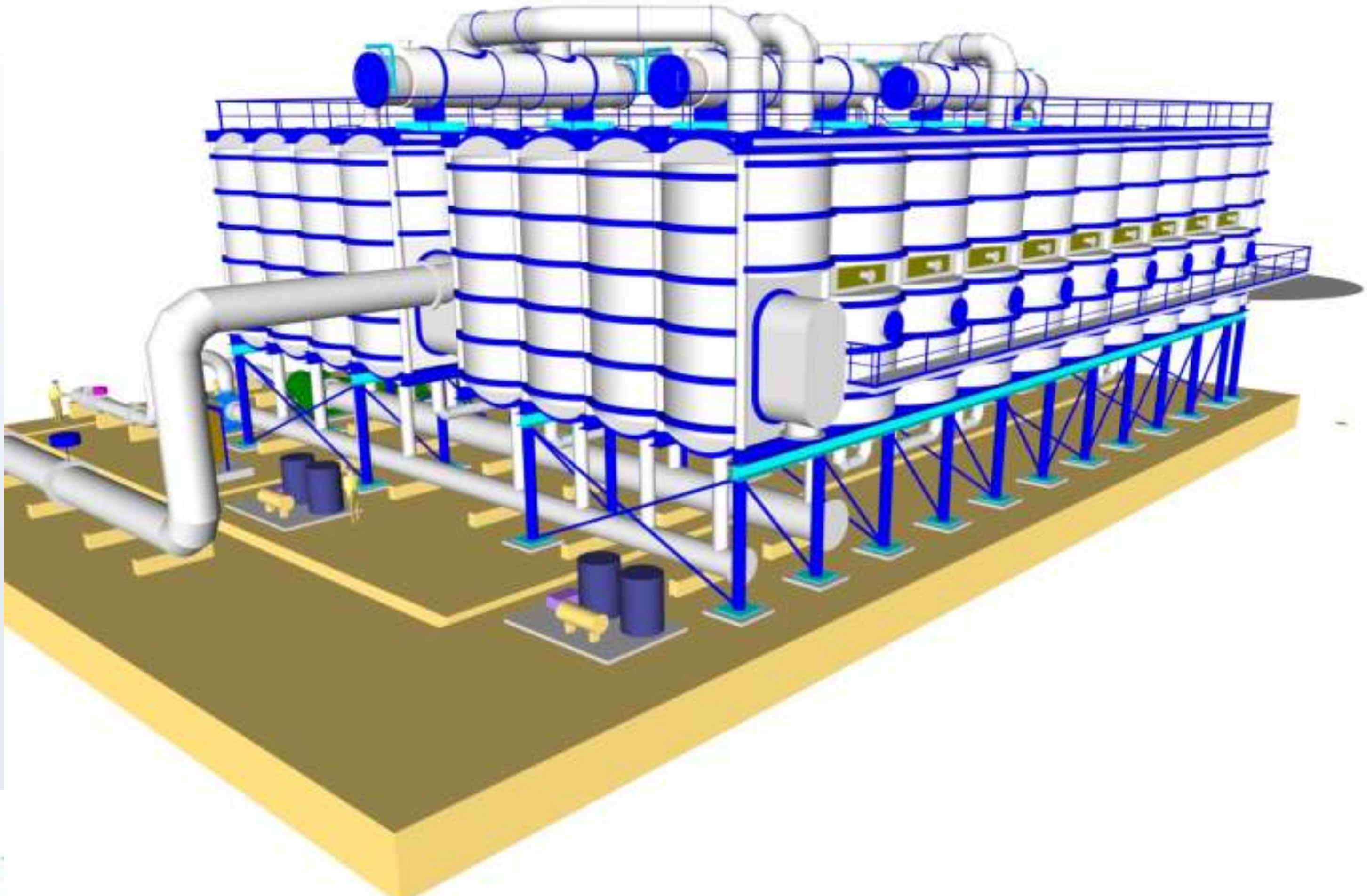
Desalination Projects : MED layout

CELL 2C



Seawater abstraction

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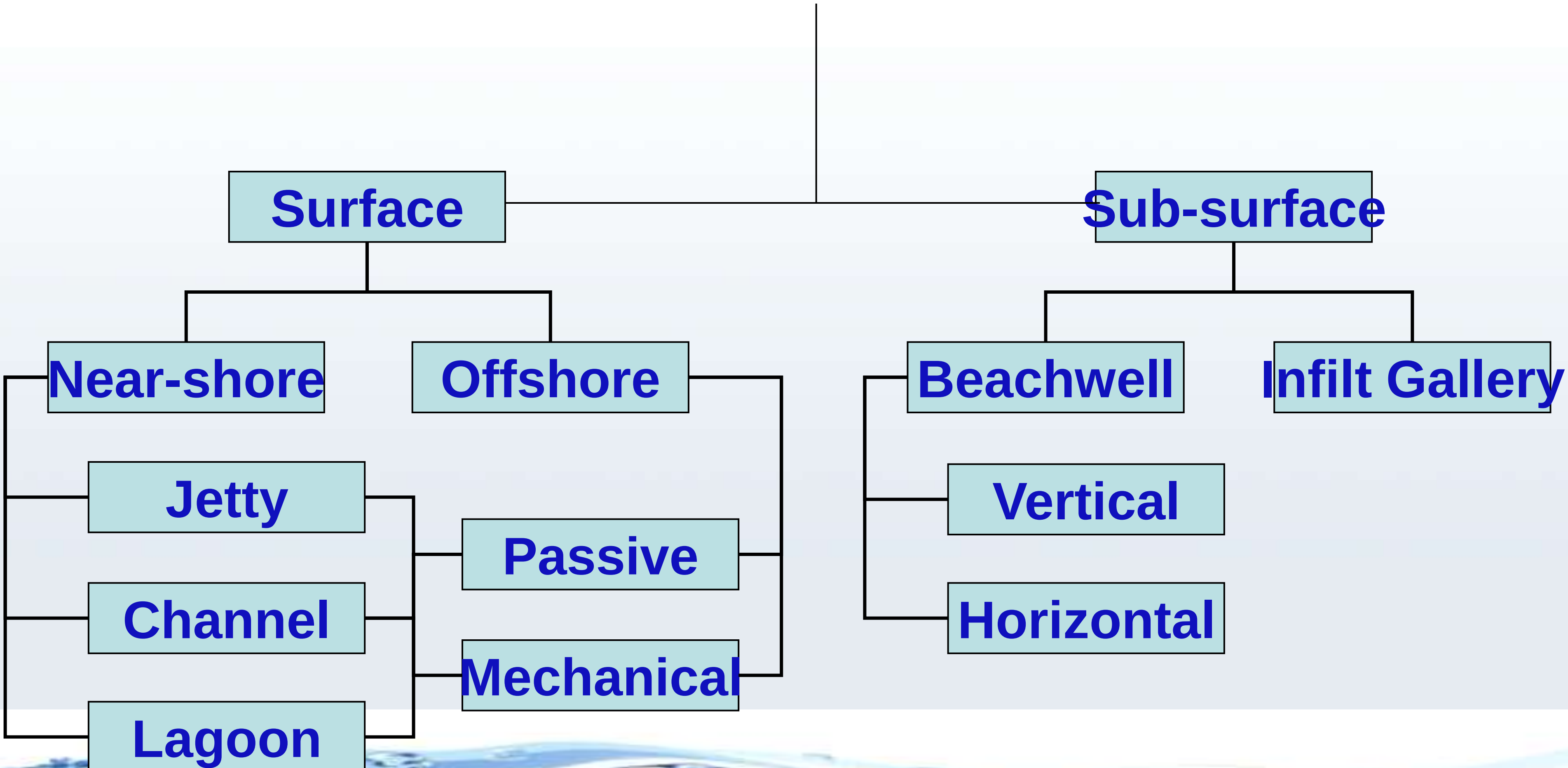
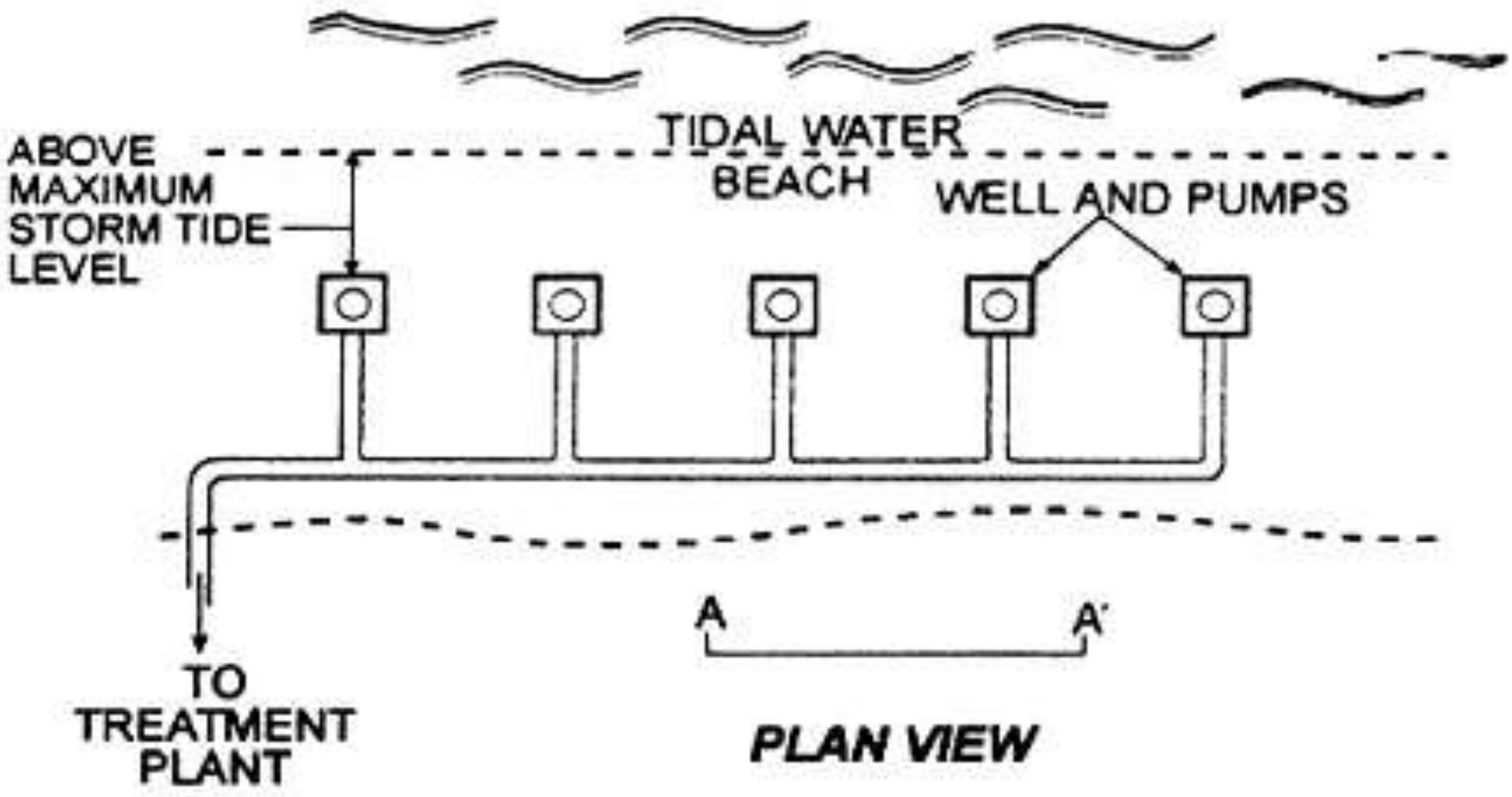
Intake Design Options



- **Groundwater Wells**



- **Groundwater Wells**

The adoption of wells is generally restricted to those conditions where raw water demand is low (less than 2000 m3/hr).

Normally the use of well fields to supply seawater feed to RO plants offers several benefits
These include a natural filtration system that removes several potentially damaging materials such as heavy oils and debris and offers a better feed water quality to the RO plant.

In general well fields offer lower construction and maintenance costs with respect to other seawater intake structures.
Soil permeability is critical for the design of a beach well.
Testing permeability is essential

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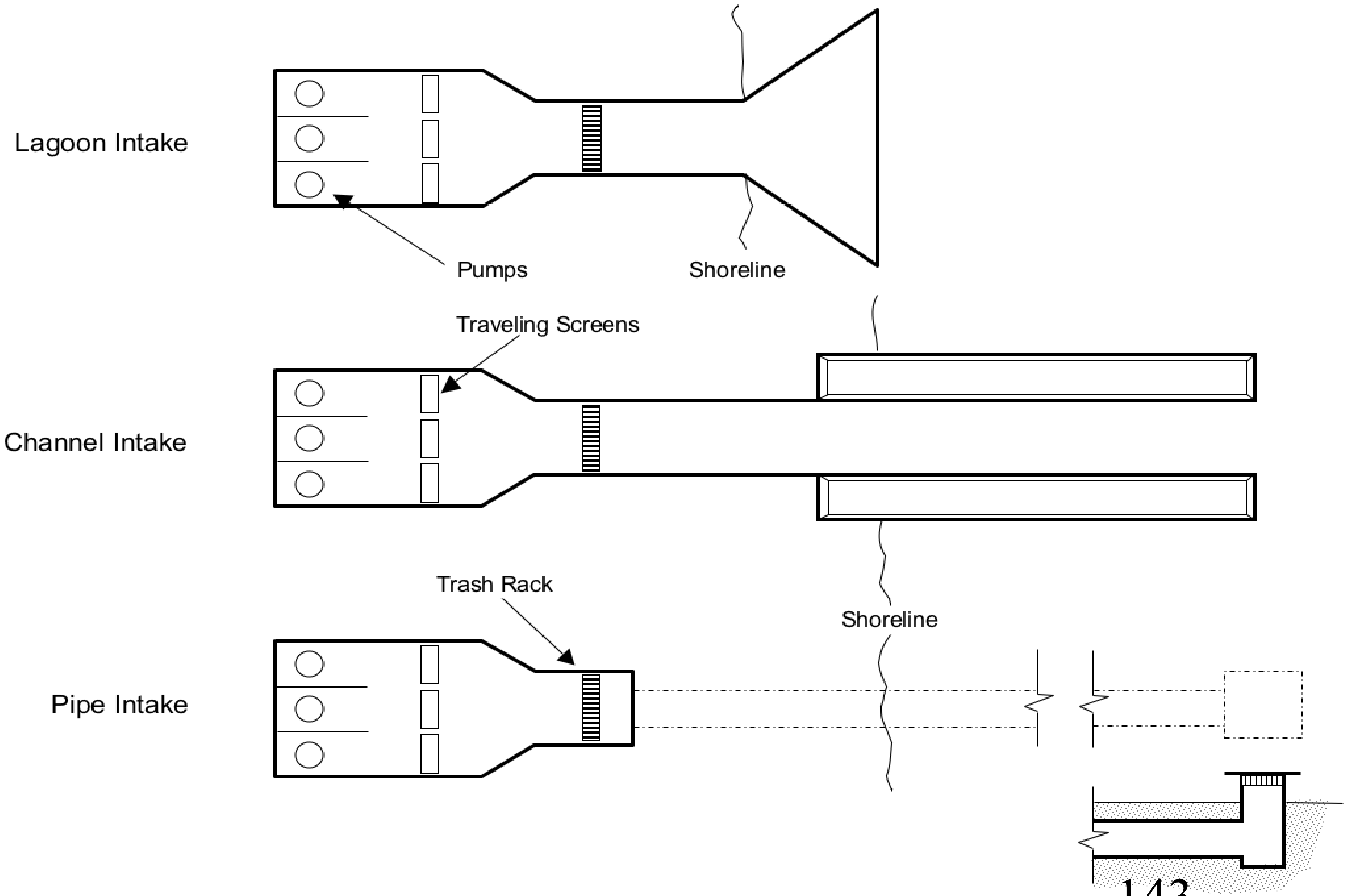
Open seawater Intake Configurations



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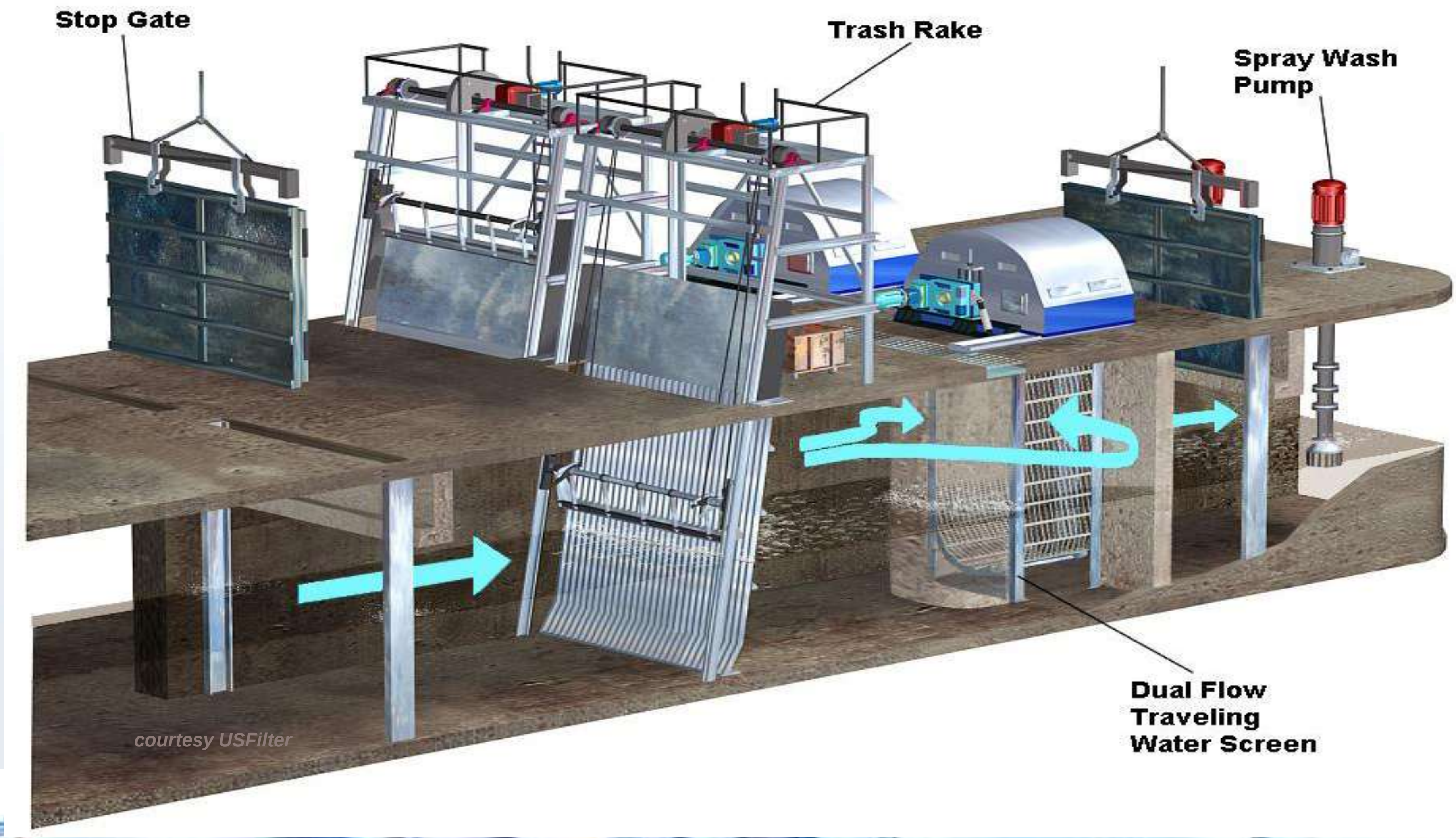
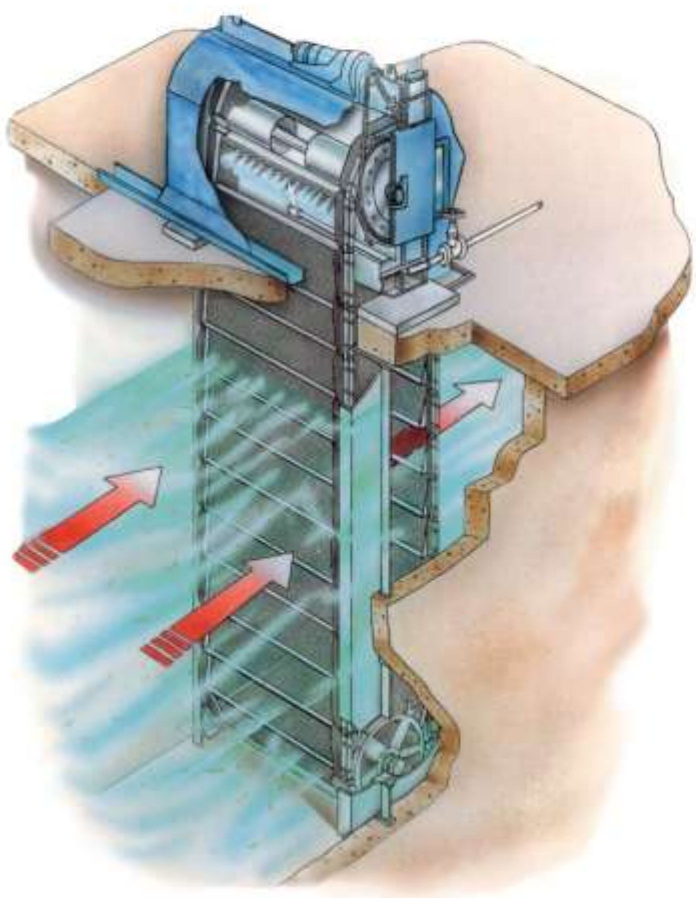
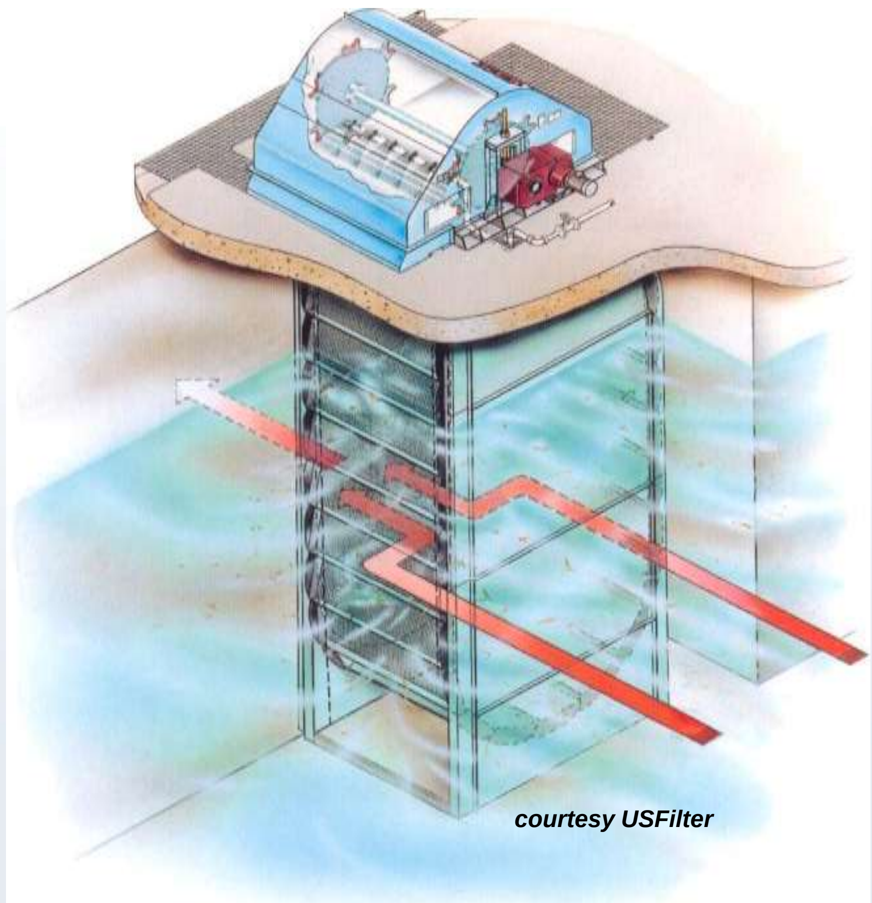
Open Seawater Intake



Travelling Water (Band) Screen



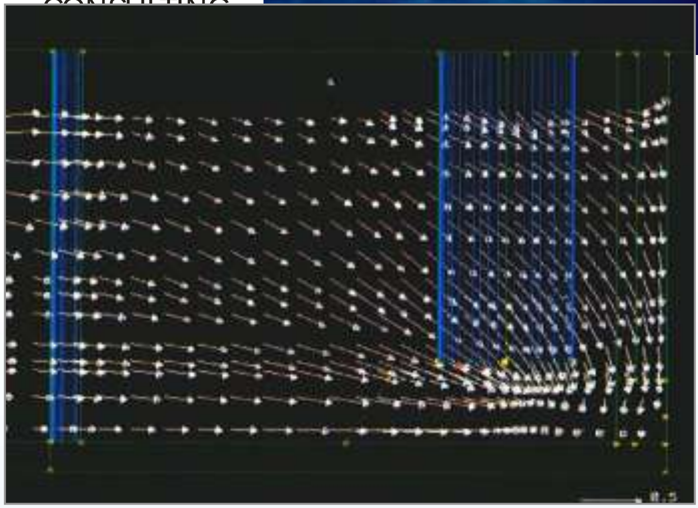
Through-Flow



Dual-Flow

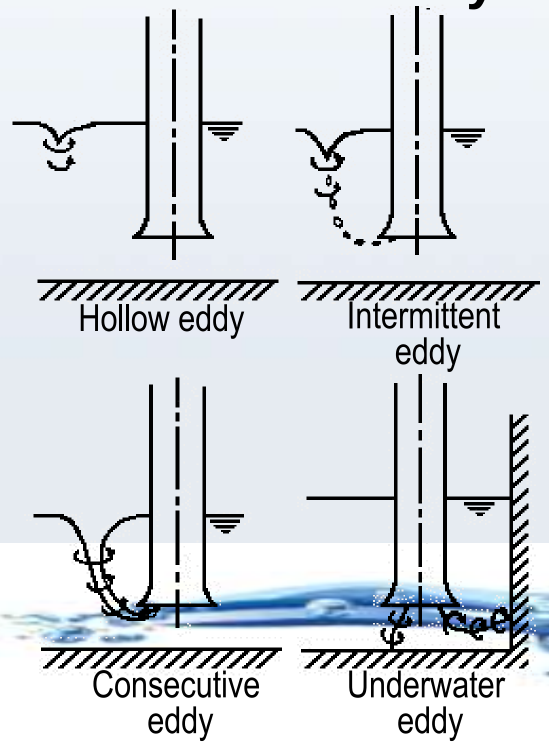
The Intake Model Test for Circulating Water Pump

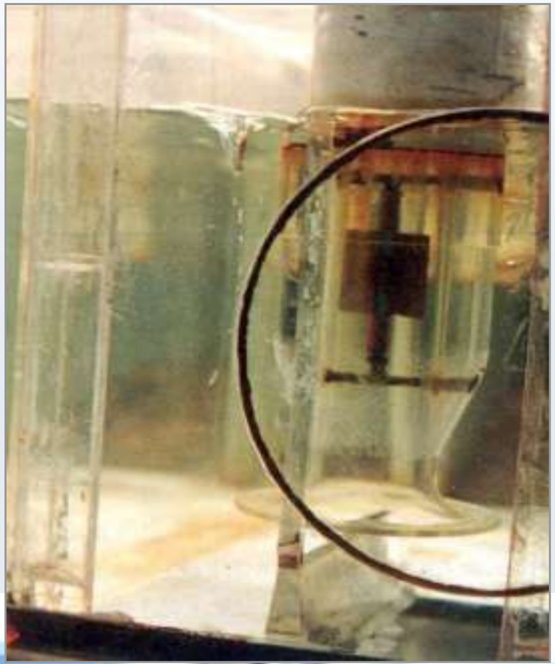
When circulating water pump is operated in the inappropriate intake sump, oscillation and noise appear which gives serious influences on the pump performances.
Therefore, the intake sump should be ensured through the model test and computer analysis in case of uncertain layout arrangement.



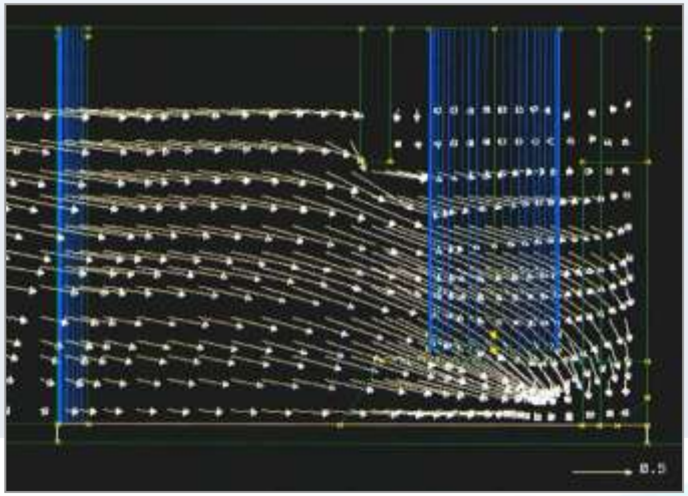
Analysis - Flow velocity distribution just near the pump (before remodeling)

The form of eddy





Model Test - Intermittent eddy



Analysis - Flow velocity distribution just near the pump (after remodeling)

Typical test simulation to be carried out

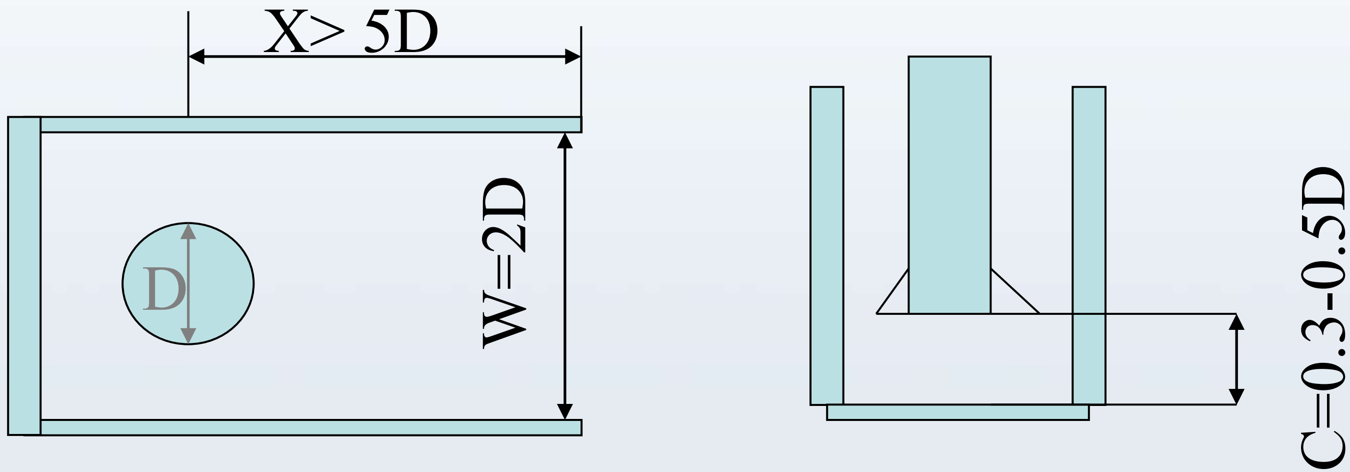
High Specific Speed (Ns) Pump Test Loop

Suction Sump Model Test

Suction Sump Model Test Loop

Hydraulic institute standards

- Dimensions are in proportional ration given seawater supply pump bellmouth and intake dimensions.



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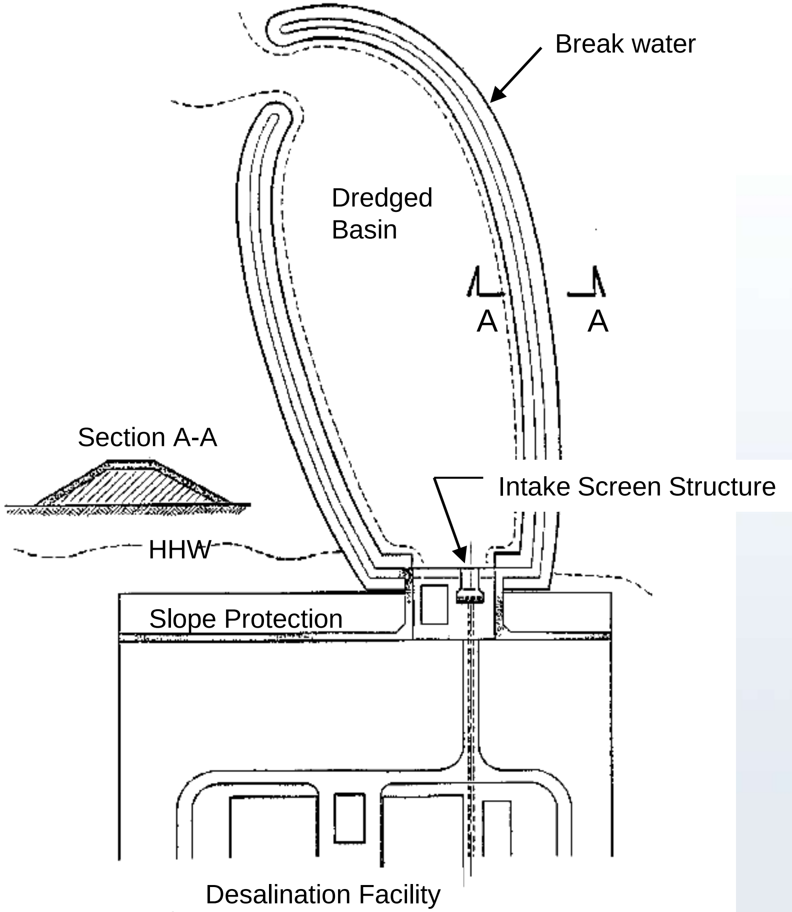
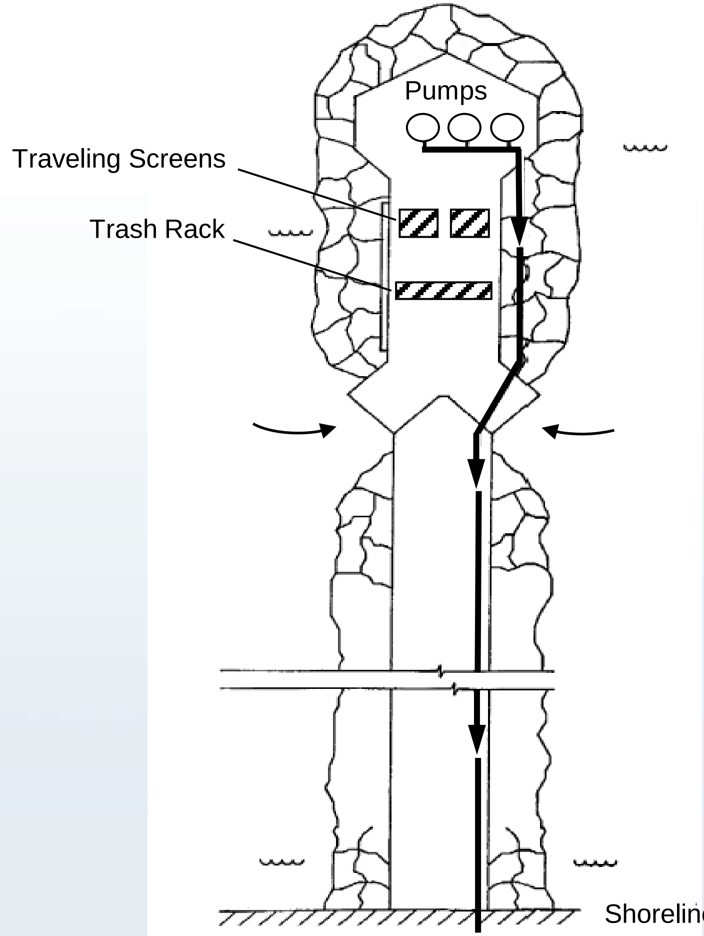
Intake Arrangements



Channel Intake



Jetty Intake

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

The SWRO Desalination Process

1) Seawater intake

- Open intake or
- Well intake

2) Pre-treatment intake

- Flocculation
- Disinfection
- Pre-filtration
- Addition of anti-scalant
- Fine-filtration

3) Desalination

- High-pressure system
- Ro-modules
- Energy recovery system
- Membrane cleaning

4) Post-treatment

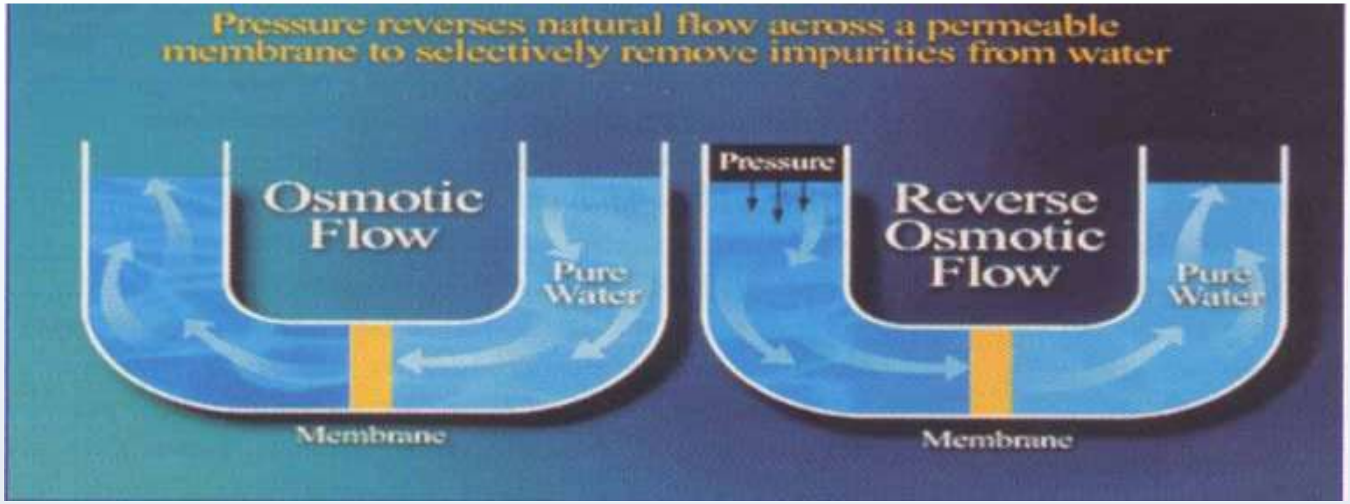
- Hardness and pH adjustment
- Microbiological control

5) Fresh water distribution

6) Effluents disposal

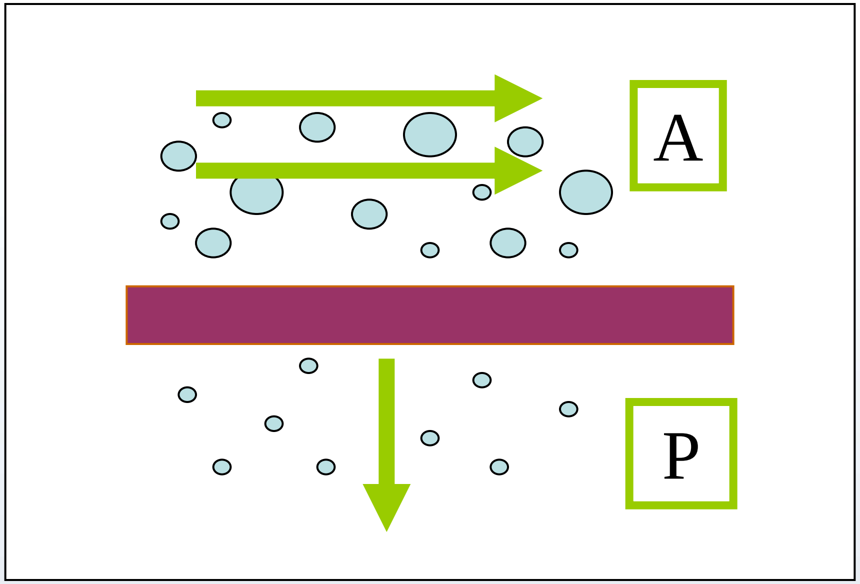
Basics of RO Technology

RO technology relies on membranes permeable to water but not to dissolved salts



- Pressure is the driving force of the process. It has to be sufficiently high to overcome the osmotic pressure of the saline seawater . The higher the salts the higher the pressure which is necessary

The membrane is a barrier between two phases that permits preferential and selective crossing of one or more kind of fluid mixture from one phase to the other.



The driving forces can be different such as :

-difference in pressure,

-difference in concentration,

-difference in chemical potential

-Others

Typically industrial RO – UF processes are *pressure driven.*

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Transport Model in a Pressure Membrane

Two types of filtration → Dead-end → Cross-flow

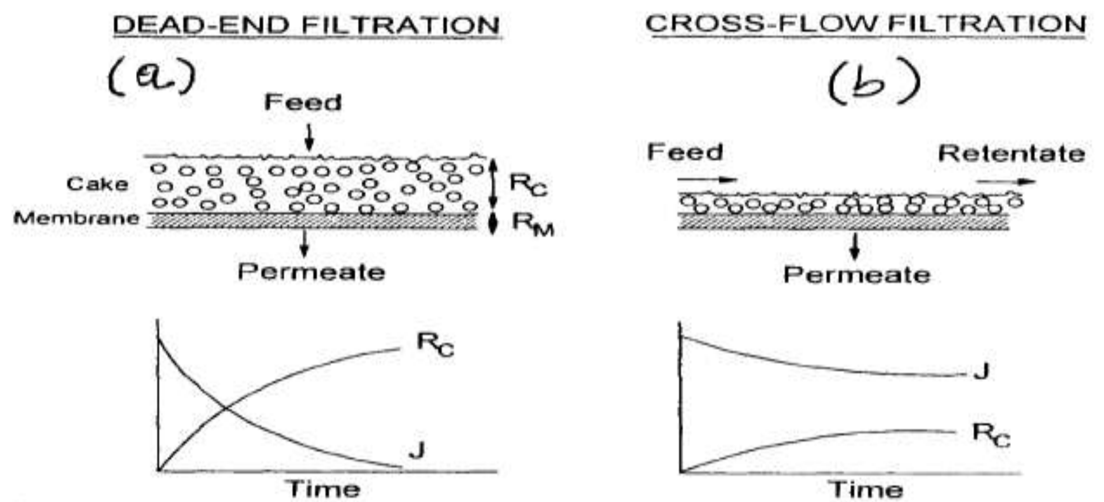

Figure 4.4. *Difference between dead-end (conventional) filtration and cross-flow filtration. R_C is the resistance of the cake formed on the membrane by the impermeable solutes, R_M is the resistance of the membrane, and J is the flux.*

Cross flow filtration is better for high concentration, because the tangential flux close to the membrane reduces polarization phenomenon

Particles that can’t permeate through the membrane, tends to accumulate close to membrane surface

Decrease membrane performance

Reversible process

The negative aspects of polarization can be reduced using appropriate flux configuration

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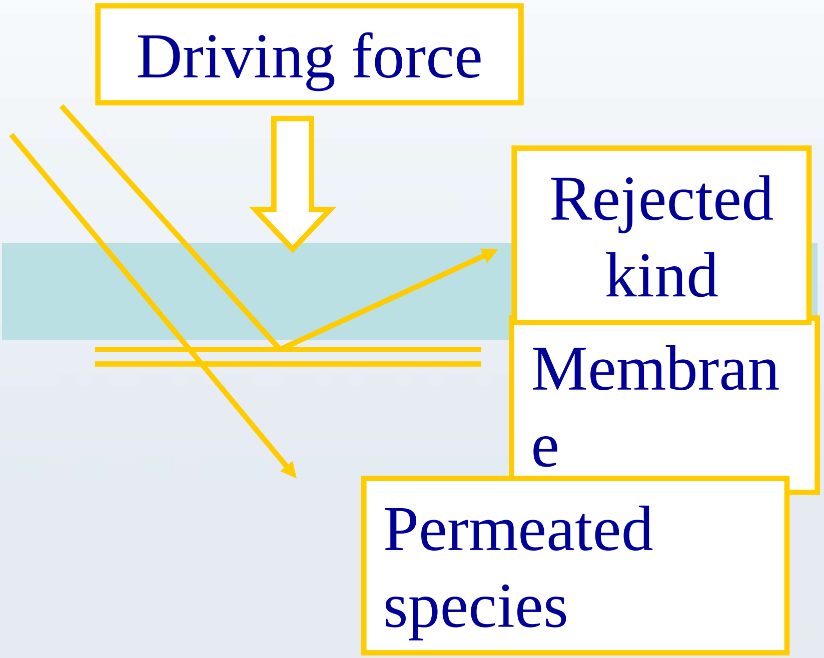
MEMBRANE FEATURES

Scheme of membrane separation



Parameter that characterized membrane performance

1) Flux rate(L $m^{-2}h^{-1}$)

Permeate flux per unit of membrane surface

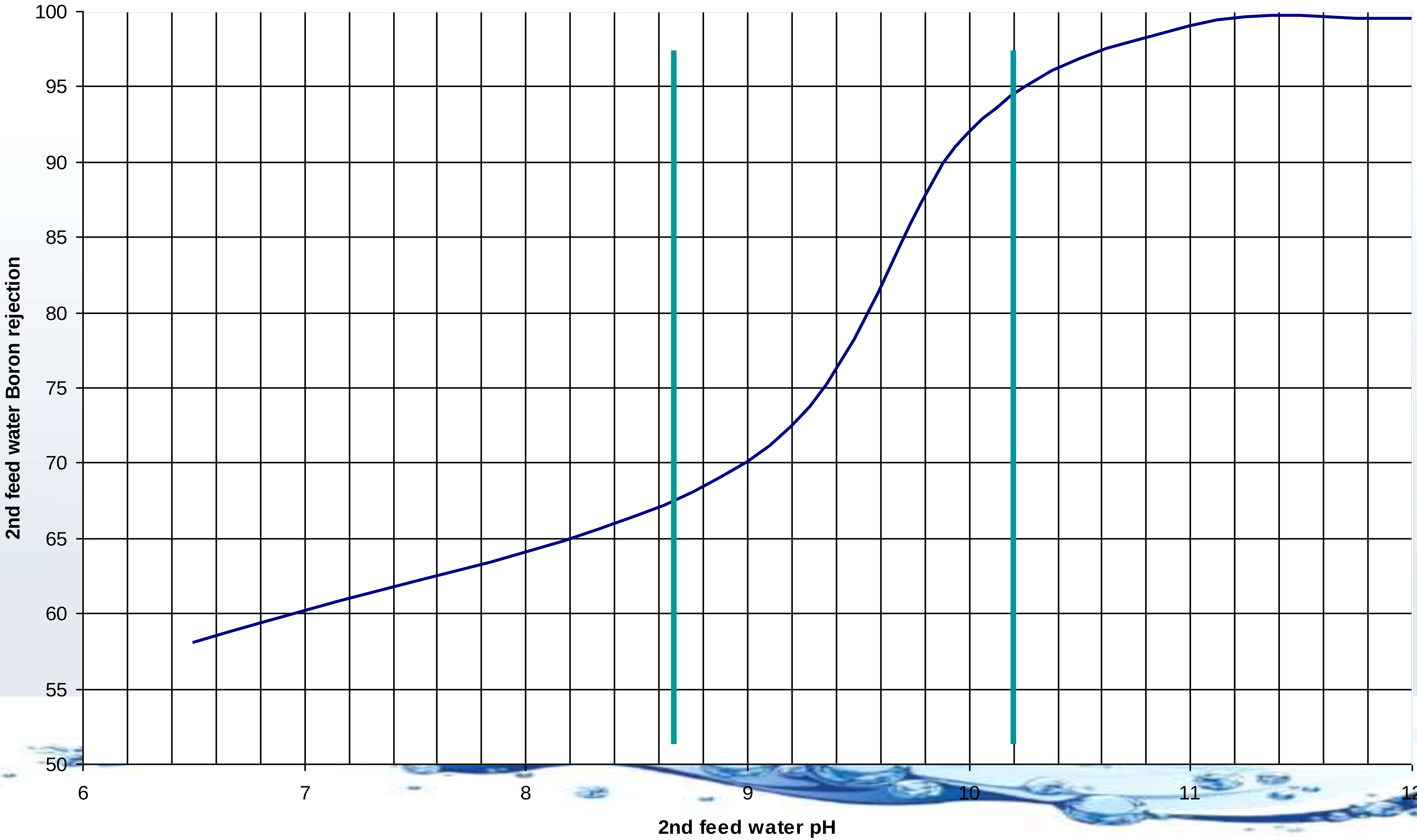
depends on: driving force
velocity of recirculation
temperature
feed concentration

2) Rejection of components

$$R\% = 100 \times \frac{[Feed\%] - [Permeate\%]}{[Feed\%]}$$

membrane process *are dynamic and not equilibrium*

Boron rejection



Exercise: Flux calculation

Membrane flux: $\dfrac{\text{Product output}}{(\text{n° membrane x membrane's surface})}$

$$Flux = \frac{}{n_m} \frac{\dot{m}_p}{S_m}$$

Product output = m_p

Number of membrane = n_m

membrane's surface) = S_m

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Flux calculation

MV (see fomsheet E6)	un.	20-lug	14-ott	26-ott	%
Reverse osmosis Summer					
Gross Product water Output 1st pass	m3/h		10.832	10.770	-1%
Nb of RO trains on duty	un.	16	16,0	15,0	-6%
Nbof trains in stand by	un.	0			
Product water Output per train of 1st pass	m3/h	677	677,0	718,0	6%
1st pass membranes per train	un.	1274	1.274	1.379	8%
1st pass membranes		TM820-369	TM820-370	TM820-370	
Membranes' surface	**m2**	**34,374**	**34,374**	**34,374**	
Membrane flux MV	**l/h/m2**	**15,46**	**15,46**	**15,15**	**-2%**
Reverse osmosis Winter					
Gross Product water Output 1st pass (uncahnged)	m3/h	10.832	10.832	10.770	-1%
Nb of RO trains on duty	un.	16	15,0	14,0	-7%
Nb of RO trains on stand by		0	1,0	1,0	
Product water Output per train of 1st pass (calculated)	m3/h	677	722,1	769,3	7%
1st pass membranes per train	un.	1274	1.274	1.379	8%
1st pass membranes model		TM820-369	TM820-370	TM820-370	
Membranes' surface	**m2**	**34,374**	**34,374**	**34,374**	
Membrane flux MV	**l/h/m2**	**15,46**	**16,49**	**16,23**	**-2%**
OD (see fomsheet E6)	un.	f	14-ott	26-ott	%
Reverse osmosis					
Product water Output per train of 1st pass	m3/h		486,0	486,0	0%
1st pass membranes per train	un.		1.078	1.078	0%
1st pass membranes			SR-HR380	SR-HR380	
Membranes' surface	**m2**		**35,300**	**35,300**	
Membrane flux OD	**l/h/m2**		**12,77**	**12,77**	**0%**

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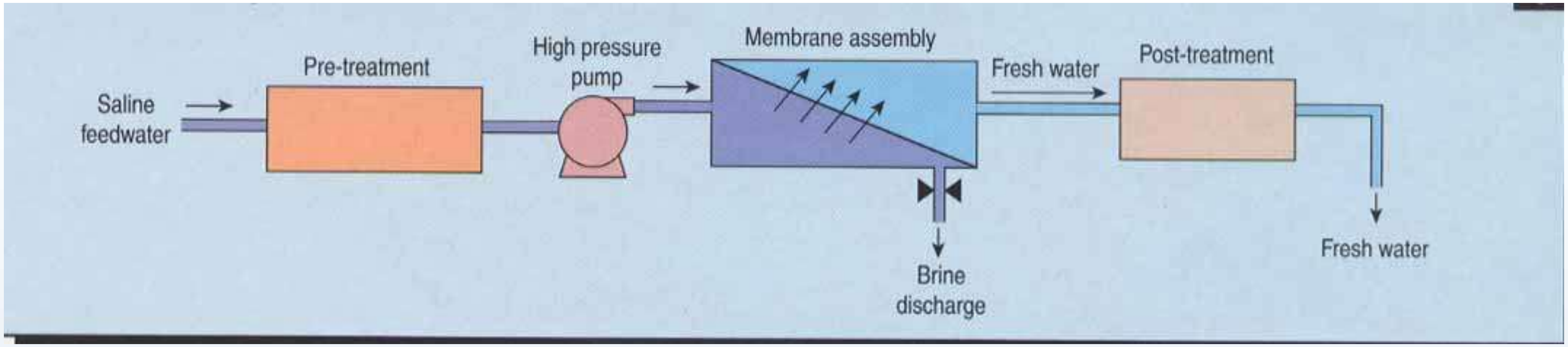
- In an industrial plant the principles of RO are implemented in the basic flow sheet as below



- Main plant components are :
  - Seawater intake and initial filtration
  - Pre-treatment →
    - Conventional
    - Membrane (Ultra filtration micro filtration)
  - High pressure pumps
  - RO membranes

- 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

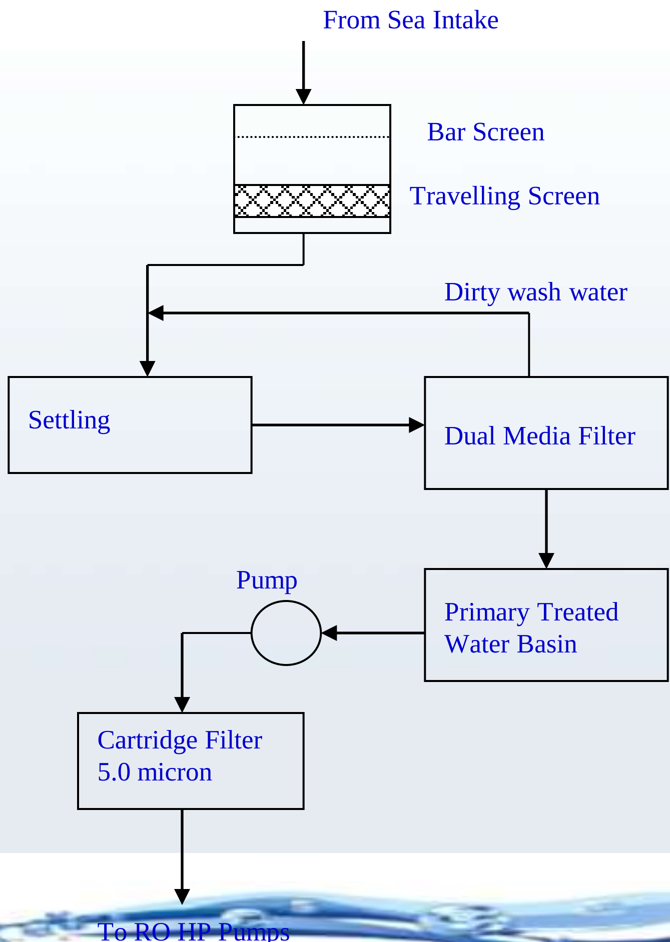
In particular the critical components leading to operational problems in the past have been the pre-treatment

Traditional feed pre-treatments:

- Mechanical treatments (media filters, cartridge filters)
- Extensive chemical treatments for fouling, bio-fouling and scaling prevention ($FeCl_3$, $NaHSO_4$, H_2SO_4)
- Additives for prevention of corrosion and membrane preservation

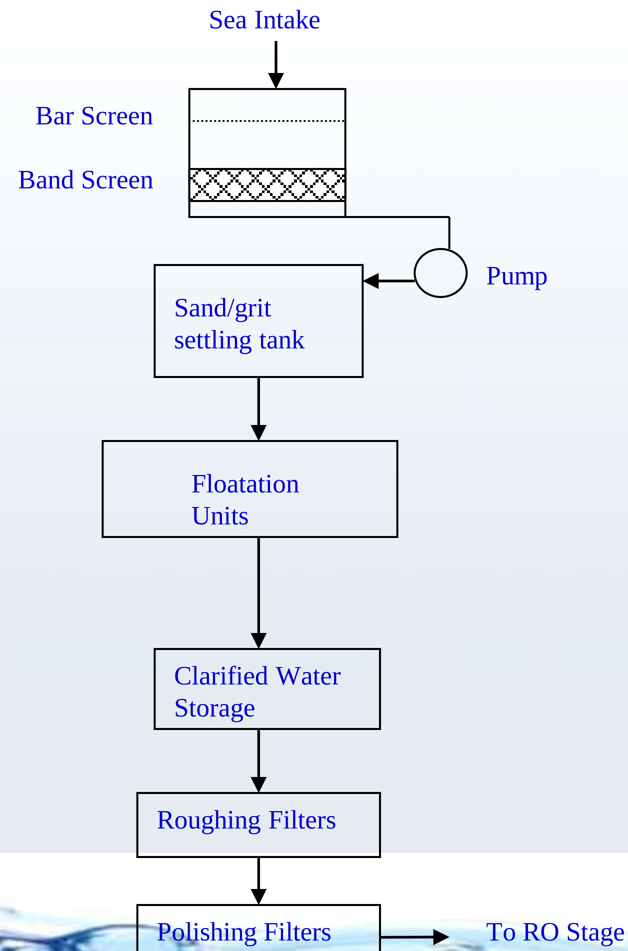
Various possible schemes

Option 1



Pre - treatment

Full Scale Plant



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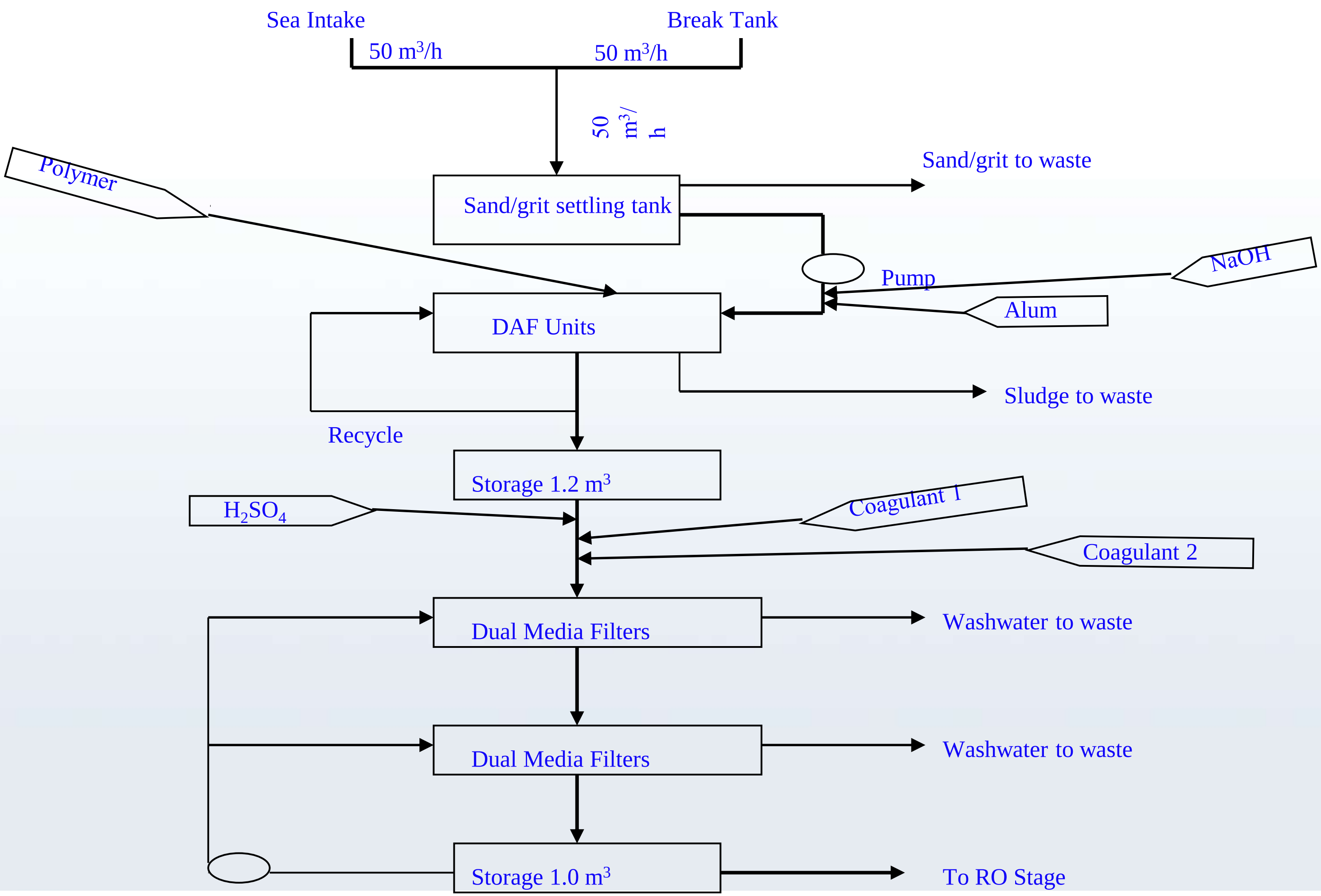
Mass Balance Diagram - Pilot Plant
Conventional Pre-treatment



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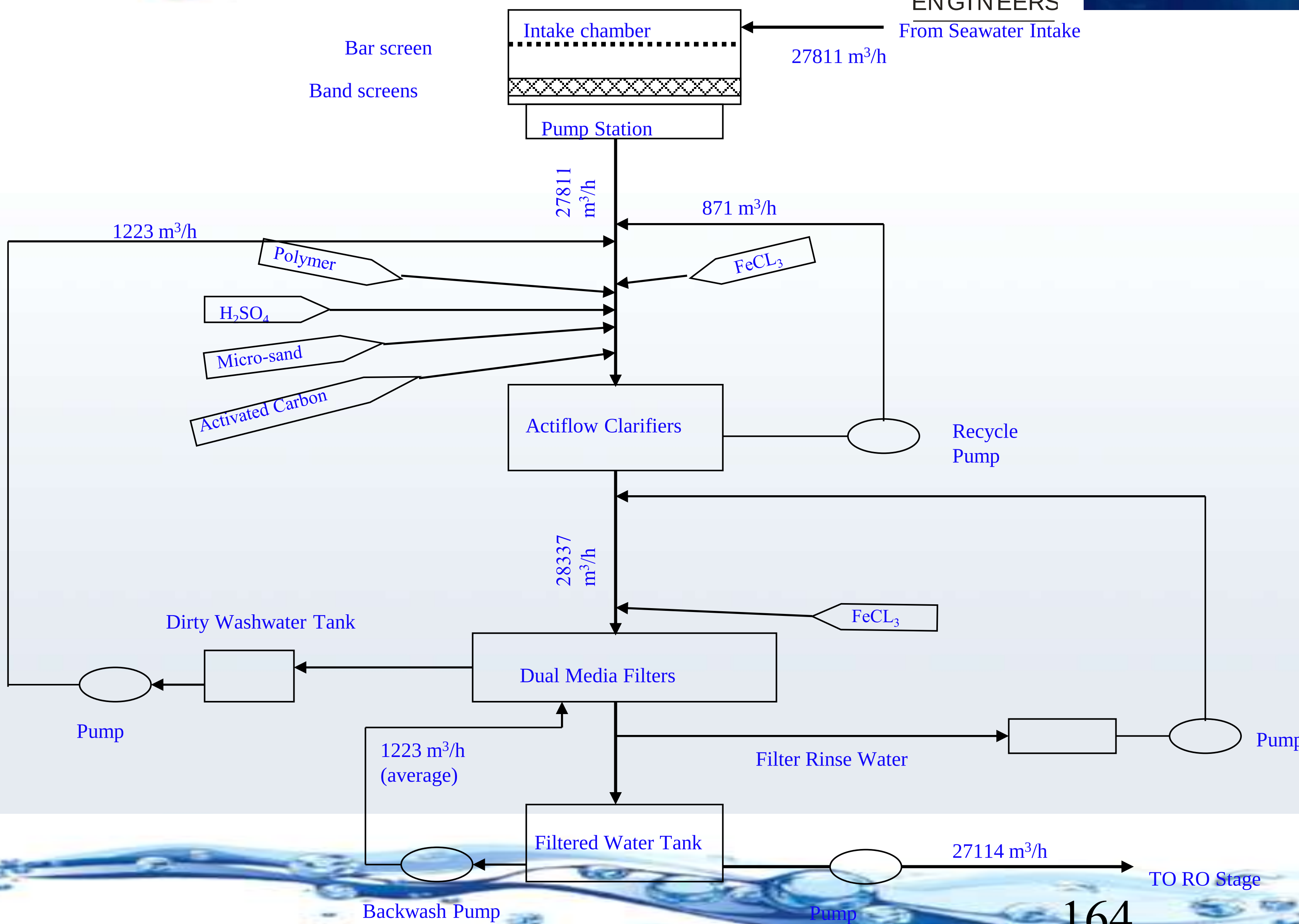
Mass Balance Diagram - Full Scale

Pre-treatment



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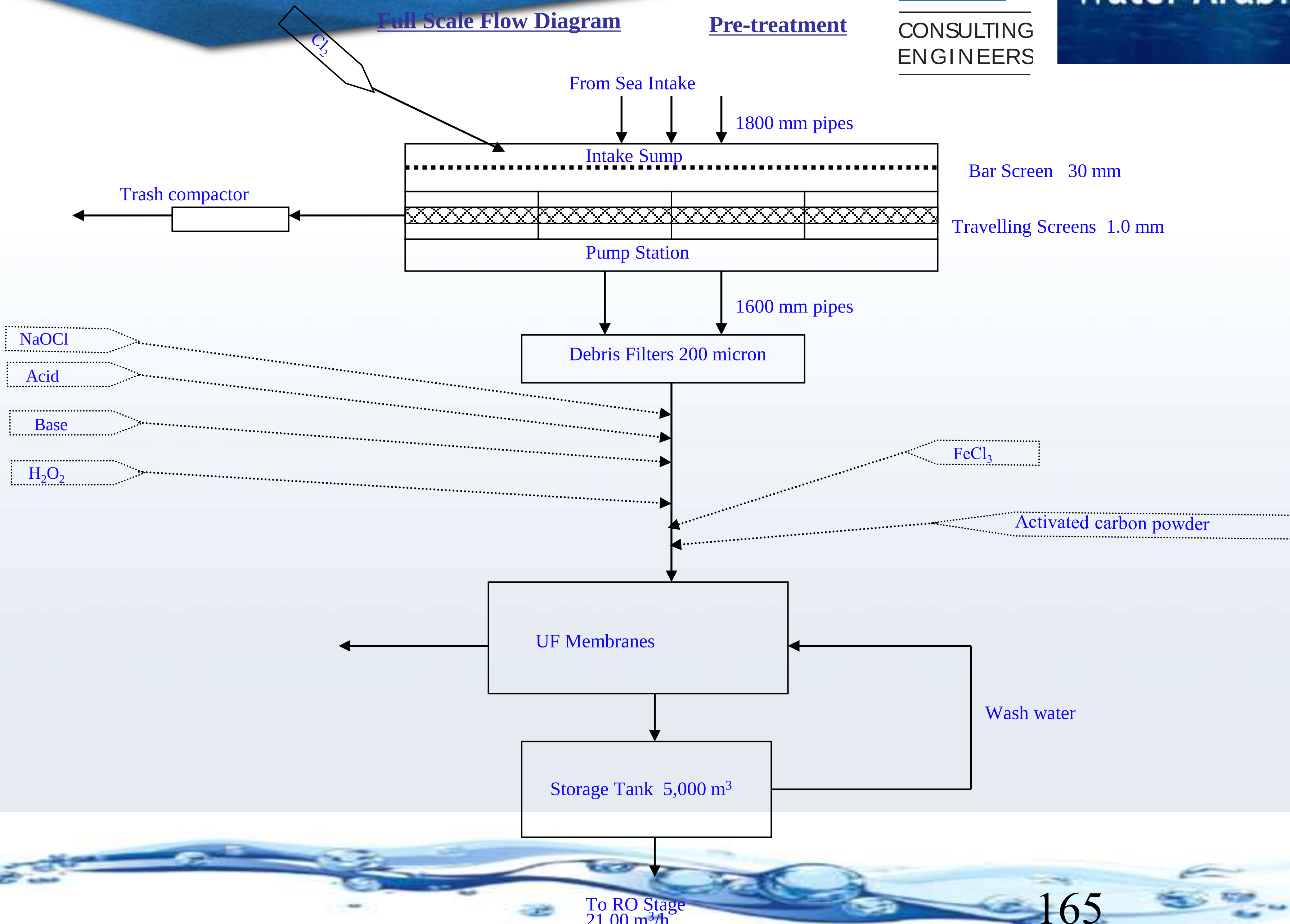
Full Scale Flow Diagram

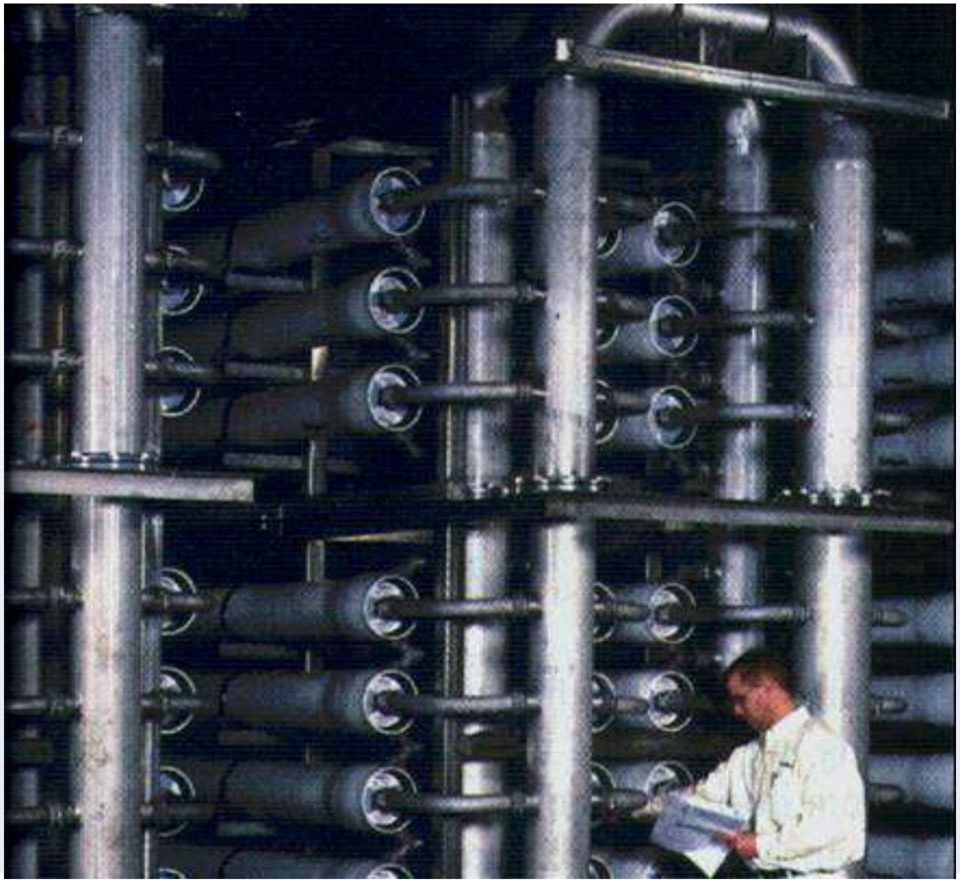
Pre-treatment



Conventional pre-treatment chemicals

- Primary coagulant dosage of ferric chloride (15-21 L/1000m^3 $FeCl_2$ 40%) for surface charge neutralization
- Chlorination (11-22 L/1000m^3 Sodium Hypochlorite, 6.5%) for controlling biological growth
- Sodium bisulphite (38%, 0.18-1.8 L/1000m^3) added to remove residual chlorine

MF/UF Pre-treatment



In 1995 it was estimated that less than 25 MGD installed capacity was in operation in North America; five years later that number has grown to over 400 MGD.

About seven different MF/UF manufacturers are based in the USA, Japan, France, the Netherlands and Canada. MF and UF systems in the 2 to 4 MGD capacity range are priced at about \$0.45 per gallon of capacity; MF/UF systems capable of 25 to 40 MGD are priced at about \$0.25 per gallon of capacity.

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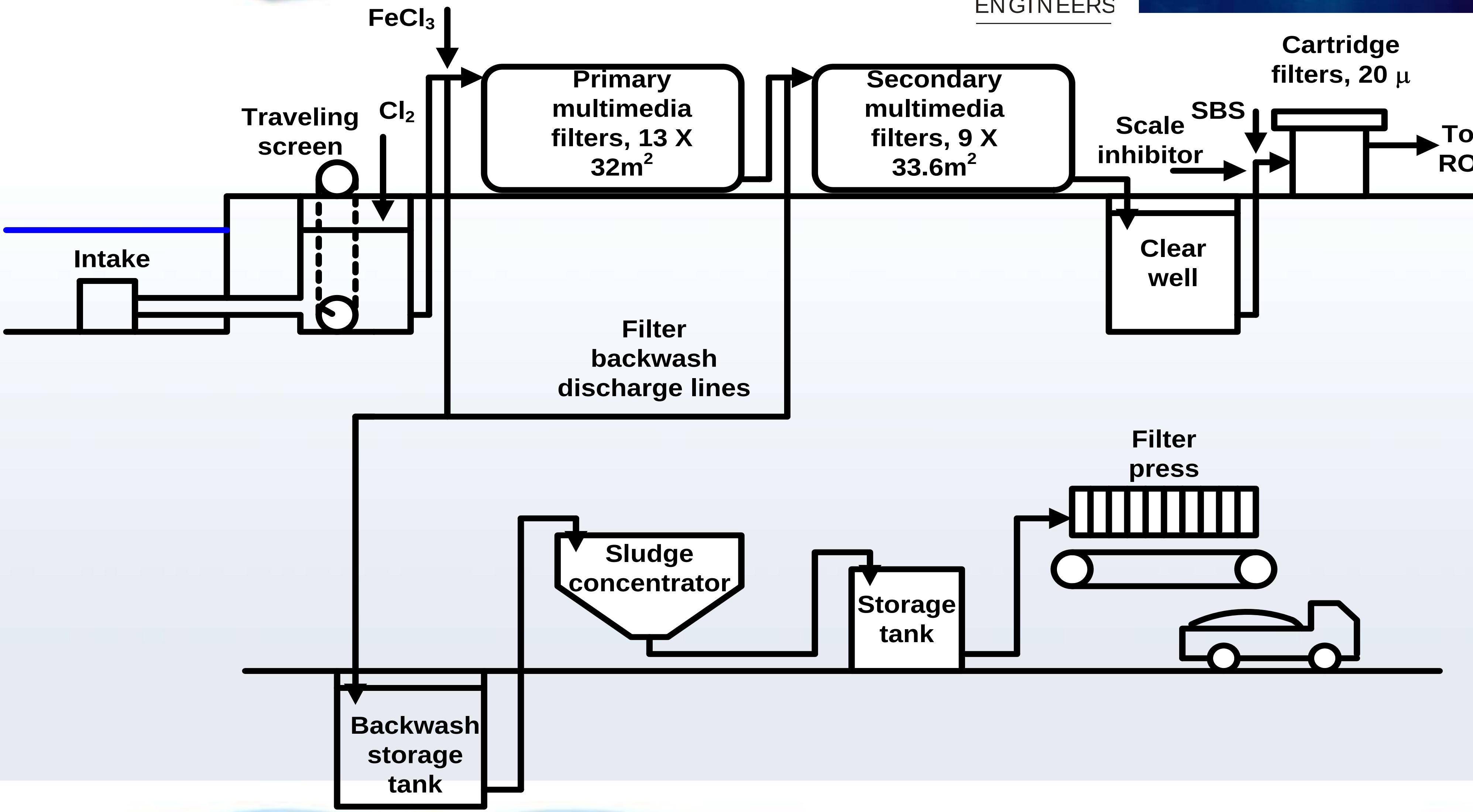
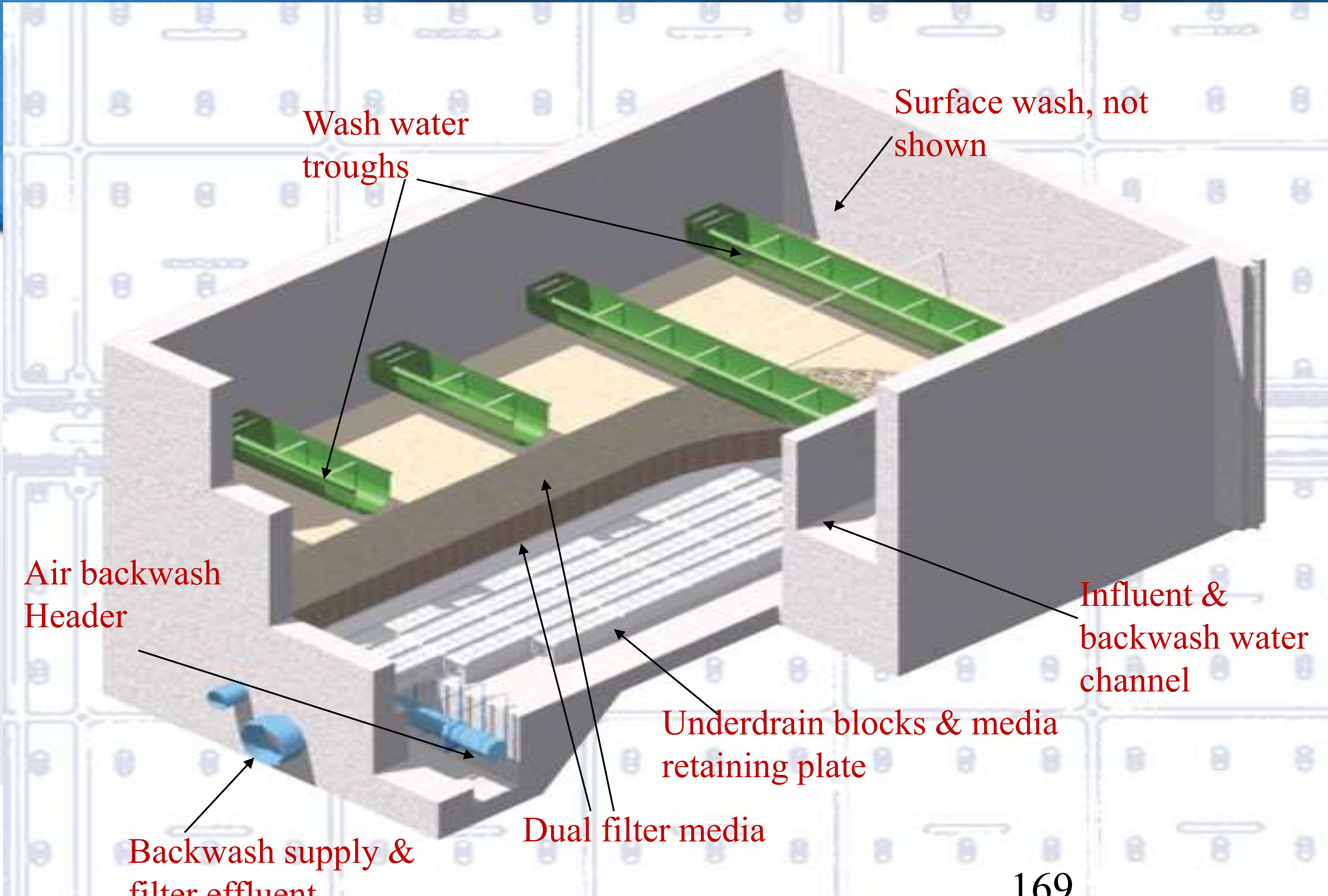
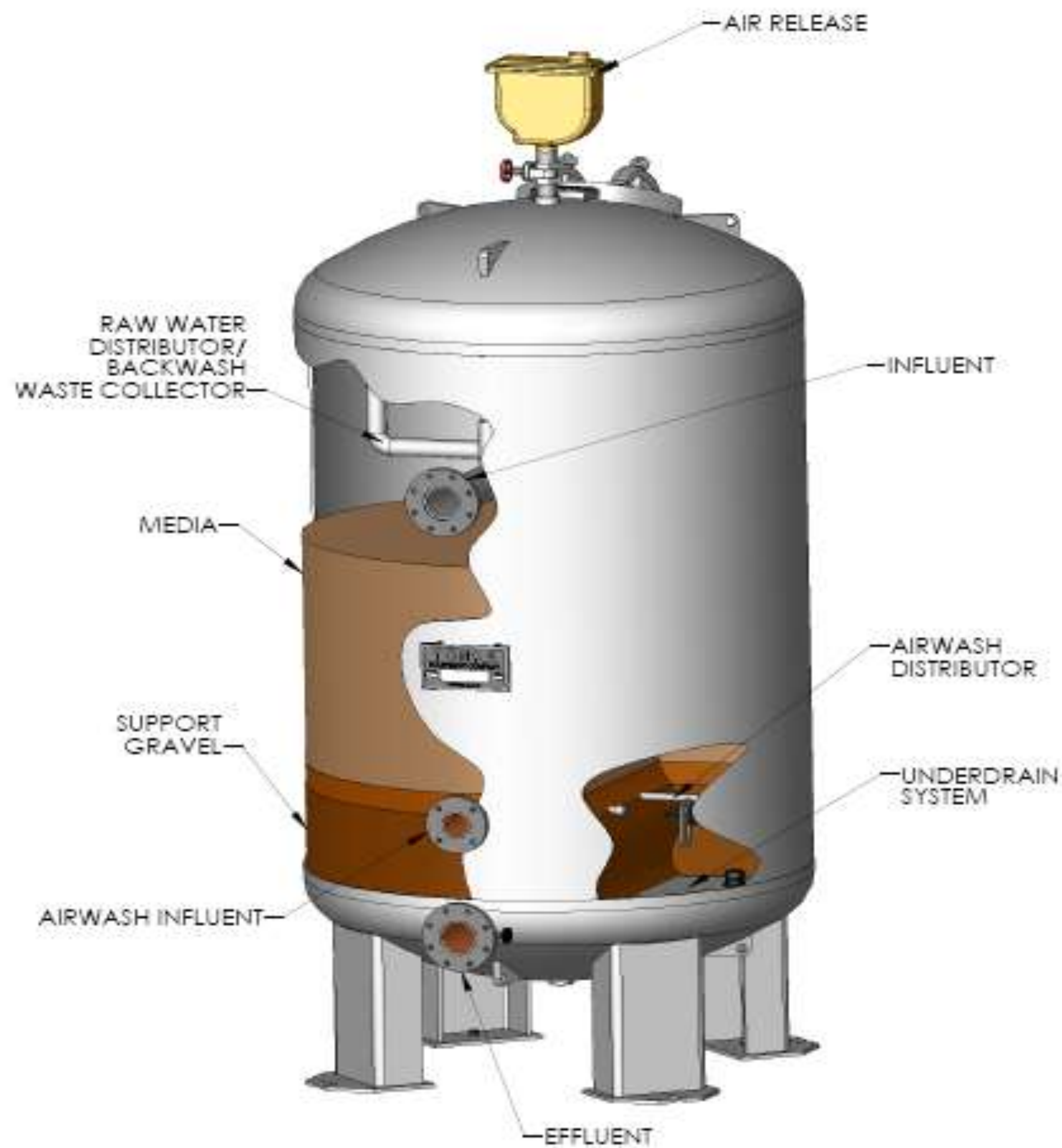
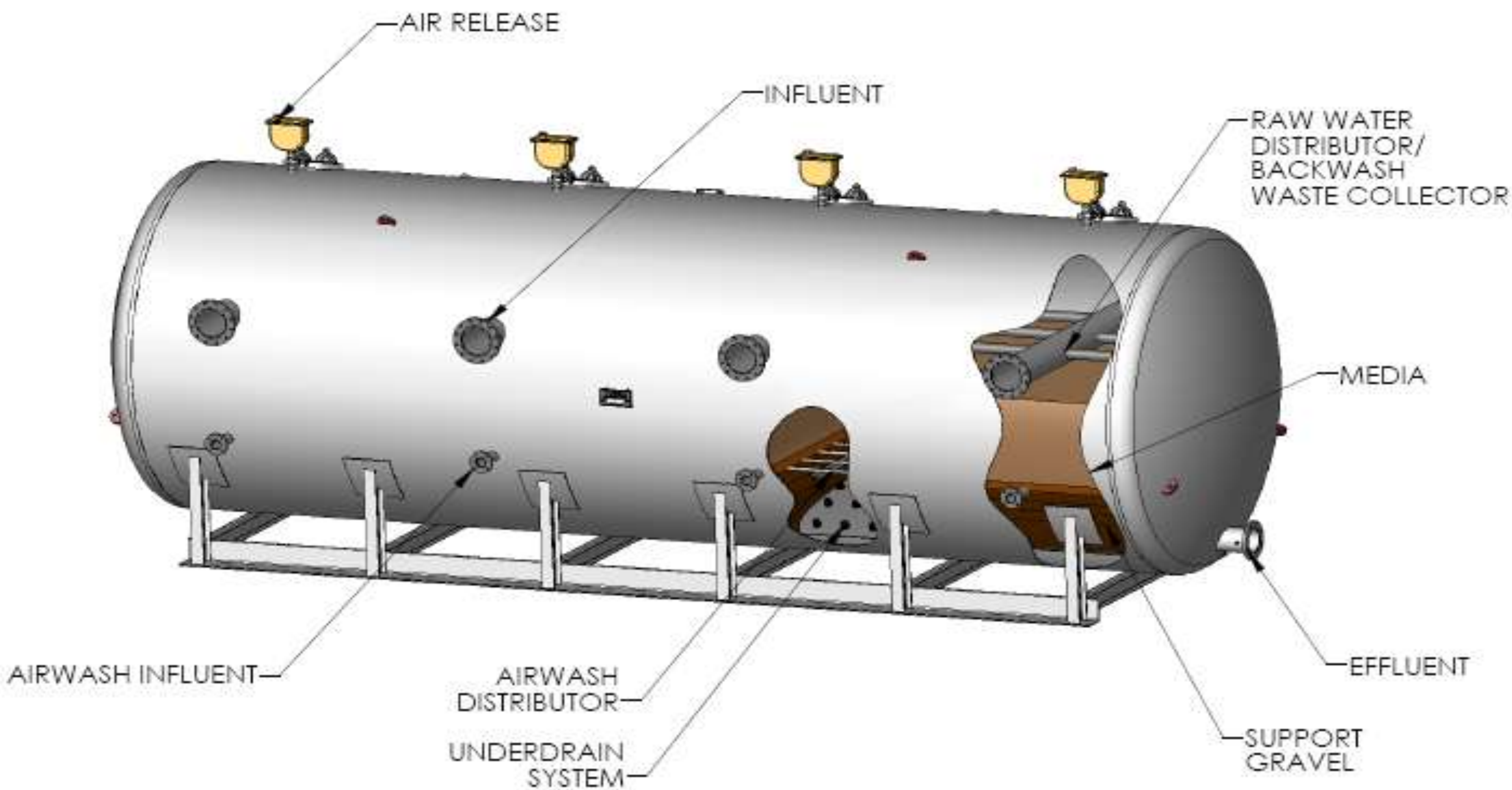


Configuration of two stage media filtration system in seawater RO plant

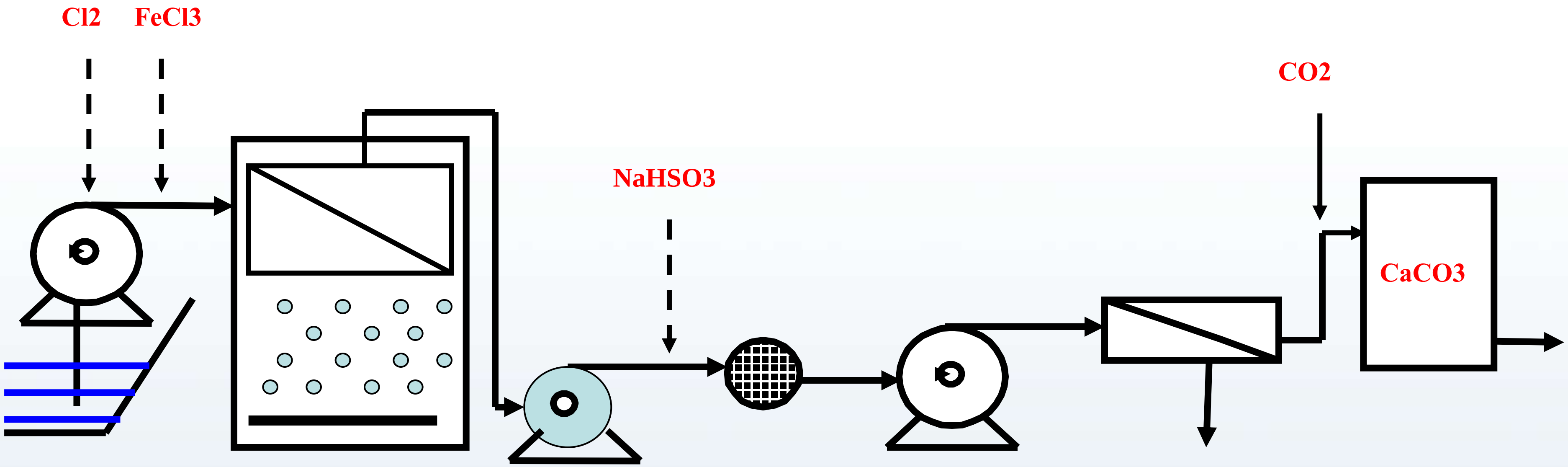


Dual media, gravity filter configuration (Courtesy of Infilco-Degremont)

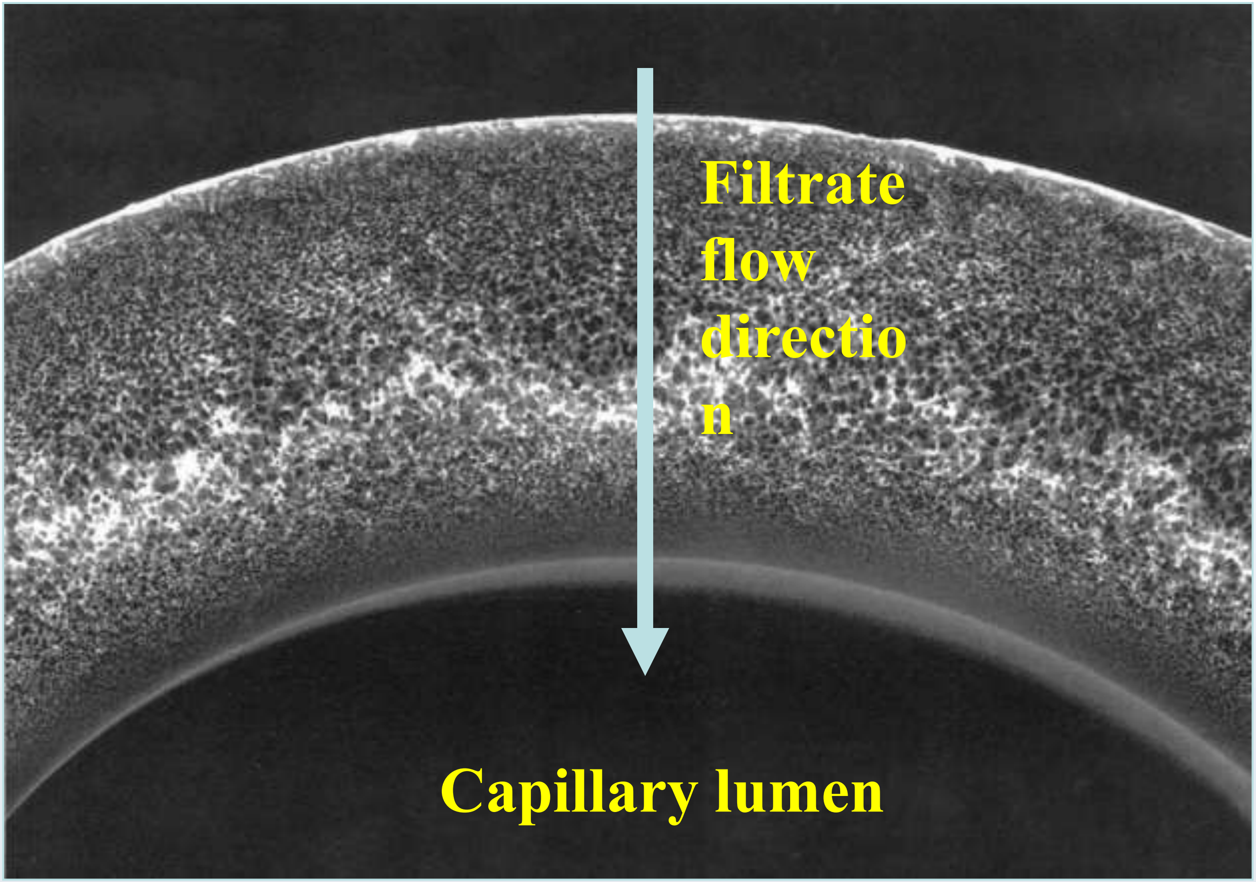

AIR RELEASE
RAW WATER
DISTRIBUTOR/
BACKWASH
WASTE COLLECTOR
INFLUENT
MEDIA
AIRWASH
DISTRIBUTOR
SUPPORT
GRAVEL
UNDERDRAIN
SYSTEM
AIRWASH INFLUENT
EFFLUENT



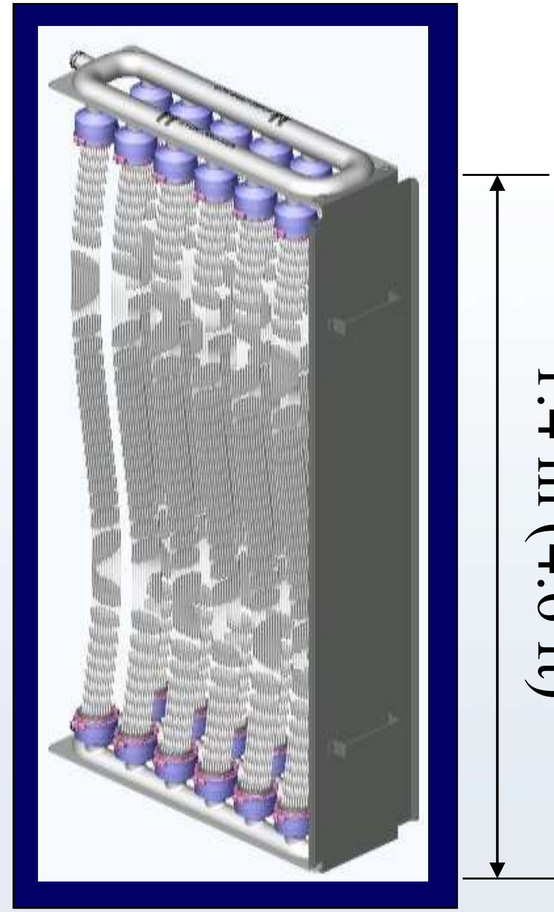
Dual media, horizontal pressure filter configuration (Courtesy of Tonka Equipment Company)



Configuration of RO seawater system with membrane (UF/MF) pretreatment



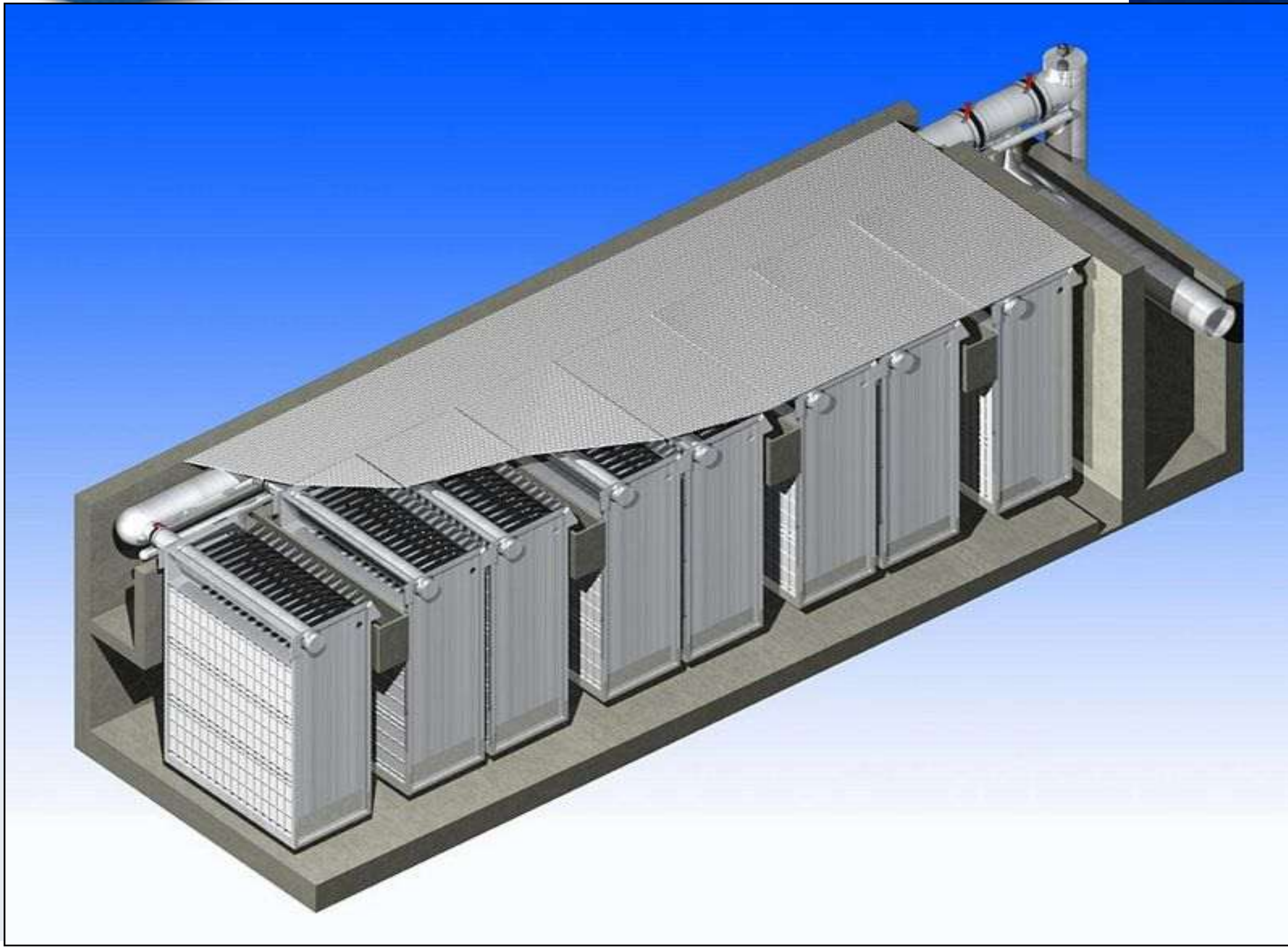
Cross section of capillary fiber



Membrane module
250 m2, 100 m3/d
(2700 ft2, 26,000 gpd)

Figure 62. Submersible capillary technology


ZENON
ZENON
ZENON



Design concept of submersible system (Courtesy Zenon Corporation)

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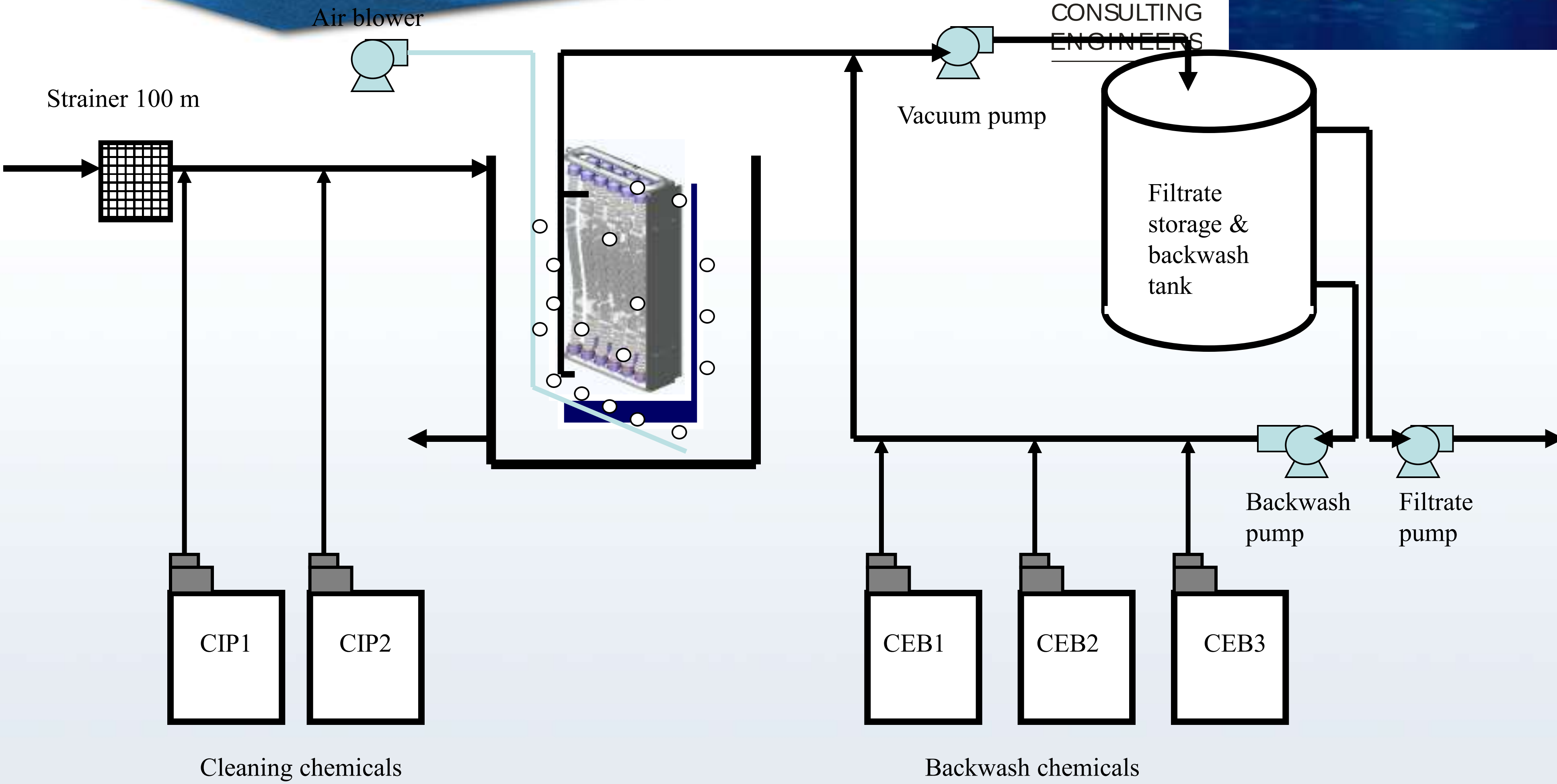
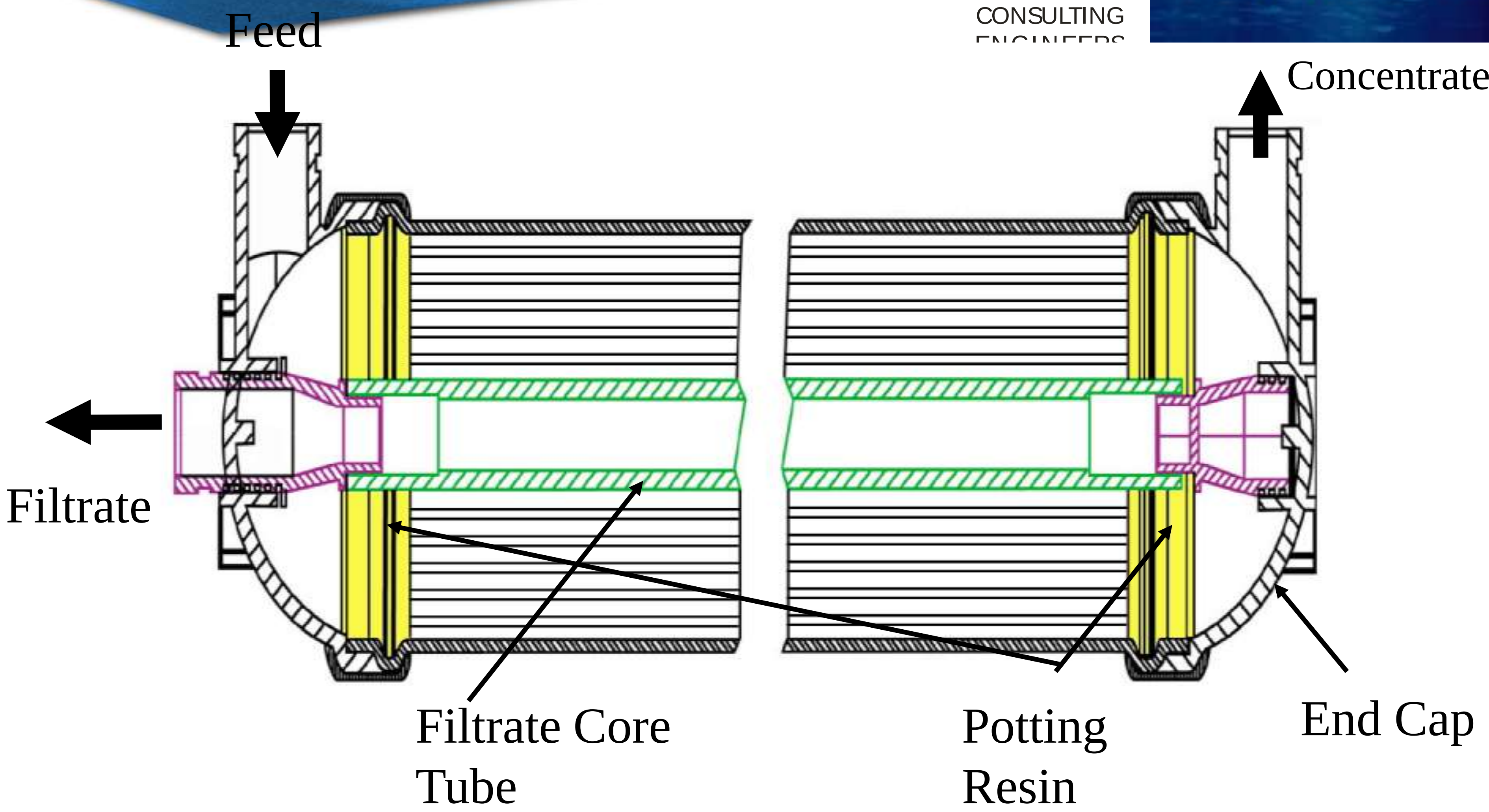


Flow diagram of submersible capillary membrane plant

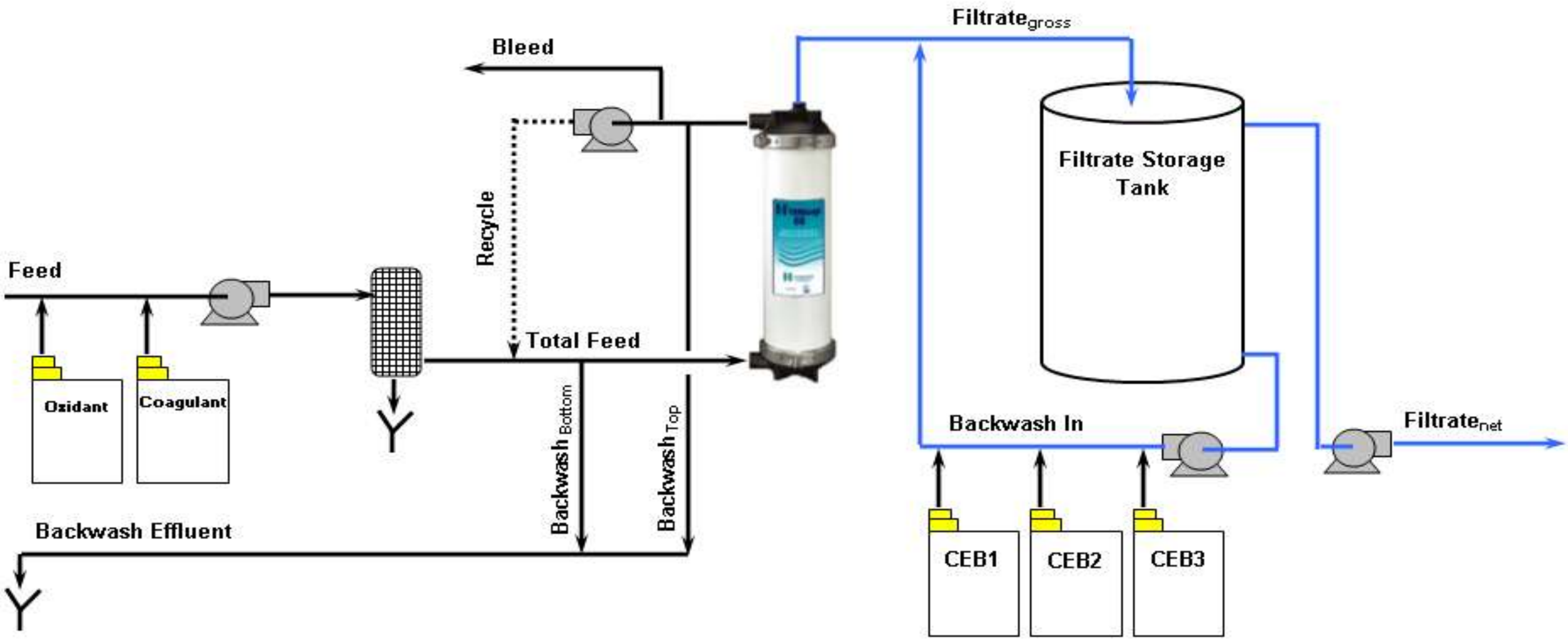


Configuration of pressure driven UF/MF membrane module.

HYDRAcap 40: 320 ft^2 (30 m^2)

HYDRAcap 60: 500 ft^2 (46 m^2)

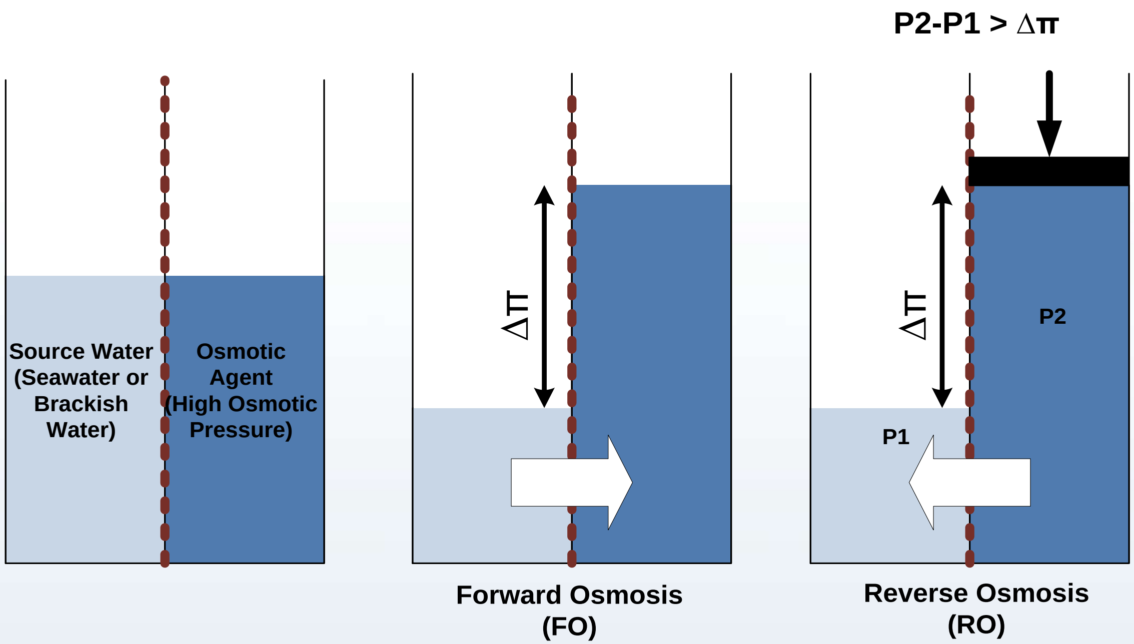
Figure 67. Pressure driven capillary UF module



Flow diagram of pressure driven capillary membrane unit

Forward osmosis

Forward Osmosis

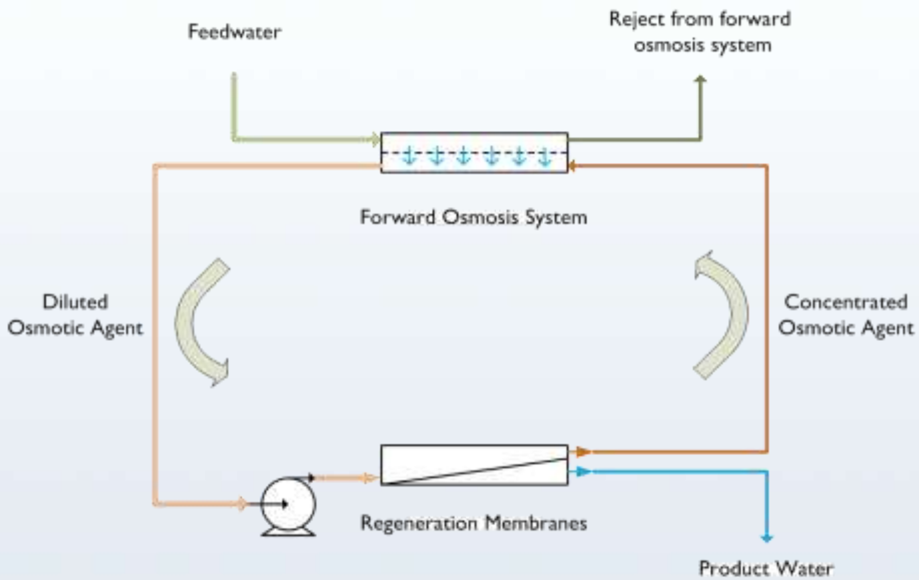


- *FO can dilute a solution of higher osmotic pressure using a solution of lower osmotic pressure*
- *FO can concentrate a solution of lower osmotic pressure using another of higher osmotic pressure*

Applications:

- Emergency drinks from brackish or sea water
- Power generation (MW)
- Enhanced oil recovery (MW)
- Fracture water (MW)
- Thermal desalination feedwater softening (MW)
- Desalination (MW)
- Water substitution (MW)

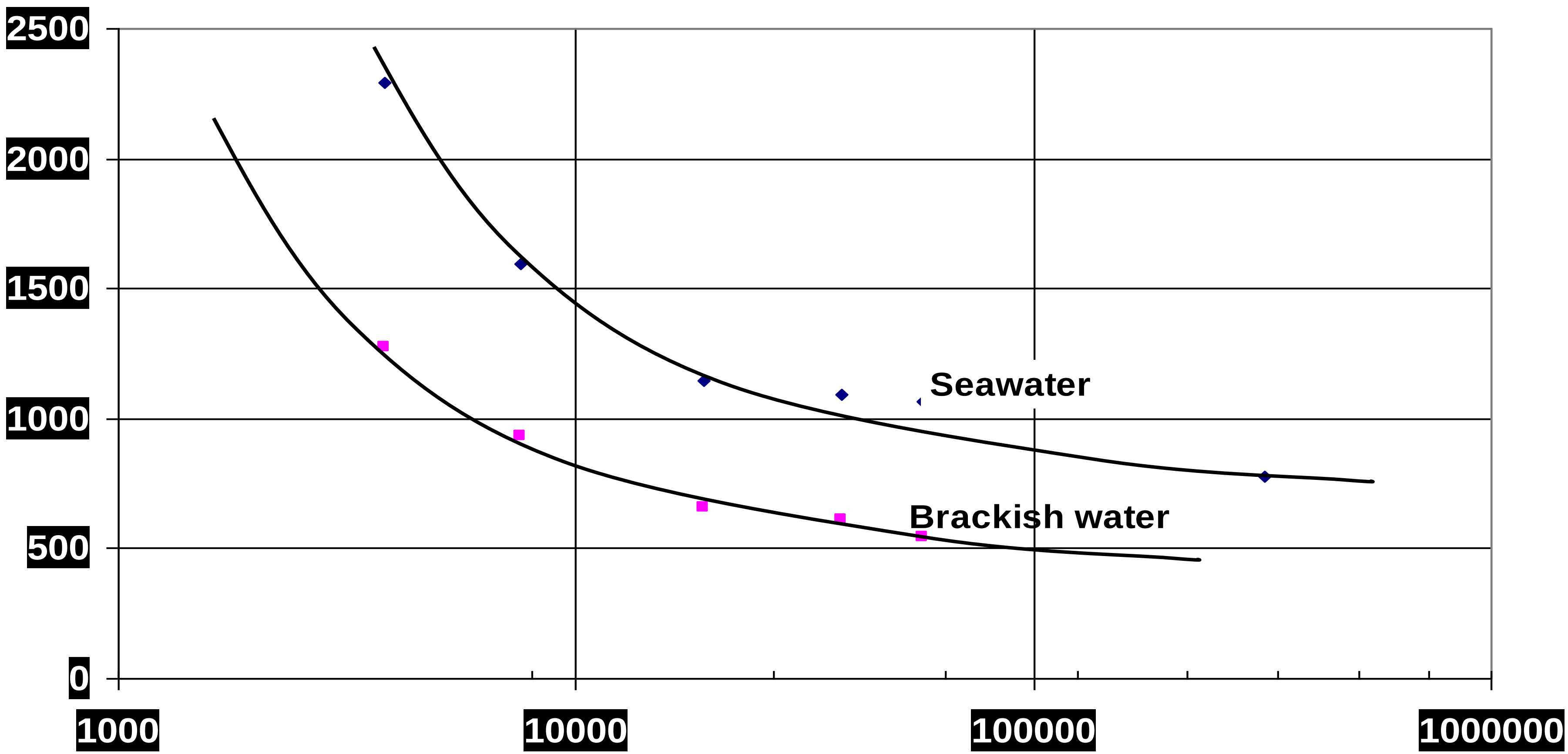
Forward Osmosis Desalination



Benefits:

- Proven low rate of fouling of FO membranes
- Proven low rate of fouling of regeneration RO membranes
- Lower fouling propensity delivers energy consumption reduction of up to 30% relative to reverse osmosis – site dependent
- Lower salt passage relative to conventional reverse osmosis
- Inherently low product boron levels, when compared to conventional reverse osmosis
- Higher availability than conventional reverse osmos plant due to low fouling and simple cleaning when required

Investment cost - RO process



Desalination cost UDATED 2005 $US/m³)

Seawater

- *Very large scale plants* — *0,50 - 0,80*
- *Large scale plants* — *1,00 - 1,50*
- *Small plants* — *2,00 - 3,00*

Brackish water

- *Large scale plants* — *0,20 - 0,40*
- *Small plants* — *0,50 - 0,70*

Recent prices - seawater – RO (*)

Site	Capacity m3/d	Start production	Cost $/m3
EILAT (Israël)	20.000	1997	0,72
LARNACA (Chypre)	56.000	2001	0,83
TAMPA (Floride)	106.000	2003	0,56*
ASHKELON (Israël)	320.000	2004	0,54

(*) Mark Wilf – MEDRC – Cyprus – 6/ 8 December 2004

Possible alternatives for different processes

	- direct cycle ⟷ recycling	
	- transversal tubes ⟷ longitudinal tubes	
MSF	- T_{max} or TBT : 90 ° C ⟷ 110 ° C	
	- ratio or GOR : 7 ⟷ 10	
	- material : Cu-Ni ⟷ titanium	
	- Forward cycle ⟷ Backward cycle	
	- horizontal tubes - wet ⟷ plate evaporators	
MED	- T_{max} or TBT : 55 ° C ⟷ 120 ° C	
	- MED with or without vapor compression	
	- ratio or GOR : 4 ⟷ 12	
	- spiral wound ⟷ hollow fiber	
	- 1 pass ⟷ 2 pass	
RO	- with or without energy recovery	
	- energy recovery : Pelton T ⟷ pressure exchanger, DWEER	
	- conventional pretreatment ⟷ membranes MF / UF / NF	
	- electro-pomp HP with or without speed variation	

Investment cost of different processes

	Process	$\$/m^3/day$
Seawater	MSF	1.200 – 2.500
	MED	1.000 – 2.000
	VC	1.000 – 1.600
	RO	800 – 2.000
Brackish water	RO	200 – 500
	ED	300 - 400

SUSTAINABILITY ISSUES RELATED TO DESALINATION

Energy recovery devices for SWRO applications

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ENERGY RECOVERY SYSTEM -

- **ENERGY RECOVERY SYSTEM**
  - **ISOBARIC SYSTEM**
    - **DWEER**
    - **ERI**
    - **AQUALYNG RECUPERATOR**
  - **CENTRIFUGAL / ROTARY SYSTEM**
    - **PELTON WHEEL**
    - **TURBO CHARGER**
    - **FRANCIS TURBINE**

EFFICIENCY WILL BE >95%

MIXING WILL BE 3 TO 6%

MORE CAPEX

MAX. EFFICIENCY 82 – 70%

NOT CONSIDERED

LOW CAPEX

MAX. EFFICIENCY 89%. SYSTEM EFFICIENCY – 78%

MORE THAN PELTON WHEEL

MAX. EFFICIENCY 85%. SYSTEM EFFICIENCY – 70%

LESS CAPEX.

ENERGY USE AND EFFICIENCY

Figure 11. Maximum SEC values of first-pass RO with different energy recovery systems

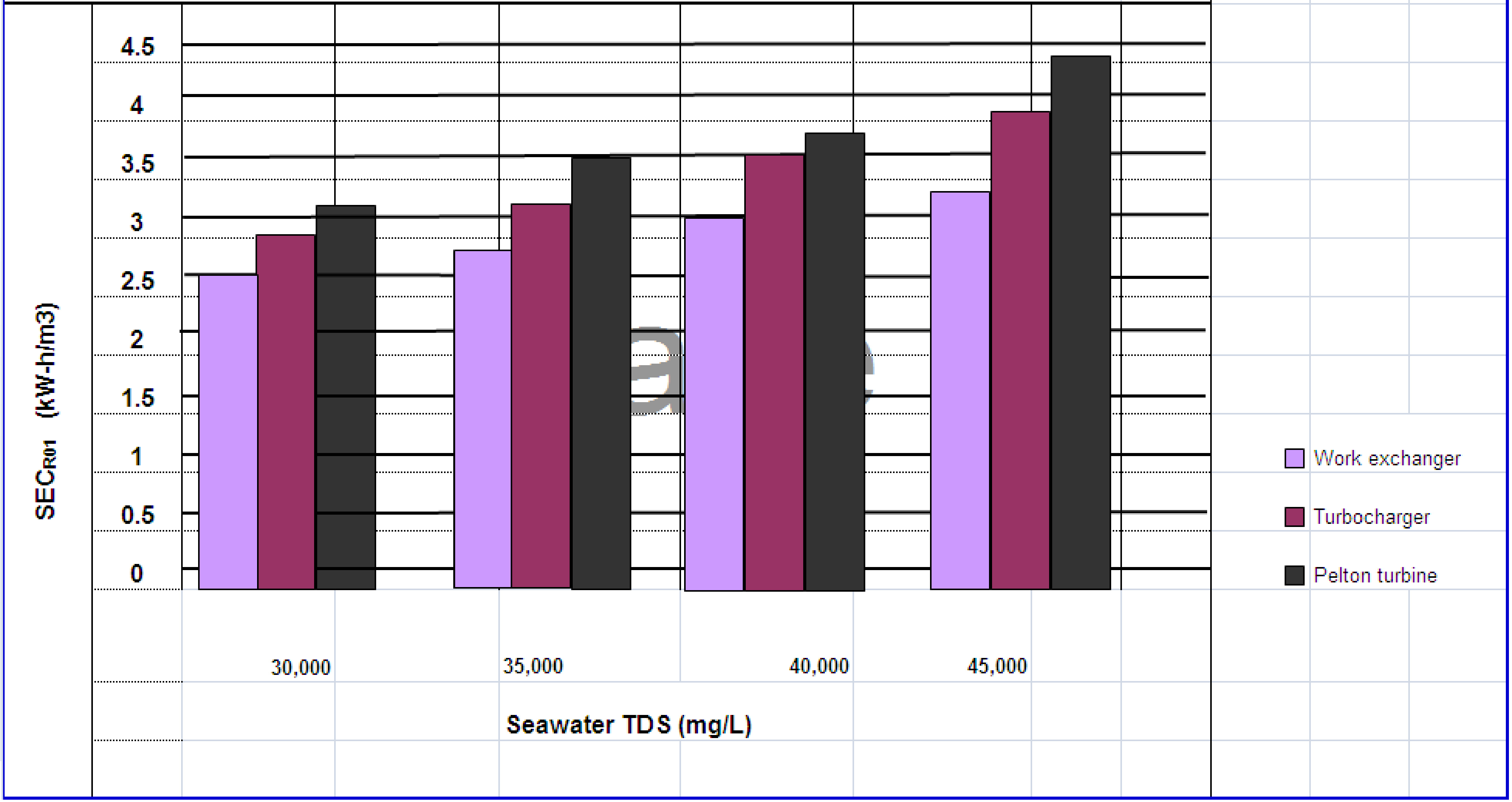
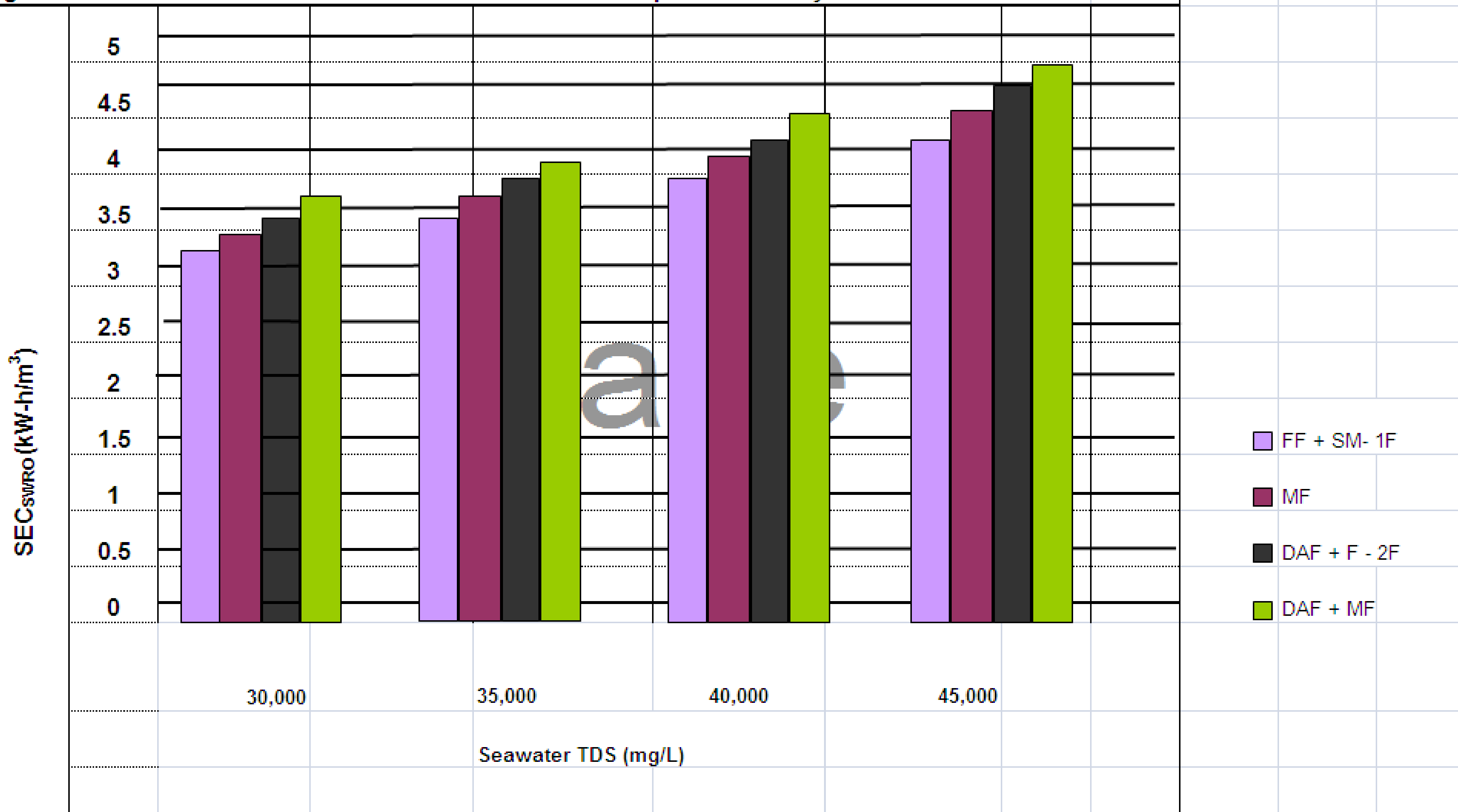


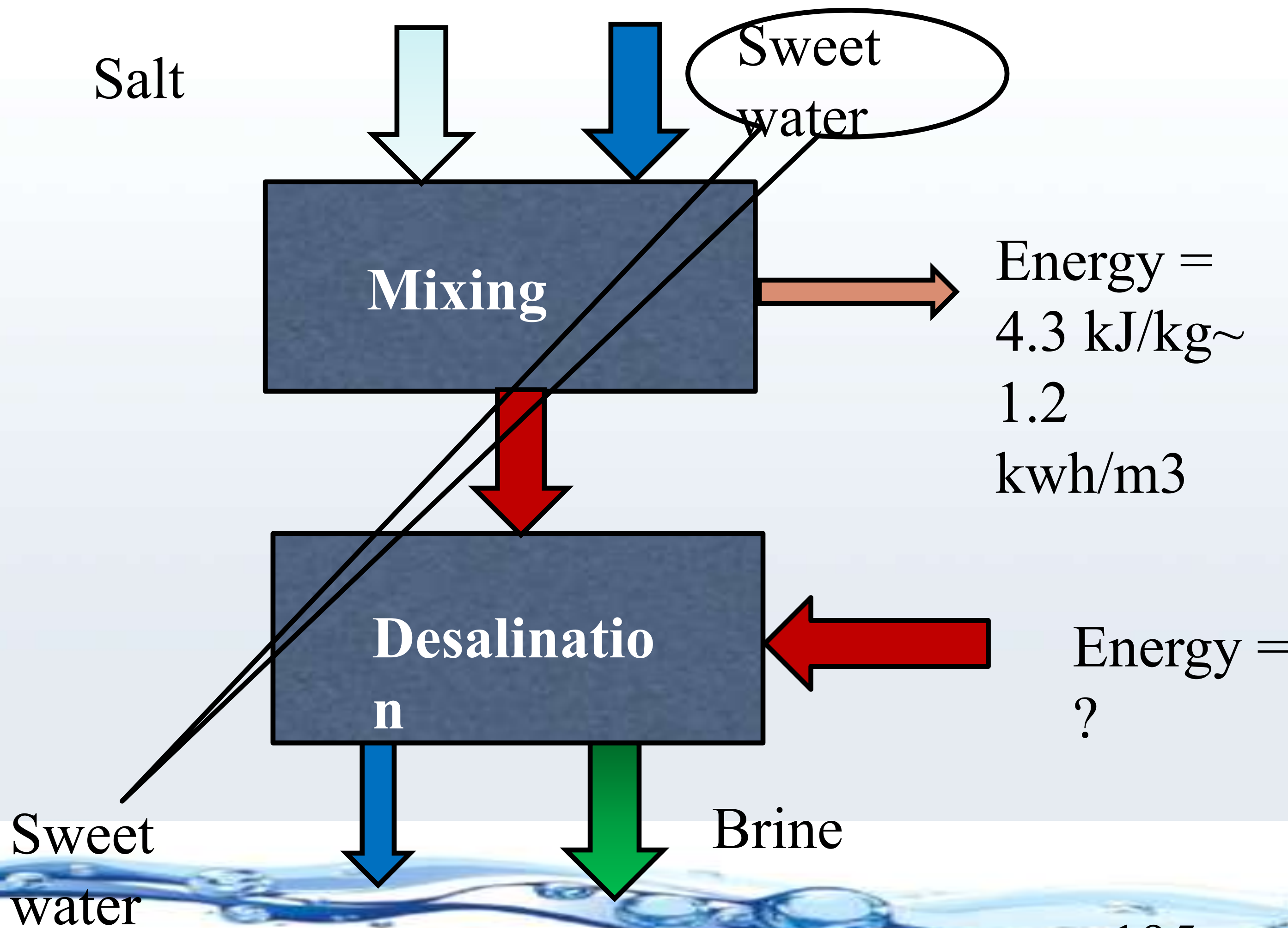
Figure 12. Maximum SEC values of SWRO Plant with different pretreatment systems



Major Sustainability issues related to desalination plants:

1) High energy footprint per unit of product water
2) Impact of process flow discharge: blowdown brine salinity and seawater heat rejected temperature

Energy footprint per unit of product water



energy footprint per unit of product water

1.Energy consumption of status of art desalination projects

- Studies have been carried out showing that potable water with TDS lower than 500 mg/l could be obtained with SWRO technology with less than 2.5 kwh/m^3.

- Minimum bottom threshold (theoretical) for power requirements for SWRO is depending on TDS ranging between 1.2-1.5 kwh/m^3

Energy footprint per unit of product water

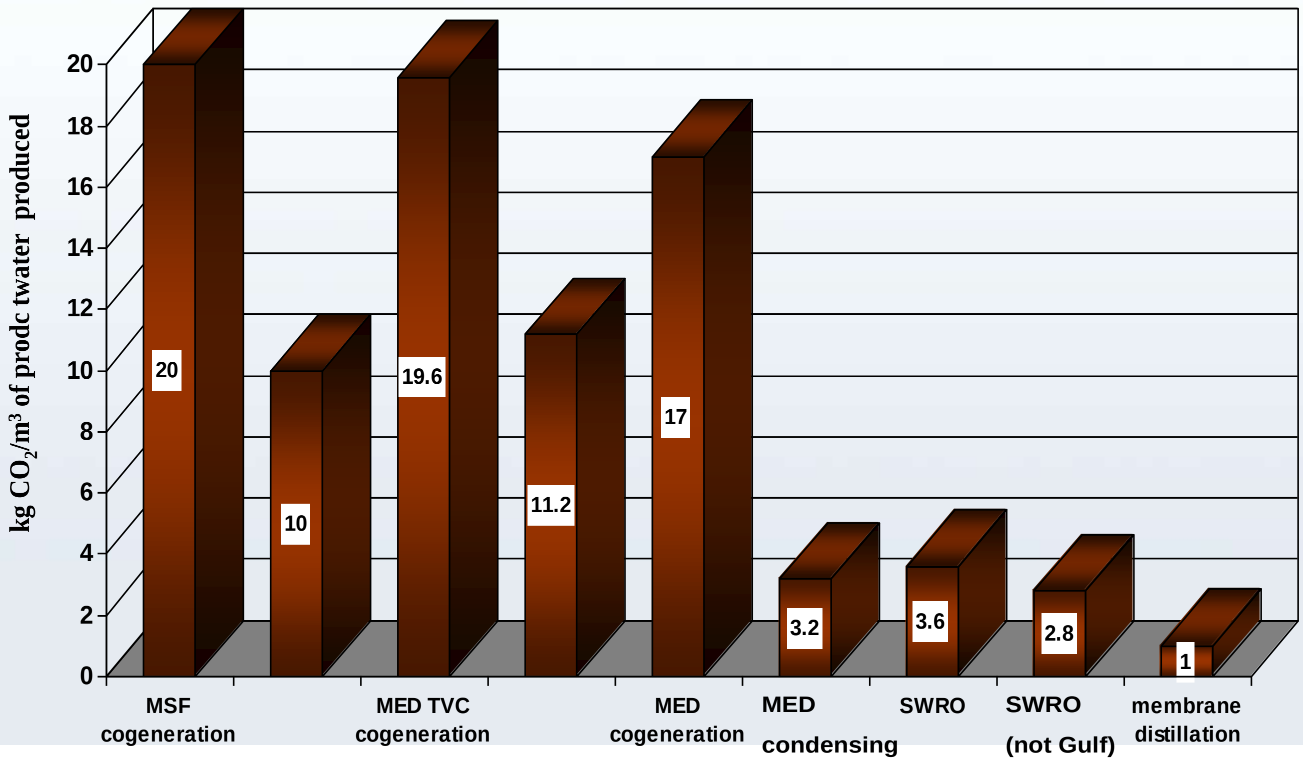
2. in terms of CO_2 related emissions

Grid Emission Factor

- In parts of the world that are heavily reliant on coal the grid emission factor is somewhere near 0.8TCO_2/MWH.
- Whereas where there is lots of new and efficient system the grid it tends to be lower e.g 0.5TCO_2/MWH

Energy footprint per unit of product water

2. in terms of CO_2 related emissions



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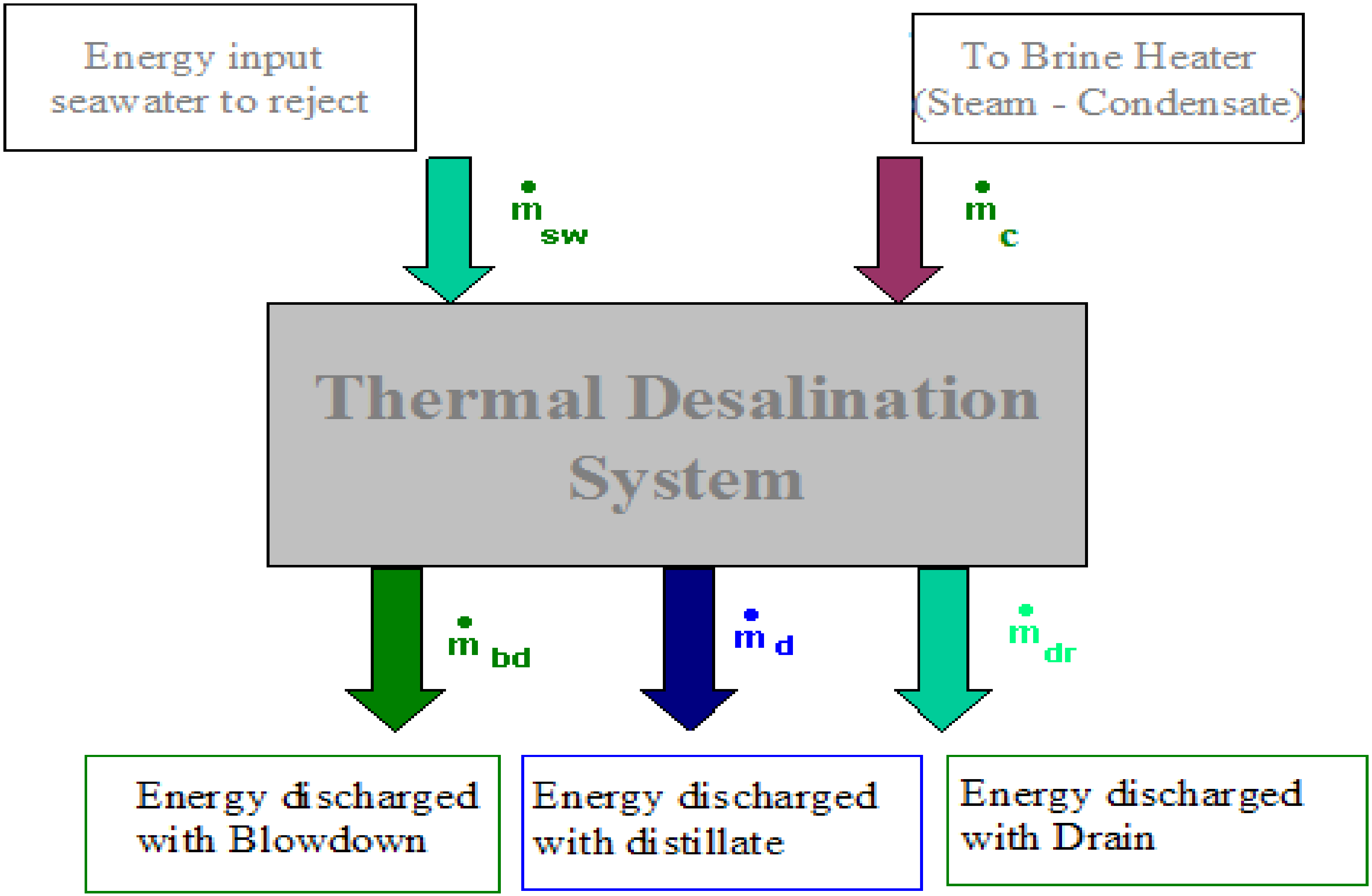
Seawater impact



Seawater impact

Operating Efficiencies

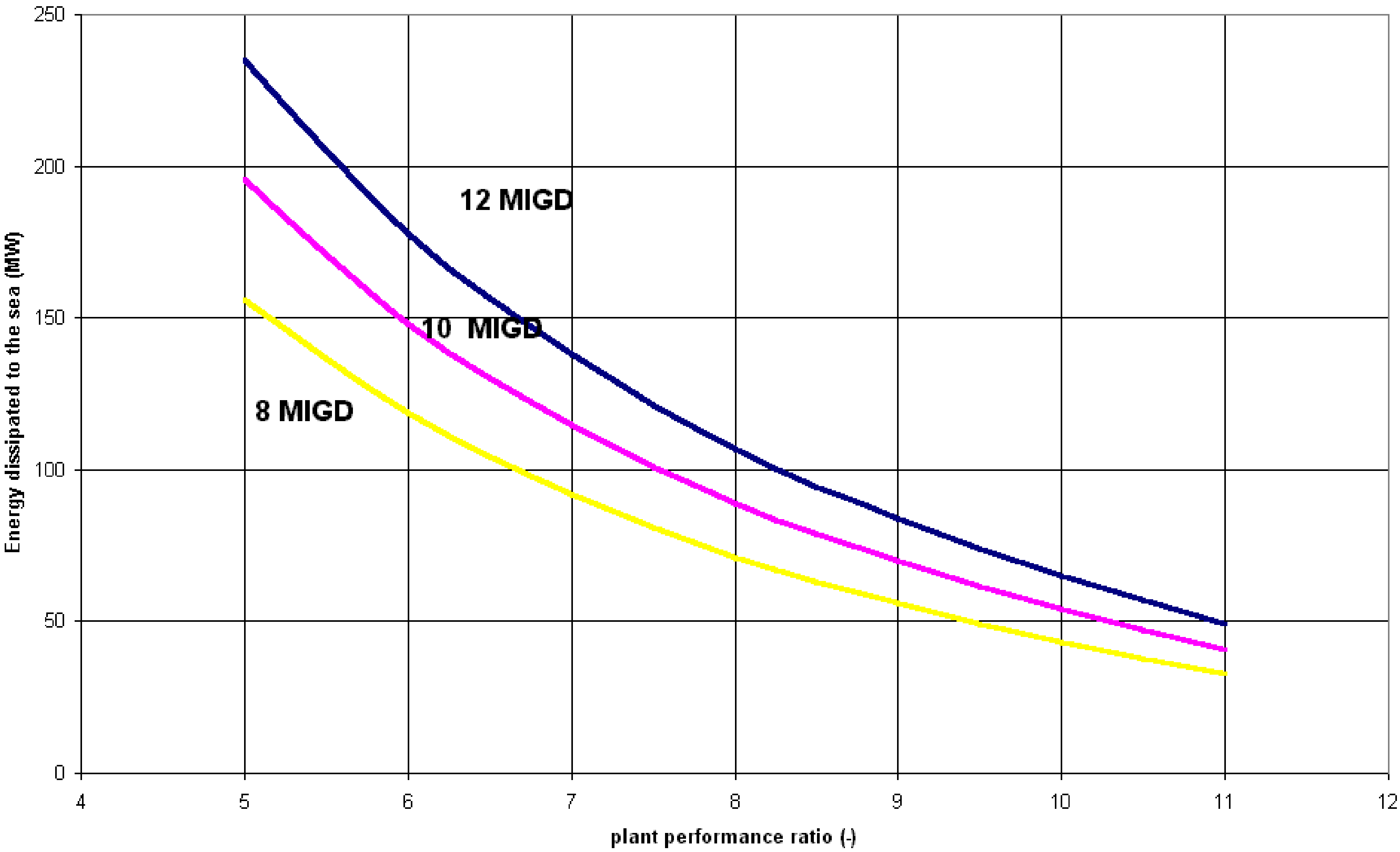
$$P_D = D \cdot \left(\frac{H_v}{\eta} - H_D\right)$$

P_D = power dissipated in the sea

D = Distillate produced

η = plant efficiency

H = enthalpy (v refer to steam D refer to distillate


250
200
150
100
50
0
4
5
6
7
8
9
10
11
12
Energy dissipated to the sea (MW)
plant performance ratio (-)
12 MIGD
10 MIGD
8 MIGD

Operating Efficiencies

At a given discharge enthalpy and production plant efficiency sharply decrease the heat dissipated to the sea

At high efficiency the difference between the heat dissipation with increasing plant size decrease

What are the results in a comparison ?

Environmental impacts in power generation and desalination processes			
Reference process	Type of process	Energy dissipated in the environment MW	TDS increase with respect to the uptake
Power generation 100 MW	Conventional cycle	50	0
	Combined cycle	10	0
Desalination plant 7.2 MIGD	MSF (performance ratio 9)	120	15-20 %
	MED (performance ratio 9)	100	15-20 %
	SWRO	0	50-80 %

Differential temperature across thermal desalination plants are quite high

10 ° C to (extreme of) 14 ° C in summer compared to max 5 in power plants

Winter operation the ΔT is even more severe 17 ° C to (extreme of) 20 °C

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Differential temperature comparison between power and desalination processes

Reference process	Type of process	Differential temperature across the process [°C]	
Power generation 150 MW	Conventional cycle	3-5	
	Combined cycle	5	
Desalination plant 7.2 MIGD	MSF (performance ratio 9)	Summer	Winter
		8-12	Up to 18
	MED (performance ratio 9)	10	
	SWRO	0-1	

MATCHING WATER AND POWER GENERATION ; AVOIDING INEFFICIENCIES

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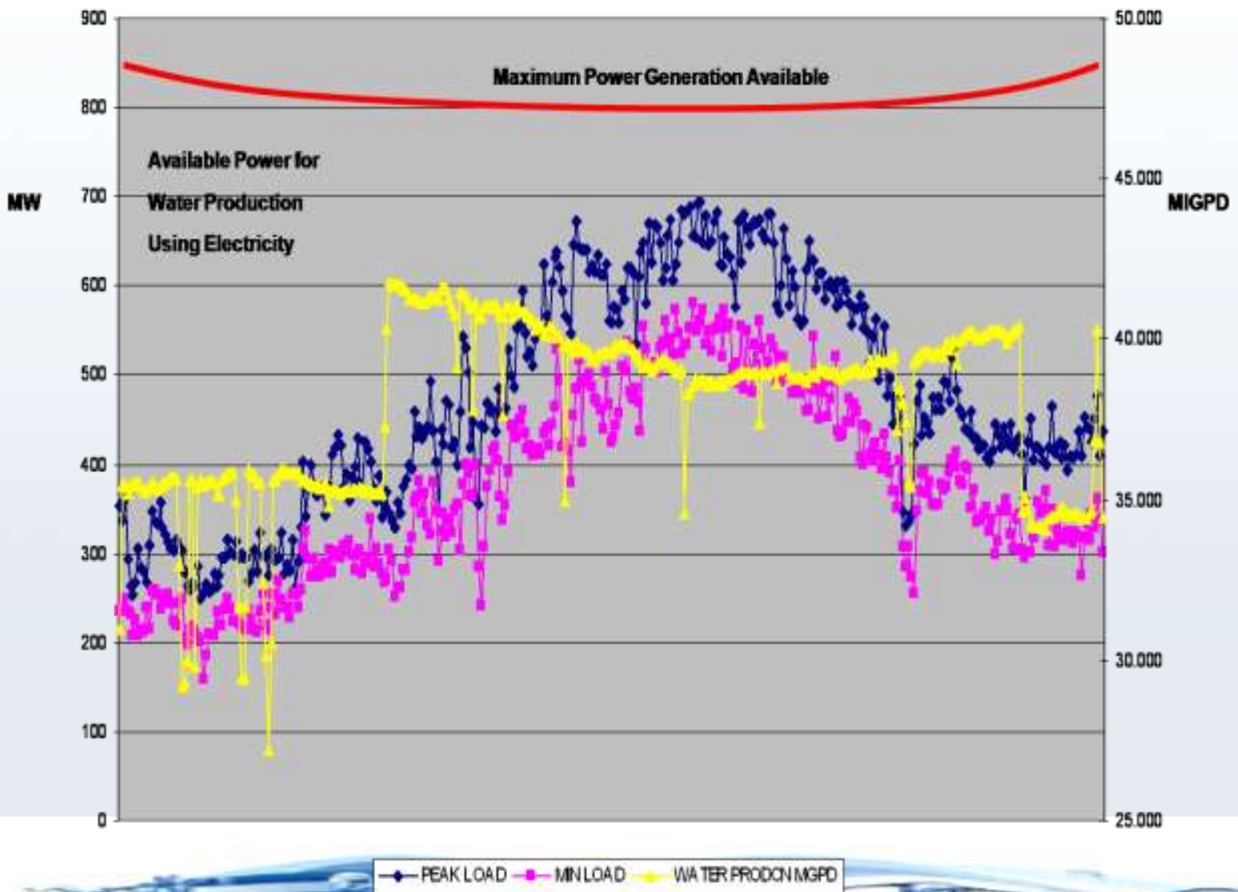
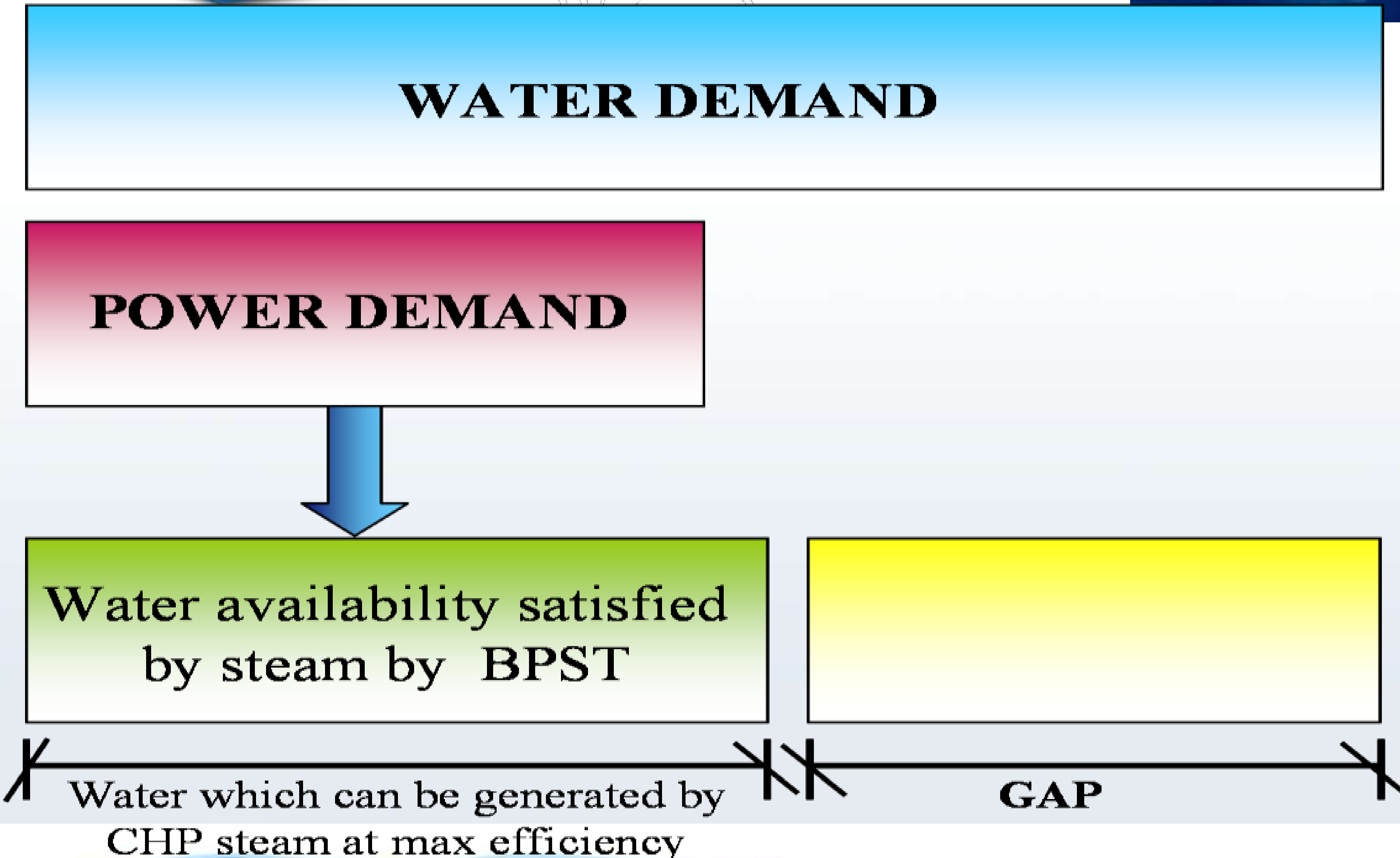
The energy situation

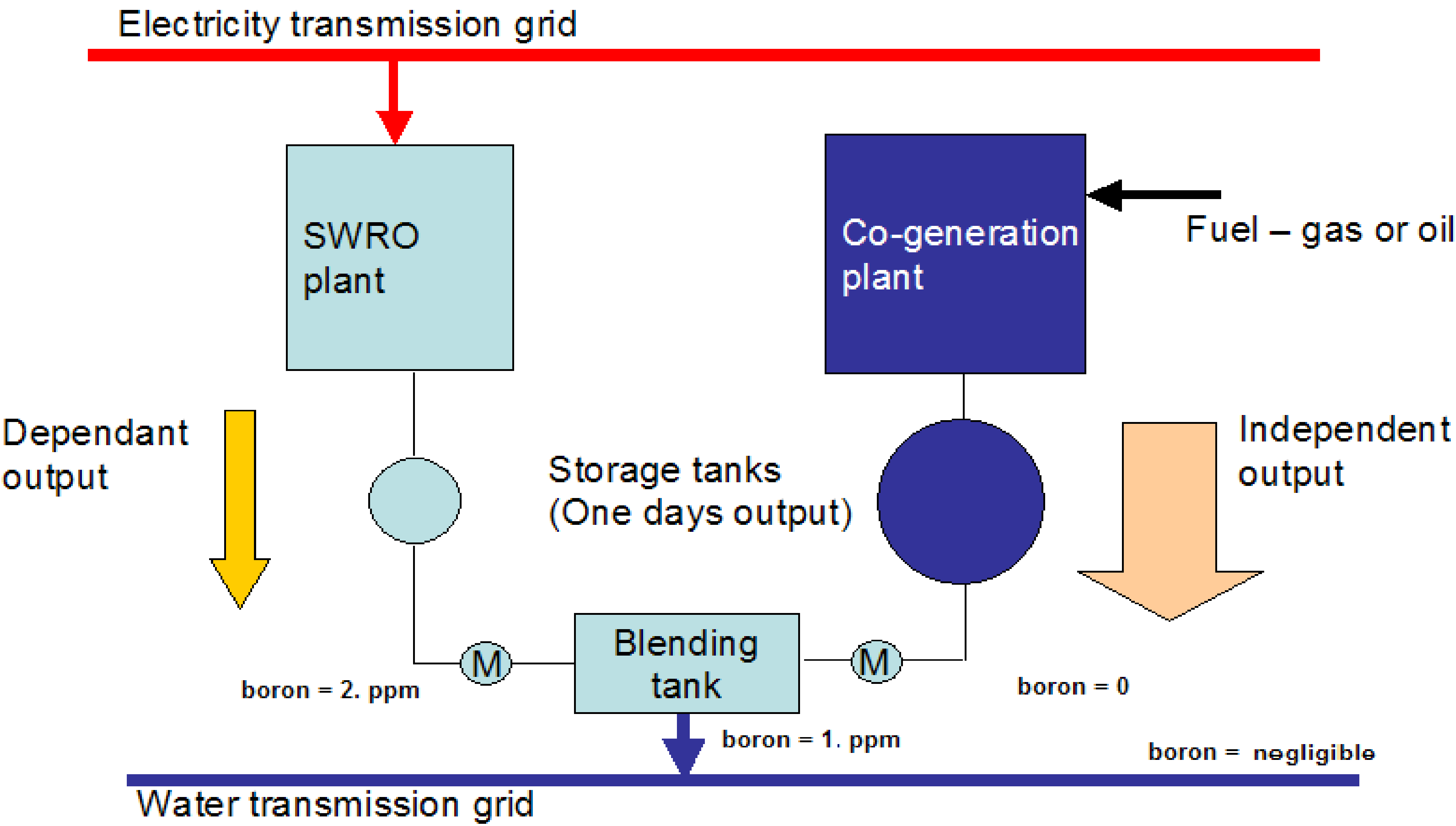


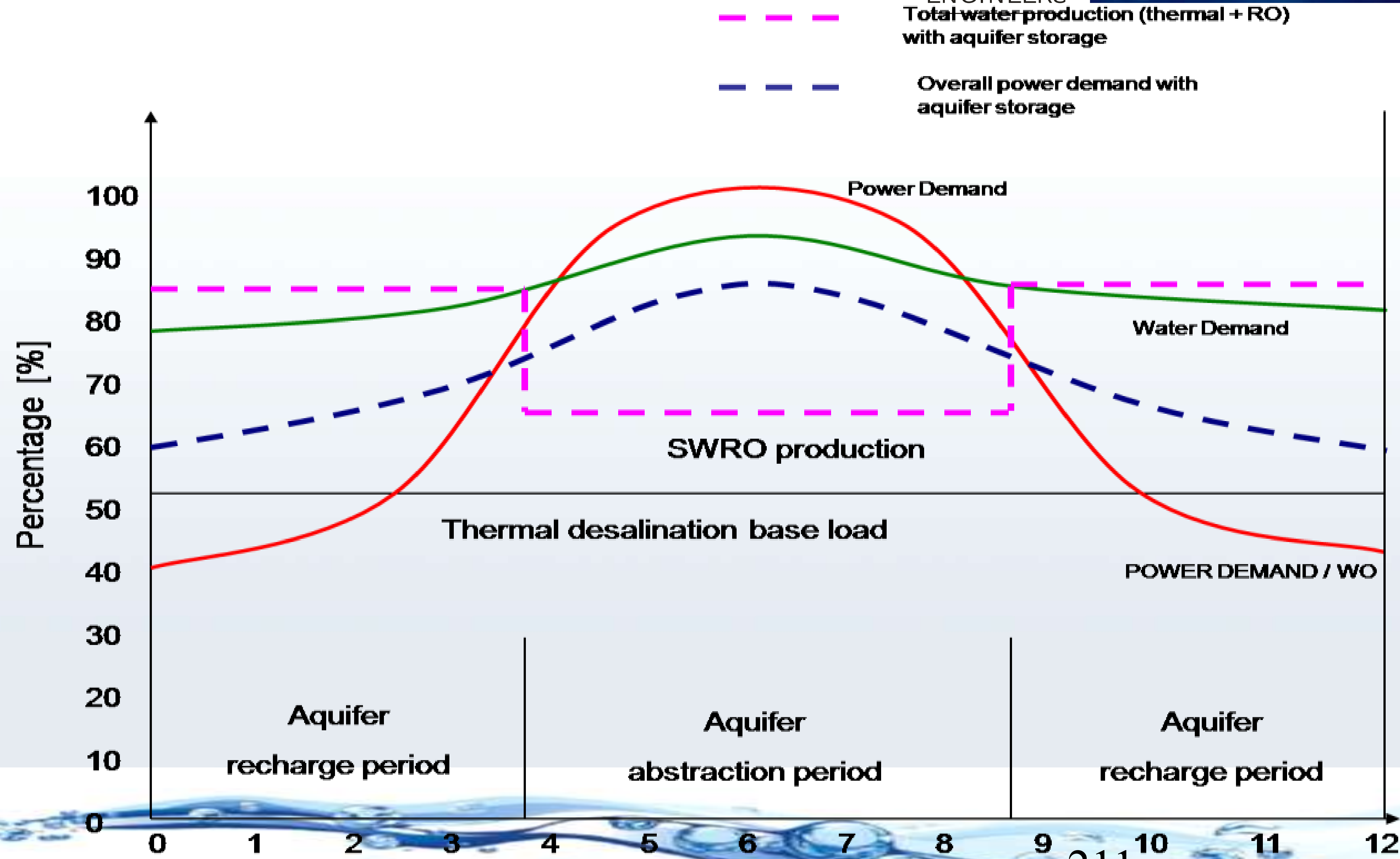
Data Courtesy of SEWA Layyah Power Plant

Despite all thermal desalination plant are installed as cogeneration the winter summer unbalance of water and power demand generate tremendous inefficiencies

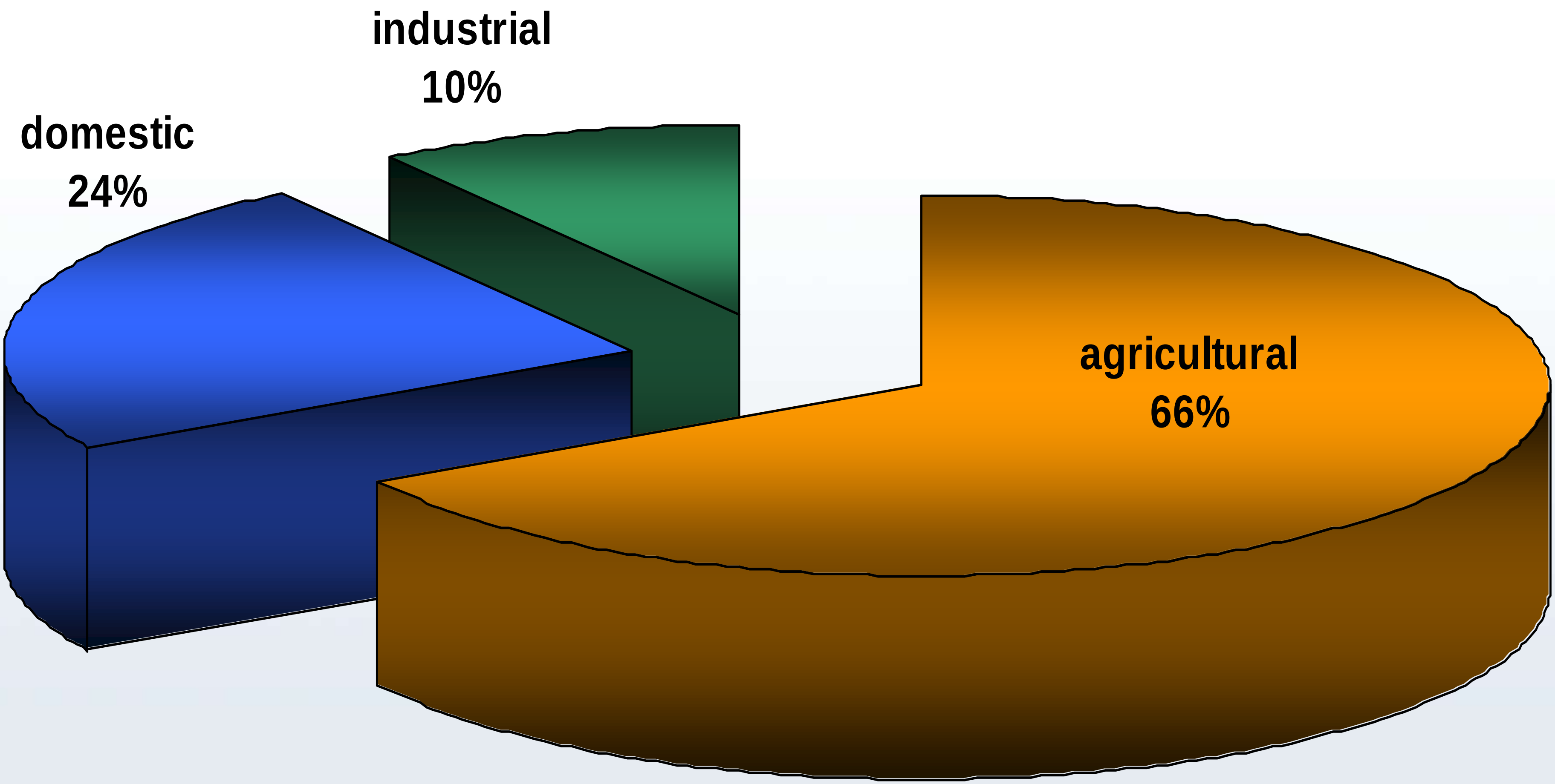

WATER DEMAND
POWER DEMAND
Water availability satisfied by steam by BPST
Water which can be generated by CHP steam at max efficiency
GAP

What can we do to avoid this inefficiency ?


Electricity transmission grid
SWRO plant
Co-generation plant
Fuel – gas or oil
Dependant output
Storage tanks
(One days output)
Independent output
M
Blending tank
M
boron = 2. ppm
boron = 0
boron = 1. ppm
boron = negligible
Water transmission grid


Total water production (thermal + RO) with aquifer storage
Overall power demand with aquifer storage
Power Demand
Water Demand
SWRO production
Thermal desalination base load
POWER DEMAND / WO
Aquifer recharge period
Aquifer abstraction period
Aquifer recharge period
Percentage [%]
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12

IMPROVING EFFICIENCY AT PLANNING STAGE


industrial
10%
domestic
24%
agricultural
66%

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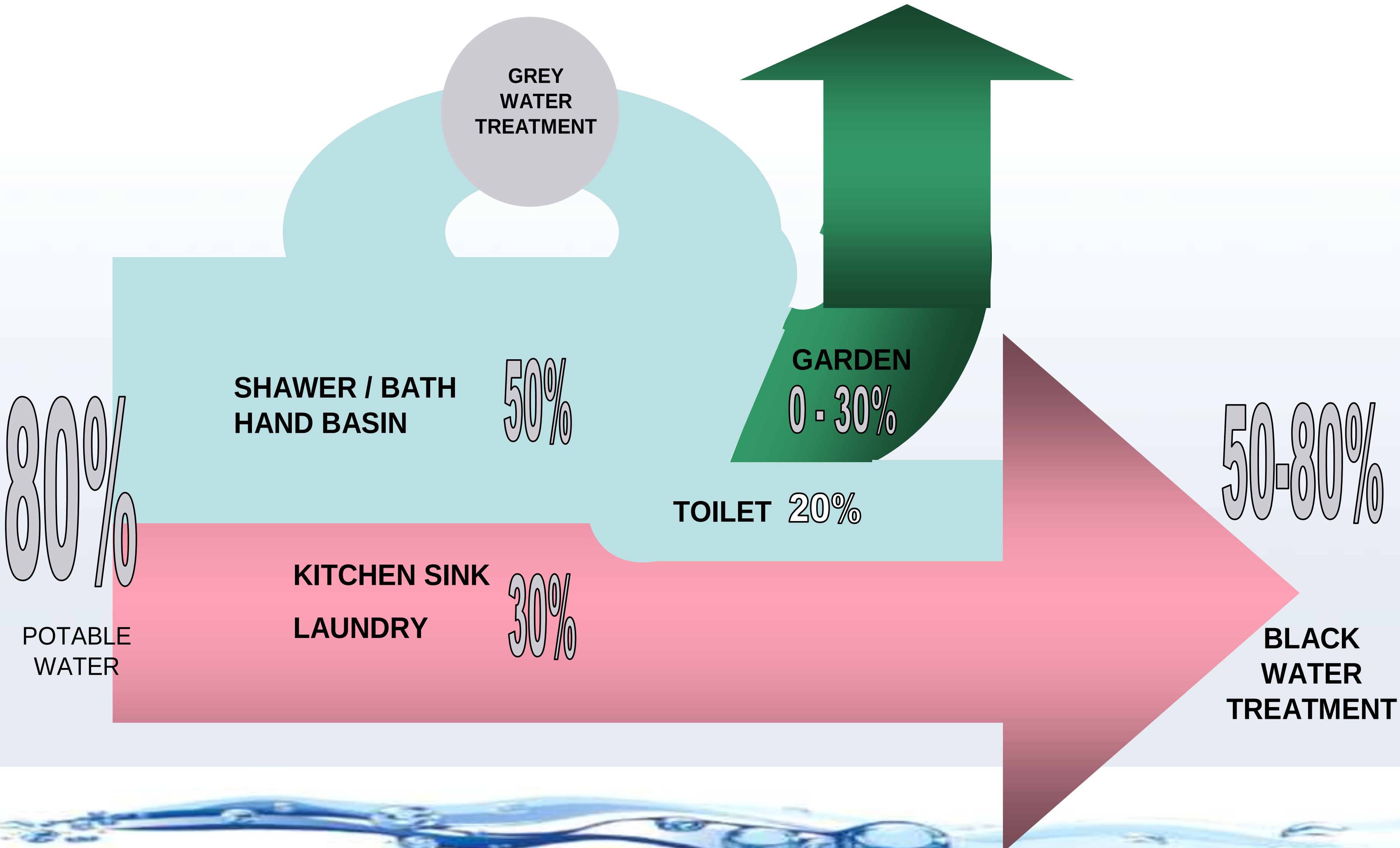

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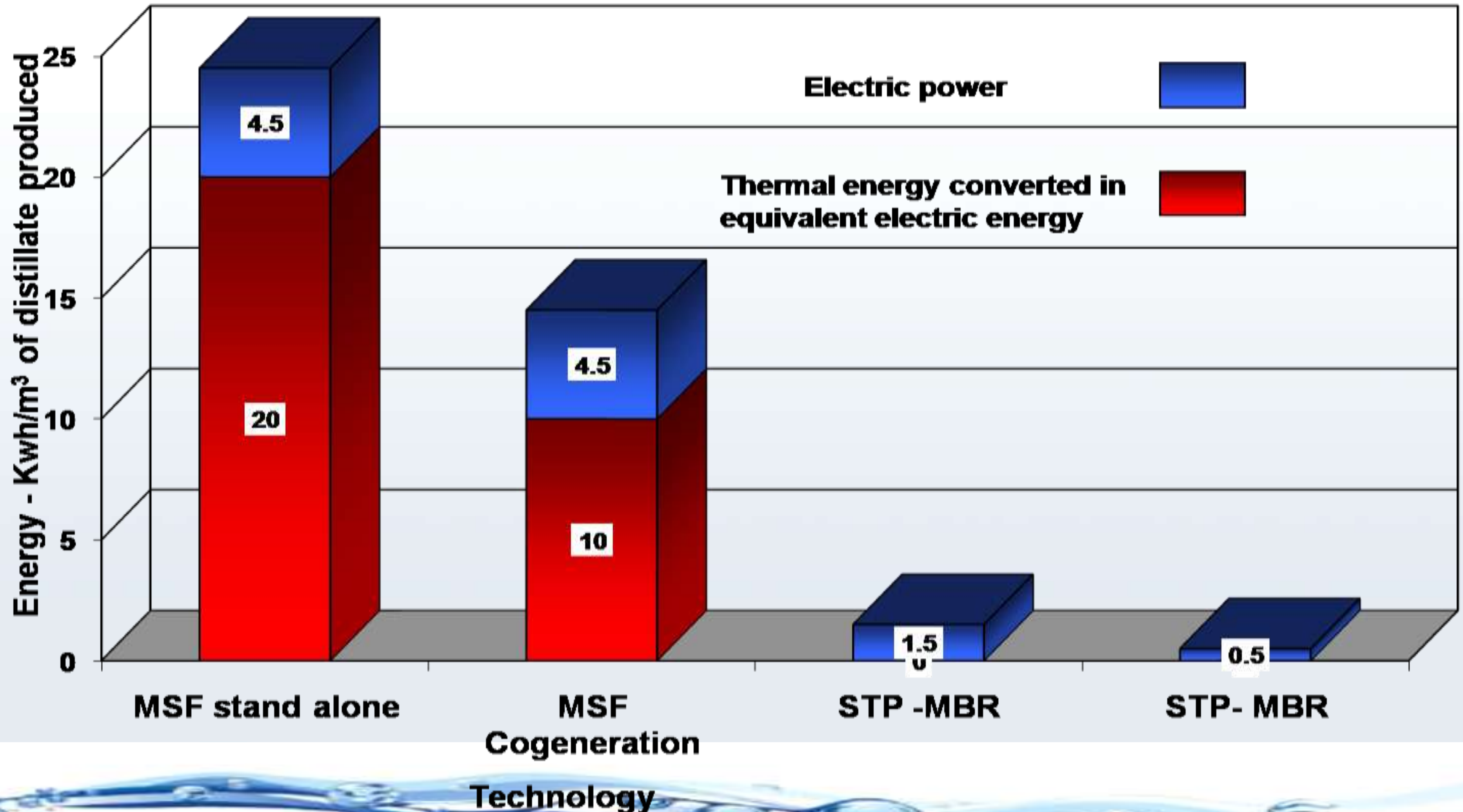

End of the course

- Thanks
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