Salt Partners

New Membranes make Salt Production from Desalination Reject Even More Profitable

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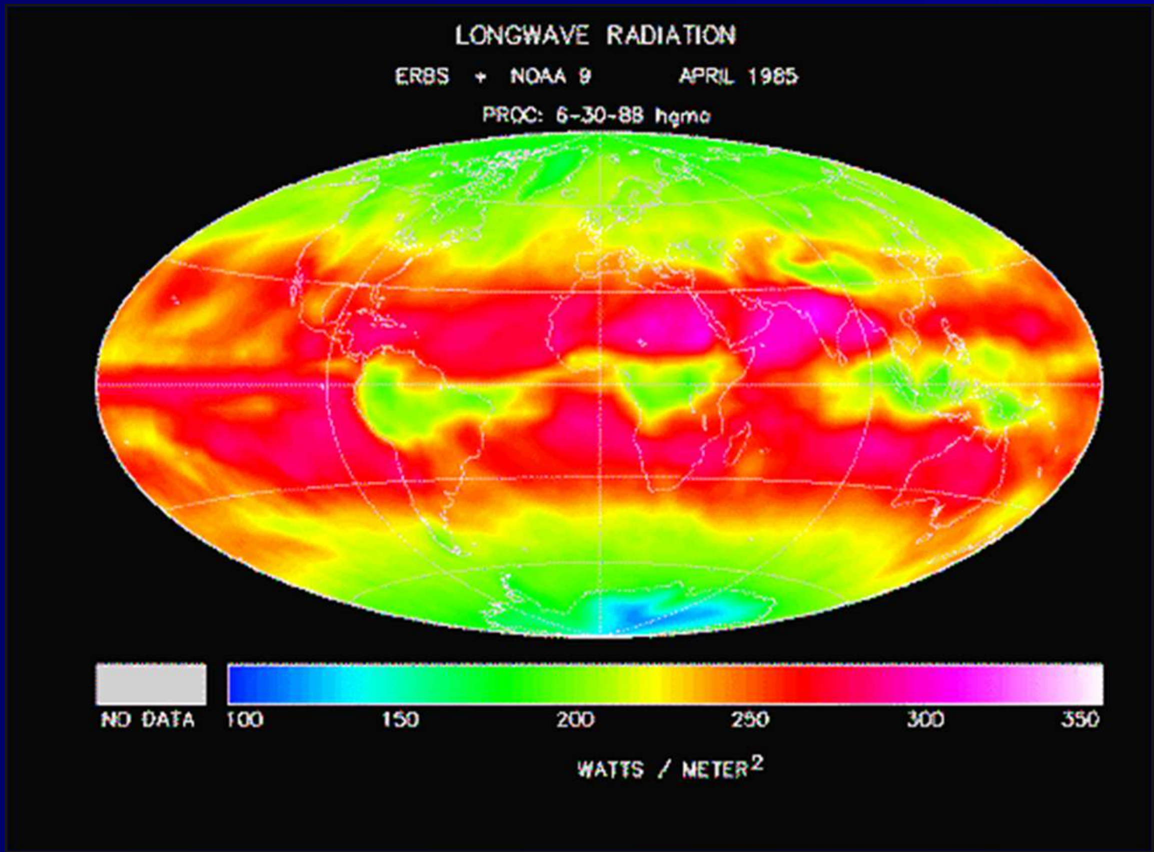
Solar Energy (Insolation) on the Planet Earth



NASA

The Earth is receiving approx. 1'368 W/m2 of solar energy. Part of the solar energy is absorbed by the clouds. No solar energy is received during the night. Thus the solar energy received on the planet surface – the insolation – is only a fraction of the total solar energy received. Most insolation is received in:

Caribbean Sea
North Africa
South Africa
Middle East
Western India
Western Australia

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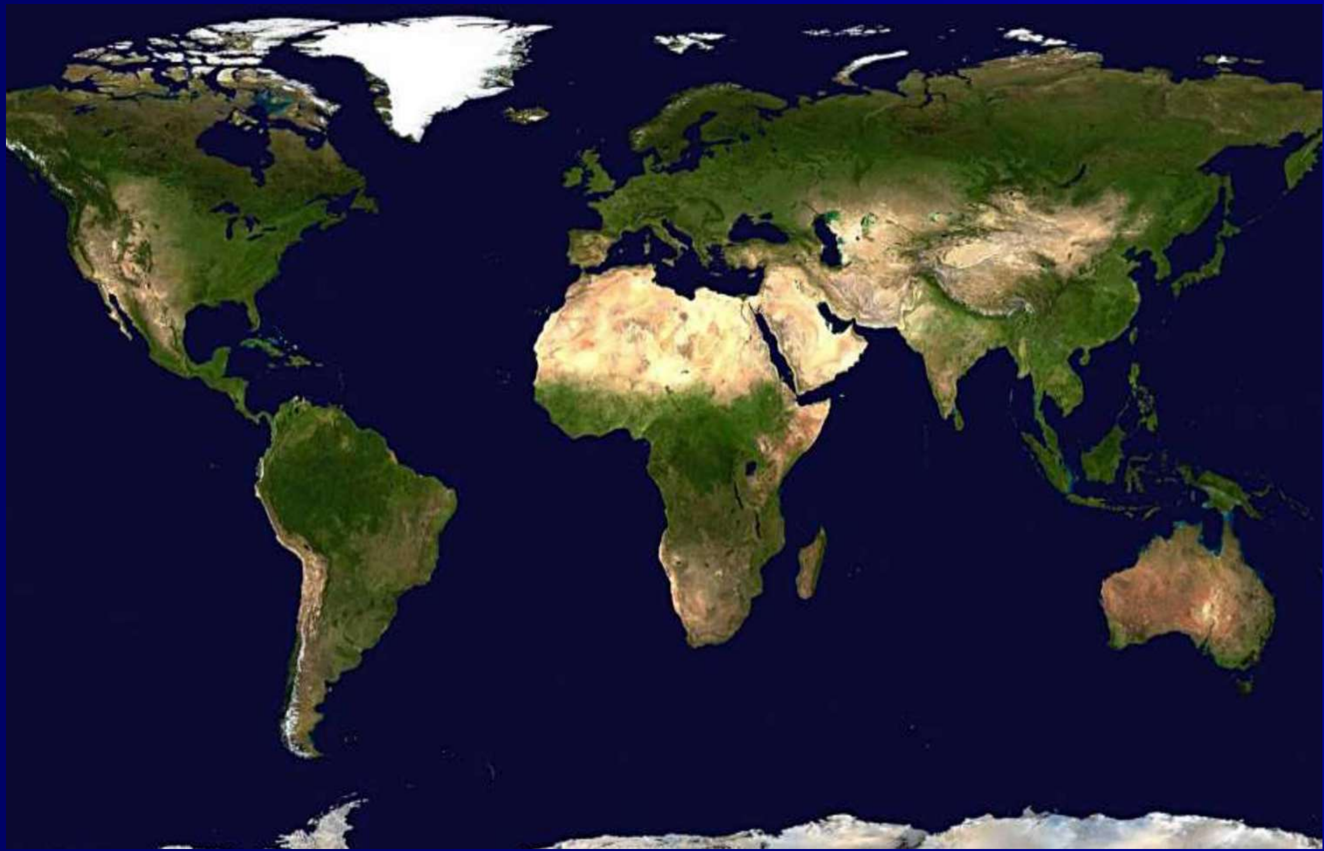
Water Scarcity on the Planet Earth



NASA

Locations with the highest insolation are also locations with the highest rates of evaporation and highest scarcity of water. Sea water available along the seashore of these locations is – after desalination – the source of water.

The same locations could be – under circumstances – also suitable for solar or thermal salt production.

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Is Salt Production from Desalination Reject Feasible?

Obstacles:

- Desalination reject contains only about 6% dissolved salts:
- Desalination reject contains only about 5% NaCl;
- Desalination reject contains inhibitors, which disturb crystallisation;
- Construction of solar ponds on sand is expensive;
- Thermal and electrical energy for evaporation is expensive.

Can the obstacles be overcome?

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Chemistry of Sea Water – Open Oceans

Salt	Concentration (3.5°Be)
$CaCO_3$	0.0113 %
$CaSO_4$	0.1385 %
NaCl	2.6610 %
$MgSO_4$	0.2086 %
$MgCl_2$	0.3302 %
KCl	0.0723 %
NaBr	0.0083 %
Total Salts	3.4302 %

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Chemistry of Sea Water – Start of $CaSO_4$ Crystallisation

Salt	Concentration (11.94°Be)
CaCO3	0.0054 %
CaSO4	0.4632 %
NaCl	9.1690 %
MgSO4	0.7430 %
MgCl2	1.1050 %
KCl	0.2486 %
NaBr	0.0287 %
Total Salts	11.7629 %

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Chemistry of Sea Water – Start of NaCl Crystallisation

Salt	Concentration (26.0°Be)
$CaCO_3$	0.0010 %
$CaSO_4$	0.1149 %
NaCl	22.0250 %
$MgSO_4$	1.8100 %
$MgCl_2$	2.6490 %
KCl	0.5963 %
NaBr	0.0689 %
Total Salts	27.2651 %

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Chemistry of Sea Water – Discharge of Bitterns

Salt	Concentration (28.53°Be)
$CaCO_3$	0.0010 %
$CaSO_4$	0.0565 %
NaCl	15.5180 %
$MgSO_4$	4.5870 %
$MgCl_2$	6.7000 %
KCl	1.5030 %
NaBr	0.1730 %
Total Salts	28.5385 %

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Evaporation of Sea Water – Volume Change

Specific Gravity	Density (°Be)	Volume (litres)
1.0247	3.50	1'000.0
1.0897	11.94	273.6
1.2185	26.00	102.0
1.2450	28.53	39.4

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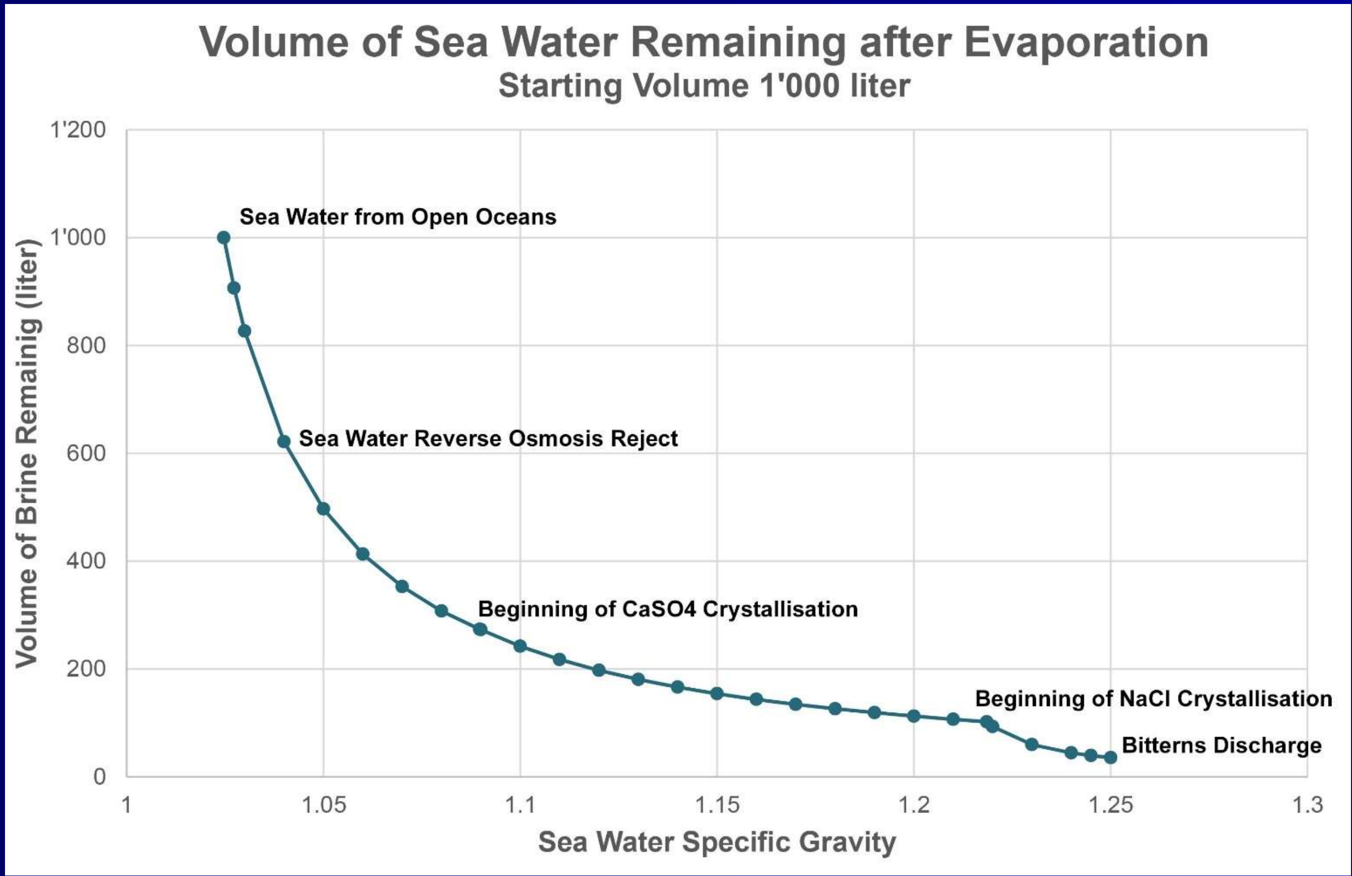
Volume of Sea Water during Evaporation



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When sea water evaporates or water is being removed in a desalination process, the volume is reduced and the concentration is rising. 96.45% of water is removed to crystallise 23.05 kg of NaCl from the original 1’000 l of sea water

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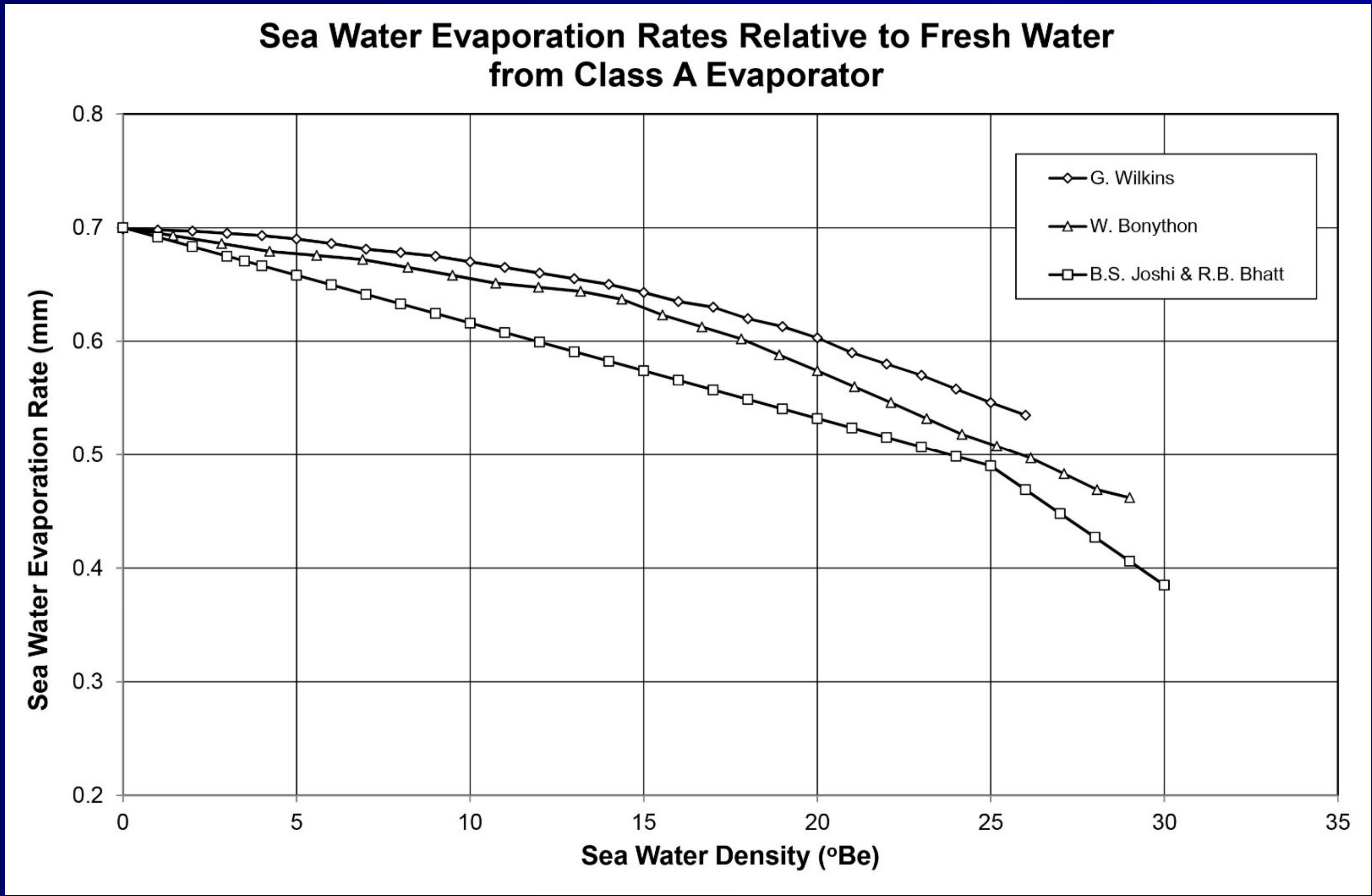
Sea Water Evaporation Rates



Sea water evaporates from solar ponds more slowly than drinking water from Class A evaporator.

The correlation is empirical.

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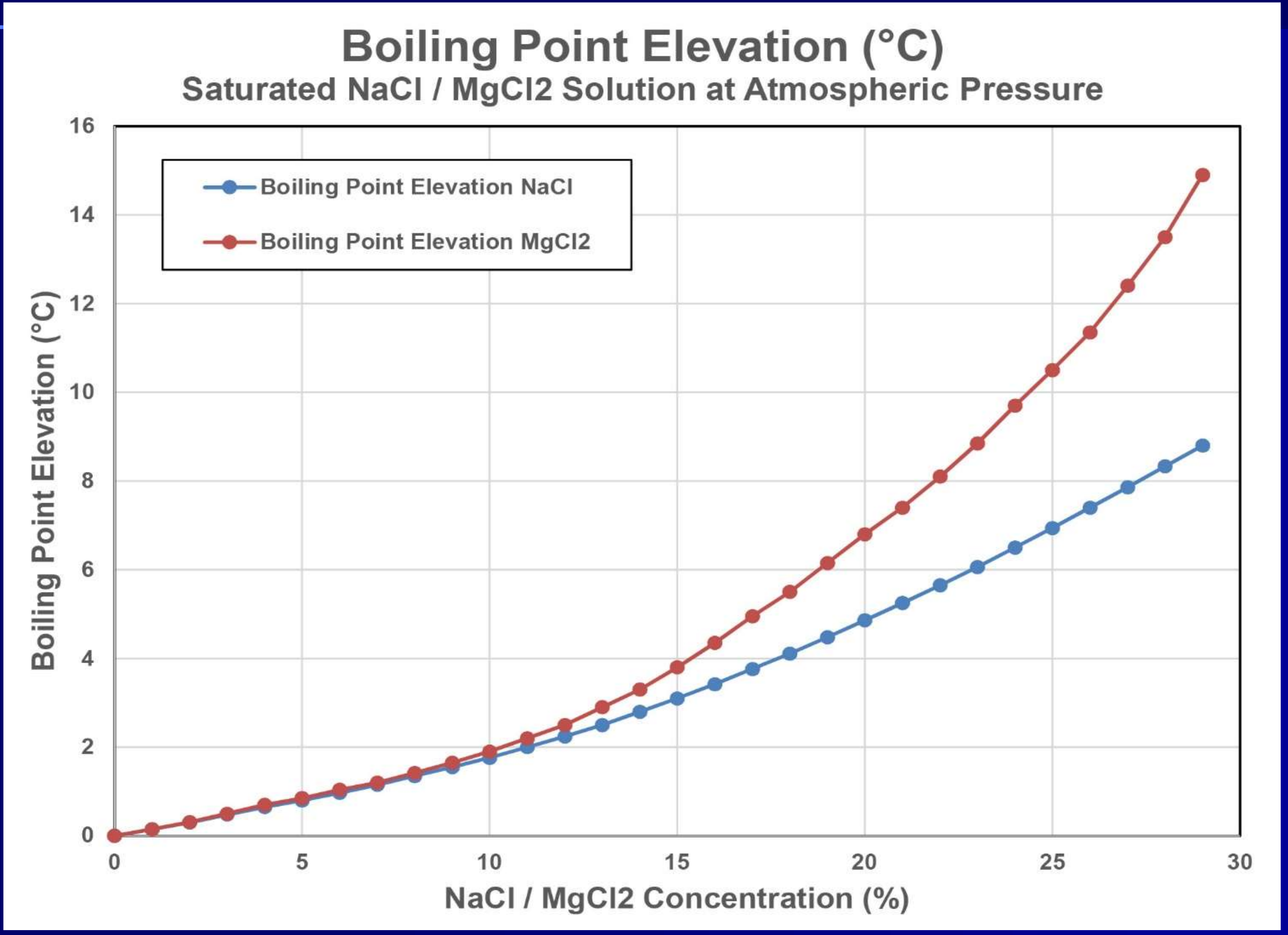
Boiling Point Elevation



Salt solution boils at a temperature that is higher than the temperature of water at the same pressure.

Polyvalent ions elevate the boiling point more than monovalent ions.

The higher the concentration, the higher is the boiling point elevation

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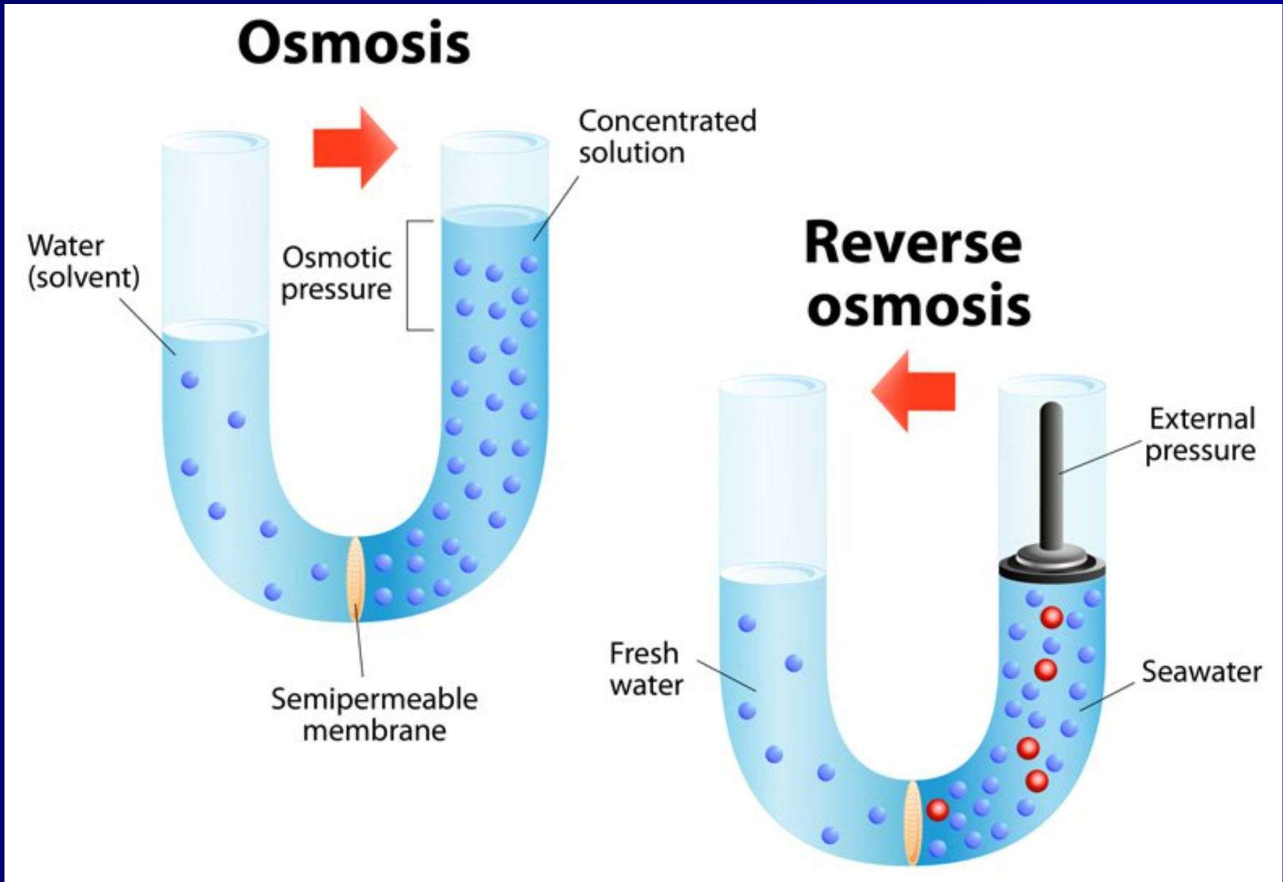
Osmosis and Reverse Osmosis



VectorStock

Concentrated salt solution pulls water through membrane from diluted solution up to the point of equilibrium pressure called the osmotic pressure.

When concentrated solution is under sufficient pressure, water flows through the membrane. This is called Reverse Osmosis (RO) or Sea Water Reverse Osmosis (SWRO)

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Osmotic Pressure of Concentrated Sea Water

1 mol/l of dissolved ions causes approx. 25 bar osmotic pressure.

1 mol of sodium ions (Na^+) weighs 23 gram, 1 mol of chloride ions (Cl^-) weighs 35.5 gram, 1 mol of sodium chloride (NaCl), weighing 58.5 gram, dissolved in 1 litre of brine causes approx. 50 bar osmotic pressure.

1 mol of magnesium ions (Mg^{++}) weighs 24 gram, 2 mol of chloride ions (Cl^-) weighs 71 g, 1 mol of magnesium chloride ($MgCl_2$), weighing 95 gram, dissolved in 1 litre of brine causes approx. 75 bar osmotic pressure.

Polyamide thin-film composite membrane operating at max. 83 bar (1'200 psig) can recover approx. 400 litres drinking water from 1 m2 of sea water and reject approx. 600 litres of sea water concentrated up to approx. 6% total dissolved solids (TDS).

How can additional water and salt be recovered from the reject?

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Concentrating Sea Water beyond 6%

Within the framework of a Project No. 3387, Salt Partners had to determine the most economic technology out of the following then available options:

- **Processing with or without brine purification (chemical, membranes, etc.)**
- **Solar concentration and crystallisation;**
- **Thermal evaporation and crystallisation;**
- **Electrodialysis;**
- **Flash or falling film evaporation;**
- **Multiple effect evaporation / crystallisation with forced circulation;**
- **Mechanical or thermal vapour recompression, etc.**

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Project No. 3387 Execution

For Project No. 3387 Salt Partners:

- **Contacted a large number of potential vendors;**
- **Received prequalification documents from 15 vendors;**
- **Received 5 detailed proposals;**
- **Reviewed and evaluated the proposals by means of a financial model;**
- **Submitted final project report with recommendations;**
- **Salt Partners recommendations were accepted for implementation.**

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Technologies Proposed for Project No. 3387

Vendor	Technology
A	6 lines of 6 multiple effect evaporators each
B1	Nanofiltration, reverse osmosis, 3-effect falling film evaporators, NaCl crystallisation by company B2
B2	7-effect falling film evaporators, 5-effect evaporation and crystallisation with forced circulation
C	5-effect evaporation and crystallisation with forced circulation, single flash evaporation and crystallisation, gypsum slurry
D	Nanofiltration, degassing, 7-effect falling film evaporators, 5-effect evaporation and crystallisation with forced circulation
E	15-stage flash evaporation, 5-effect evaporation and crystallisation with forced circulation, gypsum slurry

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Economic Evaluation of Technologies

Costs given in USD per ton of salt product

Vendor	A	B	C	D	E
Power	15.6	14.4	12.2	13.9	6.2
Steam	12.2	11.7	12.5	9.9	9.9
Membranes		0.6		0.6	
Chemicals		15.9		0.1	1.5
Wages	0.8	0.8	0.9	0.8	0.8
Maintenance	19.4	6.4	9.0	9.3	5.6
General	4.5	4.5	4.5	4.5	4.5
Production cost	52.5	54.4	39.0	39.1	28.6

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Economic Evaluation of Technologies

Annual figures given in USD mio. per ton of product, investment in USD mio.

Vendor	A	B	C	D	E
Sales	15.0	15.0	14.1	15.0	15.0
Operating cost	- 10.5	- 10.9	- 7.3	- 8.0	- 5.7
Depreciation	- 5.2	- 1.7	- 2.3	- 2.5	- 1.5
Gross Earnings	- 0.7	2.4	4.5	4.6	7.8
Tax	0	- 0.8	- 1.5	- 1.5	- 2.6
Net Earnings	- 0.7	1.6	3.0	3.1	5.2
Investment	129.2	42.8	56.6	61.8	37.5
Return on Investment	- 0.5%	5.5%	8%	7.5%	21%

Return on investment calculated over the life of the project

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Economic Evaluation of Technologies

Investment in mio USD. Return on equity based on project capacity to borrow

Vendor	A	B	C	D	E
Investment	129.2	42.8	56.6	61.8	37.5
Equity *)	100%	82%	72%	70%	30%
Return on Investment	- 0.5%	5.5%	8%	7.5%	21%
Return on Equity **)	- 1%	6%	8%	9%	55%

*) Equity expressed as percentage of total investment.

**) Average return on equity over project life expressed as percentage per annum including initial years with lower capacity utilisation and years in which interest on long term loan is paid.

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Project No. 3387 under construction

Driving of reinforced cast concrete piles 50 meters deep into the ground.

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New UHP Reverse Osmosis Membranes

Recently, new reverse osmosis membranes became available that can operate at up to 120 bar g.

- **2 mol of sodium chloride (NaCl), weighing 117 gram, dissolved in 1 litre of brine causes approx. 100 bar osmotic pressure;**
- **If polyvalent ions are removed, almost double concentration of the desalination reject can be achieved;**
- **Starting from higher concentration, the investment and operating cost of the project No. 3387 will be reduced.**

Will the new membranes improve the economy of salt production from desalination reject?

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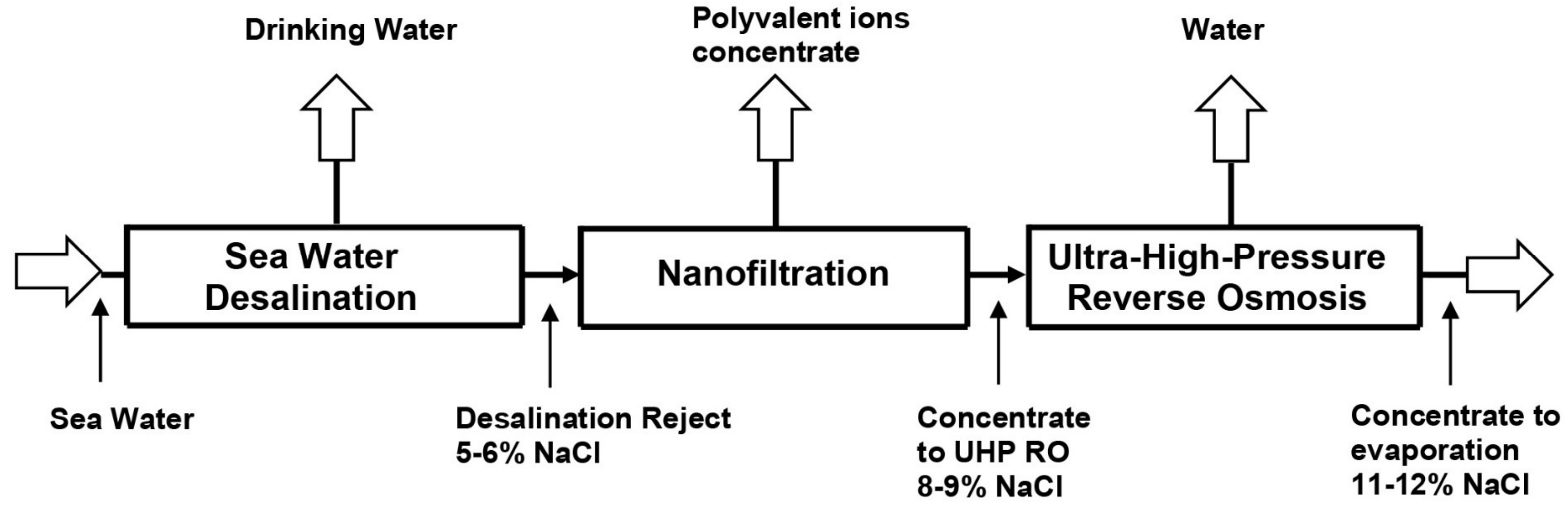
New SWRO-NF-UHPRO Process Flowsheet



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Nanofiltration of Sea Water Desalination Reject

Ion	Rejection	Permeation
Sodium	5%	95%
Potassium	14%	86%
Calcium	23%	77%
Magnesium	76%	24%
Chloride	4%	96%
Sulphate	98%	2%
Bicarbonate	86%	14%

DOW

Nanofiltration can remove polyvalent ions, prevent calcium sulphate crystallisation (scaling) and facilitate better performance of UHP RO

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Economic Evaluation of the SWRO-NF-UHPRO Process

Investment in mio USD. Return on equity based on project capacity to borrow

Vendor	**E (Original Project 3387)**	**E (With new membranes)**
Investment	37.5	36.6
Equity *)	30%	30%
Return on Investment	21%	28%
Return on Equity **)	55%	74%

*) Equity expressed as percentage of total investment.

**) Average return on equity over project life expressed as percentage per annum including initial years with lower capacity utilisation and years in which interest on long term loan is paid.

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Other Nanofiltration Applications

Nanofiltration is applicable also for the following salt from desalination reject production options:

- **Nanofiltration before sea water reverse osmosis improves water production efficiency due to lower concentration of polyvalent ions in the feed;**
- **Nanofiltration removes antiscalants from desalination reject facilitating undisturbed solar salt crystallisation.**

Economy of these applications needs to be examined on case-to-case bases.

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Middle East

Middle East countries have abundant sources of hydrocarbons needed for production of plastics, petrochemicals, organic intermediates, etc., which require chlorine for organic synthesis and therefore salt for electrolysis.

They have not only the highest insolation for production of solar salt but also the highest drinking water requirement.

In the Middle East, simultaneous production of salt and water makes a lot of sense.

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Middle East development projects

Some of the most spectacular petrochemical projects are being implemented in the Middle East, for example the Sadara Chemicals, a joint venture between Dow and Saudi Aramco, who invested 20 billion US dollars to produce 26 high value chemicals and plastics from natural hydrocarbons and salt. Salt Partners supplied the salt plant.

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Sadara Ethylene Cracker

Source: Arab News, August 29, 2016

Sadara ethylene cracker, consisting of 12 furnaces, 7 will cracking natural gas and 5 cracking naphtha, 3 of those cracking also natural gas.

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Conclusions

Production of salt from sea water desalination reject makes sense when:

- Desalination of sea water is necessary;
- Additional water production is required;
- Cost of power and steam is acceptable;
- Markets can absorb the salt at adequate prices.

New high pressure reverse osmosis membranes improve the economy of salt from sea water desalination reject production.

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Why not turn your salt into gold?

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