# Osmotic power plants

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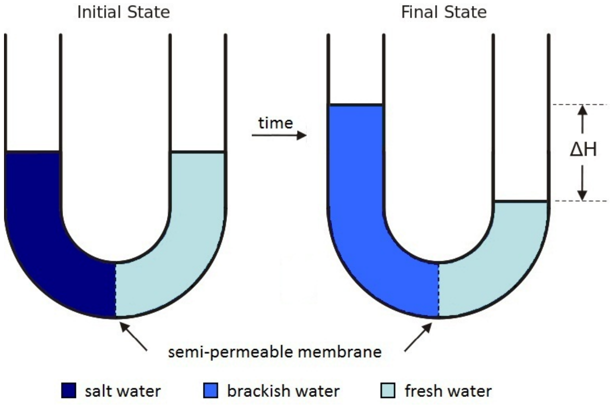
## Introduction

- Due to the natural fluctuations of solar and wind power generation, additional renewable but stable energy sources are desired.
- An osmotic power plant uses the so called "mixing entropy". Only fresh water and salt water are required.
- In 2009 Statkraft built the first osmotic test power plant.

# Principle of osmosis

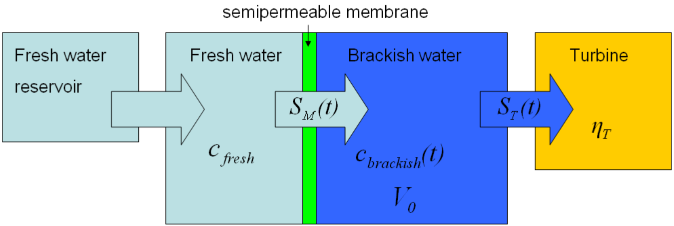



$$p_{hydro} = \rho \cdot g \cdot \Delta H$$

Steady state for
$p_{osm} = p_{hydro}$

Difference in concentration leads to the “osmotic pressure”.

Oceanic salt water (salinity of 3.5 %): $p_{osm} = 28.8\,\text{bar}$
$\Rightarrow \Delta E^{theo} = 2.88\,\text{MJ}$ per $1\,\text{m}^3$ fresh water

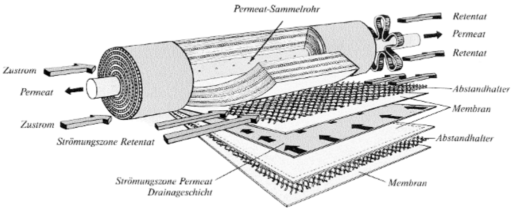



Due to dilution the concentration difference decreases!
$\Rightarrow$ lower osmotic pressure $\Rightarrow$ lower power output

Current membranes: $\sim 3\,\frac{\mathrm{W}}{\mathrm{m}^2}$

Packing density of $1000\,\mathrm{m}^2$ membrane in $1\,\mathrm{m}^3$ module.

Developed for and used in desalination plants.

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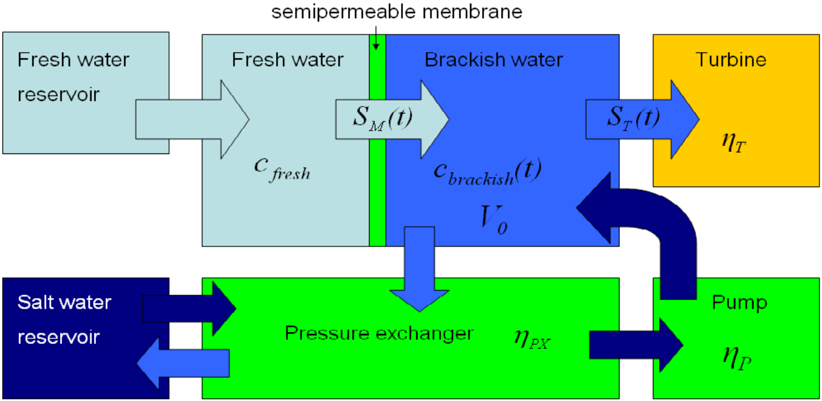



Resulting power of the plant: $P_{PP} = P_{turbine} - P_{pump}$

Higher concentration means higher $P_{turbine}$ but also higher $P_{pump}$.

Two valves can be controlled externally. $\Rightarrow$ two optimisations

# Quantitative results of the optimisations

## Concentration optimisation: Getting the most energy

Inefficiency of the pressure exchanger leads to:

$c_{brackish} = x \cdot c_{salt}$, $0 \le x \le 1$, $x$ depends on the efficiencies.

Realistic value: $x = 0.75$

## Pressure optimisation: Making the most money

$p_{operating} = f \cdot p_{osmotic}^{(brackish)}$, $0 \le f \le 1$, $f$ depends on the economy.

Higher operating pressure leads to less membrane flow:

Power: $P \sim A \cdot (f - f^2)$, Efficiency: $\eta = f \cdot 0.54$

$f = \frac{1}{2}$: optimal power, but low energy output

$f \approx 1$: optimal efficiency, but very low power per membrane area

Realistic value: $f = 0.7 - 0.9$

Rhine river ($S_M = 2300 \, \frac{\mathrm{m}^3}{\mathrm{s}}$): $P = 2.1\,\mathrm{GW}$

# Economy

- High investment costs: Depending strongly on the required membrane area
- Current quality ($\sim 3\,\frac{\mathrm{W}}{\mathrm{m}^2}$) and prices ($\sim 30\,\frac{\mathrm{Euro}}{\mathrm{m}^2}$), neglecting technical losses: Generation costs of around $12.5\,\frac{\mathrm{Eurocent}}{\mathrm{kWh}}$
- Would be cheaper than solar power, competitive to wind power. [3]

# Salt lakes

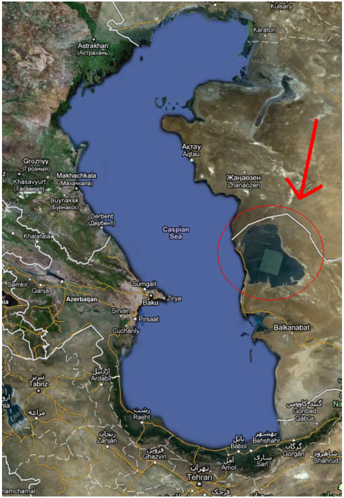
*Parameters:* $f = 0.7$, $S_M = 100\,\frac{m^3}{s}$

## Dead Sea:

Mean salinity: 28 %, $P_{PP} = 0.9\,\mathrm{GW}$
Red Sea-Dead Sea Canal:
Since 2005 Israel, Jordan and Palestine check the feasibility.

## Kara-Bogas-Gol:

Mean salinity: 34 %, $P_{PP} = 1.0\,\mathrm{GW}$
Largest global brackish water reservoir: The Caspian Sea
$\Rightarrow$ A much larger $S_M$ can be used!




Kara-Bogas-Gol [Google Maps]

# Potential and Conclusions:

- Global electric energy consumption 2009: 20000 TWh
- (River) Potential of osmotic power: $E_{global}^{year} = 14400\,\text{TWh}$
- Due to ecology and economy only around 1600 TWh usable
- Osmotic power will not solve the global energy problem but offers a stable and cheap energy supply of up to 8 % of the global demand.
- By using natural and artificial salt lakes these values can increase dramatically.
- On local scales osmotic power could become an important component of the energy supply, next to salt lakes the dominating one.

# Sources


- [1] Dinger et al., 2011: *Osmosekraftwerke und ihr Potential*, Bachelor-Thesis, Universitaet Heidelberg
- [2] Fliessbach, 2010: *Statistische Physik*, Spektrum
- [3] Kost and Schlegl, 2010. *Studie Stromgestehungskosten Erneuerbare Energien*, Fraunhofer-Institut fuer solare Energiesysteme.
- [4] Melin and Rautenbach, 2007: *Membranverfahren*, Springer
- [5] Zeuner et al., 2011: *Das weltweite Potential von Mischungsentropiekraftwerken*, Bachelor-Thesis, Universitaet Heidelberg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# Looking for a location

Problems:

- Low salinity of the sea
- Brackish water zone: Pipeline system or dam required
- River delta
- Pollution: mud and algae
- Nature reserves
- Frozen rivers

- Giant rivers ($>7000\,\frac{m^3}{s}$, 50% of global river water) almost not usable.
- Potential in Germany: Only Elbe and Weser end in the sea. Elbe with large brackish water zone and port of Hamburg not suitable.