OSMOTIC POWER
Availability

- The globally available power has been estimated to be between 1.4 and 2.6TW
- Mixing 1m³ of river water with 1m³ of sea water at 293K gives 1.4MJ
- But mixing 1m³ of river water with “infinite” m³ of sea water gives 2.3MJ
- Mississippi with an average discharge of 17000 m³/s has a potential of 40 GW of which 9.8GW is technically possible to convert to electricity

[2]
History

- One first mentions of this was done in 1954 by R.E. Pattle [8]
- During the 1970s osmotic power made progress as the membrane technology was developed by Loeb S. [6]
- Has again become more popular as the price of energy has gone up and the demand for green energy has increased
- The properties of the membrane has been and still are the problem for a successful deployment of the concept

[2]
Work from a salt power plant

- The mixing of sea water with fresh water gives a (mixing) exergy effect that can be exploited.
- **Osmosis** leads to transport of water across the membrane from the fresh to salt side solution.

The Gibbs energy of mixing gives the maximum work obtainable from the process at constant temperature and pressure.

\[ -W_{\text{ideal}} = \Delta_{\text{mix}} G \]
Work from a salt power plant

- This gives a hydrostatic pressure difference
- Installing a membrane system at 120-150 m below fresh water intake allows for a significant extra hydro power effect

In the present case, the mixing process is primarily driven by the entropy of mixing, $\Delta_{\text{mix}}S$, because $\Delta_{\text{mix}}H \approx 0$. We want to estimate the order of magnitude of $T\Delta_{\text{mix}}S$. Consider therefore the mixing of one mole of pure water into an excess of salt solution (with $n_w$ moles of water and $n_s$ moles of salt). The pure water has molar entropy $S_w^0$. We assume that the partial molar entropy of salt, $S_s$, and water, $S_w$, remain constant during mixing. This gives

$$\Delta_{\text{mix}}S = [(n_w + 1)S_w + n_sS_s] - [(n_wS_w + n_sS_s) + S_w^0] = S_w - S_w^0$$

$$= -R \ln x_w$$

[7]
Work from a salt power plant

- The fresh water will go through the membrane, against a pressure difference; the pressure on the sea water side is not high enough to prevent the fresh water movement.

\[ \Delta_{\text{mix}} G = -T \Delta_{\text{mix}} S = RT \ln x_w = -30.1 \text{ J/mol or } -1.60 \text{ kJ/kg water} \]
Work from a salt power plant

- In reality, only part of the potential energy is recovered; the unit can’t be as low as 163 m below the fresh water intake.
- Entropy production in the membrane (combined heat and mass transfer) is important.

This means that a saline power plant can deliver maximum 1.60 kJ work per kg of water transported between the two energy levels. Or when 1 m$^3$/s of river water is mixed with 1 m$^3$/s of sea water, the maximum power attainable is 1.6 MW. The available energy corresponds to the potential energy change of lifting one m$^3$ of water to a height of 163 m. The calculated height is the maximum depth for the position of the membrane module in Fig. When work is extracted from the power plant, the mixture will lose some internal energy. This cooling is of the order of 0.1 °C, and is thus not significant.

[7]
Time evolution of solution pressure in a rigid container [1]

- An ideal membrane is compared to a membrane with a small leakage. $t_1$ can be of the order of a couple of minutes to a few days.

A schematic view of a membrane[5]

- The membrane consists of a support structure and of the “active component”, the skin. The concentration difference between $C_4$ and $C_3$ drives the system.
- The membrane material can be biological or synthetic, cellulose acetate has been for instance used.
Efficiency of the membrane [1]

Figure 14 a) Efficiency of the skin as a function of the water flux - solute flux ratio ($\psi = J_1/J_2$). The following parameter values were used: $\pi_3 - \pi_{\text{osm}} = 24$ bar, $p_1 - p_2 = p_3 - p_1 = 0$ bar, $T = 298$ K. The symbol $\pi_{1(2)}$ means that the osmotic pressure can be estimated either from Position 1 or 2. In the former case the results correspond to the efficiency of the total membrane and in the latter case to the efficiency of the skin. b) The membrane structure.
The power efficiency of the membrane

The efficiency has increased from 0.1W/m² to 3 during the research at Statkraft [4]
Schematic view of a osmotic power plant [3]

- This plant can be run at the surface of the earth due to the pressure exchanger.
- The pressure exchanger uses 2/3 of the pressurized water.
- The pressure exchanger could be swapped for a pump but that is even a worse of an idea.
- How to run the pressure exchanger is important for the production of electricity.
- An average 25 MW plant is calculated to need 5 million m² of membranes.
Prototype by Statkraft

- Was started the 24 of November in Tofte outside Oslo, Norway
- The plant is equipped with 2000m² of membranes
- The design capacity is 10kW, but that is not yet the production
The development of the concept of osmotic power at Statkraft [6]
References:


