

Chemical Engineering Thermodynamics
Quiz 6
February 20, 2019

Power could be generated by mixing of salt and fresh water using a semi-permeable membrane. Fresh water “wants to” dilute salt water (*meaning that dilution lowers the Gibbs free energy*). This can lead to a pressure if a barrier for salt that allows free passage of water (a *semipermeable membrane*) connects a salt water bath to a fresh water bath.

For our purposes the membrane bank is a pump that moves water from the fresh to the salt streams. The pressure in the salt stream is determined by the osmotic pressure related to the salinity of the sea water. Determine the viability of this as a power source by calculating the net energy production from the layout shown below. The dashed line in the central box is the membrane that “pumps” pure water to dilute the salt water. The pressurized salt water drives a turbine to produce electricity between streams 4 and 3. All streams are liquid water with $V = 1000 \text{ cm}^3/\text{kg}$ and the parameters listed in the table ($1 \text{ J} = 1 \text{ MPa cm}^3$).

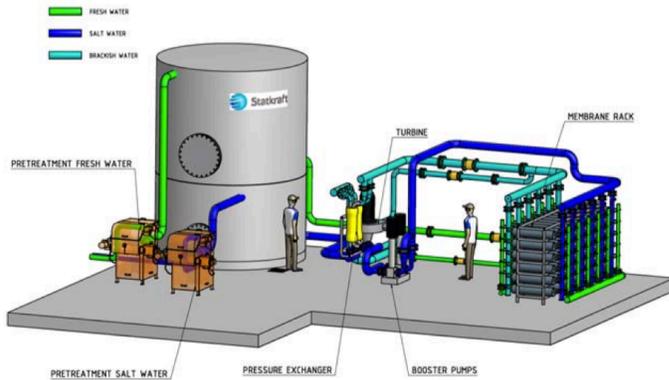
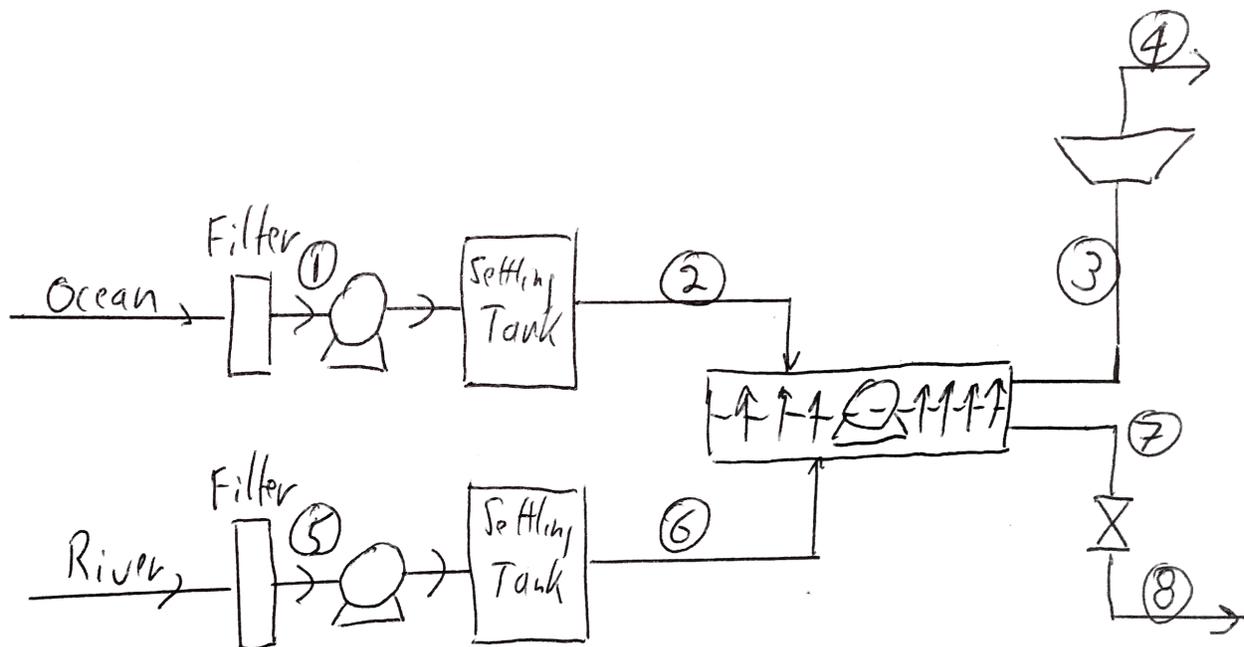


Illustration text: *The prototype at the East coast of Norway*

[https://www.statkraft.com/globalassets/old-contains-the-old-folder-structure/documents/waterpower_xvi - power production based on osmotic pressure_tcm21-4795.pdf](https://www.statkraft.com/globalassets/old-contains-the-old-folder-structure/documents/waterpower_xvi_-_power_production_based_on_osmotic_pressure_tcm21-4795.pdf)

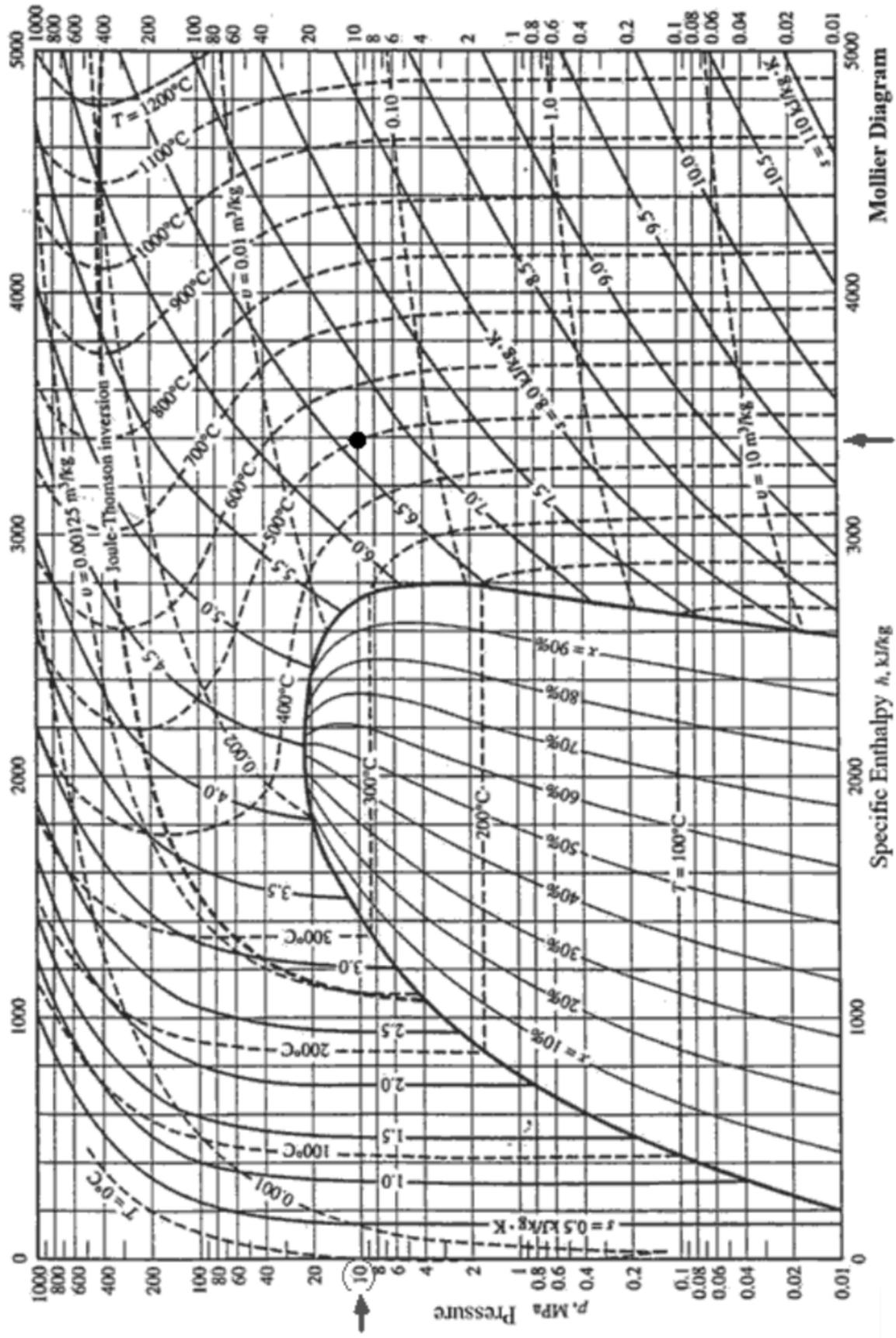


Stream	State	dm/dt, kg/s	T, °C	P, Mpa	η_e	H, kJ/kg	S, kJ/(kg °K)	ΔH , kJ/kg
1	L	1	10	0.1				--
2'	L	1	10	1.5				
2	L	1	10	1.5	0.8			
3	L	1.5	10	1.5	0.8			--
4'	L	1.5	10	0.1				
4	L	1.5	10	0.1	0.9			
5	L	1	10	0.1				--
6'	L	1	10	0.15				
6	L	1	10	0.15	0.8			
7	L	0.5	10	0.15				--
8	L	0.5	10	0.1				--

- Fill out the missing values from the table. **For the pumps and turbine use $W_s' = V\Delta P$ but also show the points on the chart below as best you can to get H for streams 1 and 5 and S for all streams. Assume the charts apply to salt and fresh water.**
- Find the total work that is produced (or consumed) by this operation in kJ/s (note that the streams have different flow rates). What flow rate would be needed for a 50 MW power plant? Does this seem like a viable energy source compared to a Rankine cycle power plant?
- What is the efficiency of the membrane as a pump?
- Calculate the kinetic energy change of the throttle (change in $\frac{1}{2} mv^2$). Assume a 15 cm inner diameter pipe ($A = \pi r^2$) and constant density (specific volume is 1000 cm³/kg).
- Extra credit: Give an alternative use of the ocean near the coast for power generation; describe a means to measure the potential of your proposed method as a power source.*

Summary of Process and General Rules

Nozzle	$\Delta S = 0$ $\Delta H = \Delta(1/2 mv^2)$	Isothermal	$(\Delta S)_T = R \ln[V_2/V_1]$ i.g. $= -R \ln[P_2/P_1]$ $(\Delta H)_T = 0$
Throttle	$\Delta S = -R \ln(P_2/P_1)$ (i.g.) $\Delta H = 1/2 mv^2$ Generally $\Delta H = 0$	Ideal Mixing	$\Delta S_{\text{mix}} = -R \sum x_i \ln x_i$
Pump	$\Delta S = 0$ for adiabatic reversible $\Delta H = W_s = \Delta H' / \eta_{\text{eff}}$	Adiabatic, Reversible	$\Delta S = 0$
Turbine	$\Delta S = 0$ for adiabatic reversible $\Delta H = W_s = \Delta H' \eta_{\text{eff}}$	Isobaric	$(dS)_P = C_p (dT)_P / T$ $(dS/dT)_P = C_p / T$
	Carnot (Use °K)	Constant Volume	$(dS)_V = C_v (dT)_V / T$ $(dS/dT)_V = C_v / T$
Engine	$\eta_{\text{eff}} = (T_H - T_C) / T_H$	Phase Change	$\Delta S_{\text{trans}} = \Delta H_{\text{trans}} / T_{\text{trans}}$
Refrigerator	$COP = T_C / (T_H - T_C)$		
Heat Pump	$COP = T_H / (T_H - T_C)$		



Answers: Chemical Engineering Thermodynamics
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Stream	State	dm/dt , kg/s	T , °C	P , Mpa	η_e	H , kJ/kg	S , kJ/(kg °K)	ΔH , kJ/kg
1	L	1	10	0.1		30	0.2	--
2'	L	1	10	1.5		31.4	0.2	1.40
2	L	1	10	1.5	0.8	31.8	0.2	1.75
3	L	1.5	10	1.5	0.8	31.8	0.2	--
4'	L	1.5	10	0.1		30.4	0.2	-1.40
4	L	1.5	10	0.1	0.85	30.5	0.2	-1.25
5	L	1	10	0.1		30	0.2	--
6'	L	1	10	0.15		30.1	0.2	0.05
6	L	1	10	0.15	0.8	30.1	0.2	0.06
7	L	0.5	10	0.15		30.1	0.2	--
8	L	0.5	10	0.1		30.1	0.2	--

b) $1\text{ kg/s } 1.75\text{ kJ/kg} - 1.5\text{ kg/s } 1.25\text{ kJ/s} + 0.06\text{ kJ/kg } 1\text{ kg/s} = -0.065\text{ kJ/s}$ for 1 kg/s flow. $50,000\text{ kW}/0.06\text{ kW} = 800,000\text{ kg/s}$ which is the total flow rate of a moderate sized river like the Ohio. So this would not seem to be a viable energy source.

c) Pump 6 to 3 with 0.5 kg/s flow rate $\Delta P = 1.4\text{ MPa}$ so 1.4 kJ/kg
 $\Delta H_{6-3} = 1.7\text{ kJ/kg}$

Efficiency Pump = Ideal Power/Actual Power (larger) = $1.4\text{ kJ/kg} / 1.7\text{ kJ/kg} = 0.824$

d) The flow rates are the same and there is assumed no density change so there is no velocity change so this is 0.

e) Tidal Power-> Calculate the potential energy of raising a large amount of water

Wave Power-> Calculate the kinetic energy with the frequency and height of the waves or potential energy of raising and dropping water a meter or so with the frequency of the waves

Tidal Flow-> Use a kinetic energy calculation. Eventually a pressure head and $V\Delta P$.

