Problem 1: Electrodialysis

A total of 325 m³/day of an aqueous solution of 3,000 ppm of NaCl is to be desalinated to 400 ppm by electrodialysis, with a 40% conversion of this solution to potable water. The system used has four stages in series; all liquid travels from one stage to the next. Each stage has three parallel stacks with 150 cell pairs in each stack. The fractional desalination (or $c_{out}/c_{in}$) will be the same for each stage.

The expected current efficiency is $\xi = 90\%$. The applied voltage for the first stage is 220 Vdc. Each cell pair has an area of 1,160 cm². Calculate the current density $i$ in mA/cm², the current $I$ in A, and the power requirement in kW for the first stage.

Problem 2: Boiling Point Elevation and Osmotic Coefficient

Consider a solvent containing a non-volatile solutes (e.g., water with salt in it) at a temperature $T_s$. The solution is in equilibrium with pure vapor of the solvent at this temperature. The pure solvent has a saturation temperature (or boiling point) $T_{bp}$ at this pressure, with $T_s > T_{bp}$. Let $\tilde{G}_w^v$ be the partial molar Gibbs energy of solvent in the vapor phase and $\tilde{G}_w^l$ be the partial molar Gibbs energy of solvent in the liquid phase.

A. If $\Delta_{vap}G_w$ is the change in molar Gibbs energy of the pure solvent when it vaporizes at temperature $T_s$ (which is above the normal boiling point), show that

$$\ln a_w = \frac{\Delta_{vap}G_w}{RT_s}$$

where $a_w$ is the chemical activity of the solvent in the solution at temperature $T_s$.

B. Use the result of A to show that

$$-\ln a_w = \frac{\Delta_{vap}H_w}{RT_{bp}^2} \left( T_s - T_{bp} \right)$$

To do this, note that $\Delta_{vap}G_w$ is zero at $T_{bp}$, but becomes increasingly negative as $T$ increase beyond $T_{bp}$. In doing this, you may assume that $\Delta_{vap}H_w$ and $\Delta_{vap}S_w$ are independent of temperature for temperatures near $T_{bp}$.

C. The osmotic coefficient, $\phi$, is related to the chemical activity as

$$\ln a_w \equiv -\phi M_w \left( 10^{-3} \text{ kg/g} \right) \left( \sum_i m_i \right)$$

where \( M_w \) is the molar mass of the solvent in grams/mol and \( \sum_i m_i \) is the sum of the molalities of all solutes. Use the data for \( \phi \) that was distributed in class to find the point boiling elevation, \( T_s - T_{bp} \), of aqueous sodium chloride solution at molalities of \( m_{NaCl} = 0.5, 0.62, 1.0, \) and 2.0 mol NaCl/kg H₂O and a pressure of 1 bar.

### PROBLEM 3: SEA SALT, SODIUM CHLORIDE, AND VAPOR PRESSURE

Values of the osmotic coefficient for seawater are as follow, where \( w \) is the mass fraction of sea salt.*

<table>
<thead>
<tr>
<th>Temperature of 25°C</th>
<th>Temperature of 100°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w ) (%)</td>
<td>( \phi )</td>
</tr>
<tr>
<td>1.0</td>
<td>0.9052</td>
</tr>
<tr>
<td>2.0</td>
<td>0.9007</td>
</tr>
<tr>
<td>3.45</td>
<td>0.9048</td>
</tr>
<tr>
<td>4.0</td>
<td>0.9080</td>
</tr>
</tbody>
</table>

A. If we wish to make an aqueous sodium chloride solution have the same chemical activity for water, \( a_w \), as seawater at 25°C and 34,500 ppm, what molality and mass fraction should the sodium chloride solution have? What about at 100°C? For this seawater, \( \Sigma_i m_i = 1.134 \) mol/kg.

B. For low pressures, the chemical activity of solvent in solution, \( a_w \), is equal to the vapor pressure of the solvent divided by the vapor pressure (or saturation pressure) of the pure solvent at the same temperature:

\[
a_w = \frac{p_{vap,w}}{p_{sat,w}(T)}.
\]

(When the solvent is ideal, with \( \gamma_w = 1 \), this becomes Raoult’s law, as discussed in class.) Use the data for \( \phi \) to calculate the vapor pressure of seawater at 34,500 ppm and temperatures of 25°C and 100°C.

C. Compare the vapor pressures obtained in Part B to those obtained using Raoult’s law under the same conditions. What do you conclude?