2.500 Desalination and Water Purification

Spring 2009

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Homework Set #1
Due 24 February 2009

Problem 1: Ionic strength of seawater

Mixed electrolytes are characterized by the *ionic strength*, I

$$I = \frac{1}{2} \sum_i m_i z_i^2$$

in which m_i is the molality of each ion in solution and z_i is the valence of the ion. Using the data for standard seawater ($35{,}000$ ppm) distributed in the first lecture, calculate the ionic strength of seawater and compare it to that of 0.62 molal aqueous sodium chloride.

Problem 2: Heats of solution

In class, we considered the heat of solution of sodium chloride in water ($\Delta H_{\text{sol}} = +3.88$ kJ/mol). This is a relatively small heat of solution. The following quick calculations are for some other salts, which have substantially larger heats of solution.

For each substance, determine the temperature change when 5.0 g of solute are added to 50.0 g of water in an adiabatic container. Take properties at 25°C and 1 atm.

- **A.** Calcium chloride ($CaCl_2$): $\Delta H_{\text{sol}} = -81.3$ kJ/mol. The calcium chloride is assumed to be anhydrous (i.e., assumed not to contain any bound water as it often does).

- **B.** Magnesium sulfate ($MgSO_4$): $\Delta H_{\text{sol}} = -90.9$ kJ/mol. The magnesium sulfate is assumed to be anhydrous; it often forms a heptahydrate, $MgSO_4\cdot(7H_2O)$, known as Epsom Salt.

- **C.** Calcium sulfate ($CaSO_4$): $\Delta H_{\text{sol}} = -19.2$ kJ/mol. The calcium sulfate is assumed to be anhydrous; depending upon the degree of hydration, it may take the form of gypsum or Plaster of Paris.

- **D.** Ammonium nitrate (NH_4NO_3): $\Delta H_{\text{sol}} = +25.7$ kJ/mol. The typical "cold pack" contains ammonium nitrate and water.

Problem 3: Least work of separation

- **A.** What is the least work required per kilogram of fresh water to recover 69% of the water from a 35000 ppm seawater stream? Model the seawater stream as aqueous NaCl at 0.62 mol/kg and set temperature to 25°C and pressure to 1 bar.

B. What is the least work required per kilogram of fresh water to recover 67% of the water from a 5000 ppm brackish water stream? Assume that the only solute in the brackish water is NaCl.

C. In our least work calculations, we have normally assumed that the product stream contains 0 ppm of salt. For membrane-based separation processes, this is unrealistic: product water (or *permeate*) will contain TDS of 60 to 300 ppm. Suppose that the product streams in Parts A and B contain 200 ppm of NaCl. Does the least work increase or decrease? By how much (in kJ/kg) does the least work change?

D. In class, we calculated the least work (in kJ/kg) to separate a small amount of fresh water from a large volume of 3.5 wt% aqueous NaCl solution. Measurements show that the activity of water in seawater at 3.45 wt% is $a_w = 0.9816$, about 0.36% higher. What is the least work in this case? Explain your result.

Problem 4: Alkalinity

A sample of ground water has 410 mg HCO_3^- per liter and a pH of 7.6.

A. Do we need to know the concentration of CO_3^{2-} to determine alkalinity? Why or why not?

B. What is the concentration of OH^- in mol/L?

C. What is the alkalinity as mg $CaCO_3$/L?

Problem 5: What makes water undrinkable?

We have seen that various substances are undesirable in drinking water. Please refer to the literature to determine what maximum concentration limits, if any, apply to the following substances. Make a table that gives the substance, the typical concentration limit, and the reason that this limit (or no limit) applies.

A good starting point for information is the World Health Organization's (WHO's) *Guidelines for Drinking Water*, 3rd ed., which is available on the course Stellar site. (This is a massive document, best read onscreen; it can be searched using Acrobat's search tool.) WHO also has a standard for desalinated water, which is also on the Stellar site.

Be aware that different agencies set different legal or practical limits on concentrations. For example, USEPA rules may differ from EU rules and/or from WHO guidelines. If you cite a standard, be sure to name the source.

A. Boron, B (or borate, BO_3^{3-})

B. Bromide, Br^- (which can form bromate, BrO_3^-, when water is disinfected with ozone)

C. Chloride, Cl^-

D. Flouride, Fl^-

E. Hardness: Calcium, Ca^{2+}, and magnesium, Mg^{2+}

F. Nitrate, NO_3^-, and nitrite, NO_2^-

G. Phosphate, PO_4^{3-}

H. Potassium, K^+

I. Silica, SiO_2

J. Sodium, Na^+

K. Sulfate, SO_4^{2-}

L. Total coliform

M. Total dissolved solids, TDS

Please remember that this is only a small subset of the substances that affect the potability of water. In particular, toxic metals, organic compounds, microorganisms, and by-products of disinfection must also be monitored and controlled. For further details, see: http://www.epa.gov/safewater/contaminants/