umn. The equilibrium relationship is $C_S^* = 20(C_L^*)^{1/2}$, and the operating-line relationship is $C_S = 5C_L$, where C_S is g solute/l resin and C_L is g solute/l solution.

11.5. In a cross-flow ultrafiltration unit, a protein of MW = 3×10^5 da is separated from the fermentation broth by using a UF membrane. The flow rate of liquid through a tube of diameter $d = 2$ cm and length $L = 50$ cm is $Q = 2$ l/min. The flow regime is turbulent, $f = 0.0005$, and $C_4 = 2$ [atm (s/cm)^2]. The inlet pressure is $P_i = 2$ atm. Protein concentrations in the solution and on gel film are $C_B = 30$ mg/l and $C_G = 100$ g/l, respectively.

- **a.** Determine the exit pressure (P_0).
- **b.** Determine the transmembrane pressure drop (ΔP_M).
- **c.** If the mass transfer coefficient (k) for protein flux is $k = 5$ cm/s, determine the flux of liquid through the UF membrane (J).
- **d.** If the resistance of the filter is $R_M = 0.002$ atm · cm^2 · s/cm^3, determine the cake resistance, R_G.

11.6. Components A and B of a binary mixture are to be separated in a chromatographic column. The adsorption isotherms of these compounds are given by the following equations:

$$m_A = f_A(c) = \frac{k_1 C_A}{k_2 + C_A}$$

$$m_B = f_B(c) = \frac{k_1' C_B}{k_2' + C_B}$$

where $k_1 = 0.2$ mg solute A absorbed/mg adsorbent

$k_2 = 0.1$ mg solute/ml liquid

$k'_1 = 0.05$ mg solute B adsorbed/mg adsorbent

$k'_2 = 0.02$ mg solute/ml liquid

The bed contains 3 g of very fine support particles. The bed volume is 150 ml, bed porosity is $\varepsilon = 0.35$, and the cross-sectional area of the bed is $A = 6$ cm^2. If the volume of the mixture added is $\Delta V = 50$ ml, determine the following:

- **a.** Position of each band A and B in the column, L_A and L_B (or ΔX_A and ΔX_B).
- **b.** L_A/L_B; $R_{fA} = L_A/L_c$; $R_{fB} = L_B/L_c$ when $C_A = 10^{-1}$ mg/ml and $C_B = 0.05$ mg/ml in liquid phase at equilibrium.

11.7. Consider the use of gel chromatography to separate two proteins A and B. The partition coefficient (K_D) for A is 0.5 and for B is 0.15. V_o, the void volume in the column, is 20 cm^3. V_i, the void volume within the gel particles, is 30 cm^3. The total volume of the column is 60 cm^3. The flow rate of elutant is 100 cm^3/h. Ignoring dispersion and other effects, how long will it take for A to exit the column? How long for B?

11.8. Biomass present in a fermentation broth is to be separated by vacuum filtration. Filter and broth characteristics are given below.

$$A = 50 \text{ m}^2, \qquad \Delta P = 0.01 \text{ N/m}^2, \qquad C = 15 \text{ kg/m}^3$$

$$\mu = 0.003 \text{ kg/m-s}, \qquad \alpha = 2 \text{ m/kg}$$

- **a.** If rate of filtration has a constant value of $dV/dt = 50$ l/min, determine the cake and filter resistances at $t = 30$ min.
- **b.** Determine the filter surface area (A) required to filter 5000 l broth within 60 min with the same pressure drop across the filter.