11.9. A fermentation broth with a protein concentration of C_0 = 100 mg/l and flow rate of Q = 4 m^3/h is passed through two downflow adsorption columns connected in series. The adsorption isotherm is: $q = 4C^{1/4}$. Assuming the system is in equilibrium, calculate the following:

- **a.** Minimum amount of activated carbon required for two days of operation if removal efficiency for the column is E = 50%.
- **b.** Protein concentration in the effluent of the second column is desired to be C = 0.5 mg/L. Determine the minimum amount of activated carbon required for two days of operation.

11.10. In a cross-flow ultrafiltration system used for filtration of proteins from a fermentation broth, gel resistance increases with protein concentration according to the following equation:

$$R_g = 0.5 + 0.01(C), \text{ where } C \text{ is in mg/l.}$$

Pressure at the entrance of the system is P_i = 6 atm and at the exit is P_0 = 2 atm. The shell side of the filter is open to the atmosphere, resulting in P_f = 1 atm. The membrane resistance is R_M = 0.5 atm/(mg/$m^2 \cdot$ h), and protein concentration in the broth is C = 100 mg/l. Determine:

- **a.** The pressure drop across the membrane.
- **b.** Filtration flux.
- **c.** Rejection coefficient of the membrane for effluent protein concentration of C_f = 5 mg/l.

11.11. A solute protein is to be separated from a liquid phase in a chromatographic column. The adsorption isotherm is given by the following equation:

$$C_S = kC_L^2$$

where C_S is the solute concentration in solid phase (mg solute/mg adsorbent) and C_L is the liquid phase concentration of solute (mg solute/ml liquid). Use the following information:

$$k = 0.4, \qquad \varepsilon = 0.3, \qquad A = 25 \text{ cm}^2,$$

$$\mu = 10 \text{ g ads}/100 \text{ ml column} = 100 \text{ mg/ml}$$

- **a.** For V = 400 ml and X = 25 cm determine the equilibrium solute concentrations in liquid and solid phases.
- **b.** Determine the ratio of travel distances of solute to solvent, R_f.

11.12. Consider the scale-up of a chromatography column for purification of a protein. A column of 40 cm length is used with a superficial velocity of 40 cm/h. The peak concentration of the target protein exits at a time of 100 min. The standard deviation of the peak is 14 min.

- **a.** How long must you wait to collect 90% of the protein?
- **b.** If the same column is used, but velocity is increased to 60 cm/h and external or Taylor dispersion controls, what will be the value of σ?
- **c.** If the column is lengthened to 60 cm while the velocity is at 60 cm/h, how will σ change? Will the peak be sharper or broader than at 40 cm/h with a 40-cm column?