the internal surfaces of the stationary phase based on a unit volume of stationary phase (i.e., the solid matrix and the pore space) (M, or g liter^{-1})

x longitudinal distance in the column (cm)

x fraction of separand in the mobile phase at long times $[\varepsilon/\varepsilon + (1-\varepsilon)\varepsilon^*(1+K_{eq})]$

Greek Letters

γ $1 + K_{eq}(1-\varepsilon)/\varepsilon$

ε column void fraction (dimensionless)

ε^* effective volume fraction of the stationary phase that is accessible to the separand (dimensionless)

ξ $(kK_{eq}x/v)(1-\varepsilon)$ (dimensionless)

μ viscosity of mobile phase (g cm^{-1} s^{-1})

ρ density of fluid (g cm^{-3})

ρ_c bulk density of adsorbent (g cm^{-3})

σ standard deviation for a peak (s)

τ $k(t - x\varepsilon/v)$ (dimensionless)

τ column residence time (V_L/Q) (s)

ϕ c/c_0 (dimensionless)

ψ q/q_0 (dimensionless)

Subscripts

i, j components i, j

$n-1, n$ columns $n-1, n$ in a series of columns

PROBLEMS

7.1 **Freundlich versus Langmuir Isotherm** Apply both the Freundlich isotherm and the Langmuir isotherm to the set of data shown in Table P7.1. Determine the applicable constants for the two different isotherms. Which is better, and why?

7.2 **Langmuir Isotherm** For the Langmuir isotherm [Equation (7.2.6)], determine the relationship between the equilibrium constant K_{eq} and the mobile phase concentration $[c]$ when the adsorbent is half-saturated.

7.3 **Three Binding Solutes** Derive the isotherms for three binding solutes that all compete for the same sites on the resin. If $K_{eq2} < K_{eq1} < K_{eq3}$, qualitatively describe the effects of the following situations:

(a) c_1 is very small compared to c_2 and c_3.

(b) $K_{eq3} \gg K_{eq1}$

(c) c_2 is low initially, and increases throughout the elution process.

7.4 **Solute Binding to Two Binding Sites** Derive an isotherm for a single solute molecule that binds simultaneously to two binding sites. An example of this would be a divalent cation binding to a carboxymethyl-derivatized resin. Use this expression to generate an example isotherm.

7.5 **Dispersion versus Molecular Diffusivity** What is the difference between the effective dispersivity $\mathscr{D}_{eff}$ and molecular diffusivity $\mathscr{D}_m$? What are the units for each?

7.6 **Prediction of the Break-Point Time in Fixed-Bed Adsorption** At low concentrations, the equilibrium for the antibiotic novobiocin and Dowex 21K anion exchange resin is linear,

$$q_i = 125c_i^*$$

for q_i and c_i^* in units of milligrams per milliliter. For the range of concentrations where this isotherm is valid, the mass transfer coefficient K_a averages 82 h^{-1}. Assuming a linear isotherm, estimate the break-point time (where $c_i/c_{i0} = 0.05$) in a fixed-bed adsorber with a bed length of 20 cm and superficial velocity of 40 cm/h. (Data from P. A. Belter, F. L. Cunningham, and J. W. Chen, "Development of a recovery process for novobiocin," *Biotechnol. Bioeng.*, vol. 15, p. 533, 1973.)