$\rho_0$ density of medium (g $cm^{-3}$)
$\Sigma$ operation constant of a centrifuge ($cm^2$)
$\phi$ volume fraction of particles (dimensionless)
$\omega$ angular velocity (rad $s^{-1}$)
$\Omega$ drag reduction factor [Equation (5.6.2)] (dimensionless)

## PROBLEMS

**5.1 Sedimentation versus Filtration** Four particulate materials, A, B, C and D, are suspended in water (density = 1.00 g/$cm^3$) and have the properties given in Table P5.1. Choose between sedimentation and filtration for the separation of the following pairs of particles from one another in mixed suspensions in water. Explain your answer in each case.
(a) A from B
(b) B from C
(c) C from D

**5.2 Strategies for Product Separation** Yeast cells ($a = 3\,\mu$m) in a fermentor secrete a low molecular weight product at a concentration that produces uniform rod-shaped crystals $2 \times 6\,\mu$m at about 20 times the number concentration (particles/ml) as the cells. Using concise statements, design two possible strategies that take advantage of the particulate nature of the product to separate the product from the broth and from the cells. What additional information about the product crystals would be useful?

**5.3 Isopycnic Sedimentation** You wish to capture 3 $\mu$m particles in a linear density gradient having a density of 1.12 g/$cm^3$ at the bottom and 1.00 at the top. You layer a thin particle suspension on the top of the 6 cm column of fluid with a viscosity of 1.0 cp and allow particles to settle at 1 *g*.
(a) How long must you wait for the particles you want (density = 1.07 g/$cm^3$) to sediment to within 0.1 cm of their isopycnic level? Is it possible to determine the time required for particles to sediment to *exactly* their isopycnic level?
(b) If instead of 1 *g* you use a centrifuge running at 800 rpm, and the top of the fluid is 5 cm from the center of rotation, how long must you centrifuge for the particles to move to within 0.1 cm of their isopycnic level?

**TABLE P5.1**

| Particle name | Density (g/$cm^3$) | Radius ($\mu$m) |
|---|---|---|
| A | 1.05 | 10 |
| B | 1.05 | 12 |
| C | 1.01 | 50 |
| D | 1.04 | 25 |

**5.4 Time Required for Sedimentation by Gravity** A certain reagent is added to a suspension of cells 4 $\mu$m in diameter. These cells have a density of 1.08 g/$cm^3$, and they are suspended in liquid with a density of 1.00 g/$cm^3$ and viscosity of 1.0 cp. This reagent causes about half of the cells to form fairly solid aggregates, all of which are 90 $\mu$m in diameter and have density midway between that of the liquid and the cells. How much time is required for all the aggregates to sediment to within 1 cm of the bottom of a vessel filled with suspension that is 0.5 m high? Approximately what fraction of the single cells would have sedimented to this depth in the same amount of time? How much time is required for all the single cells to sediment to within 1 cm of the bottom of the vessel?

**5.5 Time Required for Sedimentation in a Centrifuge** Using the results of Problem 5.4, determine the diameter and speed of a centrifuge required to reduce the total sedimentation time for the aggregates by a factor of 10, assuming you will use containers that are 20 cm high in the centrifuge. Also assume that the center of rotation is 3 cm from the tops of the containers. How much time must the same centrifuge be operated to also sediment all the single cells? For simplicity, assume a swinging-bucket type of centrifuge, in which the axis of the cylindrical vessel is horizontal, hence parallel to the direction of sedimentation.

**5.6 Determination of Sigma for a New Pilot Scale Centrifuge** You test a new pilot scale centrifuge by doing a breakthrough experiment using yeast as test particles. The yeast were previously found to sediment at 100 $\mu$m/s in a laboratory centrifuge operated at an acceleration of $500 \times g$. The breakthrough flow rate is found to be 10 liters/min. What is the sigma ($\Sigma$) of this new centrifuge?

**5.7 Bench Scale Tests for a Tubular Bowl Centrifuge** You can bench-test a tubular bowl separation by first characterizing the product in a test tube centrifugation. Without actually knowing the size and density of the particles in the suspension, derive an expression for the angular velocity required to capture the