is 5×10^{-6} cm^2/s. Beads of calcium alginate are most conveniently made as spheres with a 4-mm diameter. Assume the beads are made 25% by volume of plant cells. Assume the plant cells are 90% water and that the diffusivity of IAA in the gel is the same as in water. If the external concentration is maintained at 2 μmol, will IAA penetrate to the center of the bead?

13.2. Gel-immobilized cells of *Papaver somniferum* (opium poppy) can make codeine from codeinone. The rate of codeinone uptake is first order, with a rate constant of 3.3×10^{-8} l/g cells dry weight-s. The diffusivity of codeinone in the gel is 0.2×10^{-9} m^2/s. For a gel particle of 4-mm diameter with a 25% volume loading of cells (95% water), what will be the effectiveness factor?

13.3. The $k_L a$ of a small bubble column (2 l) has been measured as 20 h^{-1} at an airflow of 4 l/m in. If the rate of oxygen uptake by a culture of *Catharanthus roseus* is 0.2 mmol O$_2$/g dry weight-h and if the critical oxygen concentration must be above 10% of saturation (about 8 mg/l), what is the maximum concentration of cells that can be maintained in the reactor?

13.4. *C. roseus* cells immobilized in Ca-alginate beads of diameter 0.5 mm are used for production of indole alkaloids (IA) in a fluidized-bed bioreactor. The rate limiting nutrient is glucose and no intraparticle diffusion limitations exist. Use the following data: Flow rate of the feed: Q = 1 l/h, Glucose in the feed: S_o = 30 g/l, Plant Cell Concentration: X = 6 g/l reac. The rate constant for IA formation: k = 5 d^{-1} (g/l)$^{-1}$ K_s = 0.4 g/l, Column diameter: D_o = 0.15 m. Growth is negligible and Monod kinetics is valid. Determine the following:

  a. For 95% glucose conversion determine required hydraulic residence time, volume, and the height of the column

  b. If $Y_{p/s}$ is 0.02 g IA/g glu, determine IA concentration in the effluent and the productivity.