9.7. In a fluidized-bed biofilm reactor, cells are attached on spherical plastic particles to form biofilms of average thickness $L = 0.5$ mm. The bed is used to remove carbon compounds from a waste-water stream. The feed flow rate and concentration of total fermentable carbon compounds in the feed are $F = 2$ l/h and $S = 2000$ mg/l. The diameter of the column is 10 cm. The kinetic constants of the microbial population are $r_m = 50$ mg S/cm$^3 \cdot$ h and $K_S = 25$ mg S/cm^3. The specific surface area of the biofilm in the reactor is 2.5 cm^2/cm^3. Assuming first-order reaction kinetics and an average effectiveness factor of $\eta = 0.7$ throughout the column, determine the required height of the column for effluent total carbon concentration of $S_{0i} = 100$ mg/l.

9.8 Glucose is converted to ethanol by immobilized yeast cells entrapped in gel beads. The specific rate of ethanol production is: $q_P = 0.2$ g ethanol/g-cell-h. The effectiveness factor for an average bead is 0.8. Each bead contains 50 g/L of cells. The voids volume in the column is 40%. Assume growth is negligible (all glucose is converted into ethanol). The feed flow rate is $F = 400$ l/h and glucose concentration in the feed is $S_{0\mathrm{i}} = 150$ g glucose/l. The diameter of the column is 1 m and the yield coefficient is about 0.49 g ethanol/g glucose. The column height is 4 m.

a. What is the glucose conversion at the exit of the column?

b. What is the ethanol concentration in the exit stream?

9.9 Consider the batch growth curve in Fig. 9.4 and the corresponding plots of dX/dt vs. X and dP/dt vs. P. (Fig. 9.7). You are asked to design a two-stage reactor system with continuous flow that will produce product P at a concentration of 0.55 g/l. You wish to minimize total reactor volume. For a flow rate of 1000 l/h what size reactors (and in what order) would you recommend?

9.10 Consider Fig. 9.9, which applies to a fed-batch system. Assume at $t = 0$, $V = 100$ l, $X = 2$ g/l, $\mu = 1$ h^{-1}, $S_0 = 4$ g/l, and $S = 0.01$ g/l. V is increased at a constant rate such that $dV/dt = 20$ l/h $= F$ (or flow rate) and X is constant at all times.

a. Derive a formula to relate μ to V and dV/dt.

b. What is μ at $t = 5$ h?

9.11 An industrial waste-water stream is fed to a stirred-tank reactor continuously and the cells are recycled back to the reactor from the bottom of the sedimentation tank placed after the reactor. The following are given for the system:

$F = 100$ l/h; $S_0 = 5000$ mg/l; $\mu_m = 0.25$ h^{-1}; $K_s = 200$ mg/l; α (recycle ratio) $= 0.6$; C (cell concentration factor) $= 2$; $Y^M_{X/S} = 0.4$. The effluent concentration is desired to be 100 mg/l.

a. Determine the required reactor volume.

b. Determine the cell concentration in the reactor and in the recycle stream.

c. If the residence time is 2 h in the sedimentation tank, determine the volume of the sedimentation tank and cell concentration in the effluent of the sedimentation tank.

9.12 A waste-water stream is treated biologically by using a reactor containing immobilized cells in porous particles. Variation of rate of substrate removal with particle size is given in the following table.

r_s (mg/l-h)	D_P(mm)
300	1
300	2
250	3
200	4
150	5
100	7
50	10