6.6. *Pseudomonas sp.* has a mass doubling time of 2.4 h when grown on acetate. The saturation constant using this substrate is 1.3 g/l (which is unusually high), and cell yield on acetate is 0.46 g cell/g acetate. If we operate a chemostat on a feed stream containing 38 g/l acetate, find the following:

a. Cell concentration when the dilution rate is one-half of the maximum

b. Substrate concentration when the dilution rate is 0.8 D_{max}

c. Maximum dilution rate

d. Cell productivity at 0.8 D_{max}

[Courtesy of E. Dunlop from "Collected Coursework Problems in Biochemical Engineering," compiled by H. W. Blanch for 1977 Am. Soc. Eng. Educ. Summer School.]

6.7. The following data were obtained in a chemostat for the growth of *E. aerogenes* on a glycerol-limited growth medium.

D, h^{-1} dilution rate	$1/D$	S, mg/ml, glycerol	$1/S$	X, mg/ml cell conc.	ΔS	$\Delta S/X$	$\Delta S/X{\cdot}D$
0.05	20	0.012	83.3	3.2	9.988	3.12	0.156
0.10	10	0.028	35.7	3.7	9.972	2.7	0.270
0.20	5.0	0.05	20	4.0	9.95	2.49	0.498
0.40	2.5	0.10	10	4.4	9.90	2.25	0.90
0.60	1.67	0.15	6.67	4.75	9.85	2.075	1.245
0.70	1.43	0.176	5.68	4.9	9.824	2.005	1.405
0.80	1.25	0.80	1.25	4.5	9.20	2.045	1.635
0.84	1.19	9.00	0.11	0.5	—	—	—

Note: $S_0 = 10$ mg/ml.

For this system, estimate the values of:

a. K_s, mg glycerol/ml

b. μ_m, h^{-1}

c. $Y_{X/S}$, mg cells/mg glycerol

d. m_s, mg glycerol/mg cell-h

[Courtesy of A. E. Humphrey from "Collected Coursework Problems in Biochemical Engineering," compiled by H. W. Blanch for 1977 Am. Soc. Eng. Educ. Summer School.]

6.8. The kinetics of microbial growth, substrate consumption, and mixed-growth-associated product formation for a chemostat culture are given by the following equations:

$$\frac{dX}{dt} = \frac{\mu_m S}{K_s + S} X$$

$$\frac{dS}{dt} = \frac{\mu_m S}{(K_s + S) Y_{X/S}} X$$

$$\frac{dP}{dt} = \alpha \frac{dX}{dt} + \beta X = (\alpha \mu_g + \beta) X$$

The kinetic parameter values are $\mu_m = 0.7\ h^{-1}$, $K_s = 20$ mg/l, $Y_{X/S} = 0.5$ g dw/g substrate, $Y_{P/X} = 0.15$ gP/g·dw, $\alpha = 0.1$, $\beta = 0.02\ h^{-1}$, and $S_0 = 1$ g/l.

a. Determine the optimal dilution rate maximizing the productivity of product formation (PD).

b. Determine the optimal dilution rate maximizing the productivity of cell (biomass) formation (DS).

[Problem adapted from one suggested by L. Erickson.]

6.9. Ethanol is to be used as a substrate for single-cell protein production in a chemostat. The available equipment can achieve an oxygen transfer rate of 10 g O_2/l of liquid per hour. Assume the kinetics of cell growth on ethanol is of the Monod type, with $\mu_m = 0.5\ h^{-1}$, $K_s = 30$ mg/l, $Y_{X/S} = 0.5$ cells/g ethanol, and $Y_{O_2/S} = 2$ g O_2/g EtOH. We wish to operate the chemostat with an ethanol concentration in the feed of 22 g/L. We also wish to maximize the biomass productivity and minimize the loss of unused ethanol in the effluent. Determine the required dilution rate and whether sufficient oxygen can be provided.

6.10. Plot the response of a culture to diauxic growth on glucose and lactose based on the following: $\mu_{glucose} = 1.0\ h^{-1}$; $\mu_{lactose} = 0.6\ h^{-1}$; $Y_{glucose} = Y_{lactose} = 0.5$; enzyme induction requires 30 min to complete. Plot cell mass, glucose, and lactose concentrations, assuming initial values of 2 g/l glucose, 3 g/l lactose, and 0.10 g/l cells.

6.11. The following data are obtained in oxidation of pesticides present in wastewater by a mixed culture of microorganisms in a continuously operating aeration tank.

D (h^{-1})	S (Pesticides), mg/l	X (mg/l)
0.05	15	162
0.11	25	210
0.24	50	250
0.39	100	235
0.52	140	220
0.7	180	205
0.82	240	170

Assuming the pesticide concentration in the feed wastewater stream as $S_0 = 500$ mg/l, determine $Y^M_{X/S}$, k_d, μ_m, and K_s.

6.12. In a chemostat you know that if a culture obeys the Monod equation, the residual substrate is independent of the feed substrate concentration. You observe that in your chemostat an increase in S_0 causes an increase in the residual substrate concentration. Your friend suggests that you consider whether the Contois equation may describe the situation better. The Contois equation (eq. 6.36) is:

$$\mu = \frac{\mu_m S}{K_{sx} X + S}$$

a. Derive an expression for S in terms of D, μ_m, K_{sx}, and X for a steady-state CFSTR (chemostat).

b. Derive an equation for S as a function of S_0, D, K_{sx}, $Y^M_{X/S}$, and μ_m.

c. If S_0 increases twofold, by how much will S increase?

6.13. *Pseudomonas putida* with $\mu_m = 0.5\ h^{-1}$ is cultivated in a continuous culture under aerobic conditions where $D = 0.28\ h^{-1}$. The carbon and energy source in the feed is lactose with a