

The reactor options described in this chapter are many. The best choice of reactor systems will ultimately be determined by the choice of biocatalyst and the requirements for product recovery and purification.

## SUGGESTIONS FOR FURTHER READING

- AIBA, S., A. E. HUMPHREY, AND N. F. MILLIS, *Biochemical Engineering*, 2d ed., Academic Press, New York, 1973.
- ATKINSON, B., AND F. MAVITUNA, *Biochemical Engineering and Biotechnology Handbook*, 2d ed., Stockton Press, New York, 1991.
- BAILEY, J. E., AND D. F. OLLIS, *Biochemical Engineering Fundamentals*, 2d ed., McGraw-Hill Book Co., New York, 1986.
- BLANCH, H. W., AND D. S. CLARK, *Biochemical Engineering*, Marcel Dekker, Inc., New York, 1996.
- CHARACKLIS, W. G., R. BAKKE, AND M. G. TRULEAR, 1991, "Fundamental Considerations of Fixed Film Systems," in M. Moo-Young, ed., *Comprehensive Biotechnology*, Vol. 4, pp. 945–961, 1985.
- CHIBATA, I., T. TOSA, AND T. SATO, "Methods of Cell Immobilization," in *Manual of Industrial Microbiology and Biotechnology*, A. L. Demain and N. A. Solomon, eds., American Society for Microbiology, Washington, DC, pp. 217–229, 1986.
- DE GOOIJER, C. D., W. A. M. BAKKER, H. H. BEEFTINK, AND J. TRAMPER, Bioreactors in Series: An Overview of Design Procedures and Practical Applications, *Enzyme Microbiol Technology* 18: 202–219, 1996.
- KARGI, F., AND M. MOO-YOUNG, "Transport Phenomena in Bioprocesses," in M. Moo-Young, ed., *Comprehensive Biotechnology*, Vol. 2, Pergamon Press, Elmsford, NY, pp. 5–55, 1985.
- KLEIN, J., AND K. D. VORLOP, "Immobilization Techniques: Cells," in M. Moo-Young, ed., *Comprehensive Biotechnology*, Vol. 2, Pergamon Press, Elmsford, NY, pp. 203–334, 1985.
- MERCILLE, S., M. JOHNSON, S. LAUTHIER, A. A. KAMEN, AND B. MASSIA, Understanding Factors that Limit the Productivity of Suspension-Based Perfusion Cultures Operated at High Medium Renewal Rates, *Biotechnology Bioengineering*, 67: 435–450, 2000.
- MIDGETT, R. E., "Solid State Fermentations," in A. L. Demain and N. A. Solomon, *Manual of Industrial Microbiology and Technology*, American Society for Microbiology, Washington, DC, pp. 66–83, 1986.
- MOO-YOUNG, M., *Bioreactor Immobilized Enzymes and Cells: Fundamentals and Applications*, Elsevier Science Publishing, Inc., New York, 1988.
- SCHROEDER, E. D., *Water and Wastewater Treatment*, McGraw-Hill Book Co., New York, 1977.
- WANG, D. I. C., AND OTHERS, *Fermentation and Enzyme Technology*. John Wiley & Sons, Inc., 1979.
- WEBSTER, I. A., M. L. SHULER, AND P. RONY. The Whole Cell Hollow Fiber Reactor: Effectiveness Factors, *Biotech. Bioeng.* 21: 1725–1748, 1979.

## PROBLEMS

- 9.1.** Consider a 1000-l CSTR in which biomass is being produced with glucose as the substrate. The microbial system follows a Monod relationship with  $\mu_m = 0.4 \text{ h}^{-1}$ ,  $K_S = 1.5 \text{ g/l}$  (an unusu-