12 Approaches to Modeling SSF Bioreactors

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12.1 What Are Models and Why Model SSF Bioreactors?

The key message of this book is that mathematical modeling is a powerful tool that can help in the design of SSF bioreactors and in the optimization of their performance. It is not necessary for all workers in the area of SSF to know how to construct and solve models, because modeling can be done in collaboration with colleagues with the appropriate expertise. However, even if you have no intention of undertaking the modeling work yourself, it is useful to know what models are and what they can do, because this facilitates interactions with these colleagues. The aim of Chaps. 12 to 20 is to give you an understanding of how models of SSF bioreactors are developed. These chapters do not attempt to provide the necessary background in all the mathematical and computing skills required. Rather they attempt to convey the “modeling way of thinking”. This will provide the basis for understanding the uses and limitations of the various models presented in the modeling case study chapters (Chaps. 22 to 25).

What is a mathematical model? The type of mathematical model that we are talking about in this book is a set of differential and algebraic equations that summarizes our knowledge of how a process operates. In other words, a model is a set of equations that describes how the various phenomena that occur within the system combine to control its overall performance, which, in the case of SSF bioreactors, will be evaluated in terms of growth and product formation. A model is a simplification of reality, and the equations therefore only describe the phenomena that are thought to be the most important in influencing the performance of the system. It is the modeler who, on the basis of experience with the system being modeled, decides which phenomena will be included and which will not be. As a simple example of this, amongst other factors, growth within an SSF bioreactor depends on both the $O_2$ concentration and the temperature experienced by the microorganism. However, in many models of SSF bioreactors the problem of controlling temperature is considered to be more difficult than the problem of supplying $O_2$, and therefore frequently equations describing energy generation and water transfer are written in order to predict temperatures, but equations to describe $O_2$ supply and consumption are not included within the model.
Of course, it is possible to make wrong decisions about which of the phenomena are most important, or to simply neglect to consider some phenomena that are important. If a model fails to describe the bioreactor performance well, it is essential to find out why it fails, and to then work to improve it.

The models of SSF processes that will be introduced in Chaps. 22 to 25 consist of differential equations that describe how key variables, such as biomass concentration or temperature, vary with over time and across space within a bioreactor during an SSF process. For example, a simple model of the operation of an SSF bioreactor might include equations to describe the rate of growth and heat production and the heat removal processes occurring. These equations would predict how the temperature of the substrate bed changes during the process, and the temperature would be taken into account in the calculation of the growth rate.

Models are a powerful way of summarizing our knowledge about how a system operates. When a system is as complex as an SSF process, we have a better chance of summarizing the complexity of the interactions with a model than if we simply looked at a large number of graphs of experimental results. However, models are more than simply a means of summarizing experimental data that describe system behavior. Models can be used to predict performance, and therefore can be used to identify optimal design parameters and operating conditions (Fig. 12.1). Consider the situation in which you are doing laboratory-scale work on an SSF process that is showing such promise that you intend to go to production scale. Models developed on the basis of this laboratory-scale work, combined with heat and mass transfer principles, can be used to forecast the performance of a large-scale bioreactor, before it is built. Even if the predictions are not fully accurate, this initial

![Fig. 12.1. An overview of how models can be used in the development of large-scale SSF bioreactors](image-url)