Chapter 9
Preferences, Utility Function, and Control Design of Complex Cultivation Process

ABSTRACT

This chapter demonstrates the flexibility and the diversity of the potential functions method and its conjunction with the utility theory when it describes completely analytically the complex system “decision maker-dynamical process.” The utility analytical descriptions have been built concerning the attitude of the technologist toward the dynamic process. Using these approach factors as ecology, financial perspective, social effect can be taken into account. They are included in the expert preferences via the expert attitude towards them.

The analytic construction of the utility function is an iterative “machine-learning” process. This interactivity allows a new strategy in the process of control design and in the control of the system with human participation in the final solution. The first and the most important effect of this strategy is the possibility for the analytical description of such complex systems. This has been achieved for the first time in scientific practice.

The second effect is the introduction of the iterativity in the process of forming the control as is used naturally and harmonically computer and analytical mathematical techniques.

The third effect is the fact that the process of training can be reversed towards the trainer technology expert with the aim of additional analysis and corrections.

In the control design are overcome restrictions connected with the observability of the Monod kinetics and with the singularities of the optimal control of Monod kinetic models.

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1. DESCRIPTION OF THE PROBLEM

Fermentation processes are relatively difficult objects for control. Their features have been discussed repeatedly. This has led to search for solutions via approaches and methods related to a wide range of contemporary mathematical areas. Such areas are the classical control theory (linear systems, nonlinear systems, stochastic systems, adaptive systems), the theory of systems with distributed parameters (distributed systems), the theory of variable structure systems and their main direction sliding mode control, etc. In the last decade up to date methods and approaches in the areas of functional analysis, differential geometry and its modern applications in the areas of nonlinear control systems as reduction, equivalent diffeomorphic transformation to equivalent systems and optimal control have been used (Neeleman, 2002; Pavlov, 2005; Tzonkov, 2006).

For some problems and tasks these approaches allowed completely new interpretations and solutions. For example, important biotechnological parameters of the process as the specific growth rate of the biomass can be determined only approximately by the Biotechnologist. The reason is that they not only define the quality of the yield product, but can depend on other difficult for mathematical modeling factors, such as market prices, economic and ecological considerations, social effect and others.

In our practice, such estimates have been made with precision 10-30% from maximal growth rate of the cultivation process. It is obvious that such one-step determination cannot be effective. Here the results obtained from the Decision-making theory, the Utility theory and methods for evaluations and estimations of the utility functions as stochastic programming can be used (Pavlov, 2010). One analytic description of the thinking of the biotechnologist with respect to the biotechnological process as a utility function will allow a new mathematical thinking with respect to the system Technologist-process and new mathematical modeling description as Technologist-dynamical model. This will allow far more flexible and exact description of the complex economic, ecological, social, and other factors as a part of the mathematical model and control solutions.

Among the most-widely used control models for Biotechnological Processes are the so-called unstructured models, based on mass balance. In these models, the biomass is accepted as homogeneous, without internal dynamic. Most widely used are models based on the description of the kinetic via the well-known equation of Monod or some of its modifications. As an example, a fed-batch biotechnological process is well described via well-known Monod nonlinear model (Neeleman, 2002; Tzonkov, 2006). The rates of cell growth, sugar consumption, concentration in a yeast fed-batch growth process are commonly described for all functional states according to the mass balance as follows:

\[
\begin{align*}
\dot{X} &= \mu_m \frac{S}{K_s + S} X - \frac{F}{V} X \\
\dot{S} &= -k \mu_m \frac{S}{K_s + S} X + \frac{F}{V} (S_0 - S) \\
V &= F
\end{align*}
\] (9.1.1)

Here \(X\) is the concentration of the biomass, \(S\) is the substrate concentration, \(V\) is the volume of the bioreactor. The maximal growth rate is denoted by \(\mu_m\) and \(K_s\) is the coefficient of Michaelis-Menten. With \(k\) we denote a constant typical for the corresponding process. The feeding rate is denoted by \(F\). If the process is continuous \((F/V)\) is substituted by the control \(D\), the dilution rate of the Biotechnological Process (BTP). The third equation is dropped off. This differential equation is often part of more general and complex dynamic models.