CONTROL AND AUTOMATION STRATEGIES APPLIED TO FERMENTATION PROCESSES: ADVANCES AND TRENDS

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ABSTRACT

A lot has been discussed about the shortage of petrochemical feedstocks in a long-term scenario, encouraging the development of the biobased industry to reduce fossil chemical dependence and greenhouse gas emissions. One key point of challenge for the implementation of the biotechnological unit composing this industry is its modeling and control, due to the microbial systems complexity and variations associated with the bioreactor operation. This work presents a critical review of the main control strategies and algorithms applied to bioprocesses. The classic PID feedback algorithm was found to be the main subject of study in the last decade. In the last five years, however, more studies were reported with advanced control strategies, such as nonlinear model predictive control and artificial neural networks, suggesting an increasing interest in such models to deal with non-linearities of biological systems.

1. INTRODUCTION

One of the main objectives of recent research and development of industrial fermentation processes is the establishment of economical feasible biotechnological plants through yield improvements and operational costs reduction. The main approaches to reach this objective are synthetic biology, improving genetically a microorganism to, for example, enhance a metabolic route, and the
refinement of bioprocess instrumentation and control. The last one aggregates extreme difficulties, inherent to biological processes, due to the complexities of microbial systems, leading to extensive mathematical models that consider multiple biochemical reactions and result in a set of equations with various parameters. Although, it is a major opportunity for process improvement and cost reduction.

Large variations associated to a fermenter operation hinders the development of an advanced control system. Typical factors that exemplify these variations include seasonal changes of raw materials, microbial growth and operations oscillations. Furthermore, slow dynamics associated to microbial reactors and unscheduled disturbances may result in products out of specification and bioreactor problems, such as cell wash out. Problems such as the aforementioned cause economic impact at the production unit and, therefore, advances in the control and optimization of bioprocesses are very important, minimizing losses and maximizing the use of resources (Rehm & Reed, 1996). Therefore, this work aims to discuss the main control strategies that have been under investigation in order to analyze the difficulties and trends in bioprocesses monitoring and control.

2. METHODOLOGY

The bibliographic research was realized within the scientific bases Science Direct and “Periódicos Capes”. We have considered the papers that proposed a control scheme to a bioprocess, evaluating its impact and improvement in the process between the years 2005 and 2016. The keywords used within the search engines were combinations of the keywords related to the subject of automatic control of bioprocess: “automation”, “control”, “fermentation”, “bioprocess”, “PID”, and “monitoring”.

2. CONTROL STRATEGIES

Results allowed the identification of the main control strategies applied to bioprocesses. The most used process automation algorithm is the classic PID feedback control. This algorithm consists on the proportional, integral and derivative approach, based on the present, past and future errors, respectively, to calculate the control action.

Above the conventional regulatory system are the advanced control algorithms. The main advanced strategies applied to bioprocess are the model predictive control, artificial neural network, fuzzy control and extreme-seeking control. These strategies act on the PID control loops as discussed before, calculating their appropriated setpoint. The model predictive control, as the name suggests, is a dynamic process model, which can be linear or nonlinear. It is used to optimize an objective function to calculate new setpoints for the PID control (Alvaristo, 2014). By contrast, fuzzy logic
control is based on inferences. It is based on logic functions to process qualitative and linguistic expressions in order to determine the control action (Honda & Kobayashi, 2000). The artificial neural network simulates the functionality and structure of biological neural networks using weight factors to determine the path of information within the network, converging to the control action (Stanke & Hitzmann, 2013). Finally, extremum-seeking control aims to optimize a nonlinear process in real time, constantly disturbing the parameter that is being adjusted (Dochain, 2008; Tan et al., 2010).

3. DIFFICULTIES AND TRENDS

Figure 1 shows a temporal distribution of studies addressing control applied to bioprocesses. Between 2005 and 2010, the studies have focused on the application of the traditional PID feedback control algorithm, justified by the vast knowledge of this strategy on petrochemical units. However, advanced control strategies have been more explored within the last five years for the implementation in bioprocesses, more specifically, model predictive control and artificial neural network. Extremum seeking control, although very explored since 2011, is still in early stage of development, with applications reported only in small scales. Nonetheless, this strategy is gathering further highlights due to evolution of computers processing capacities, enabling to perform faster numerical calculations for optimization purposes.

![Temporal distribution of bioprocess control studies.](image)

The increasing growing interest on advanced control strategies shows a tendency of improving bioprocess operation to compete with petrochemical routes. Many bioprocesses can be very sensitive to process disturbances, such as pharmaceutical production and anaerobic digestion (Nguyen et al, 2015) and microbial growth primarily presents slow dynamics, so that a single PID control is not the best choice to control the process. This encourage the development of advanced
control strategies that reliably maintains constant the main variables of the bioprocess (such as pH, dissolved oxygen and substrate concentration) regardless the operation mode, in order to keep the optimal conditions within the fermenter for the microbial growth. It is important to emphasize that not only advanced control strategies need development, but measurement and monitoring strategies as well. Because of the aforementioned microorganism slow dynamics, the online and direct measurement of the process variables became increasingly important. The information rapidly accessible assists the controller decision making, maintaining the fermentation at its optimal conditions.

4. CONCLUSIONS

From a brief literature overview, we have shown the importance of automatic control and monitoring of bioprocesses to its performance. The application have been studied extensively in laboratory scale. However, for industrial applications, more precise supervisory systems are needed, facilitating process optimization and decision-making. Nevertheless, mathematical models that describe adequately microbial growth, substrate consumption and product generation are object of intense study because of the complexity of metabolic routes. These models are essential to the implementation of advanced control strategies, stabilizing the production and maximizing productivity and the desired product concentration.

5. REFERENCES