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Implementation of Sliding Mode Controller with Boundary Layer for *Saccharomyces cerevisiae* Fed-batch Cultivation

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Abstract: *An implementation of sliding mode control for yeast fed-batch cultivation is presented in this paper. Developed controller has been implemented on two real fed-batch cultivations of Saccharomyces cerevisiae. The controller successfully stabilizes the process and shows a very good performance at high input disturbances.*

Keywords: *Sliding mode control, Boundary layer, Yeast fed-batch cultivation.*

Introduction

In biotechnology there are still high requirements of efficient automation systems and control algorithms. The complexity of the fed-batch processes and lack of adequate models limit the application of conventional controllers. High control algorithms have been elaborated to overcome some of disadvantages of conventional control algorithms [1, 2]. Variable structure controllers and their modifications have been elaborated for fed-batch cultivation of *Escherichia coli* [4]. If these high control algorithms are applied for fed-batch cultivation of *Saccharomyces cerevisiae*, the glucose concentration could be controlled at a low set point so that undesirable by-products like ethanol will not be produced during the cultivation. The implementation of controllers with variable structure also improves the system performance in the case of big input disturbances.

Description of fed-batch cultivation of *Saccharomyces cerevisiae*

Materials and Methods

The cultivation of the yeast *Saccharomyces cerevisiae* is performed in a 2 l reactor, developed at the *Institute of Technical Chemistry, University of Hannover, Germany*, using a *Schatzmann medium*. For the process control a *BiostatB unit* from *B. Braun* is used. Before the fed-batch, a batch cultivation was carried out to get an appropriate amount of biomass. After the end of the batch, a break of 4 hours is made to get a defined metabolic state. The values of the process parameters used for both cultivations are listed in Table 1. In the exhaust gas carbon dioxide and oxygen are measured using gasanalyzer *Modular System S710 (Sick Maihak, Hamburg)*. Off-line samples are collected almost every hour. From the off-line samples the dry biomass concentration, as well as the concentration of ethanol and glucose, are measured. The glucose concentration is measured using a glucose analyzer (YSI 2700, Yellow Springs Instruments). For the determination of ethanol a gas chromatograph (GC-14B, Shimadzu) is used. The dry biomass concentration is measured by separating the cells by centrifuge. After drying for 24h at 110°C the biomass is measured by weighing the tubes.

Table 1. Process parameters

Parameter	**Value**
Aeration rate	300 l/h
Stirrer speed	1200 rpm
Temperature	30 °C
pH	5.5
Start volume	Ca. 1.750 l
Initial value of biomass	Ca. 7.0 g/l
Glucose concentration in feed	100 g/l

For online glucose measurements a flow injection analysis (*FIA*) system, developed by *ANASYSCON Hannover, Germany*, is employed [3], which uses a sampling probe (*Flownamics E19*) to get cell-free samples for the FIA. The control of the whole FIA system as well as the measurement evaluation has been performed by the automation system *CAFCA* (*ANASYSCON, Germany*).

The determination of the time-delay is carried out in a simple reactor by measuring the changes of the conductivity. The reactor contains 200ml distilled water. At the start of the measurement 20ml of 1mol KCl solution are added as a pulse. The change of the conductivity was measured. From the plots of the conductivity vs. time the time delay is calculated.

The bioreactor, as well as the FIA measurement system is presented in Fig. 1. Fig. 2 shows the computers used for the data measurement from the FIA system, as well as the computer for the control of the process.

Fig. 1

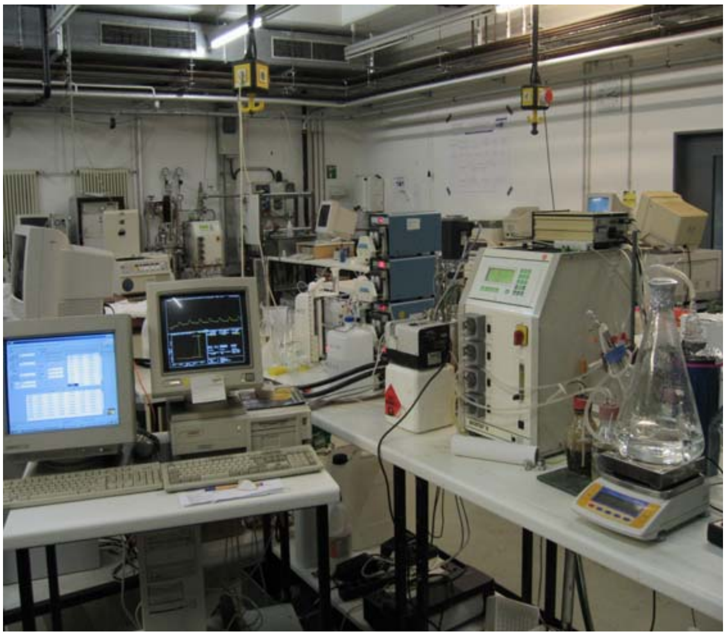

Fig. 2

Implementation of sliding mode controller for fed-batch cultivation of *Saccharomyces cerevisiae*

During the realization of a project, granted from DFG, a sliding mode controller with boundary layer has been developed and successfully implemented on two real fed-batch cultivations of *Saccharomyces cerevisiae*.

At the beginning, using *Matlab* it has been simulated a fed-batch cultivation of the *Saccharomyces cerevisiae* with time-delay 7 minutes and receiving of measurement data for substrate concentration at every 2 minutes. It has been developed a *Kalman filter*, considered the time-delay and reconstructed the state vector of the process at the current time. Based on the filter it has been synthesized a glucose concentration control with feeding rate as control variable. The control law consists of two parts:

- *feedforward* part, based on the *Kalman filter* evaluations of the maximum value of specific growth rate and the concentration of biomass;
- *feedback* part, based on the *Kalman filter* evaluation of the substrate concentration.

A comparative simulative investigation of the control law with two different *feedback* parts - conventional PI controller and sliding mode controller (SMC) with boundary layer, has been performed. The SMC has given better performance in respect of task tracking and faster fitting.

In order to be implemented the synthesized controller on the real cultivation process, a system *Kalman filter - Sliding Mode Controller with boundary layer* has been elaborated under *C++*. Developed in that way controller communicates with the *CAFCA* system and with two peristaltic pumps through RS232. The controller has been elaborated in three variants – for *DOS*, for the console work under *Windows* and with graphic interface for *Windows*.

It has been developed a convenient controller graphic interface allowed the observation in a real time of:

- the value of substrate concentration, received from *CAFCA* system;
- *Kalman filter* evaluations of the substrate and biomass concentrations, the maximum value of specific growth rate and the volume of culture medium;
- the value of the feeding rate;
- values of the *feedforward* and *feedback* parts of control.

The graphic interface allows to be changed all parameters of the controller during the cultivation. In addition it has been added the opportunity to be applied a stochastic filter, which eliminates big measurement errors.

Developed controller has been implemented on two real fed-batch cultivations of *Saccharomyces cerevisiae*. The experiments have been performed in the *Institute of Technical Chemistry – University of Hannover, Germany.* The controller successfully stabilizes the process and shows a very good performance at high input disturbances.

The following screenshot (Fig. 3) presents the result and the graphic interface of the real-time working controller for one of the two performed fed-batch cultivations of *Saccharomyces cerevisiae*.

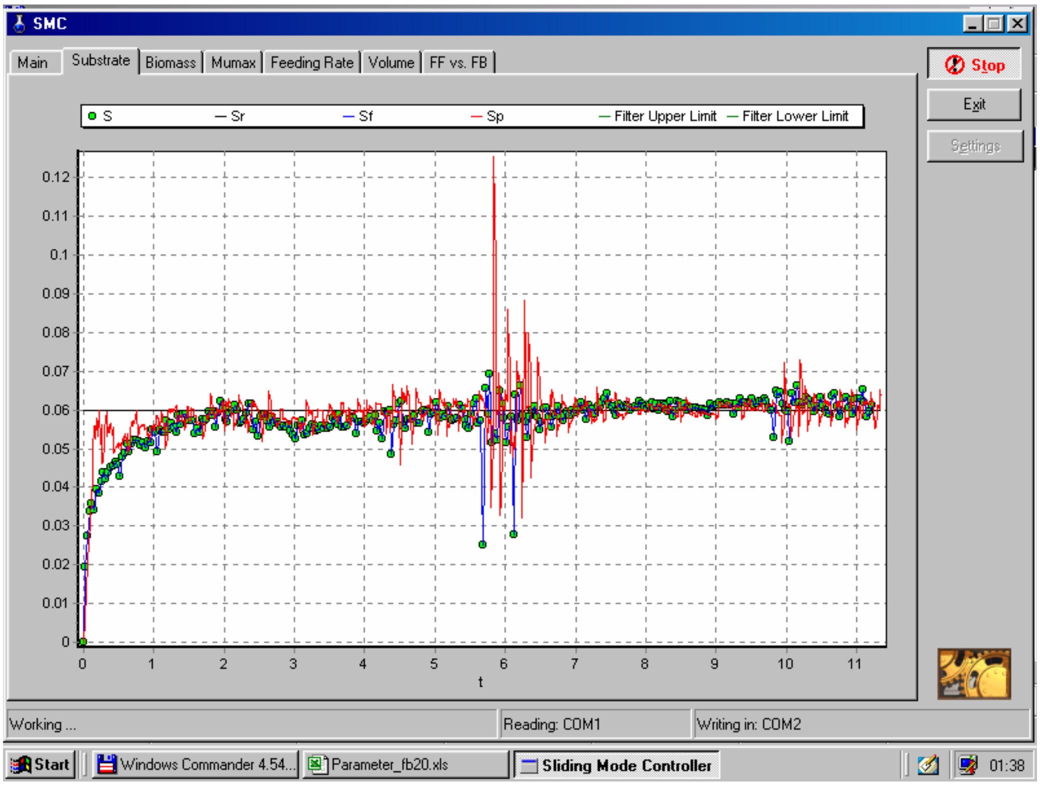

Fig. 3

The complete description of the process conditions and model, as well as the expanded development of the sliding mode controller with boundary layer, will be prepared soon and will appear in the further article.

Acknowledgements

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Conclusions

A sliding mode controller with boundary layer has been developed for a yeast fed-batch cultivation. A simulative comparison of two different *feedback* parts of the control law, namely conventional PI controller and sliding mode controller with boundary layer, has been performed. The sliding mode controller gave better performance in respect of task tracking and faster fitting. Developed controller has been implemented on two real fed-batch cultivations of *Saccharomyces cerevisiae*. The controller successfully stabilizes the process and shows a very good performance at high input disturbances.

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