Teaching process control in food engineering: dynamic simulation of a fermentation control process

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ABSTRACT

Students usually have difficulties to understand abstract concepts of process control. Implementing in teaching process the inquiry-based learning helps students to follow methods and practices similar to those of professional scientists in order to construct knowledge. The paper describes the steps reached in simulation-based learning: from experimental data obtained by the students in their practical method (study and measurement of variables to some fermentation processes) to the simulated the behaviour of the process under a feedback control system. By providing opportunities for students to check their understanding and reflect on their learning process performance is enhanced over a traditional lecture course.

Keywords: inquiry-based learning, process control, food engineering education

1. INTRODUCTION

In the food engineering higher education the process control teaching became an integral and indispensable part of the active assimilation of theoretical and practical knowledge. Many industrially important fermentation processes exhibit nonlinear and time-varying behaviour. Design of a control strategy that should provide a required control performance of key variables, such as biomass concentration from a fermentation process, may be a difficult task. Successful control requires good knowledge of the controlled process in form of an adequate mathematical model [1]. A model of a fermentation process must be both realistic and also robust. Modelling is an art but also a very important learning process. In addition to a mastery of the relevant theory, considerable insight into the actual functioning of the process is required. Once the model is established it can then be used, with reasonable confidance, to predict performance under differing process conditions, and used for process design, optimisation and control.

Control of a fermentation process is a delicate task, for at least two reasons: the process complexity, nonlinearity and non-stationarity which make modelling and parameter estimation particularly difficult; the scarcity of on-line measurements of the component concentrations (essential substrates, biomass and products of interest).

From among the new methods for engineering higher education is inquiry-based approach or simulation based learning. Inquiry-based learning is an educational strategy in which students follow methods and practices similar to those of professional scientists in order to construct knowledge [2]. It can be defined as a process of discovering new causal relations, with the learner formulating hypotheses and testing them by conducting experiments and/or making observations [3].

Teaching process control at the students from food engineering is a challenge. The present paper describes the development of a control fermentation bioprocess using inquiry-based approach or simulation based learning.

The inquiry-based learning framework has included five inquiry phases [4]:
a) orientation, that means the targets identification;

b) conceptualization concerning: laboratory experiments on different fermentation processes, dynamic model building for the fermentation process, feedback control system construction in MATLAB-Simulink computing software;

c) investigation comprised: model simulation and validation with the experimental data and tuning the controller parameters;

d) conclusion on the obtained results;

e) discussion regarded the teaching method used.

The paper presents the steps reached in simulation-based learning: from experimental data obtained by the students in their practical method (study and measurement of variables to some fermentation processes) to the simulated the behavior of the process under a feedback control system. After the steps a, b, c, d in own dynamic of the case study, the students look for solution variant established and optimal solutions.

2. METHOD FRAMEWORK

2.1. Experiment

The students have been studied some alcoholic fermentation processes in the laboratory. The research experiments have been focused on the influence of some variables to the fermentation process length, t. The selected variables were: temperature, T^0; substrate concentration, S and biomass concentration, X. A EVO continuously stirred bioreactor equipped with pH, temperature, level and stirred speed control, disolved O_2, emitted CO_2 and O_2 sensors and analysers was used. The cells concentration has been calculated on the base of three different parameters: optical density, dry substance and total cells number (Thoma room method). The glucose has been measured by DNS method and the alcohol by high performance liquid chromatography (HPLC).

2.2. Modelling

Based on the experimental bellow data obtained the students have been build or chose from speciality literature a non-linear, dynamic mathematical model for the alcoholic fermentation process (i.e. the model proposed by Sipos in [5] or [6]). In the dynamic mathematical model, as a distinct modeling principle of each phase, the evolution curve of biomass over the time for the viable cells has been used. The evolution of yeast population curve has been divided in correlation with phenomenological aspects of the development of microorganisms as follows: latent phase, growing phase and decay phase.

In MATLAB simulation system the numerical simultaneous integration of the model equations has been done and then, the S-function has been build in order to be used in a feed-back control system. Also, the simulation results of the S-function were compared with experimental data.
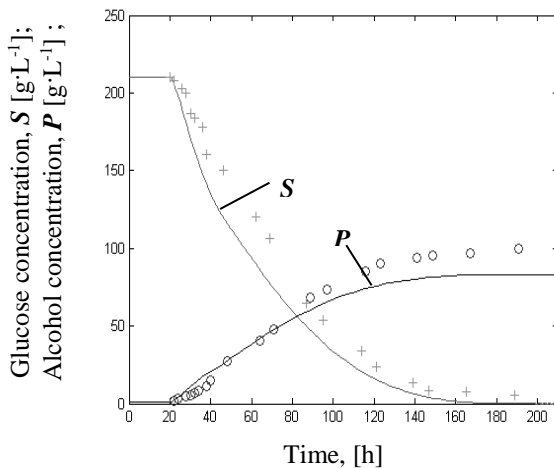
2.3. Simulation

The feedback control system of the fermentation process has been realised in MATLAB-Simulink computing software. Then, for tuning the controller parameters has been using the method of limit of stability, the Ziegler-Nichols method. To obtain the oscillation value of the gain factor K_u (or oscillation value of the proportional band PB_u) and the ultimate period P_u the process has been bringing to instability with the method of successive trials in the process.

3. RESULTS AND DISCUSSION

The fermentation process model chosed by the studens is described by a set of non-linear equations corresponding to the physiological phases of yeast cells: substrate, biomass and alcohol dynamic behaviour, heat transfer equations and the dependence of kinetic parameters on temperature.
At this point the students were challenged to find an explanation for each model. With the help of the teacher and the literature they have proposed and discussed each of the alternatives.

Figures 1, 2 and 3 show the simulation results of the model used (the model proposed by Sipos in [5, 6]) considering the following initial values: the initial substrate concentration was 210 $g \cdot L^{-1}$ and the fermentation temperature was 301K.

Figure 1: Evolution of glucose and alcohol concentrations; a comparison between experimental values (o - glucose and + - alcohol) and simulation results (continuous lines)
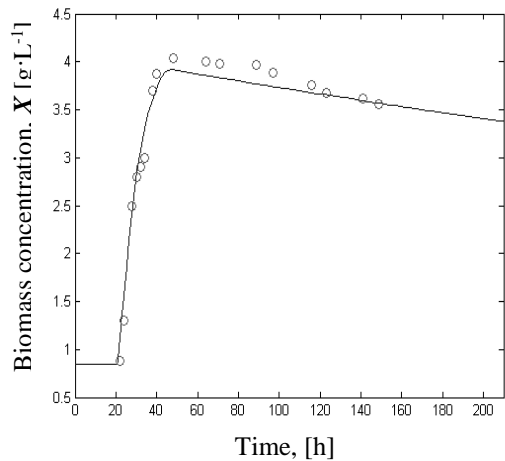

Figure 2: Comparison between the biomass simulation results (continuous line) and experimental data (o)
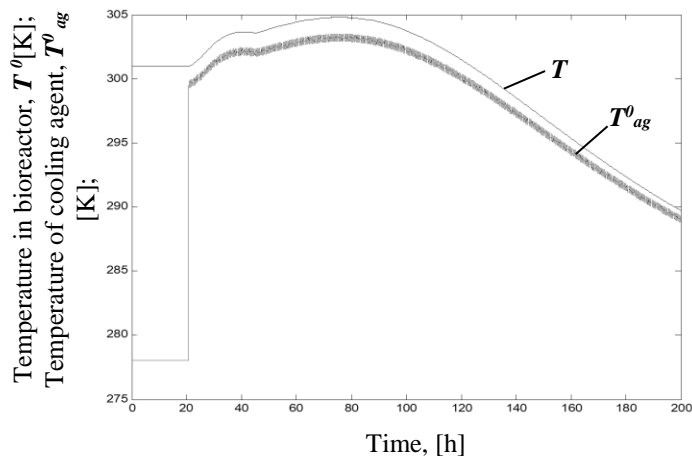
Figure 3: Temperatures of the fermentation medium and cooling agent (simulation results)

On the fermentation process model was realised a concentration control loop measuring the output concentration of substrate, S. Block diagrama of the concentation control is presented in figure 4.
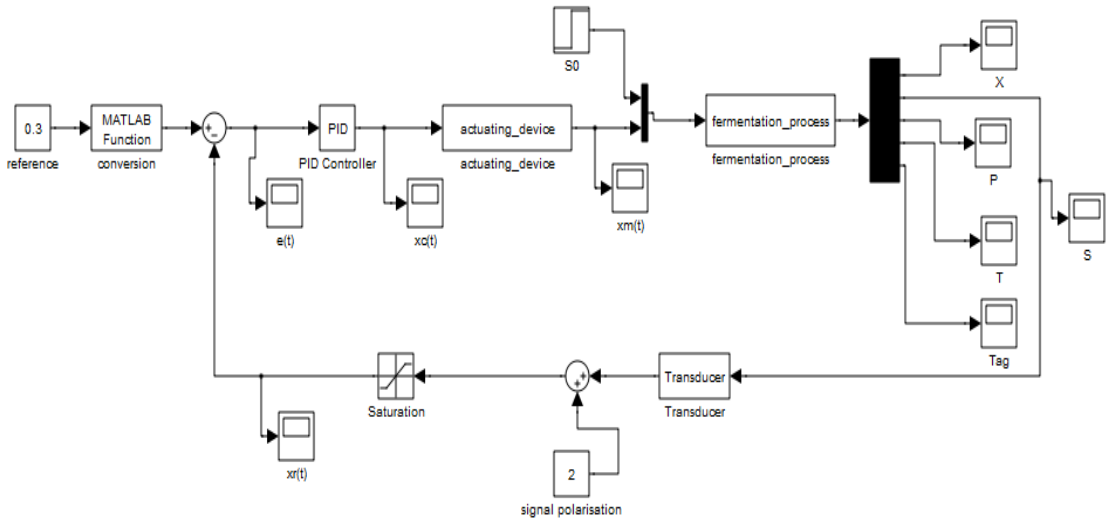

Figure 4: Block diagrama of the concentation control of a fermentation process

The optimal settings of the controller, according to Ziegler and Nichols are given in table 1.

Table 1: The optimal controller settings in the fermentation process control loop.

Optimal controller parameter	Controller structure		
	P	*PI*	*PID*
PB [%]	2.76	3.04	2.346
T_i [min]	-	0.332	0.2
T_d [min]	-	-	0.048

The behavior of the control loop in the three cases of optimal setting are given in figure 5.

a.

b.

c.
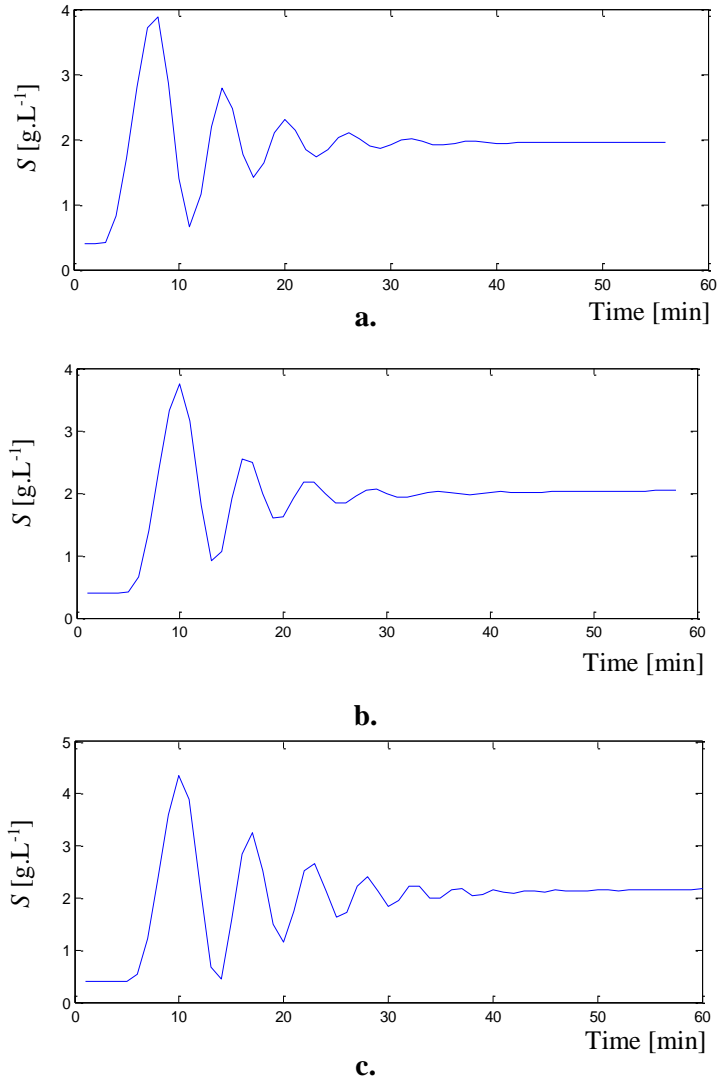
**Figure 5: Behavior of the concentration control system in the fermentation process
for: a. *P* controller; b. *PI* controller and c. *PID* controller**

As it can be observed in figure 5, the most stabile control of the fermentation process is with *P* controller.

The student can simulate the behaviour of the technological system (including the SRA) in extreme situations concerning raw material characteristics, disturbances of (see sensory analysis!), disturbances that may occur due to the failure of the regulator. All of them are realized in a much shorter time and without requiring the physical construction of the whole technological system. These are just some of the advantages of this teaching mode.

4. CONCLUSIONS

This paper describes an implementation of inquiry-based approach methode in theaching process control at the food engineering higher education classroom. The goal of this class is to make students

responsible for constructing their own understanding of the material and leav the instructor to serve as the facilitator of this learning. The results of this educational method prove a higher motivation in students' research work; the study environment is nearest of the real applications from the food industries.

There were some advantages of the simulation-based learning of process control in food engineering education as against the classical education learning: modelling improves understanding, help in experimental design, models may be used for design and control; through step by step simulation the students can visualize the dynamic behaviour of the variables that characterise the fermentation process and the behaviour of the variables control system.

Simulation-based learning offers to the students more advantages: performing individual and team student work, originality and practical usefulness, interdisciplinary fields.

REFERENCES

[1] Andrášik, A., Mészáros, A., & de Azevedo, S. F. (2004). On-line tuning of a neural PID controller based on plant hybrid modeling. *Computers and Chemical Engineering, 28*, 1499–1509.

[2] Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61.

[3] Belton, D. J. (2016). Teaching process simulation usingvideo-enhanced and discovery /inquiry– based learning:Methodology and analysis within atheoretical framework for skill acquisition. *Education for chemical engineers*, *17*, 54–64.

[4] Aulls, M. W., Kaur Magon, J., & Shore, B. M. (2015). The distinction between inquiry-based instruction and non-inquiry-based instruction in higher education: A case study of what happens as inquiry in 16 education courses in three universities. *Teaching and Teacher Education*, *51*, 147-161.

[5] Sipos, A., Meyer, X. M., & Strehaiano, P. (2007). Development of a non-linear, dynamic mathematical model for the alcoholic fermentation. *Acta Alimentaria Hungarica*, *36*, 429-438.

[6] Șipoș, A., & Imre-Lucaci, A. (2014). Statistical processing and dynamic modeling of an alcoholic fermention process. *Studia Universitatis Babeș-Bolyai Chemia*, *3*, 17-28.