Simulation of a Proportional-Integral-Derivative Control for Continuous Bioreactor

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Abstract: In a continuous bioreactor, feed is added, and the product flow is removed at a constant rate. The objective is to maintain the system at a steady state with high product formation. This can produce a very productive process, with a low operating cost. However, there are operational challenges, especially on an industrial scale, because they require tightly controlled conditions and strong monitoring methods. For long operation, the system suffers a higher risk of contamination. This paper investigated the PID (Proportional integral Derivative) control strategy of a continuous bioreactor. Several tuning methods of PID controller were used for controller parameters determination (i.e., Direct Synthesis, Ziegler-Nichols (Z-N), and Tyreus-Luyben (TLC)). The results of the closed-loop simulation for servo (setpoint tracking) problems are presented in this paper for each method and compared. The results showed that the three method works well qualitatively. However, the process model of the system needs to be modified by introducing 5 hrs time delay, which is useful in obtaining cross over frequency and to make PID possible in the Direct Synthesis method.

1 INTRODUCTION

An important aspect of bioprocess control is to lay down real-time operations that are stable, less susceptible to various disturbances, close to certain circumstances, or desired profiles compatible with an optimal operating condition (Dochain, 2008). Bioprocess control itself can be defined as providing an environment that is close to optimal so that microorganisms can grow to reproduce and produce the desired product. This includes providing the right concentration of nutrients (e.g., carbon, nitrogen, oxygen, phosphorus, sulfur, minerals), eliminating toxic metabolic products (e.g., CO_2), and controlling important parameters (e.g., pH, temperature).

The dynamics model for a bioreactor system has been available (Riggs and Karim, 2006). Based on this model, Agustriyanto (2015) obtained the first-order transfer function in the Laplace domain, which then successfully controlled by the Proportional Integral (PI) controller (2016). Simulation results of a closed-loop system with PI controller tuned by direct synthesis method have been presented (Agustriyanto, 2016).

The objective of this paper is to investigate the Proportional Integral Derivative (PID) control strategy of the above continuous bioreactor.

In the next section (Method), the system being studied (continuous bioreactor) will be explained first, followed by its open-loop transfer function in the Laplace domain. PID control of the bioreactor system will also be discussed and followed by several tuning methods (Direct Synthesis, Ziegler Nichol, and Tyreus Luyben).

Section 3 (Results and Discussion) mainly presenting controller parameters and their closed-loop simulation results.

2 METHOD

2.1 Continuous Bioreactor

The continuous bioreactor being studied is presented in Figure 1 (Riggs and Karim, 2006). The model based on first principle (mass conservation) for this system is presented as follows:

$$\frac{dx}{dt} = -\frac{F_V}{V}x + \mu_{\max}x \quad (1)$$

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$$\frac{dS}{dt} = \frac{F_V}{V} S_F - \frac{F_V}{V} S - \frac{1}{Y_{xS}} \mu_{\max} x \quad (2)$$

$$\frac{dP}{dt} = -\frac{F_V}{V} P + \frac{1}{Y_{xP}} \mu_{\max} x \quad (3)$$

The cells consumed most of the substrate, and it was assumed that the cell growth followed Monod kinetics. The process variables and parameters for this bioreactor model were given in Table 1.

The feed contains sugar as a substrate (S) from grains (such as wheat, barley, corn, rice, etc.) and nutritional salts to support cell growth (x). Cells (x) consume substrate (S) and produce product (P) and CO_2. The air blower provides oxygen to cells. The exit gas consists mainly of nitrogen from the air, oxygen that is not consumed, and carbon dioxide produced by cells from sugar consumption. Cell concentration was measured with a turbidity meter, and substrate concentration was measured by an online HPLC analyzer. In industrial bio-processes, filters are normally used for all inlet and outlet flow to keep sterile conditions even though it is not shown in Figure 1.

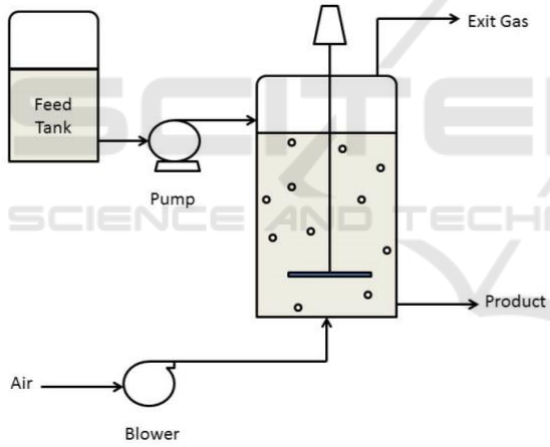

Figure 1. Continuous bioreactor system

Table 1: Process variables and parameters

Symbol	Variables & Parameters	Values & Units
F_V	Feed rate	1 m3/h
K_S	Monod's constant	0.1 g/L
P	Concentration of product	1.25 g/L
S	Concentration of substrate	25 g/L
S_F	Substrate concentration in the feed	50 g/L
t	Time	h
V	Bioreactor volume	5 m3
x	Concentration of cell	0.25 g/L
YxP	Yield factor	0.2 g-cells/ g-product
YxS	Yield coefficient	0.01 g-cells/ g-substrate
μ_{max}	The maximum specific growth rate	0.2/h

2.2 Process Transfer Function

First-order transfer function in Laplace domain for this bioreactor system has been published before (Agustriyanto, 2015) by solving the model equation (i.e Equation (1) to (3)) subject to the steady-state parameters and values are given in Table 1 using DEE (Differential Equation Editor) in Matlab. The results were re-identified using the System Identification Toolbox. This method was previously explained in Agustriyanto and Fatmawati (2013) and Agustriyanto (2014). The results are as follows (where the mark bar indicates that the variables are in the form of deviation):

$$\begin{bmatrix} \bar{x} \\ \bar{S} \\ \bar{P} \end{bmatrix} = \begin{bmatrix} \frac{-0.005}{100s+1} \\ \frac{0.54813}{96.663s+1} \\ \frac{-0.025}{100s+1} \end{bmatrix} \left[\bar{F}_v\right] \quad (4)$$

2.3 PID Control of Continuous Bioreactor

Product (P) was chosen as the variable being controlled, and the flow rate to the reactor (F_V) as the manipulating variable. Figure 2 shows the closed-loop system for the continuous bioreactor. It was assumed that the transfer function for the measurement equipment and control valve are one, so they were ignored in the figure.

PID mode was chosen for the controller, and as the system transfer function is first order, the Direct Synthesis tuning method (Seborg, 2010) or Ziegler-Nichol and Tyreus-Luyben method can be applied. It was assumed that there were 5 hrs time delay, and it was used for tuning purposes only.

The reason for using the Direct Synthesis is that we can specify the desired closed-loop transfer function, which is in this case: servo problem (Chen and Seborg, 2002). While Ziegler Nichol is a classical method that is still widely used due to its simplicity (Zalm, 2004).The Tyreus Luyben procedure is quite similar to the Ziegler Nichol, but the final controller setting is different.

2.4 Direct Synthesis (DS) Controller Tuning

Direct synthesis for a first-order process will lead to a PI controller (Agustriyanto, 2016); therefore, for this system, another approach will be used. Here, FOPTD (First Order Process with Time Delay) is used since it will give PID. The derivation to obtain a PID setting can be found elsewhere, and the resulting PID is shown in Table 2. (http://inside.mines.edu/~jjechura/ProcessDynamics/14_DirectSynthesis.pdf) . It was also assumed that the value of λ = 5 hrs.

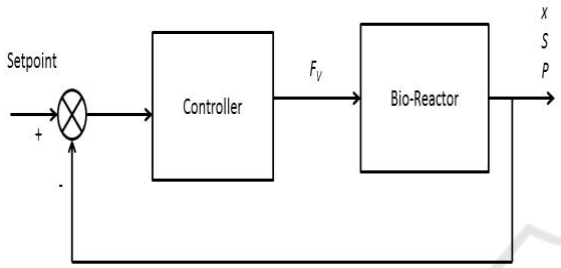

Figure 2. Close loop of the bioreactor system

2.5 Ziegler Nichols (Z-N) Controller Tuning

To use the Ziegler-Nichols method, first, we need to plot the Bode diagram (Coughanowr, 2009). Table 2 shows that controller parameters are the function of K_u and P_u.

$$K_u = \frac{1}{A} = \text{ultimate gain} \quad (5)$$

$$P_u = \frac{2\pi}{\omega_{co}} = \text{ultimate period} \quad (6)$$

$A =$ amplitude ratio at the cross over frequency (7)

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Table 2: Controller tuning formula

	Direct Synthesis	Ziegler Nichols	Tyreus Luyben
K_c	$\frac{\tau_p + \theta}{K_p \lambda}$	$0.6K_u$	$\frac{K_u}{2.2}$
τ_I	$\tau_p + \theta$	$\frac{P_u}{2}$	$2.2P_u$
τ_D	$\frac{\tau_p \theta}{\tau_p + \theta}$	$\frac{P_u}{8}$	$\frac{P_u}{6.3}$

2.6 Tyreus Luyben (TLC) Controller Tuning

Similar to the Ziegler-Nichols method, Tyreus-Luyben controller parameters are also the functions of Ku and Pu (http://pages.mtu.edu/~tbco/cm416/zn.html). These functions are shown in Table 2.

3 RESULTS AND DISCUSSION

Figure 3 shows the Bode Plot for the system being studied. It was found the value of cross-over frequency = 0.944 with the amplitude of 0.000266 at cross-over. Therefore, by using Eq.(5) and (6):

$$K_u = 3759 \quad (8)$$

$$P_u = 6{,}6599 \quad (9)$$

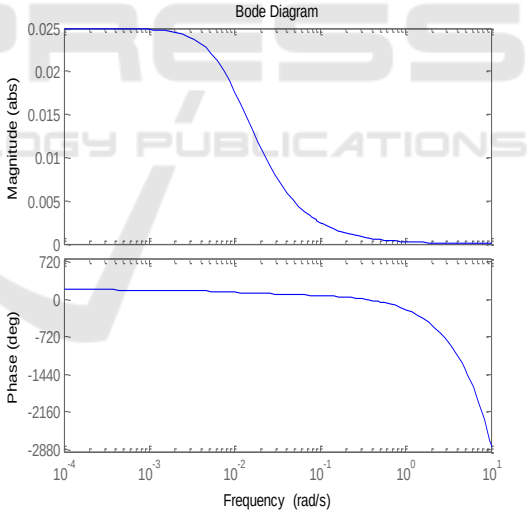

Figure 3. Bode plot

Table 3 shows controller parameter values, which are calculated according to the formula shown in Table 2.

The product concentration was successfully controlled using PID controller (Figure 4). This figure shows the performance of the PID controller tuned by three different methods (Direct Synthesis (DS), Ziegler-Nichols (Z-N), and Tyreus Luybean (TLC)). Here, the setpoint for product concentration was changed from initial (i.e., 1.25 g/L) to 1.2 g/L at t=100

hr, followed by a step up and down at t=300 hr and 400 hr to the value of 1.225 g/L and back to 1.2 g/L

Table 3: Controller tuning

	Direct Synthesis	Ziegler Nichols	Tyreus Luyben
K_c	-840	-2255.4	-1708.6
τ_I	105	3.33	14.6518
τ_D	4.7619	0.8325	1.0571

From simulation results shown in Figure 4, it can be concluded that the Ziegler-Nichols (Z-N) method of tuning will give the highest overshoot for step changes in setpoint, followed by Tyreus Luyben (TLC) and Direct Synthesis (DS). Therefore, Ziegler-Nichols also fast in reaching its new steady-state value as expected by the set point.

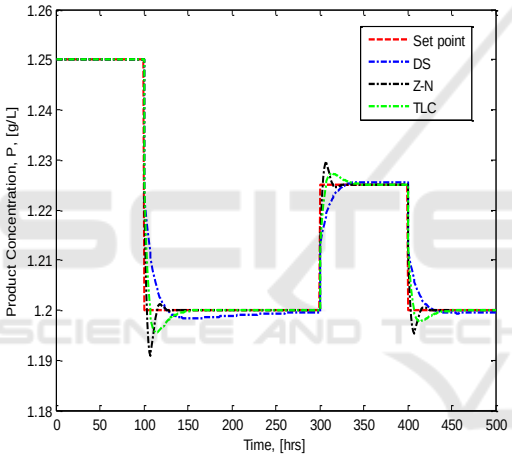

Figure 4. The plot of Product Concentration (P) vs. Time for PID Controller

Figure 5 shows the performance of uncontrolled variables (i.e., x and S) vs. time. When the product set point reduced to 1.2 g/L at t=100 hr, it can be seen that cell concentration also reduced while the substrate was increased. This is caused by different signs in-process model gain for cell and substrate, as indicated in Eq.(4).

Comparing to other published research (Husain et al., 2014), these results agree that Tyreus Luyben gave lower overshoot than Ziegler Nichols. While for Direct Synthesis, we specify the output as desired (i.e., no overshoot).

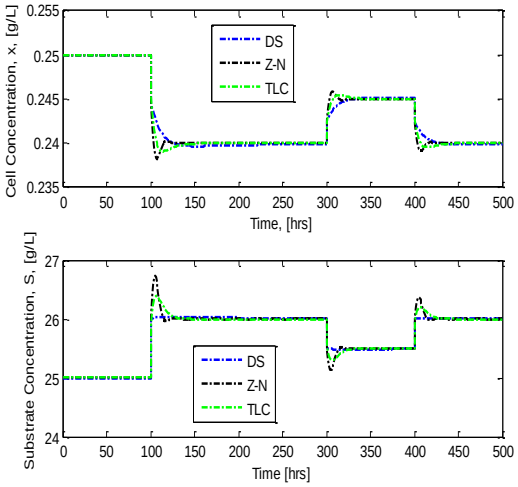

Figure 5. The plot of Cell and Substrate Concentration for PID Controller

4 CONCLUSIONS

Simulation of a PID control strategy for a continuous bioreactor system has been performed. Three different tuning methods have been applied and work well.

In implementing the method, the process model of the system needs to be modified by introducing a 5 hrs time delay. This time delay should be small enough compared to its time constant. Here we choose about 5% of the time constant. This will help in obtaining cross over frequency in Bode plot, as for the first-order process without time delay will result of none. This time delay also useful in obtaining the PID parameter in the Direct Synthesis method as the original process model will lead to the PI (not PID) controller.

REFERENCES

Dochain, D. (2008). Bioprocess Control, John Wiley and Sons, Inc.

Riggs, J.B., Karim, M.N. (2006). Chemical and Bioprocess Control, Pearson Prentice Hall.

Agustriyanto, R. (2015). Simulation of Continuous Bio-Reactor. In Proceedings of the Eight International Conference of Chemical Engineering on Science and Applications (ChESA), Banda Aceh, Indonesia.

Agustriyanto, R., Fatmawati, A. (2013). Bioprocess System Identification of Continuous Fermentation, In Proceedings of the 2nd International Conference of the Indonesian Chemical Society, Yogyakarta, Indonesia

Agustriyanto, R. (2014). Model Identification of Continuous Fermentation under Noisy Measurements, In Proceedings of the 3rd International Conference on Computation for Science and Technology (ICCST-3), Denpasar, Bali.

Agustriyanto, R. (2016). PI Control of a Continuous Bio-reactor, In Proceedings of the 6th Annual International Conference (AIC) of Syiah Kuala University, Banda Aceh, Indonesia.

Seborg, D.E., Mellichamp, D.A., Edgar, T.F. (2010). Process Dynamics and Control, John Wiley and Sons, Inc.

Chen, D., Seborg, D.E. (2002). PI/PID Controller Design Based on Direct Synthesis and Disturbance Rejection. Ind. Eng. Chem. Res., 41, 4807-4822.

Zalm, G.M. (2004). Tuning of PI/PID Controllers: Literature Overview.

https://pdfs.semanticscholar.org/b1a8/a78f2e8b0f64b29538b83e2859d8b6365b43.pdf

http://inside.mines.edu/~jjechura/ProcessDynamics/14_DirectSynthesis.pdf

Coughanowr, D.R., LeBlanc, S.E. (2009). Process Systems Analysis and Control, McGraw-Hill's.

http://pages.mtu.edu/~tbco/cm416/zn.html.

Hussain, K.M., Zepherin, R.A.R., Kumar, M.S. (2014). Comparison of Tuning Methods of PID Controllers for FOPTD System. International Journal of Innovative Research in Electrical, Electronics, Instumentation and Control Engineering, 2/3.

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