

DISCRETE-TIME MODELLING OF THE CHEESE WHEY DRINK PRODUCTION AND SERVO CONTROL OF pH

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Abstract

pH control has received considerable attention in preparation of cheese whey drink by fermentation with kefir yeast because of its critical role in quality assurance. To improve this drink rheological and sensory properties, milk and grape juice is added to the bioprocess medium. Experimental operations show that kefir yeast is very resistant to contamination.

A Self-tuning Proportional-Integral-Derivative control is applied to the bioprocess. The simulation results illustrate that the controller can bring the pH from initial value to a set value. This approach is expected to achieve the same results in practical drink production due to its features of self-tuning and robustness.

Keywords: Self-tuning PID, pH control, kefir yeast, cheese whey

PEYNİRALTI SUYU İÇECEĞİ ÜRETİMİNDE KESİKLİ ZAMAN MODELLEMESİ VE pH' IN SERVO KONTROLÜ

Özet

Peyniraltı suyundan kefir mayası ile fermentasyonu sonucu içecek elde edilmesinde, kalite güvencesi açısından, pH kontrolü kritik rol oynar. Bu içeceğin reolojik ve duyu özelliklerini geliştirmek için, biyoproses ortamına süt ve üzüm suyu eklenir. Deneysel işlemler kefir mayasının kontaminasyona dirençli olduğunu göstermektedir.

Kendinden Ayarlamalı Oransal-İntegral-Türevsel Kontrol biyoprosese uygulanmıştır. Simülasyon sonuçları kontrol edicinin pH' ı başlangıç değerinden set değerine getirdiğini göstermiştir. Bu yaklaşımın pratik içecek üretiminde aynı sonuçları, kendinden ayarlama ve her koşulda kullanılabilirlik özellikleri nedeni ile, elde etmesi beklenmektedir.

Anahtar kelimeler: Kendinden Ayarlamalı PID, pH kontrolü, kefir mayası, peyniraltı suyu

1. INTRODUCTION

Amount of cheese whey in the world is over 10^8 tonnes per year (Ozmihci and Kaygi, 2008). Cheese whey with high carbohydrate, protein and lipid contents is an important source of environmental pollution (Grba et al., 2002). Waste of cheese whey represents a significant loss of resources and causes serious pollution problems since whey has a heavy organic pollutant with a high biochemical oxygen demand (BOD) of 40 000 to 60 000 ppm and a chemical oxygen demand (COD) of 50 000 to 80 000 ppm (Ben-Hassan and Ghaly, 1994). Disposing of whey provides no valuable product, and is costly and labour demanding for the cheese manufacturers, who generally bears all the direct costs of handling and transport. Whey problem must be considered as a resource and not only as a waste effluent, in view of its large potential as a source of added value products (Pedro et al., 2010).

A large fraction of the whey is dried to produce cheese whey powders. It is mostly used for animal feeding but smaller quantities may be also used in human foods, such as ice-creams, fruit juices, baked goods, cakes, sauces, milk derivatives, etc (Pedro et al., 2010).

Paraskevopoulou et al. prepared a kefir-type drink by fermentation with kefir granules of cheese whey containing fructose, black raisin extract and milk (Paraskevopoulou et al., 2003). Kourkoutas et al. proposed a low-alcohol content drink by using continuous whey fermentation using kefir yeast (Kourkoutas et al., 2002). It was shown that kefir was highly resistant to contamination under actual industrial conditions and no serious problems in handling of raw materials and equipment were observed (Petsas et al., 2002).

The ultimate measure of food quality is determined by comparing instrumental process set point. Effective techniques are required to convert desired sensory quality targets into instrumental process set points. Food process control relies on instrumental measurements. Huang et al. simulated a dying process with the aim of bringing the pH of the liquor from any initial value to any other value (Huang et al., 2000). They developed a Self-tuning Proportional-Integral-Derivative (PID) controller with the ability to auto-tune the gains by extending model reference adaptive control.

Tan et al. developed a robust Self-tuning PID controller which is suitable for nonlinear systems. Simulation results for the level control of fluid in a spherical tank using the scheme are provided which verify the good performance of the proposed control scheme (Tan et al., 2002). Albaz et al. realized the pH control of the neutralization process of limestone with H_2SO_4 in a stirred continuous reactor by utilizing Self-tuning PID algorithm. The comparison of control performances between STPID and PID was done. The STPID shows very satisfactory control than PID. Altınten et al. applied Self-tuning PID controller with genetic algorithm to the temperature control of a jacketed batch polymerization reactor and thus tracking performance of optimal temperature profile was investigated. To obtain optimal tuning parameters of this controller, genetic algorithm was used. The fitness function was taken as the integral of the absolute value of the error (IAE). Kansha et al. proposed a Self-tuning PID controller using just-in-time learning (JITL) technique. Simulation is presented to illustrate the proposed controller and a comparison with conventional control was made (Kanska et al., 2008).

In this work, cheese whey drink is produced with kefir yeast by controlling pH value of bioreactor medium. The model is built to closely approximate the pH system by using experimental data. Instead of a real process, the model is to be used for generating the pH response. Self-tuning controller is applied.

2. EXPERIMENTAL SETUP

Bioreaction is carried out in a 1 liter glass-jacketed bioreactor as shown in Figure 1. The pH was measured with a pH meter and was recorded on-line every 1 second by a computerized data acquisition system. The PRBS signal programme was written in Visual Basic. In the experiment the PRBS signal was given to 0.5 M sodium bicarbonate (NaHCO_3) flow rate, the system dynamic response data was obtained from the on-line pH monitor.

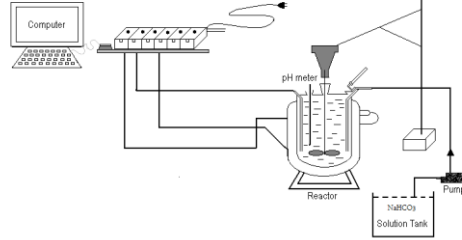


Figure 1. Experimental setup

In the experimental work, the bioreactor was first charged with pasteurized mixture which contains 350 mL cheese whey, 10 g glucose, 70 mL grape juice and 273 mL milk, and immediately inoculum (kefir yeast, 7 mL) was added. pH was monitored throughout the fermentation process.

3. SELF-TUNING PID CONTROL APPLICATION

The system model is given as:

$$y(t) = \frac{Bz^{-1}}{A} u(t) = \frac{b_0 z^{-1}}{1 + a_1 z^{-1} + a_2 z^{-2}} u(t) \quad (1)$$

where $u(t)$ is base flow rate, $y(t)$ is pH value of bioreactor mixture.

The feedback loop is disconnected. A Pseudo-Random Binary Sequence (PRBS) is added to the system input (see Figure 2) which is then employed as a forcing function (base flow rate changes) to disturb the process. The system pH changes are obtained (Figure 3). These experimental data and Bierman algorithm are utilized to evaluate b_0 , a_1 and a_2 parameters in equation (1).

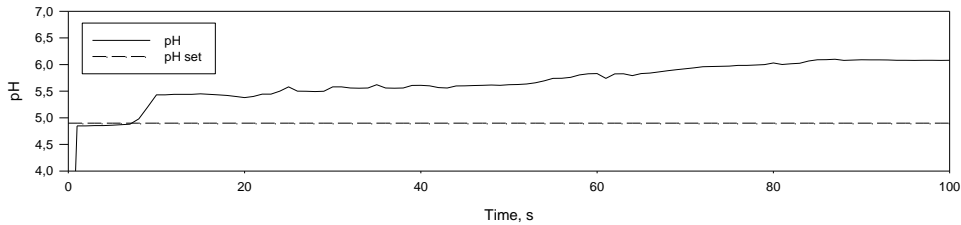


Figure 2. Experimental PRBS signal

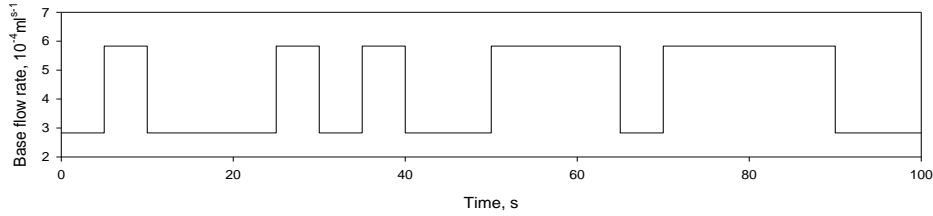


Figure 3. Base flow rate change in the face of PRBS mode

The controller equation is given as:

$$u(t) = \frac{[r(t)-y(t)](s_0+s_1z^{-1}+s_2z^{-2})}{(1-z^{-1})} \quad (2)$$

The closed loop setpoint following relationship is obtained by combining the system model equation (1) and the controller equation (2), ie:

$$y(t) = \frac{b_0z^{-1}(s_0+s_1z^{-1}+s_2z^{-2})}{(1-z^{-1})(1+a_1z^{-1}+a_2z^{-2})+b_0z^{-1}(s_0+s_1z^{-1}+s_2z^{-2})} r(t) \quad (3)$$

The equivalent chosen closed loop T polynomial is of the form:

$$T = 1 + t_1z^{-1} + t_2z^{-2} + t_3z^{-3} \quad (4)$$

The controller coefficients can be found by equating the real denominator of the closed loop equation (3) with equation (4) thus:

$$\begin{aligned} &(1 - z^{-1})(1 + a_1z^{-1} + a_2z^{-2}) \\ &+ b_0z^{-1}(s_0 + s_1z^{-1} + s_2z^{-2}) \\ &= 1 + t_1z^{-1} + t_2z^{-2} + t_3z^{-3} \end{aligned}$$

by comparing coefficients of powers of z^{-1} , we obtain:

$$s_0 = \frac{(t_1 - a_1 + 1)}{b_0} \quad (5)$$

$$s_1 = \frac{(t_2 - a_2 + a_1)}{b_0} \quad (6)$$

$$s_2 = \frac{(t_3 + a_2)}{b_0} \quad (7)$$

The necessary increment in the control signal can be obtained from:

$$\Delta u = s_0e(t) + s_1e(t-1) + s_2e(t-2)$$

It is significant to note that integral action in the controller provides steady-state following without offset even if the values of the parameters of the system or of the controller change.

4. RESULTS AND DISCUSSIONS

The PRBS signal shown in Figure 2 is given to sodium bicarbonate flow rate which is the system input. The results of pH measurements are shown in Figure 3. The initial pH of the fermenter medium (after the addition of inoculum) was 6.86. There was a steady decrease in the pH of the medium during the fermentation of cheese whey with no base flow rate addition. Since the base flow rate has a direct effect on the pH of the medium. The effect of sodium bicarbonate flow rate and pH can be deduced in the following general expression:

$$y(t) = \frac{0,0000109}{1 - 0,9276 z^{-1} - 0,0001956 z^{-2}} u(t - 1) \quad (9)$$

Modelling and simulation are considered important and integral steps in design and evaluation of dynamic systems. These steps are also paramount in the development of control techniques for dynamic systems. The model (equation (9)) is used to find closed loop response of pH by using Self-tuning control algorithm in the face of setpoint step change. In this servo control, effective tuning parameter is t_1 . The other tuning parameters t_2 and t_3 are chosen as default values which are zeros. The setpoint step change given from 5.83 to 6.09.

The controller design is generally based upon simple process model, thus ‘fine-tuning’ is often required after the controller has been initially set up. On the other hand, self-tuning controllers can provide good control even if an accurate process model is not available. The Self-tuning PID algorithm is written in MATLAB and applied to the process model for setpoint step change. The success of the control action with various t_1 values have been estimated using an integral square of the error (ISE) and an integral of absolute value of error (IAE) criterions. The various cases studied are listed in Table 1. The best closed-loop ISE and IAE values obtained for t_1 which equals 0.2.

Table 1. STPID performance criterions for various tuning variable (t_1)

t_1	$\sum e^2 = \text{ISE}$	$\sum e = \text{IAE}$
0,9	0,4259	3,1365
0,8	0,1649	1,1209
0,7	0,1108	0,6920
0,6	0,0885	0,5057
0,5	0,0772	0,4017
0,4	0,0712	0,3355
0,3	0,0683	0,2898
(0,2)	0,0676	0,2637
0,1	0,0687	0,2974
0,09	0,0689	0,3011
0,05	0,0699	0,3169
0,01	0,0711	0,3340

Clearly the magnitude of the sampling interval has a considerable influence upon the stability of the controlled variable. In this case studies, the sampling interval is chosen as 1 s.

The best setpoint tracking is obtained in Figure 4.

Discrete-time modeling of the cheese whey drink production and servo control of pH

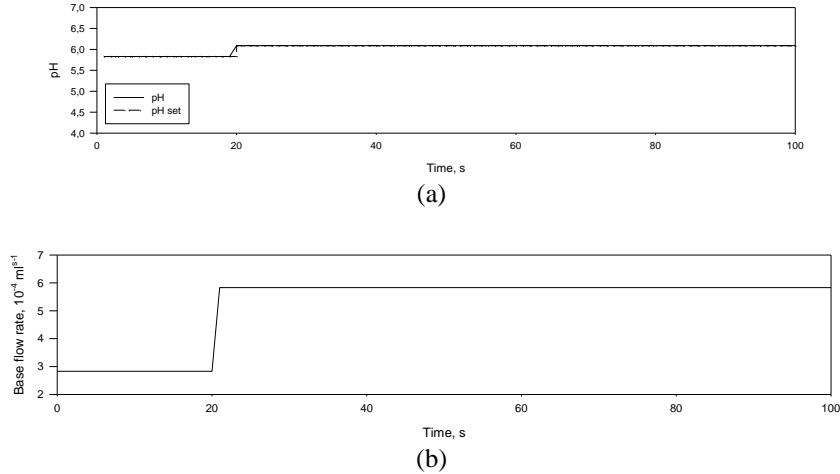


Figure 4. Self-tuning PID control of pH ($t_1=0,2$) in the face of setpoint step increase, (a) pH change (b) Base flow rate change

5. CONCLUSION

Modelling and simulation are considered important and integral steps in design, development, and evaluation of dynamic systems. These steps are also paramount in the development of control techniques for dynamic systems.

For the model identification of bioprocess, the PRBS was applied experimentally and it was employed as a forcing function to disturb the cheese whey fermentation. pH profile observed on the computer were recorded. The second order discrete time model was used. Experimental data using causes the best estimation of the model parameters.

For the control work, the best control results were obtained by using this model when tuning parameter adjusted at its the best value according to performance criterions. In the face of setpoint step change from 5.83 to 6.09, very good set point following was observed. The best control performance was obtained by tuning poles of the closed-loop where t_1 is the tuning parameter.

OPERATORS AND NOTATIONAL CONVENTIONS

- A monic polynomial in the z-domain representing the poles of the discrete-time system
- a_i parameters of A polynomial
- B polynomial in the z-domain representing the zeros of the discrete-time system
- b_i parameters of B polynomial
- $e(t)$ difference between the measured variable and set point at time t
- $r(t)$ setpoint value at time t
- $u(t)$ input variable at time t
- $y(t)$ output variable at time t
- z^{-1} backward shift operator
- t_i control tuning parameter

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