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A SATURED CONTROL FOR A CONTINUOUS ANAEROBIC BIOREACTOR

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Abstract:
The quality and operational factors in a wastewater process define a bounded region. For this reason, a satured control that ensures the depollution of a wastewater bioreactor is presented. The control input is the dilution rate and the controllable variable is a linear combination of the substrate concentrations. Some results via simulation are presented. *Copyright © 2007 IFAC*

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1. INTRODUCTION

The anaerobic wastewater treatment process has been intensively used for its high capacity to degrade concentrated and difficult substrates (Matta-Alvarez *et al.*, 2000). A suitable control strategy ensures the bioreactors performance. This is due to fact that high substrate concentrations can inhibit the bacterial growth and besides that minimum substrate washes the bioreactor. The control variable is the dilution rate, due to physical constraints remains positive and cannot be arbitrarily high. The capacity of the process allows a maximum flow rate associated to the pumping mechanism. Besides, the minimum flow rate could be zero, however this means that the plant must be stopped and this cannot be done. For this reason a minimum flow rate is commonly assigned.

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It is well known that this process can be unstable under certain variations, i.e., acidification. For this reason some control laws that avoid these variations have been reported, like the adaptive feedback of the gaseous flow-rate measurements (Perrier and Dochain, 1993), (Mailleret *et al.*, 2004) or fuzzy control of the acidic compounds (Punal *et al.*, 2000).

In this paper, an anaerobic bioreactor is considered in which organic compounds are biodegraded in absence of oxygen to produce methane. The basic model assumes that two bacterial populations are presented (Bernard *et al.*, 2001). The first one corresponds to the acidogenesis (acidogenic bacteria), that produces volatile fatty acids (VFA). The second population corresponds to the methanogenesis (methanogenic bacteria), and uses the VFA for growth and produces methane. The main idea considers a bounded control action that regulates a linear combination of the substrates concentrations. The paper is organized as

follows: In Section 2 the model, the main assumptions and the control law are described. In Section 3 numerical results are presented. And in Section 4 we give some conclusions.

2. MODEL

The model is the one considered in (Bernard *et al.*, 2001):

$$\begin{aligned}\dot{X}_1 &= (\mu_1(S_1) - \alpha D)X_1 \\ \dot{X}_2 &= (\mu_2(S_2) - \alpha D)X_2 \\ \dot{S}_1 &= D(S_{1in} - S_1) - \kappa_1\mu_1(S_1)X1 \\ \dot{S}_2 &= D(S_{2in} - S_2) + \kappa_2\mu_1(S_1)X1 \\ &\quad -\kappa_3\mu_2(S_2)X_2 \end{aligned} \tag{1}$$

where X_1, X_2, corresponds to the acidogenic and methanogenic bacterial, S_1, S_2 are substrate 1 (VFA) and substrate 2, and D corresponds to the dilution rate. Commonly, μ_1 and μ_1 are the Monod and the Haldane growth bacterial kinetic, respectively. The terms S_{1in} and S_{2in} are the substrate concentrations in the inlet. The κ_i represents the yield coefficient associated with bacterial growth. Parameter $\alpha \in [0, 1]$ represents the proportion of bacteria that are not fixed on the bed, and therefore they are affected by the dilution rate effect: $\alpha = 0$ represents an ideal fixed bed reactor, whereas $\alpha = 1$ to an ideal continuous stirred tank reactor.

It is considered that the bacterial concentrations, the substrate and the dilution rate are positive and bounded functions, i.e., X_1, X_2, S_1, S_2 and $D \in \Re^+$. Meanwhile, the kinetics $\mu_1(S_1)$ and $\mu_2(S_1)$ are bounded non-decreasing functions such that

$$\begin{aligned}\mu_1(0) &= 0 \\ \mu_1(S_1) &< \mu_{1max} \\ \forall S_1 &\geq 0 \end{aligned} \tag{2}$$

$$\begin{aligned}\mu_2(0) &= 0 \\ \mu_2(S_2) &\leq \mu_{2max} = \mu_2(S2^*) \\ \forall S_2 &\geq 0 \end{aligned} \tag{3}$$

The aim of the control is to drive a linear combination of the substrate in a bounded operation region where

$$S_\lambda = S_1 + \lambda S_2 \tag{4}$$

is the variable to regulate.

To propose a control law, we analyze first the dynamic in (4),

$$\begin{aligned}\dot{S}_\lambda &= D\left[S_{\lambda in} - S_\lambda\right] + X_1\mu(S_1)(\kappa_2 - \lambda\kappa_1) \\ &\quad -\kappa_3\lambda\mu_2(S_2)X2 \end{aligned} \tag{5}$$

From (5), we can see that in the steady state an unique value in the dilution rate ($\bar{D}$) corresponds to a ($\bar{S_\lambda}$). Moreover, $A = \left\{\bar{X_1}, \bar{X_2}, \bar{S_1}, \bar{S_2}, \bar{D}\right\}$ defines the steady state set in the bioreactor (1).

In the aim regulation of S_λ it is also required a bounded region so,

$$S_{\lambda min} \leq \bar{S_\lambda} \leq S_{\lambda max} \tag{6}$$

And

$$D_{min} \leq \bar{D} \leq D_{max} \tag{7}$$

For this reason, the following control law is proposed

$$\begin{aligned}D &= D_{prom}\left[2 - \frac{2}{1 + exp(-\beta\left|S_\lambda\right|)}\right] \\ &\quad + D_{min} \end{aligned} \tag{8}$$

where $D_{prom} = \frac{D_{max} - D_{min}}{\gamma}$ and $\beta > 0$ is an adjusting parameter. By looking (8) it can be seen that for $0 \leq \bar{S_\lambda} < \infty$, $\bar{D}$ is bounded accordingly,

$$D_{min} \leq \bar{D} \leq \frac{1}{\gamma}[D_{max} - D_{min}(\lambda - 1)] \tag{9}$$

For $\gamma = 1$, $\bar{D} = D_{max}$ and for $\gamma = 2$, $\bar{D} = \frac{1}{2}[D_{max} - D_{min}]$, which is the arithmetic average. Therefore, depending on how tight the bounded region need to be, γ would be chosen.

Meanwhile, to adjust β, we considerer the control dynamic

$$\dot{D} = -\beta e^{-\beta\left|\bar{S_\lambda}\right|} \tag{10}$$

Equation (10) shows that control convergence is achieve with rate $\beta > 0$. However, selecting large values of β results in a fast control convergence rate, which in turns results in a poor performance and even causes instabilities. Instead, it is recommended to choose β near the natural time responses (dilution rate), i.e., $0 < \beta \leq \bar{D}$.

Considering the steady state in (5) we have

$$\begin{aligned}\bar{S_\lambda} &= S_{\lambda in} \\ &\quad + \frac{1}{\bar{D}}\mu_1(\bar{S_1})\left[\bar{X_1}(\kappa_2 - \lambda\kappa_1) - \kappa_3\lambda\bar{X_2}\right] \end{aligned} \tag{11}$$

From (2) and the fact that D, X_1, X_2 are bounded, we have the following condition

$$S_{\lambda max} < S_{\lambda in} \tag{12}$$

Moreover, a bounded input (7) corresponds to a bounded state (6) if the following inequalities are satisfied

$$
\begin{aligned}
X_{1min} < X_1(t) &< \frac{S_{1in}}{\kappa_1 \alpha} \\
0 < X_2(t) &< \frac{T_{2in}}{\kappa_3 \alpha} \\
S_{1min} < S_1(t) &< S_{1in} \\
T_{2min} < T_2 &< T_{2in}
\end{aligned} \tag{13}
$$

where $T_2 = S_2 + \frac{\kappa_2}{\kappa_1} S_1$ is as in (Grognard and Bernard, 2006).

From the above, our main contribution in this paper corresponds to the control law proposed (8).

3. SIMULATIONS

Some numerical results are presented by using the control (8) in the anaerobic bioreactor (1). The bioreactor parameters are obtained from (Bernard *et al.*, 2001). For comparison the following bounded and initial conditions as in (Grognard and Bernard, 2006) have been chosen.

$S_{\lambda max} = 1.5$	$S_{\lambda min} = 1.3$
$S_{1in} = 15$	$S_{2in} = 15$
$D_{min} = 0.15$	$D_{max} = 0.5$
$\lambda = 0.0064$	

The initial conditions and the control parameters are: $S_1, S_2, X_1, X_2 = [15, 15, 0.1, 0.1]$ and $\beta = 0.01, \gamma = 1.5$, respectively.

In Figure 1 and Figure 2, the control performance and the one in (Grognard and Bernard, 2006) are presented respectively.

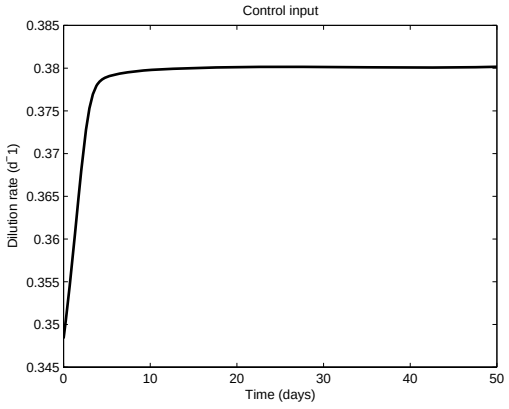

Fig. 1. Designed bounded control

The control proposed here fulfills the bounded requirements showing a good performance. Although the control in (Grognard and Bernard, 2006) also meet the bounded requirements, its performance is oscillatory, this could cause instability problems in the bacterial growth.

The substrates S_1, S_2 are presented in Figure 3, and in Figure 4, the bacterial growth. Both states S_i and X_i reached the steady state with

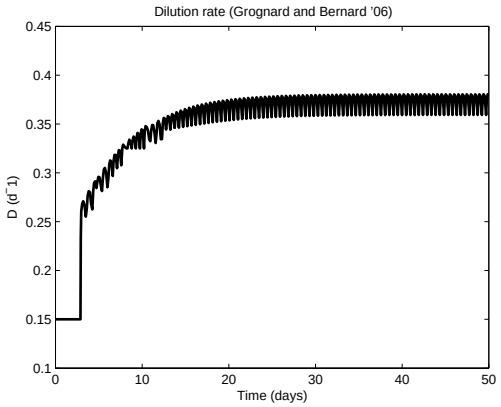

Fig. 2. Bounded control reported in Grognard and Bernard, 2006

a fast and smooth convergence. The substrate concentration is high in the reactor start up, whereas the bacterial growth is low. After some time (30 days,) the bacterial concentrations are increased and the pollution concentrations are decreased inside to their bounded values.

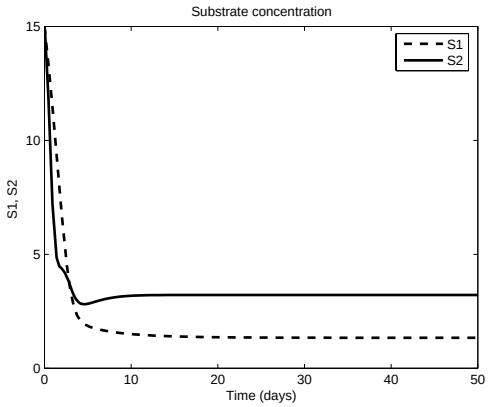

Fig. 3. Substrate concentrations

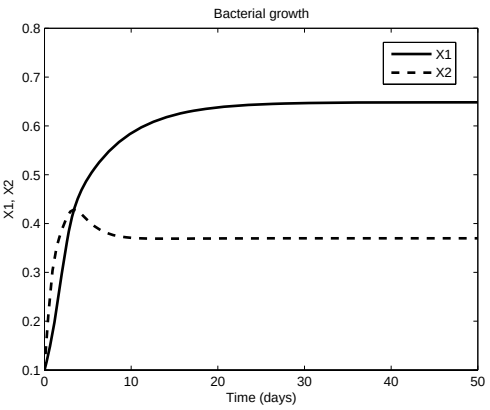

Fig. 4. Bacterial growth

Finally, the control variable, S_λ, is presented in Figure 5. It can be seen that the bounded limits are meet.

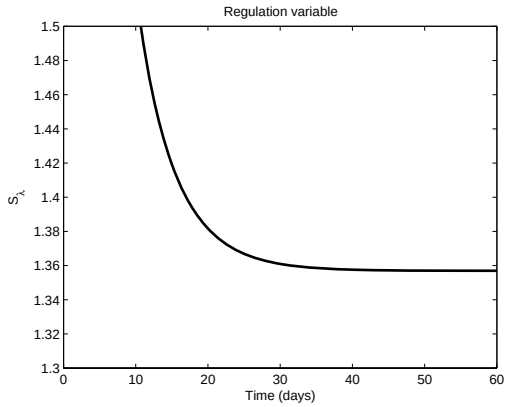

Fig. 5. Control variable

4. CONCLUSIONS

A bounded control for the dilution rate in an anaerobic bioreactor was designed. Some conditions in the control parameters were explained.

The control shows a good performance and meets the desired bounded region.

A linear combination S_λ of the substrates was chosen as control regulation and was driven inside the bounded region previously specified.

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