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AUTOMATION OF THE ACCLIMATION PHASE IN A SEQUENCING BATCH REACTOR DEGRADING INHIBITORY COMPOUNDS

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Abstract: An automatic strategy for acclimation of biomass to 4-chlorophenol in a sequencing batch reactor was evaluated. It combines an I/O linearizing plus PID controller to regulate the dissolved oxygen within the reactor at a given setpoint using the airflow rate, and a simple algorithm for establishing the end of the reaction phase using the manipulated airflow signal. The strategy was tested experimentally, obtaining results that indicate that itis a viable alternative for automatic acclimation of biomass for toxic wastewater treatment in a SBR.

Keywords: Acclimation, dissolved oxygen control, wastewater treatment, PID control, SBR

1. INTRODUCTION

Industrial wastewater containing toxic organic compounds is difficult to treat by conventional biological wastewater treatment processes, due to several factors that include the variability of the wastewater flow and composition, as well as the presence of compounds that may be inhibitors to the microorganisms under relatively low concentrations. However, sequencing batch reactors (SBR) have been shown to be a viable alternative (Wilderer *et al.*, 2001).

A sequencing batch reactor operates in five well defined phases: fill, react, settle, draw, and idle. During the first phase the reactor is filled from a minimal volume to an operating volume as fast as possible. Next, during the reaction phase enough time is allowed for the microorganisms to completely biodegrade the compounds to be treated. After this, a settling phase is started and afterwards a draw phase removes the treated supernatant. Finally an idle phase is allowed before starting the next cycle.

The first step to biodegrade toxic substances in a wastewater treatment plant is the acclimation of the microorganisms. Different mechanisms have been described to explain the acclimation phase and in aerobic microbial communities, it ranges from several hours to several days (Wiggings *et al.*, 1987). It has been shown that a suitable acclimation strategy, where the reaction phase is stopped as soon as degradation has occurred, produces a microbial community with higher specific activity and excellent sludge characteristics even after long term operation (Moreno and Buitrón, 2004). Such an acclimation strategy implies continuous monitoring of the substrate concentration within the reactor, which may increase costs, not only due to the necessary laboratory analyses, but also due to the personnel that has to perform this task. With a pilot bioreactor this is usually not a problem, since these are routine analyses, but in the field this may not be possible.

An automatic acclimation strategy in principle could be programmed using the dissolved oxygen (DO) concentration as measured variable, since its dynamics may be described by (Spanjers *et al.*, 1996)

$$\frac{\mathrm{d}y}{\mathrm{d}t} = (y_{\mathrm{in}} - y)D_{\mathrm{in}} + (y_{\mathrm{sat}} - y)k_L a - r, \qquad (1)$$

where $y(t)$ is the DO concentration inside the reactor (assumed equal throughout the mixed liquor), y_{in} is the DO concentration in the influent (usually zero), y_{sat} is the dissolved oxygen saturation constant, and $D_{\mathrm{in}}(t) = V(t)/Q_{\mathrm{in}}(t)$ is the dilution rate, with V the current volume and Q_{in} the inflow rate. On the other hand $k_L a$ is the oxygen mass transfer coefficient, which depends (usually nonlinearly) on the airflow rate $Q_{\mathrm{air}}(t)$ and the physicochemical properties of the diffusers and mixed liquor. In a batch reactor, during the reaction phase the above equation simplifies to

$$\frac{\mathrm{d}y}{\mathrm{d}t} = (y_{\mathrm{sat}} - y)k_L a - r, \qquad y(0) = y_0, \qquad (2)$$

with y_0 the DO concentration in the reactor immediately after filling. What makes it possible to use dissolved oxygen as monitoring variable is the fact that the respiration rate $r(t)$ in the above equation can be decomposed in two parts: one proportional to the biomass growth rate and thus to the substrate degradation rate $\mu X(t)$ and another one consisting of the endogenous respiration rate $bX(t)$, which is almost constant, since biomass concentration $X(t)$ has slow dynamics in one SBR cycle (Olsson *et al.*, 2005)

$$r = \frac{1}{Y_O}\mu X + bX \qquad (3)$$

It is then clear that if some parameters are known, the dissolved oxygen dynamics may somehow give an indication of the respiration rate and thus of the biomass activity upon degrading the substrate. Therefore, this information may be used to determine when to stop the reaction. Recall that in a batch reactor, the degradation rate μX depends on the substrate concentration, tending to zero when substrate is depleted.

Assume first that the airflow rate Q_{air} is constant during the reaction and therefore $k_L a$ also remains constant. After complete biodegradation it happens that $r = bX$, which is constant and usually small. Therefore, dissolved oxygen will exponentially reach a steady state $y_{\mathrm{ss}} = y_{\mathrm{sat}} - bX/k_L a$ with rate $k_L a$. To detect the end of the reaction one needs only to observe such an exponential behavior on the signal $y(t)$. This is indeed possible when the biomass is already acclimated, since μX is significantly larger than bX during biodegradation. This implies that it dominates during the reaction and thus the DO concentration curve reaches significantly low values for a sufficient airflow rate, from which its exponential convergence to y_{ss} may be observed. This in fact has been used in a so-called *variable time control* strategy to enhance biodegradation capacities in a SBR treating synthetic wastewater with high concentrations of 4-chlorophenol (Buitrón *et al.*, 2005). However, during the first cycles of acclimation, this strategy is not applicable, mainly because the metabolic respiration rate μX is rather small compared to endogenous respiration. This is clearly illustrated in a figure by Moreno-Andrade and Buitrón (2004), where a constant airflow of 1.5 L/min was used during the whole acclimation period. To implement such a control strategy an operator should know in advance which value of Q_{air} to set in order to observe such a behavior of the DO signal without compromising the degradation because of limiting dissolved oxygen conditions.

The previous discussion motivates the need for a better automatic control strategy for acclimation. The present study proposes such a strategy, which first implements a controller to regulate dissolved oxygen at a suitable setpoint by manipulating the airflow rate, and then uses the manipulated variable in an algorithm to detect mineralization.

Implementing a dissolved oxygen controller is not an easy task for batch systems, because the degradation rate is not nearly constant, as in continuous systems. There are several control strategies that have been proposed for activated sludge systems, that range from simple PID controllers to adaptive or model predictive schemes (Olsson *et al.*, 2005; Lindberg and Carlsson, 1996; Chotkowski *et al.*, 2005), but these may not be applicable to batch systems, as previously discussed. The controller proposed here is an I/O linearizing scheme using Q_{air} as input and DO concentration as output, coupled with a PID controller with antiwindup.

In the next section, the materials and methods used are explained, including the experimental bioreactor setup, the analyses performed, the DO controller, and the automatic end-of-reaction detection algorithm. Following this, in the next section results are presented and discussed, and finally some conclusions are given.

2. MATERIALS AND METHODS

2.1 Sequencing batch reactor

The bioreactor consisted of a jacketed 10 L cylindrical tank with a conical bottom, with a minimal volume of $V_{\mathrm{min}} = 3$ L, an operating volume of