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Fuzzy iterative learning control applied in a biological reactor using a reduced number of measures

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ABSTRACT

There exist some processes difficult to control as the chemical ones, a common problem takes place when the output cannot be measured on-line, and so, closed-loop control cannot be implemented. In this work an iterative learning control type proportional-derivative is analyzed and theoretical results are shown, this control is applied to a biological reactor to degrade phenol by working in discontinuous batch state, as the measures of the substrata concentrations are taken by hand, it was proposed to have a sample time of one hour. To guarantee convergence and to improve the control, cubic splines were used to interpolate the measures. Fuzzy logic was used to compute the control gains used to build the control signal. Simulation results are shown and the control signals are presented through iterations, here it is possible to see that the error is smaller using fuzzy logic to compute the control signal when iterations run.

1. Introduction

There exists a lot of chemicals and biochemical systems where it is not possible to measure all state variables that exists in the process [1]. In this type of processes, the control just to be made in open-loop, and the input to the process, usually the xenobiotic substance, is the inlet to the reactor [2]; this input is a load profile computed by an expert in the process. In this case the xenobiotic component is a toxic substance that should not to be present in the water, for example phenol derivations [3].

To biodegrade the phenol, a sequencing batch reactor (SBR) can be used, it is a process designed to work in unstable conditions, this kind of processes has some phases that are iterated with a particular time period, depending on the kind of treatment and the physiologic state of process [4]. In this work, the SBR is a recipient that contains waste water, where activated sludge works to consume a xenobiotic substance as the phenol, which is present in water deposits due textile factories and the wood treatment. The use of granular reactors can improve the results but with these reactors the main problem is their construction, it is difficult to build them in huge scale, and the actuators required consume a lot of energy.

One problem to control a SBR is that there does not exists on-line sensors for some substrates, so closed-loop control cannot be implemented, it is possible to use states observers to estimate the concentrations and to make a closed-loop [5–8], this implies to measure all possible state variables for which there exists sensors. The biotechnological processes are

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nonlinear and not well known systems to easily design the observers required, in this way, the fuzzy logic can be used to have an approached model and to used it for the observers design [9–11].

Another control technique for these processes is the iterative learning control (ILC), as in the processes the substrata concentrations are obtained after some treatment in the measures as spectrography; it is not possible to have the substrata concentrations in real time. Fortunately, it is possible to use the information from previous iterations of the SBR to build the next control signal (the load profile); usually, to tune the controller, the model must to be considered [12], but by using fuzzy logic, the control gains can be adapted [13,14].

The ILC was developed initially for robotics, where a robot must to make some action many times [15], each time the tracking error from the previous iteration is used to build the control signal for the next iteration. As the SBR works in iterations, this idea is used in the reactor because some substances concentrations are unknown after certain time, there exists some results for ILC in nonlinear systems [16], also its fuzzy version to control processes [13], the main problem is that the analysis for this controllers is for continuous time systems or in fact, when the sample time is small enough. In this work, the measures are supposed to be made by hand, so, it is not possible to guarantee a small sample time. The main idea was to interpolate measures to have a sample time of one hour to reduce cost and to help the technics whom work in the laboratory, and to use fuzzy logic to compute the control gains.

Some theoretical results are presented in this work and there was made a comparison between simulation results by using a proportional-derivative (*PD*) ILC with a sample time of 1.2 min; and the simulation where the measures were taken each hour and interpolated with cubic splines to have a virtual sample time of 1.2 min, and the control gains were computed using fuzzy logic.

This work is organized as follows: first the bioprocess description is shown in Section 2, and the subSection 2.1 shows the model used for simulation. In Section 3 it is presented the iterative learning control with some assumptions used in subSection 3.1 for an analytic study to determine the ILC convergence. The Section 4 has some concepts about fuzzy logic and its use to implement a fuzzy ILC type *PD*. The comparative results are in Section 5, and a discussion about errors is in Section 6. Finally, conclusions are in Section 7. Appendix A shows the proof for the theoretic results given in subSection 3.1.

2. Bioprocess description

The phenol is a chemical product used to produce resins, explosives, perfume, disinfectants, tints and it is present in the petrol and gas industrial residues; it is difficult to treat this substance due it is an inhibitor for the microbial grow-up [3]. However, this substance cans arrive to water deposits and it is toxic for the people, so water for consumption must to be treated in a special way.

There are some techniques to purify wastewater, for example the biofiltration, it uses microorganisms to remove pollution, another purification process is the granular biomass, this technique has the bigger rate of purification [17], the main problem for bioreactors with granular biomass is that it is required a lot of energy to purify important quantities of water; finally, the activated sludge is the common treatment applied for wastewater, here, the biomass has the appearance of sludge, this technique was used in this work. The principal bacteria in the microbial consortium in this case is the *pseudomonas putida*, furthermore, it has a big activity of digestion for organic material. This living cells are called the biomass.

The aim in this reactor is to see the xenobiotic substance as food for the microorganisms, basically, this reactor is a tank where biological reactions take place in a liquid medium. To make that bacteria consume the toxic elements, they must to be acclimated to the phenol.

The SBR process operates in five phases, first the reactor is filled with wastewater containing the toxic elements, it is made by using some filling profile, if huge quantities of phenol ingress, the bacteria can die due pollution and with a low inlet, there will be not enough food for microorganisms. The next step is the reaction, here, some actuators are turned-on, as the aeration and the agitation, it is made to propitiate the reaction and to guaranty that the concentrations are the same in the entire reactor. Then, all actuators are turned-off and the biomass is deposited at the bottom. After the sedimentation, the clear water can be retired from the top of reactor where the water has not pollution; finally, a dead time is used to relax the biomass in this phase, and to have similar initial conditions to the last one, before to continue with the next cycle.

2.1. Biodegradation model

To get the simulation results, a model for the bioprocess must to be used. The experimentation to have an approached model was made in the Autonomous University of Hidalgo State, the mass balance differential equations are (1)

$$\begin{pmatrix} \dot{X}(t) \\ \dot{S}_1(t) \\ \dot{S}_2(t) \\ \dot{V}(t) \end{pmatrix} = \begin{pmatrix} \mu(t)X(t) \\ -q_{S_1}(t)X(t) \\ v_{S_2}(t)X(t) - q_{S_2}(t)X(t) \\ 0 \end{pmatrix} + \begin{pmatrix} X(t) \\ \left(S_1^{in} - S_1(t)\right) \\ -S_2(t) \\ 1 \end{pmatrix} D(t), \tag{1}$$

where $X(t)$ it the biomass concentration, $S_1(t)$ is the phenol concentration, $S_2(t)$ is the metabolic intermediate concentration which is also toxic and $V(t)$ is the volume of liquid inside the reactor; $D(t)$ is the dilution rate and it is the input of the system.