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Degradation of a mixture of municipal wastewater and phenol in an aerobic optimally controlled SBR

Iván Moreno-Andrade[1], Leonardo Jimenez[1], Jaime Pérez[1], Manuel J. Betancur[2], Jaime A. Moreno[2], Alejandro Vargas[1] and Germán Buitrón[1*]

Environmental Bioprocesses[1] and Automation[2] departments, Institute of Engineering, National University of Mexico (UNAM), Circuito Escolar, Edif. 5, Ciudad Universitaria, 04510 Mexico D.F., Mexico.
*Email: gbm@pumas.iingen.unam.mx

Abstract. This work presents the results of the application of an optimally controlled influent flow rate strategy to biodegrade, in a discontinuous reactor, a mixture of municipal wastewater and different concentrations of phenol when used as a toxic compound model. The influent is fed into the reactor in such a way to obtain the maximal degradation rate avoiding the inhibition of the microorganisms. Such an optimal strategy was able to manage increments of phenol concentrations in the influent up to 7000 mg/L without any problem. It was shown that the optimally controlled influent flow rate strategy is a good and reliable tool when a discontinuous reactor is bound to degrade an industrial wastewater.
Keywords: SBR, phenol, optimal control strategy

Introduction

Many industrial processes generating wastewater containing toxic compounds are characterized by their variability. In the chemical, pharmaceutical, plastic, and petrochemical industries, for some cases, production processes are in batch. Because of the high variations in flow and concentration of contaminants in industrial wastewater, usual treatment processes do not obtain satisfactory removal efficiencies. Besides, due to its toxicity, the biological treatment of industrial wastes containing high phenol concentrations is inefficient because of the inhibition of the microorganisms (Buitrón *et al.*, 2003).

The Sequencing Batch Reactor (SBR) is a bioreactor that operates under five well-defined phases: fill, react, settle, draw, and idle. In the standard operation mode, the duration of these phases is typically determined by an expert operator based on his experience and exhaustive testing in the laboratory with a pilot plant. In particular, the reaction phase is sufficiently long to allow the toxic substances to be effectively biodegraded. The settle and draw phases are fixed in duration by the characteristics and constraints of the activated sludge and the reactor itself. Such an operational strategy can be named Fixed Timing Control strategy (FTC). A SBR operated under FTC presents several constraints when applied to toxic wastewater degradation: inhibition of the microorganisms, problems with shock loads of toxic compounds, deacclimation and problems of microorganism starvation, and low efficiencies regarding the removal of toxic compounds (Buitrón and Moreno 2002). In order to overcome the problems discussed above several operation modes have been presented using the dissolved oxygen (DO) concentration (Sheppard and Cooper, 1990). Betancur *et al.* (2004) described the mathematical development of a new strategy called Event-Driven Time Optimal Control strategy (ED-TOC) to robustly control the influent flow rate in such a way to try to maximize the reaction rate of a discontinuous process treating inhibitory compounds.

This work presents the results of the application of the ED-TOC strategy to biodegrade, in a discontinuous reactor, a mixture of municipal wastewater and different concentrations of phenol used a model of toxic compound.

Methodology

An aerobic automated Sequencing Batch Reactor (SBR) system of 7L and an exchange volume of 57% was used. The airflow rate was 2.0 L/min and the temperature was maintained at 20ºC inside the reactor. The reactor was inoculated with 500 mgVSS/L coming from a municipal activated sludge wastewater treatment plant. A mixture of municipal wastewater and high concentrations of phenol was used as a sole source of carbon and energy. Phenol concentration was measured taking samples and processing them offline using the colorimetric technique of 4-aminoantipyrine (Standard Methods, 1992). Total and volatile suspended solids, as well as Chemical Oxygen Demand (COD), were determined according also to the Standard Methods (1992).

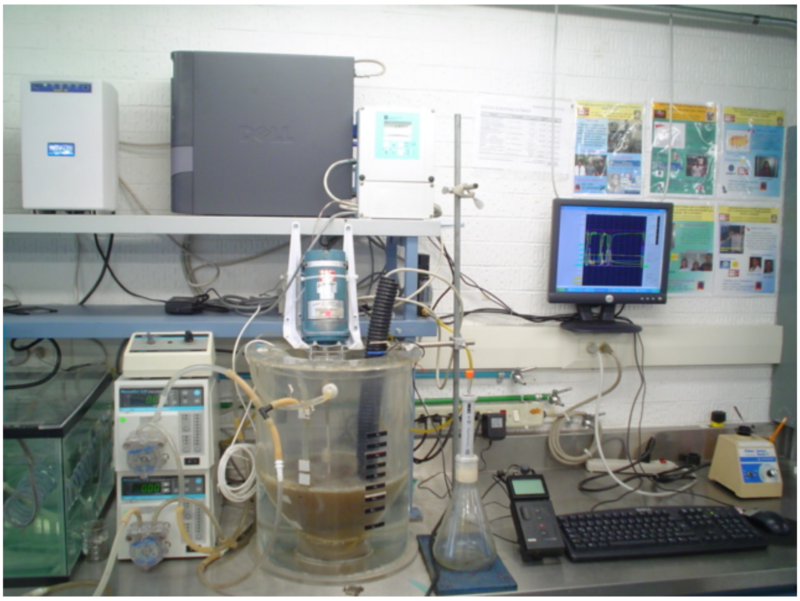

Figure 1. Experimental assembly showing the reactor set-up

The experimental design considered four different sets of initial concentration loads of phenol (350, 700, 1500, 3000 and 7000mg/L of phenol) in the mixture with municipal wastewater. The SBR was operated under the following strategy: preaeration time (15 min), filling time (5 min), reaction time (variable depending on the necessary time to reach a total degradation of the mixture) and settling time (30 min). The ED-TOC strategy was applied to control the reaction phase, *i.e.* the ED-TOC strategy finds a variable (named gamma) related to the reaction rate. Such a variable can be estimated in real time by using the DO concentration and the volume of the reactor, as it was described in detail by Betancur *et al.* (2004). The influent flow rate is then controlled in such a manner that the reaction rate is close to the maximal value. This is obtained by maintaining an optimal substrate concentration in the reactor due as a consequence of the controlled filling. The optimal substrate concentration is the S* in the Haldane curve, *i.e.* the value at which the maximal growth rate or substrate degradation rate is observed. The controller tries to maintain the substrate concentration around S* in order to avoid biomass inhibition.

Results and Discussion

The application of the ED-TOC strategy showed that it is possible to degrade a mixture of municipal wastewater and phenol. The mixture presented a total COD of 1227. 2087, 4350, 6380 and 14470 for the five initial phenol concentrations (350, 700, 1500, 3000 and 7000 mg/L. Note that the increase in COD is due to the increase of phenol. The municipal wastewater alone has 270 mgCOD/L in average. When the phenol concentration was 350 mg/L in the influent, the reaction rate took around 2 h. It was possible to biodegrade shock loads of 700, 1500, 3000 and 7000mg/L of phenol contained in the municipal wastewater without any inhibition problems. The removal efficiencies were up to 98% as chemical oxygen demand and 100% as phenol. In other studies using SBR it has been reported that the degradation of phenol concentrations as high as 1300 mg/L cause problems of inhibition and a total loss of the activity of the microbial consortia is presented (Yoong *et al.,* 2000).

Figure 2 shows the degradation of the mixture of toxic wastewater for the case of 350 mg/L of phenol (1227 mgCOD/L in the mixture with wastewater). When the substrate is filled the DO decreases (Figure 2, point 1) until the substrate concentration is higher than S* and an inhibition starts; then, the DO increases (point 2), indicating that the maximal degradation rate in the Haldane curve has been passed. At this point the fill is stopped and the degradation rate of the phenol is near its maximum. Once the substrate is degraded, the DO starts to increase again (point 3) and the filling pump is turned on. This behavior is maintained until the total volume of the reactor is reached. The operation mode can be explained as if in the reactor several mini-batches took place during a cycle. At the end of the reaction the DO increases to the saturation value. For the example showed, the inhibition never occurred due to the fact that phenol concentration in the bulk of the liquid in the reactor was around S* and was never higher than 120 mg/L during the whole reaction. The use of the ED-TOC strategy can minimize the volume of the reactors because it is not necessary to dilute high concentrated toxic wastewater as in the usual operation mode in order to avoid inhibition.

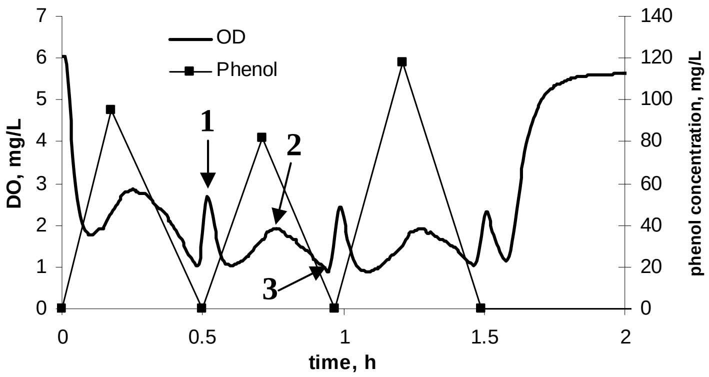

Figure 2. Degradation kinetics of a mixture of municipal wastewater and 350 mg/L of phenol using the EDTOC strategy. See the explanation in the text.

Figure 3 shows the kinetic degradation of a shock load for degradation of 700, 1500, 3000 and 7000 mg of phenol in the mixture. It is possible to observe the same behavior in the control strategy as in the figure 2.

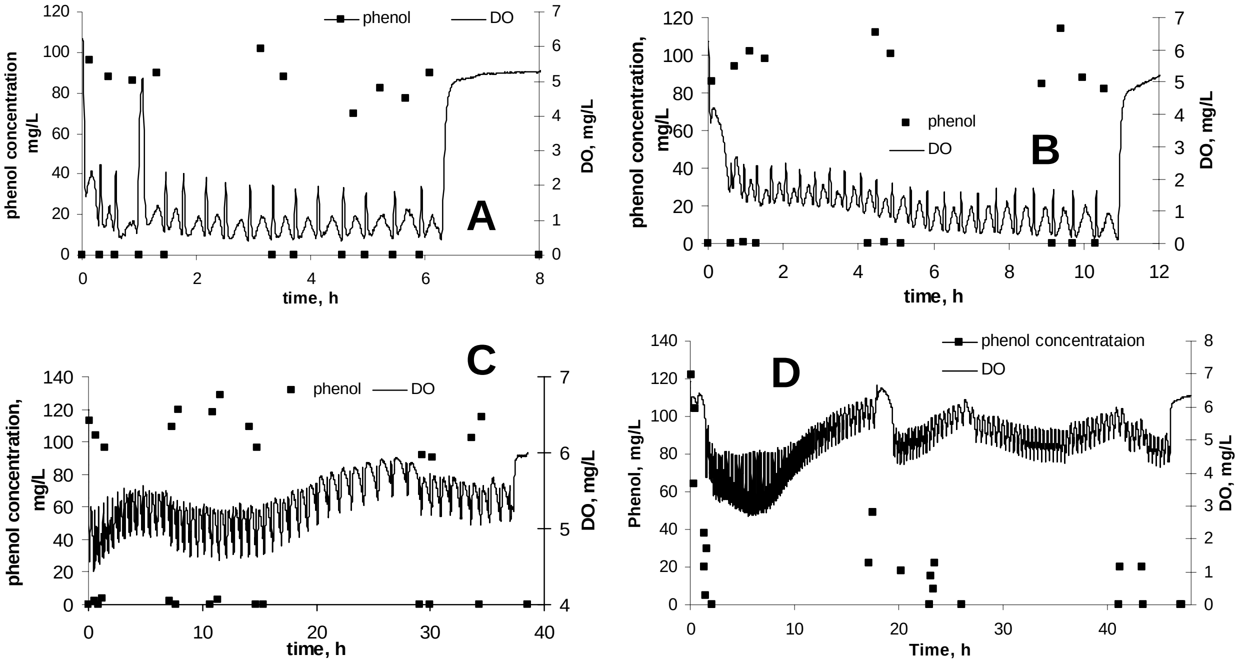

Figure 3. Degradation kinetic of a mixture of municipal wastewater and A)700, B) 1500, C)3000 and D)7000 mg/L of phenol mixed in a municipal wastewater using the EDTOC strategy.

Figure 4 shows a detail of the degradation kinetics of a shock load of 7000 mg of phenol in the mixture. It is possible to observe the same behavior in the control strategy as in the degradation of 350 mg of phenol in the mixture, as shown in figure 2. It can be observed that phenol concentration never was higher than 120 mg/L, as in the case of 350 mg/L. These results confirm that higher phenol concentrations that otherwise in a usual batch operation would be inhibitory can indeed be treated with the proposed strategy. In theory any phenol concentration could be degraded by this control strategy.

An important point of discussion is that with the FTC strategy it is not possible to degrade influents with concentrations higher than 1300 mg/L (Yoong *et al.*, 2000). However, the EDTOC strategy could theoretically degrade any amount of toxic in the influent, without even measuring it. It is shown that indeed it is possible to degrade a concentration of 7000 mg of phenol/L in the mixture. This concentration is more than 5 times higher than the value that would cause an permanent and possibly lethal inhibition using the FTC strategy in the sequential discontinuous reactors.

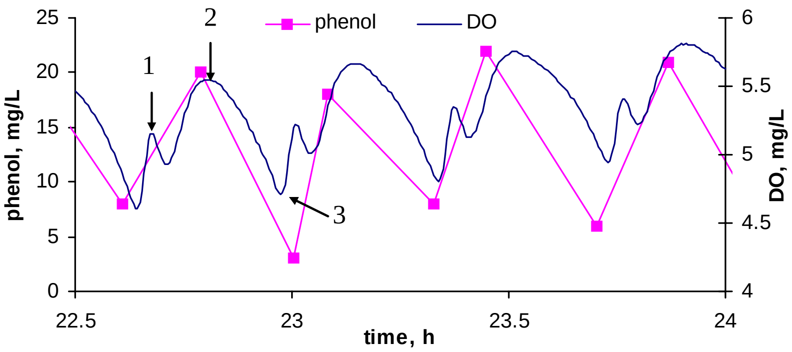

Figure 4. Detail of degradation kinetic of a mixture of municipal wastewater and 7000 mg/L of phenol using the EDTOC strategy. The points correspond to the explanation of the points in figure 2

Conclusions

The application of an optimal control strategy for a discontinuous reactor (ED-TOC) for the degradation of a mixture of municipal wastewater and phenol was presented. Good performance of the reactor operated with the ED-TOC strategy was obtained since the degradation and mineralization of the mixture with a high load of phenol was efficiently completed. The ED-TOC strategy was able to manage increments of toxic concentrations in the influent up to 7000mg/L of phenol in the municipal wastewater without inhibition problems.

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