Automated sequencing batch bioreactor under extreme peaks of 4-chlorophenol

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Abstract The operation of a sequencing batch bioreactor is evaluated when high concentration peaks of a toxic compound (4-chlorophenol, 4CP) are introduced into the reactor. A control strategy based on the dissolved oxygen concentration, measured on line, is utilized. To detect the end of the reaction period, the automated system search for the moment when the dissolved oxygen has passed by a minimum, as a consequence of the metabolic activity of the microorganisms and right after to a maximum due to the saturation of the water (similar to the self-cycling fermentation, SCF, strategy). The dissolved oxygen signal was sent to a personal computer via data acquisition and control using MATLAB and the SIMULINK package. The system operating under the automated strategy presented a stable operation when the acclimated microorganisms (to an initial concentration of 350 mg 4CP/L), were exposed to a punctual concentration peaks of 600 mg 4CP/L. The 4CP concentrations peaks superior or equals to 1,050 mg/L only disturbed the system from a short to a medium term (one month). The 1,400 mg/L peak caused a shutdown in the metabolic activity of the microorganisms that led to the reactor failure. The biomass acclimated with the SCF strategy can partially support the variations of the toxic influent since, at the moment in which the influent become inhibitory, there is a failure of the system.

Keywords Automation; 4-chlorophenol; concentration peaks; SBR process; self-cycling fermentation

Introduction

Because of the high variations in flow and concentration of contaminants in industrial wastewater, treatment processes do not obtain satisfactory removal efficiencies. This is the case for intermittent industrial operation, which sometimes generates sudden increases of toxic substrate concentrations (concentration peaks). Generally, the reactor volume used to efficiently biodegrade toxic compounds is too big. With the use of new control strategies and non-conventional aerobic processes like the Sequencing Batch Reactor (SBR) the preceding problems can be overcome. A reduction of the cycle time of the SBR increases the quantity of water that can be treated by the tank. As the fill, settle, draw and idle phases are usually of fixed time or not controllable by the operator, the cycle time of the SBR can be reduced if reaction time can be diminished. Several approaches have been presented in this matter using dissolved oxygen (DO) concentration or the carbon dioxide evolution rate (CER) to determine the end of the reaction period of a SBR.

Sheppard and Cooper (1990) proposed a control strategy in which the length of the growth period is controlled by the biological activity in an aerobic reactor. The control strategy, called Self-Cycling Fermentation (SCF), is based on the close correlation between dissolved oxygen concentration in the reactor and cellular respiration. In the presence of excess limiting substrate, the oxygen uptake rate of bacterial culture increases, and DO level decreases. Once the limiting substrate is exhausted, the oxygen uptake rate slows, and concentration of DO increases sharply. The method has also been applied for the treatment of Kraft process waters (Milet and Duff, 1998) and agro-industrial wastewater (Nguyen *et al*., 2000). Buitrón *et al*. (1992, 1993) demonstrated the ability of the CER to serve as a control parameter during the acclimation and biodegradation of phenol by an aerobic mixed culture. This approach is similar to the SCF, but here the mineralization of the substance is used to determine the end of the reaction period.

In this paper, the operation of a SBR is evaluated when high concentration peaks of a toxic compound (4-chlorophenol) are introduced into the reactor. The SBR is operated using a control strategy based on the dissolved oxygen concentration measured on line.

Methodology

A pilot system using an aerobic reactor of 7 litres of useful volume is used to treat synthetic wastewater containing 4-chlorophenol (4CP). The exchange ratio in the reactor is 4/7 and the airflow is 2 litres per minute. An automatic temperature controller based on a recycling water pump was used to maintain a constant temperature of 20°C inside the reactor (PolyScience model 210). Dissolved oxygen was measured using an electronic meter (YSI model 52) coupled to a computer. The input and output water flows were controlled using peristaltic pumps, which could be read and controlled by the computer (Cole-Palmer model 7523, Masterflex series). Additionally, the computer could also control a mixer and a valve that turned on the aerator.

The reactor was inoculated with microorganisms coming from an activated sludge treatment plant. A cell retention time of 20 days was maintained. The treatment process used is SBR type with 5 steps: filling, reaction, sedimentation, decanting and an idle period. These steps are controlled with the automated system. A control strategy based on the dissolved oxygen concentration measured on line is utilized. As a consequence of the metabolic activity of the microorganisms, there is a consumption of dissolved oxygen during the degradation of the organic matter. To detect the end of the reaction, the automated system searches for the moment when the dissolved oxygen has passed a minimum and right after reached a maximum due to the saturation of the water. The dissolved oxygen signal was sent to a PC via data acquisition and control using MATLAB and the SIMULINK package.

The experimental strategy was as follows. First, the acclimation of the microorganisms to a constant toxic concentration of 350 mg 4CP/L was accomplished. Then, the introduction of punctual concentration peaks of the toxic (700, 1,050 and 1,400 mg/l de 4-chlorophenol) was done.

Synthetic wastewater was prepared with ordinary tap water and a substrate of 4-chlorophenol (4-CP) as the sole source of carbon and energy. Nutrients such as nitrogen, phosphorus and oligoelements were added as recommended by AFNOR (1985). Four litres were exchanged each cycle, starting with a volume of three litres. The settling phase would start after almost complete substrate degradation. The substrate concentration was measured taking samples and processing them offline using colorimetric techniques with 4-aminoantipyrine method (*Standard Methods*, 1992). To determine the biomass concentration at a given instant, total and volatile suspended solids analysis was made (*Standard Methods*, 1992). Total organic carbon analysis was also performed to test whether 4-CP was truly being mineralized (Shimadzu TOC-5050). The next process variables were followed: degradation time (T_d), temperature (T°), presence of metabolite, total suspended solids in the reactor and in the effluent, sludge volumetric index, toxic concentration in the effluent, specific degradation rate (qx), total organic carbon (TOC), specific oxygen uptake rate and cell retention time (θx). Before, during and after every concentration peak, we perform a kinetic study of the reaction phase.

Results and discussion

Reactor operation

The reactor was operated over 475 cycles (90 days) under the SCF strategy. Figures 1 and 2

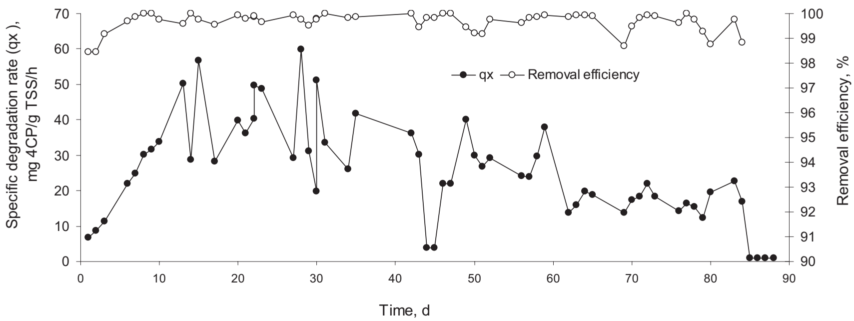

Figure 1 Specific degradation rate and removal efficiency as a function of time

showed the overall behavior of the reactor. The reactor was normally operated with an initial influent concentration of 350 mg 4CP/L (200 mg 4CP/L in the reactor). Once the biomass was acclimated, the peak experiments started. A peak was introduced, and after the reactor was let to recover, feeding it with the normal influent concentration. 4CP removal efficiency was always superior to 98%, except for the last days where the 1,400 mg/L peak was applied. Specific degradation rate, qx, varied from 30 to 60 mg 4CP/gTSS/h. On day 45, when a peak of 1,050 mg 4CP/L was introduced, the qx decreases to around 4 mg 4CP/gTSS/h. The sludge volumetric index (SVI) obtained was on average 28 ML/g, indicating the excellent characteristics of the sludge (Figure 2).

Peak of 700 mg 4CF/L

The general behavior of the bioreactor controlled with the SFC strategy shows that the punctual concentration peaks of 700 mg/L of 4-chlorophenol (400 mg/L of 4-chlorophenol in the bulk of the reactor, due to the exchange ratio of 4/7) do not disturb the process when the microorganisms are acclimated to a 4-chlorophenol concentration of 350 mg/L as depicted in Figure 3. The degradation time during this peak passed from 1.5 hour to 3.5 hours. The original degradation time of the cycle was recovered after the peak and the process variables were not affected in a significant way.

Peak of 1,050 mg 4CF/L

The 1,050 mg/L peaks (600 mg/L in the reactor) showed that the treatment process was affected since the degradation time rose 23 times (230%), as depicted in Figure 4. The original degradation time after the peaks was not recovered, as well as the other process variables. For this peak the mineralization was not completed (≅ 65 mg/L as TOC after 35 hours) and the activity based on respirometry decreases. What is more, the treatment process was affected for several days (more than one month) after the 1,050 mg/L peaks.

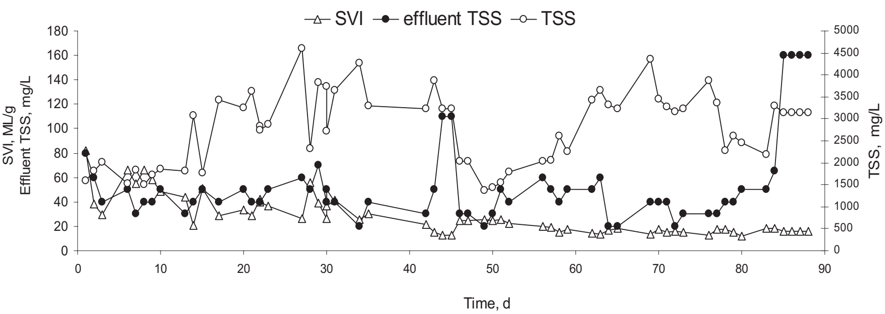

Figure 2 TSS in the mixed liquor and in the effluent and sludge volumetric index as a function of time

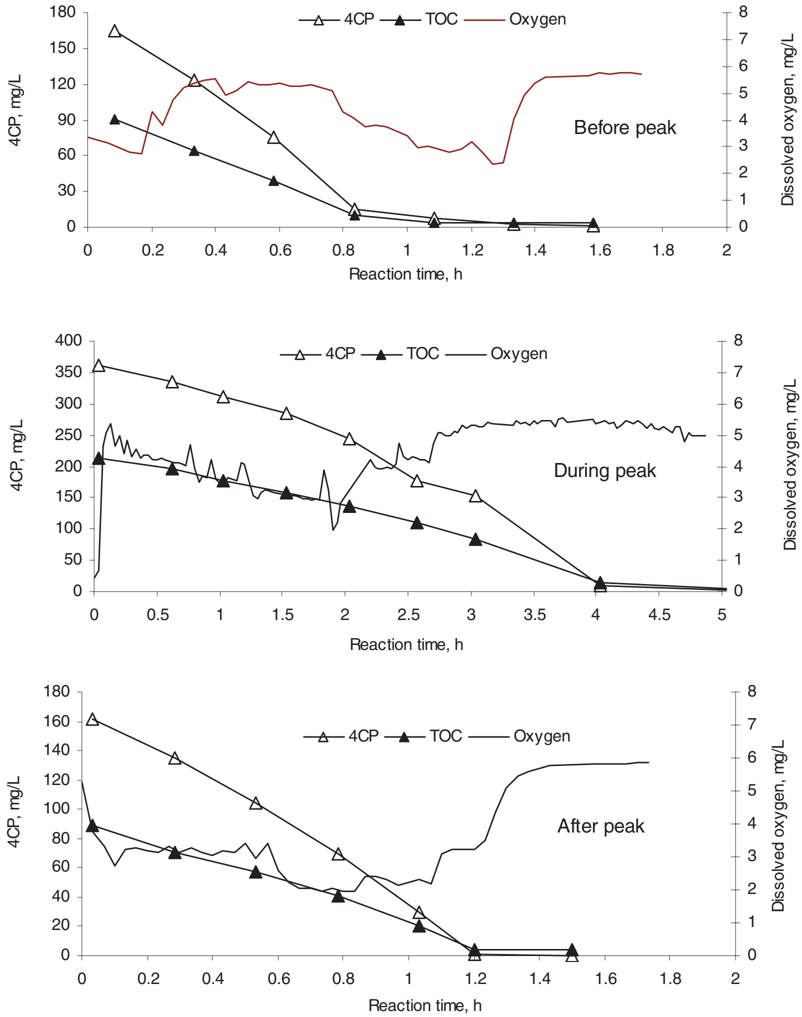

Figure 3 Kinetics obtained before, during and after the 700 mg4CP/L peak

Peak of 1,400 mg 4CF/L

In the case of the 1,400 mg/L peak (800 mg/L in the reactor), the degradation time could not be determined since the microorganisms did not consume oxygen and substrate in a significant way. The reaction was cut after 72 hours and there was no respirometric activity after this period indicating a toxic effect on the biomass and its inactivation.

Respirometic activity

The respiratory activity of the biomass was determined by taken a sample of the mixed liquor at the end of the cycle under study. A predetermined biomass quantity was added to a saturated-oxygen solution with 4CP (25 mg/L) and nutrients in a closed reactor. The DO was followed and the maximal slope of the curve was evaluated. The relative specific oxygen uptake rates were calculated for the 700, 1,050 and 1,400 mg/L peaks in order to compare the data (Figure 5). It can be see that for the case of 700 mg/L there was an increase (around 60%) of the respirometric activity with respect to the initial value, indicating that such influent concentration stimulates the microorganisms rather than produce inhibition. On the contrary, 1,050 mg/L produces inhibition (around 70%) during the peak and even after it. In this case, the reactor took several cycles to recover the initial capabilities, but it is

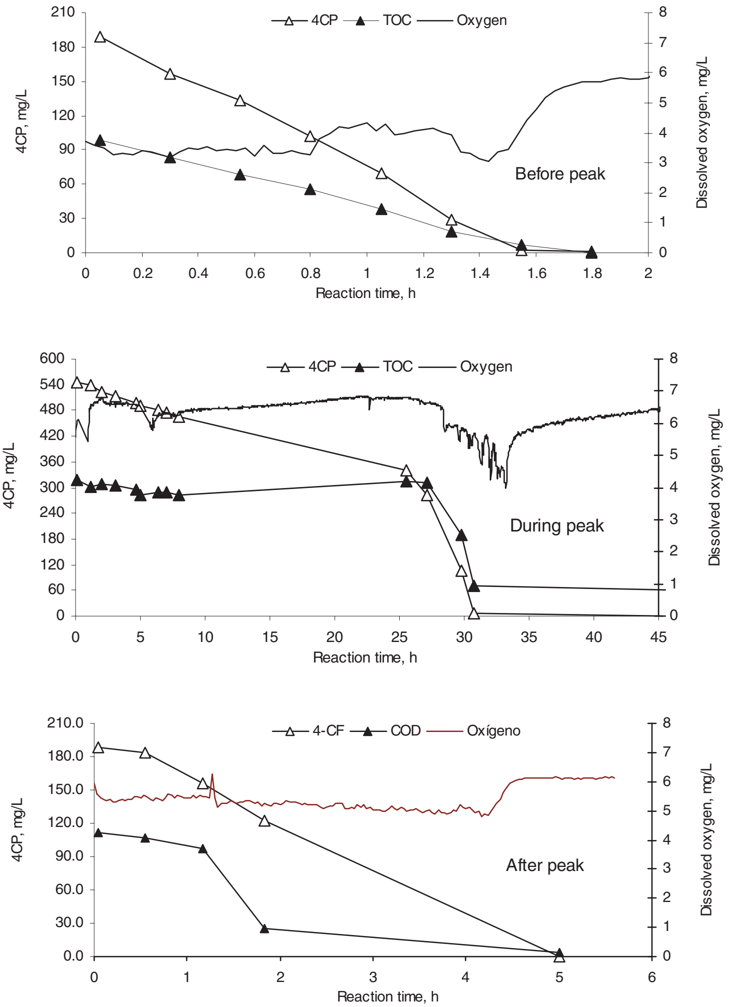

Figure 4 Kinetics obtained before, during and after the 1,050 mg 4CP/L peak

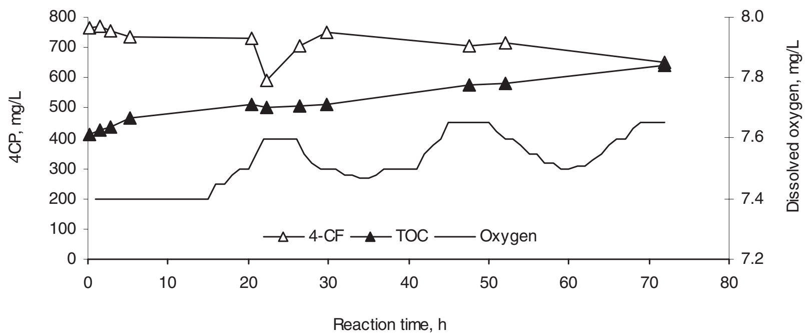

Figure 4 Kinetic obtained during the 1,400 mg 4CP/L peak

clear that the SCF strategy could lead the reactor to stability. In the case of the peak of 1,400 mg/L, there was a failure of the reactor; the respirometric activity of the microorganisms was null indicating a severe inhibition.

Table 1 summarises the operational behavior of the reactor as a consequence of the toxic peaks introduced. It is clear that the maximal concentration that can support the SBR

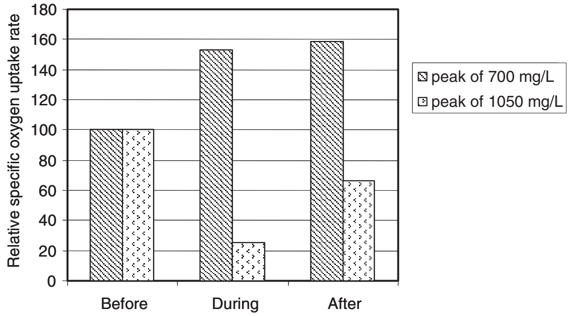

Figure 5 Relative specific oxygen uptake rate obtained for the 700 and 1,050 mg/L peaks

Table 1 Influence of the concentration peaks under every process variable

Process variables	Peak loads, mg/L		
	700	1,050	1,400
Degradation time	3.5 h	35 h	>72 h
Metabolite	No	Yes	Biomass death
TSS/TSSe/SVI	Stables	↑ TSSe and ↑ SVI	–
qx	qx before ≅ qx after	qx before > qx after	Biomass death
TOC	Complete mineralization	Incomplete mineralization	No mineralization
O_2 uptake rate	↑ with the peak	↓ with the peak	= 0
Removal efficiency	99.9%	99.2%	18.3%

operated under the SCF strategy is around 700 mg/L. Beyond this concentration the reactors became unstable. Up to 1,050 mg/L, it was possible for the reactor to continue functioning, but as consequence of the peak, the flocs were disrupted causing an increase of the TSS in the effluent. Furthermore, during the peak there was an incomplete mineralization of the initial carbon. The large problem was presented with the 1,400 mg/L peak since the biomass suffered a severe inhibition that causes its death.

Conclusions

The system operating under the SCF strategy presented a stable operation when the acclimated microorganisms were exposed to a punctual 4-chlorophenol concentration peaks of 600 mg/L. The 4-chlorophenol concentrations peaks superior or equal to 1,050 mg/L only disturbed the system from a short to a medium term (one month). The 1,400 mg/L peak caused a shutdown in the metabolic activity of the microorganisms that led to the reactor failure. The biomass acclimated with the SCF strategy can partially support the variations of the toxic influent since, at the moment in which the influent become inhibitory, there is a failure of the system.

Acknowledgemets

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