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Approximate expressions of a SBR for wastewater treatment: Comparison with numeric solutions and application to predict the biomass concentration in real cases

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ABSTRACT

Most industrial wastewater treatment systems often operate under transient conditions, causing several operational problems. An effective solution is the use of Sequencing Batch Reactors (SBR). In general, a great number of simulations are necessary to solve SBRs mathematical models in order to evaluate the effect of the operational conditions on the performance of the reactor. In this work, a set of analytical equations that represent the effect of the operational parameters on the performance of a SBR was developed. The obtained equations adequately represent the change of the organic substrate, ammonia, biomass, oxygen and soluble microbial products as a function of time within a single operation cycle of the SBR. The equations also predict the steady-state concentrations as a function of several operational parameters, avoiding the problem of performing a great number of simulations. Based on real SBR data, the biomass growth yield and the decay factor for two synthetic wastewaters were obtained. Using these coefficients, the proposed equations adequately predicted the biomass concentration in real cases.

1. Introduction

Most industrial processes generate wastewaters which are characterized by their variability of flowrate, composition and concentration of organic compounds. As a result, wastewater treatment systems often operate under transient conditions, causing operational problems related with low removal efficiencies and poor settling properties of the sludge (Edwards, 1995). To solve these problems, an effective approach is the use of Sequencing Batch Reactors (SBR). In general, SBR include five well-defined phases: fill, react, settle, draw and idle (Annesini et al., 2014). These phases can be optimized for each particular case. The main advantages of SBR in comparison with other biological treatments are high flexibility, simple running, compact layout, better control of shock loads, possibility of achieving anoxic or anaerobic conditions in the same tank and good oxygen contact with microorganisms and substrates (Tomei et al., 2004; Wang et al., 2014). For these reasons, SBRs have been used for the treatment of domestic wastewaters (Mines and Milton, 1998; Bagheri et al .,2015) and wastewater from many industries, such as dairy (Yahi et al., 2014), olive mill (Chiavola et al., 2014), pharmaceuticals (Lefebvre et al., 2014), tannery (Ganesh et al., 2006), textile (Kapdan and Ozturk, 2005) and phenolic compounds (Tomei et al., 2004).

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Mathematical models to be used for the design and operation of SBRs especially under transient conditions are important tools to improve the performance of this process. In general, mathematical models of SBR consist of a biokinetic model and equations that represent the operation of the SBR. The biokinetic model represents the relationship between the rates of substrates consumption and biomass growth. Activated sludge model #1 (ASM1) and its progeny are the most employed models to predict the activated sludge and SBR systems. In the first version, ASM1 was comprised by 13 compounds and 8 processes with 19 parameters, five of which are stoichiometric and the other 14 are kinetic. The last version (ASM3) is comprised by 13 compounds and 12 processes with 21 kinetic parameters and 15 stoichiometric coefficients (Henze et al., 2000). Once the most suitable biokinetic model is selected, these equations are combined with the equations that represent the operation of the SBR (e.g., mass balances for the relevant compounds, for example). In particular, the solids retention time (θ_C) is a key designing parameter for biological wastewater treatment systems. For example, effluent water quality, oxygen demand, biomass concentration and wasted sludge quantity are controlled by θ_C (Kapdan and Ozturk, 2005; Wu et al., 2011). Moreover, several studies demonstrated that biodegradation of toxic compounds is strongly affected by θ_C through the selection of suitable species to degrade these compounds (Kapdan and Ozturk, 2005; Kim et al., 2005).

Due to the intrinsic complexity of SBR models, the use of simulation platforms is mandatory (Pambrun et al., 2008; Mines and Milton, 1998). While some kinetic coefficients and wastewater characteristics may be assumed, others must be evaluated from suitable experiments (Henze et al., 2000). It must be noted that a huge number of simulations are necessary to evaluate the effect of the solids or hydraulic retention time and the operating conditions (aerobic/anaerobic and the duration time of the reaction phase) on the performance of the SBR. For this reason, in this work a set of analytical equations that represent the effect of the operational parameters on the performance of a SBR was obtained. Then, based on real SBR data, these equations were employed to obtain the two model coefficients necessary to represent the biomass concentration in the SBR. The proposed equations were used to simulate the effect of the solids retention time and type of substrate on the biomass concentration of a SBR under transient conditions.

2. Materials and methods

2.1. Chemicals and reagents

Phenol (loose crystals, >99%) was obtained from Sigma (St. Lois, MO, USA). All inorganic salts were commercial products of reagent grade from Anedra (San Fernando, Argentina). Dehydrated cheese whey was from Food S.A. (Villa Maipú, Argentina).

2.2. Activated sludge

Activated sludge used in this study was cultured in laboratory scale (2.5 L) SBRs. In all cases, reactors were operated at an hydraulic retention time (θ_H) of 80 h. Different solids retention time (θ_C) were obtained by direct wastage of appropriate volumes of the mixed liquor three times a week. Because five feeding cycles a week were performed, the average total time of each cycle was $t_T = 33.6$ h. Taking into account that all other operations (filling, purge, sedimentation, discharge) comprised 2 h, the average length of the reaction phase was $t_R = 31.6$ h. During the reaction phase, aeration was provided at the bottom of the reactor through an air-stone using two air pumps at 2 L min^{-1}; dissolved oxygen (DO) concentration was maintained above 4 mgO_2 L^{-1}. With regard to the settling phase, biomass settling was considered ideal, leading to perfect retention of the biomass. In this sense, suspended solids could not be detected in the supernatant after settling phase. Because the settling phase duration (30 min) represented less than 1.5% of the global cycle duration time (t_T), the biomass decay during this phase was considered negligible.

Three SBRs were used in this work:

- SBR-A was fed with a model wastewater with the following composition (Lobo et al., 2013): $(NH_4)_2SO_4$ 940 mg, K_2HPO_4 500 mg and KH_2PO_4 250 mg; all components were diluted in 1 L of tap water. Once the reactor was filled, 2500 mg of dehydrated cheese whey (CW) was added to obtain an initial organic substrate concentration (S_{S0}) of 1000 mgCOD L^{-1}.
- SBR-B was fed with model wastewater with phenol (Ph) as the sole carbon-limiting source (Nuhoglu and Yalcin, 2005): $(NH_4)_2SO_4$ 226 mg L^{-1}, K_2HPO_4 500 mg L^{-1}, KH_2PO_4 250 mg L^{-1} $MgSO_4.7H_2O$ 25.2 mg L^{-1}, $MnSO_4{\cdot}H_2O$ 2.52 mg L^{-1}, $CaCl_2$ 2 mg L^{-1}, $FeCl_3$ 1.2 mg L^{-1}. An appropriate volume of a concentrated stock solution of phenol was added to obtain an initial concentration of 300 mgPh L^{-1}, which corresponded to $S_{S0} = 714$ mgCOD L^{-1}. pH was adjusted to 7.0 ± 0.05 by adding a few drops of concentrated solutions of NaOH or HCl. The inoculum of this reactor was obtained from SBR-A.
- SBR-C was used to study the effect of alternating the type of the carbon source of the feeding (cheese whey or phenol) on the biomass concentration (X) of the reactor. This study comprised five feeding phases. During Phases I, III and V, SBR-C was fed with the model wastewater of the dairy industry with cheese whey as the carbon source; in these cases $S_{S0} = 1000$ mgCOD L^{-1}. In Phases II and IV, the reactor was fed with a culture medium with 300 mg L^{-1} of phenol as the carbon source. When the reactor was fed with cheese whey (Phases I, III and V) θ_C was 40 d; during the feeding phases with phenol (II and IV), θ_C was increased to 45 days to prevent the biomass washout. In all cases, the hydraulic retention time was 80 h.

Initial biomass concentration (X_0) and soluble chemical oxygen demand (sCOD) were determined at the beginning of the operation cycle in each reactor.

2.3. Analytical procedures

Total suspended solids (TSS) were used as a measure for the biomass concentration (X) (Lobo et al., 2013). Duplicate biomass measurements were performed; average and maximum relative errors for TSS were 4% and 13%, respectively. Soluble COD (sCOD) was determined as follows: 3 mL of culture samples were centrifuged for 5 min at 13,000 rpm (Eppendorf 5415 C); then COD of the supernatant was determined using a commercial test (Hach Cat. No. 21259). Samples digestion (2 h at 150 °C) was performed in a Hach COD Reactor 45600; a Hach DR 2000 photometer was used for the absorbance determination of the digested samples.