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Kinetic modeling of aerobic biodegradation of high oil and grease rendering wastewater

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Abstract

Batch scale activated sludge kinetic studies were undertaken for the treatment of pet food wastewater characterized by oil and grease concentrations of up to 21,500 mg/L, COD and BOD concentrations of 75,000 and 60,000 mg/L, respectively as well as effluent from the batch dissolved air flotation (DAF) system. The conducted kinetics studies showed that Haldane Model fit the substrates and biomass data better than Monod model in DAF-pretreated wastewater, while the modified hydrolysis Monod model better fit the raw wastewater kinetic data. For the DAF pretreated batches, Haldane Model kinetic coefficients k, K_S, Y and K_i values of 1.28–5.35 gCOD/gVSS-d, 17,833–23,477 mg/L, 0.13–0.41 mgVSS/mgCOD and 48,168 mg/L, respectively were obtained reflecting the slow biodegradation rate. Modified hydrolysis Monod model kinetic constants for the raw wastewater i.e., k, K_S, Y, and K_H varied from 1–1.3 gCOD/gVSS-d, 5580–5600 mgCOD/l, 0.08–0.85 mgVSS/mgCOD, and 0.21–0.66 d^{-1}, respectively.

Keywords: Activated sludge; High strength; Bio-kinetics modeling; Monod; Haldane; Hydrolysis

1. Introduction

Knowledge of biokinetics is essential for biological wastewater system design and optimization of operational conditions (Contreras et al., 2001; Nakhla and Al-Harazin, 1993). In the case of pure cultures and limited substrate growth, it has been experimentally found that the kinetics of substrate or nutrient biodegradation can be defined by Monod model (Monod, 1949). Kinetics modeling of high strength wastewaters by the Monod model has been widely reported in the literature. Wandrey and Aivasidis (1983) and Chang et al. (1983) used the Monod model in describing acetate biodegradation. Neufeld and Valiknac (1979) and Hsu (1986) used the Monod model for analysis of phenolic and petrochemical wastewater treatment data. However, the Haldane model, a further development of the Monod model to include substrate inhibition, was also widely used in modeling high strength inhibitory wastewater (Nakhla and Al-Harazin, 1993; Vavilin and Lokshina, 1996).

Many industrial wastewaters, including food processing wastes, invariably contain colloidal and particulate organics that undergo hydrolysis prior to biodegradation. Morgenroth et al. (2002) have reviewed the kinetic modeling of hydrolysis in municipal wastewater treatment and noted that the most widely used kinetic model was first order with respect to particulate substrate (Janning et al., 1998; Sperandio and Paul, 2000). In the various activated sludge models i.e., ASM 1 (Henze et al., 1987), ASM 2 (Henze et al., 1995), ASM 2d (Henze et al., 1999) and ASM 3 (Gujer et al., 1999), a Monod-type model incorporating the ratio of particulate substrate to heterotrophic biomass was employed in lieu of the substrate. Saravanane et al. (2001) modeled

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the anaerobic hydrolysis of starch wastewater by a first-order model with respect to particulate substrate and a half-order model with respect to biomass. Palmowski and Muller (2003) have developed a first-order hydrolysis model for fibrous materials i.e., hay and rice based on surface area. While the modeling of municipal wastewaters and other industrial wastewaters that are characterized by low colloidal and particulate fraction has been thoroughly explored, the modeling of particulate organics in industrial wastes has not drawn much attention.

The main objective of this study was to investigate aerobic biodegradation kinetics for high oil and grease wastewater. During this activated sludge study, the Monod and Haldane models were investigated. Although the Monod and Haldane models are appropriate for describing the biokinetics of substrate degradation, in some cases, they lead to inaccurate results (Alagappan and Cowan, 2001). Therefore, a modified Monod model including first-order hydrolysis of particulate organic matter was also evaluated for delineation of biokinetics of the rendering wastewater. The obtained results were also compared to the first-order and zero-order modeling results discussed before (Liu et al., 2004).

2. Methodology

2.1. Kinetic model selection

Biokinetic coefficients are usually obtained either by observing substrate depletion with time in batch experiments, and then fitting the data with an appropriate model (Simpkins and Alexander, 1984) or by respirometric studies (Kappeler and Gujer, 1992). Respirometric studies are mostly suitable for determination of biokinetic coefficients for soluble substrates since oxygen consumption and substrate biodegradation are stoichiometrically related at all times. For particulate and hydrolysable substrates, oxygen uptake is affected only if growth is substrate limited and therefore respiration rate is dominated by the hydrolysed substrate. Furthermore, the hydrolysis process does not consume oxygen, thus precluding direct determination of hydrolysis rate coefficient from oxygen uptake rate (OUR) data. Accordingly, in a mixture of soluble and particulate substrates in a closed batch, in the first phase the OUR is governed by the rate of soluble substrate degradation while hydrolysis is proceeding unnoticed, until the readily biodegradable soluble substrate is consumed. Generally both the hydrolysis coefficient and particulate substrate concentrations are only obtained by iterative curve fitting (Kappeler and Gujer, 1992; Orhon et al., 1995). Another complication of respirometric studies is that detailed characterization of wastewater in accordance with activated sludge models is needed, which is well beyond the scope of this work.

Many kinetic modeling studies showed that non-linear data fitting methods yield mathematically superior kinetic coefficients compared to linear regression methods (Prats and Rodriguez, 1992; Ritchie and Prvan, 1996). Monod Model and Haldane Model parameters were previously obtained by non-linear regressions (Nakhla and Al-Harazin, 1993; Wandrey and Aivasidis, 1983). Both models will be simulated in this study in order to determine the optimal kinetic coefficients for this high strength wastewater. The two models are shown in Eqs. (1a), (1b) and (2a), (2b) respectively. The hydraulic regime in all bioreactors was assumed to be completely mixed and, thus, the continuously stirred tank reactor (CSTR) model was used.

$$\frac{dS}{dt} = -\frac{kXS}{K_S + S} \tag{1a}$$

$$\frac{dX}{dt} = Y\frac{dS}{dt} - K_b X \tag{1b}$$

$$\frac{dS}{dt} = -\frac{kXS}{K_S + S + \frac{S^2}{K_i}} \tag{2a}$$

$$\frac{dX}{dt} = Y\frac{dS}{dt} - K_b X \tag{2b}$$

where S and X are substrate and biomass concentrations respectively, mg/L; k is max substrate consumption rate, mg COD/mg VSS-d; K_S is halfsaturation concentration, mg COD/L; K_i is Haldane inhibition constant, mg COD/L; Y is yield of biomass to substrate, mg VSS/mg COD; K_b is decay constant, 1/d.

In addition to the above models, considering that the raw wastewater is laden with particulate organics, a modified Monod model incorporating a hydrolysis process is also considered in this study. Therefore, the modified model with hydrolysis coefficient has been developed to simulate the kinetics for this wastewater, which is shown as Eqs. (3a)–(3c).

$$\frac{dS}{dt} = -\frac{kX_a S}{K_S + S} + 1.42 K_H X_S \tag{3a}$$

$$\frac{dX_a}{dt} = Y\frac{dS}{dt} - K_b X_a \tag{3b}$$

$$\frac{dX_S}{dt} = -K_H X_S \tag{3c}$$

where K_H is first-order hydrolysis rate constant, 1/d; X_S is slowly biodegradable particulate substrate, mg/L; X_a is active biomass concentration, mg/L.

The ratio of particulate COD to VSS, mg pCOD/mg VSS, derived from the raw wastewater characterization data (see Fig. 1) was 1.42. It must be asserted that the factor of ~1.42 mg pCOD/mg VSS does not necessarily reflect biomass content based on the widely accepted formulation of $C_5H_7O_2N$, and this agreement is merely