Modelling the change in the oxidation coefficient during the aerobic degradation of phenol by acclimated activated sludge

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ABSTRACT

In this work the aerobic degradation of phenol by acclimated activated sludge was studied. Results demonstrate that while the phenol removal rate by acclimated activated sludge follows the Monod model, the oxygen uptake rate obeys a Haldane-type equation. The phenol oxidation coefficient obtained at different intial phenol concentrations ranged from 1.9 to 2.6 mol $O_2 \cdot mol^{-1}$ phenol. A mathematical model based on a simplified version of the catalytic mechanism of the enzyme phenol 2-monooxygenase was developed to predict transient phenol concentrations and oxygen requirements by phenol-acclimated activated sludge in batch reactors under different initial phenol concentrations. The proposed model not only adequately represents the experimental results of the present paper, but also those reported by other authors. Particular cases of the proposed model are discussed.

Keywords: oxygen uptake rate; phenol; biodegradation; biokinetic model; respirometry

INTRODUCTION

Phenolic compounds are considered to be a major group of hazardous environmental pollutants. Several industries, such as petroleum processing plants, oil refineries, coke oven and pharmaceuticals, generate large amounts of phenolic wastewaters (Lepik and Tenno, 2011; Pramparo et al., 2012). Phenol is used as an intermediate in the production of phenolic resins, which are used in the plywood, adhesive, construction, automotive and appliance industries, in the production of synthetic fibres and for epoxy resin precursors. Besides, phenolic compounds are naturally present in some foodstuffs, in human and animal wastes, and in decomposing organic material, and are produced from the metabolism of proteins (Lin and Juang, 2009).

Phenols can be removed from industrial effluents by several physicochemical methods. Separation technologies include distillation, liquid–liquid extraction, adsorption over activated carbons and polymeric and inorganic adsorbents, membrane pervaporation and membrane–solvent extraction. Destruction technologies such as non-catalytic, supercritical and catalytic wet air oxidation, ozonation, non-catalytic, catalytic and enzymatic peroxide wet oxidation, electrochemical and photocatalytic oxidation have also been studied. As a general rule, all these treatments are usually complex and very expensive; for these reasons, biological methods are preferred (Busca et al., 2008).

Many aerobic bacteria and mixed cultures are capable of degrading aromatic compounds as the sole carbon and energy source (El-Naas et al., 2009; Banerjee and Ghoshal, 2010). Batch and semi-continuous systems with suspended or immobilised biomass were used to study phenol degradation kinetics (Orupold et al., 2001; Nuhoglu and Yalcin, 2005; Tziotzios et al., 2005). The most used model to describe the dependence of biomass growth, phenol and oxygen consumption rates on a self-inhibitory substrate, such as phenol, is the Haldane equation with a constant yield (Christen et al., 2012; Pramparo et al., 2012). Although the Haldane model can be derived from an enzymatic mechanism, not all the enzymes involved in phenol metabolism can be represented by this mechanism. In particular, the first step in the aerobic biodegradation of phenol comprises the oxidation of phenol to catechol by the enzyme phenol 2-monooxygenase (PH2MO). The catalytic mechanism of PH2MO is complex, involving FAD and 3 substrates (molecular oxygen, phenol and NADPH) (Enroth et al., 1998).

Due to the lack of fit of the traditional approach (e.g., the Haldane equation with a constant yield), several authors (Feitkenhauer et al., 2001; Nuhoglu and Yalcin, 2005; Ben-Youssef and Vázquez-Rodríguez, 2011) have proposed different modifications to the traditional model. However, those models were developed on an empirical base, i.e. the study of phenol degradation and biomass growth kinetics and then the fitting of an appropriate mathematical model to the obtained results. Additionally, most studies concerning the aerobic degradation of phenol have been performed using pure cultures, low concentration ranges of phenol, or even a single initial concentration of phenol. In this sense, further investigation is necessary to understand phenol biodegradation under more realistic conditions, especially in biological wastewater treatment systems where the concentration of phenol can vary over a wide range (Alcocer et al., 2007; Banerjee and Ghoshal, 2010; El-Naas et al., 2010).

Knowledge of microbial substrate consumption kinetics is important for accurate prediction of the quality of the treatment process effluent. One key feature is the relationship between phenol concentration and the rates of substrate and oxygen consumption (Kumar et al., 2005; Nuhoglu and Yalcin.

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