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Kinetic modeling of bioregeneration of chlorophenol-loaded granular activated carbon in simultaneous adsorption and biodegradation processes

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ABSTRACT

A kinetic model incorporating adsorption, desorption and biodegradation processes was developed to describe the bioregeneration of granular activated carbon (GAC) loaded with 4-chlorophenol (4-CP) and 2,4-dichlorophenol (2,4-DCP), respectively, in simultaneous adsorption and biodegradation processes. The model was numerically solved and the results showed that the kinetic model was well-fitted ($R^2 > 0.83$) to the experimental data at different GAC dosages and at various initial 4-CP and 2,4-DCP concentrations. The rate of bioregeneration in simultaneous adsorption and biodegradation processes was influenced by the ratio of initial chlorophenol concentration to GAC dosage. Enhancement in the rate of bioregeneration was achieved by using the lowest ratio under either one of the following experimental conditions: (1) increasing initial chlorophenol concentration at constant GAC dosage and (2) increasing GAC dosage at constant initial chlorophenol concentration. It was found that the rate enhancement was more pronounced under the second experimental condition.

1. Introduction

The synergistic combination of adsorption and biodegradation processes has long been recognized by many researchers (Orshansky and Narkis, 1997; Dash et al., 2008; Orozco et al., 2010). Application of these two processes simultaneously has been proven to be successful in the complete removal of pollutants even at above acclimated concentration of the biomass (Oh et al., 2011). As simultaneous adsorption and biodegradation occur, the active sites of the adsorbent could be biologically regenerated through various mechanisms thus prolonging its service period (Lee and Lim, 2005; Mayer et al., 2008). Many mathematical models have been proposed to describe the adsorption and biodegradation processes with most of them applicable only to the continuous system such as the biological activated carbon filters and powdered activated carbon treatment system (Leitao et al., 1996; Liang et al., 2007; Lin and Leu, 2008; Nath and Bhakhar, 2011).

For batch studies, modeling of the courses of bioregeneration was mostly limited to sequential adsorption and biodegradation processes. In many cases, a simple first-order model was employed to describe the kinetics of the adsorbed substrate over time (Kim et al., 1997; Ivancev-Tumbas et al., 1998; Vinitnantharat et al., 2001; Aktaş and Çeçen, 2007, 2010). This is clearly inadequate. In a recent study, Ng et al. (2010) proposed a two-step kinetic model consisting of desorption and biodegradation processes, both of which were assumed to follow first-order kinetics, to describe the bioregeneration of powdered activated carbon and activated rice husk loaded with phenolic compounds. The model, however, could not be used to describe the courses of bioregeneration in simultaneous adsorption and biodegradation processes since the model did not take into account the adsorption process in the bulk solution. Despite the mathematical simplicity of the batch system relative to the continuous system, kinetic modeling of bioregeneration in simultaneous adsorption and biodegradation has not been reported to date.

In light of the above observation, the objective of this study is to develop a kinetic model incorporating the adsorption process of second-order kinetics, the desorption process of first-order kinetics and the Haldane model for biodegradation to describe the rate of bioregeneration of granular activated carbon (GAC) loaded with 4-chlorophenol (4-CP) and 2,4-dichlorophenol (2,4-DCP), respectively, in simultaneous adsorption and biodegradation processes in a batch system.

2. Material

2.1. Cultivation of chlorophenol-acclimated biomass

The chlorophenol-acclimated biomasses were cultured using the mixed-culture seeds obtained from a local municipal sewage treatment plant. Two laboratory-scale sequencing batch reactors (SBRs) were operated through five operational periods, namely FILL, REACT, SETTLE, DRAW and IDLE at the time ratio of

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