The use of simultaneous chemical precipitation in modified activated sludge systems exhibiting biological excess phosphate removal Part 6: Modelling of simultaneous chemical-biological P removal – Review of existing models

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Abstract

This paper reviews three published models for simultaneous chemical phosphorus precipitation in activated sludge systems using metal salts. In the first, a chemical equilibrium approach is used, based on observations made from batch and continuous-flow tests, a theoretical formula for metal (e.g. ferric) hydroxy-phosphate and a set of metal phosphate complexes or ion pairs for dissolved orthophosphate (orthoP) species. Apart from applying the precipitation stoichiometry observed in admixture with activated sludge, in this model no interaction between the chemical and biological mechanisms is accounted for and no biological processes are modelled. In the second model, a combined equilibrium-kinetic approach is used to model the chemical and biological processes. The chemical and biological processes become kinetically linked through soluble orthoP as a variable. This model includes biological processes for conventional activated sludge systems, but does not include biological excess P removal processes (BEPR). Apart from this limitation, a potential problem in the combined equilibrium-kinetic approach was identified: The precipitation reactions were modelled based on equilibrium chemistry and assumed to be complete at the start of simulation; precipitate, therefore, could not form dynamically during the ensuing kinetic simulation. Furthermore, the model predictions were very sensitive to the choice of certain key equilibrium (or solubility product) constants. The third approach was to model the precipitation (and dissolution) reactions as kinetic processes within a fully kinetic model for activated systems, including the processes for BEPR. This approach depends on the appropriate selection of rate constants for the forward (precipitation) and reverse (dissolution) reactions. In effect, a number of reactions from equilibrium chemistry are combined and replaced with one "surrogate" reaction having its own apparent equilibrium constant. The kinetic approach offers a number of advantages but is still subject to the limitation that it requires calibration against actual data from activated sludge systems in which simultaneous precipitation is applied. Moreover, interaction between the chemical and biological P removal mechanisms in the model is confined to "competition" for available soluble orthoP. This aspect requires further examination.

Introduction

Mathematical models of modified activated sludge systems incorporating biological nutrient removal (BNR) are well-established (*inter alia* Dold et al., 1991; Wentzel et al., 1992, Henze et al., 1995). These models serve a useful function as research and design tools, and are also emerging as operator aids by making possible the real-time simulation of full-scale activated sludge plants (Thornberg, 1995). Until very recently, simultaneous chemical precipitation reactions have not been incorporated into models of biological phosphate removal in activated sludge systems. With the prevalence of simultaneous chemical addition to BNR systems, there exists a need for a more comprehensive combined chemical-biological model.

At present, there are three main mathematical (or mechanistic) models for the biological processes in BNR systems: the UCT model (or UCTPHO, in computer program format) (Wentzel et al., 1992); the IAWQ ASM 2 model (Henze et al., 1995; Wentzel and Ekama, 1995) and the Dold model (or "BIOWIN" in computer program format) (Barker and Dold, 1997). These models differ in detail on certain key processes, but do not differ in concept and, if appropriately calibrated, will produce similar results for many applications. In this study, the objective was not to compare or evaluate the various models in respect of the biological processes, but rather to review the manner in which the chemical P removal processes may be incorporated into the biological model(s). In order to do this, it is first necessary to review the different approaches taken in modelling the chemical P removal processes.

In the literature there are three main approaches to modelling the chemical P removal processes:

- A chemical equilibrium approach (e.g. Luedecke et al., 1989);
- A combined chemical equilibrium-kinetic model approach (e.g. Briggs, 1996);
- A kinetic model approach (e.g. Henze et al., 1995).

The aim of this paper is to review these three approaches in detail in order to compare their relative merits and hence, to select one as a means of modelling the data gathered during the experimental investigation on simultaneous chemical-biological P removal carried out during this study (Parts 3, 4 & 5 of this series of papers - De Haas et al. 2000a, b; 2001).

The chemical model of Luedecke et al. (1989)

Luedecke et al. (1989) developed a chemical model for phosphate precipitation with ferric (iron III) salts in aqueous systems and applied it to a conventional activated sludge system. Their model represents an important contribution towards developing a combined chemical-biological model for P removal in activated sludge systems and is worthy of detailed examination.

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