Chapter 7
Modelling and Control of Nitrogen and Phosphorus Removing Systems

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ABSTRACT

A wide variety of technologies addressing nutrient removal in wastewater treatment have been developed in the latest years. In order to be able to design, manage, operate, optimise and benchmark these novel technologies with potentially existing standard technologies, detailed modelling of nutrient removal becomes essential. Nutrient removal is prominently considered, with different degrees of complexity, in the commonly used Activated Sludge Models (ASM). However, the description of nutrient-related compounds in these standard models is not sufficiently detailed for novel and not so novel technologies. Furthermore, the environmental evaluation of a process, which includes an estimation of the greenhouse gas release, would require a more complex process to represent nitrogen removal. This chapter reviews the current state of nutrient removal modelling, with special focus on the needs created by emerging technologies in nitrogen and phosphorus removal, paying special attention to the objectives that must be evaluated for each technology.

INTRODUCTION

Mathematical models can serve as essential tools to help understand governing mechanisms in wastewater treatment processes and therefore modelling is central in current procedures of process design and optimisation. In particular, dynamic models, i.e. where variables change with time, are especially relevant in municipal wastewater treatment as input variations caused by changes in influent flowrate and influent concentration are practically unavoidable. Mathematical models can also be used to evaluate alternative options of plant or reactor layouts, to test operational strategies for a smaller cost than experimental test-

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ing, or to narrow down the experimental range to be explored. Indeed, building up a sound model for a real wastewater treatment plant is a cost-intensive task as it requires staff with expertise from different fields such as reactor engineering, chemical and biochemical reaction kinetics, transport phenomena and control engineering as well as detailed knowledge about the actual plant. However, the costs of model development can be quickly compensated by an increased efficiency leading to reduced operating costs or minimized construction costs due to models allowing smaller safety margins in the design phase.

In order to facilitate and enhance the model construction and use in biological wastewater treatment, the IAWPRC (now IWA) formed a task group dedicated to provide a modelling platform in 1983. The result was a model for a single-sludge treatment featuring COD oxidation and nitrogen removal by nitrification and denitrification (Grady et al.,1986). The model was evaluated and revised later by Henze et al. (1987) resulting in the first version of the widely used activated sludge model no. 1 (ASM1). The model is based on a mechanistic interpretation of the behaviour of the microbial groups catalysing the process reactions considered in the system, as well as detailed characterization of influent wastewater composition with respect to different fractions of COD and nitrogen. Enhanced biological phosphorus removal (EBPR) was later added to a revised version of the ASM1, giving place to the ASM2d (Henze et al., 1999). A new version of the ASM1 including a better description of COD storage by heterotrophs gave place to the ASM3, although the description of removal of nitrogen did not change in this model (Gujer et al., 1999). Since then, numerous activated sludge models have been developed and evaluated, addressing different levels of detail, such as the two step nitrification and denitrification or models for phosphorus accumulating organisms (PAOs). Furthermore, a number of processes have been developed in the last two decades featuring novel processes for nutrient removal such as anaerobic ammonium oxidation (anammox) for which, new models have been quickly proposed. The models for nitrogen and phosphorus removal are respectively presented and reviewed in sections 2 and 3. The importance of pH modelling and its challenges is summarised in section 4. Finally, in section 5, the generic challenges of control in wastewater treatment plants (WWTP) are presented together and the particular control structures applied in nutrient removal.

MODELS FOR NITROGEN REMOVAL

Nitrogen removal processes have been largely dominated by nitrification-denitrification processes which are properly described with the ASM models. In the last twenty years, the development of new autotrophic nitrogen removal processes led to the parallel creation of new models thereof. Additionally, increasing environmental concerns have increased the attention to models that include the production of N_2O and other intermediates of nitrification and denitrification processes in order to mitigate its release.

Nitrification

The ASM1 includes one-step nitrification (ammonium is converted to nitrate) and one-step denitrification (nitrate is used as electron acceptor, and converted to nitrogen gas) processes.

One-step nitrification: $NH_4^+ + 2\ O_2 \rightarrow NO_3^- + H_2O + 2\ H^+$