A method to use dynamic simulation in compliance to design rules to refine WWTP planning

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Abstract The presented method aims to improve the current practice of using design procedures based on simplified steady-state assumptions for design of WWTP, by promotion of additionally use of dynamic simulation for the design refinement. This paper describes a consistent way to parameterise a dynamic simulation model in compliance with German design guidelines assuming a typical planning situation with limited information about influent composition and bio-degradability. The presented approach ensures equal sludge production and comparable nitrification and denitrification capacity of detailed simulation models compared to the results of the design guidelines. This eases the usage of dynamic simulation to refine the basic design with respect to treatment technology, equipment, automatic control and operation regimes. All results can be considered as compatible to the acknowledged design rules and may be used for the legal permission procedure of WWTP design. The work has been prepared within the framework of HSG-Sim (Hochschulgruppe Simulation, http://www.hsgsim.org), a group of researchers from Germany, Austria, Luxembourg, Poland, the Netherlands and Switzerland.

Keywords ASM3, Denitrification, Dynamic Simulation, Nitrification, Sludge Production, WWTP design

Introduction

In many countries the design of waste water treatment plants (WWTPs) is based on simplified design procedures using steady-state model assumptions. This practise is founded on an impressive pile of experiences of design engineers and the observed results of plant performance. In parallel a lot of detailed knowledge about the activated sludge process was gained over the last two decades and compiled into mathematical models. These dynamical models were meanwhile validated in many practical applications. Mathematical models can be used for plant design as well. Compared to design procedures, this approach allows a more detailed analysis of technology options and obviously also an analysis of operational performance under dynamic load situations. Although German guidelines for dimensioning like A131 (2000) recommend to improve the planning by dynamic simulation, this promising option is only very rarely used in German speaking countries so far. Simulation is used typically only used for scenario analysis in the course of planning the extension of an already existing WWTP. In this situation, it is possible to set up and calibrate a model of the existing plant and to use the gained knowledge about influent characterisation and bio-degradability to feed a model of the extended plant. But also in situations where no calibration of a model is possible (completely new plant or if the effort is not affordable), dynamic simulation can be used for design. This statement is supported by experiences for applications of the Activated Sludge Model No.1 - ASM1 (Henze et al. 2000) indicating, that in many situations the performance of the real plant can be reproduced sufficiently well using a standard parameter set of the model. In addition, the use of dynamical simulation in design situations with only sparse data about influent composition will not increase the level of uncertainty compared to the predictions use the steady-state models utilised by the typical design rules. But detailed simulations models will allow reliable comparison between different technological options and the analysis of the effect of operational measures and effects of dynamic load situations.

This paper aims to deliver a parameterisation and influent characterisation for ASM3 (Henze et al. 2000) which is in compliance to German design standards, to reduce the effort for using simulation for design purposes, to eliminate discrepancies and to improve acceptance by authorities.

Status of WWTP design and dynamic simulation

The proposed method is oriented on the design practice in German speaking countries. WWTP design is here usually based on DWA procedure A131 (2000), referred as A131 and an alternative approach HSG (Hochschulgruppenansatz, Böhnke, 1989, Dohmann, 1993), referred as HSG. Based on these design procedures, the proposed method to generate parameter sets for the ASM1 as well as for the ASM3 was applied. Due to space limitations in this paper only the results for ASM3 will be presented. The two design procedures A131 and HSG allow the design of activated sludge WWTPs for C-elimination, nitrification, de-nitrification and aerobic sludge stabilisation. The recent version of A131 introduces a COD based approach for influent characterisation and the estimation of the sludge production and oxygen demand. This approach is used as the reference case because of the obvious similarities to the COD based ASMs. Compared to A131 the HSG-approach considers the process of nitrification in a more detailed way which allows its usage in situations with very strict ammonia effluent requirements or in cases of nitrogen peak loads. Thus the HSG-approach is used as a reference for the nitrification process.

Broad experiences about activated sludge models were gained by the application of the ASM1 (Henze t al 2000). ASM1 describes C-removal and N-elimination by nitrification and denitrification. Many applications of dynamic simulation in German speaking countries are based on ASM1 using a specific data set for influent characterisation and biological parameters (Bornemann et al. 1998). For ASM3, which describes basically the same processes, broader experiences will be available in the near future. It is expected, that this model will be applied more often and will supersede the ASM1. For application of ASM3 the parameter set proposed by Koch et al. (2000) is acknowledged as good reference for municipal wastewater in German speaking countries.

Methods

Regarding the sludge production it is possible to derive on an analytical way parameters for ASM3 and ASM1. The sludge production of ASM3 depends on several aspects. But a set of minor adjustments allow an identical sludge production as predicted by A131.

Table 1: Modification of ASM3 parameter for sludge production

Parameter	A131 compliant	Koch et al. 2000
aerobic yield storage $Y_{STO,O2}$	0.8375	0.8
aerobic yield growth $Y_{H,O2}$	0.8	0.8
anoxic yield storage $Y_{STO,NO}$	0.787	0.7
aerobic yield growth $Y_{H,NO}$	0.7	0.65
$\eta_{H,end}$-reduction of decay under anoxic conditions	0.5	0.33/0.5
decay rate heterotrophic biomass $b_{H,O2}$	0.32	0.3

A A131 conformant influent characterisation was developed as well.

Regarding the nitrification process, the two design procedures A131 and HSG define a required aerobic sludge age. Including the defined safety factors the following parameters for ASM3 can be derived form this approach (see also Figure 1, Left):

Table 2: Modification of ASM3 parameters for nitrification

Parameter	HSG compliant	Koch et al. 2000
half-saturation constant growth autotrophs K_N	0.7	1
$\mu_{A, ASM3}$ Maximum growth rate of X_A [1/d]	1.3 $e^{-0.105*(20-T)}$	1.3 $e^{-0.105*(20-T)}$
safety factor f_μ, for f=1.25	0.8593	
$b_{A,ASM3}$ Decay rate of X_A [1/d]	0.18 $e^{-0.105*(20-T)}$	0.2 $e^{-0.105*(20-T)}$

Regarding the denitrification capacity (g N denitrified per g BOD influent) at the considered base situation, one will find, that ASM3 provides hardly any sensitive parameter. But it can be shown that fortunately the existing differences between ASM3 and the assumptions of A131 can be accepted (Figure 1, Right).

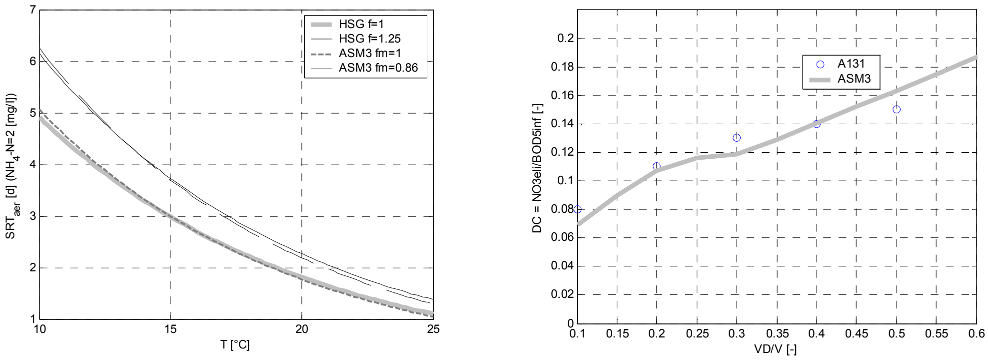

Figure 1: Left: Aerobic sludge age at equilibrium for Nitrifiers, Right: Comaprison of denitrification capacity obtained wit A131 and ASM3

Results and discussion

Dynamic simulation provides valuable options for the design of treatment plants and the integrated design of process and ICA system. The proposed methodology is expected to bridge the gap between design praxis and the application of dynamic simulation based on state of the art activated sludge models.

It was possible to derive, in an analytical way, a set of parameters ensuring the same sludge production of ASM3 and ASM1. Also the nitrification settings can be parameterised in a way that the well proven assumptions of the design procedures are met. The simulated denitrification performance is fairly in the range of the design expectations.

One interesting co-result of this analysis is the indication, that the underlying assumptions for the two design procedures A131 and HSG are not very pessimistic regarding nitrification capacity. Using the assumptions without all safety factors would result in a better simulated performance than is typically observed in simulation studies. By including a safety factor for considering non optimal nitrification conditions, the used configuration leads only to very moderately increased effluent values compared to the default assumptions from Koch et al (2000). On the other side, the proposed denitrification capacity seems to be a bit to pessimistic. It might be the case that these values count already for non optimal operational conditions of the plant (e.g. recirculation, extensive COD removal by primary clarifiers, etc.).

To come to a complete integrated design procedure (stationary pre-design, refinement using simulation) still some steps are missing. A proposal to answer one frequent question, on how to fill the typical lack of data regarding dynamic flow patterns, will be provided by a parallel paper (Langergraber et al. 2007). A logical follow-up step is, how to deal in systematic way with design safety. Finally a formalised design procedure using dynamic simulation needs to be specified, to meet engineering praxis and to gain acceptance from authorities.

References

Bornemann C., Londong J., Freund M., Nowak O., Otterpohl R. and Rolfs T. (1998): Hinweise zur dynamischen Simulation von Belebungsanlagen mit dem Belebtschlammodell Nr. 1 der IAWQ. *Korrespondenz Abwasser KA* 45(3), 455-462. [*in German*].

Böhnke, B. (1989): Bemessung der Stickstoffelimination in der Abwasserreinigung. *Korrespondenz Abwasser KA*, 9/89, 1046-1061. [*in German*].

Dohmann, M. (1993): Bemessung der Belebungsbecken nach dem Ansatz der Hochschulgruppe (HSG-Ansatz). *Korrespondenz Abwasser KA* 8/93, 1240. [*in German*].

DWA A131 (2000): ATV-DVWK Arbeitsblatt A 131: Bemessungen von einstufigen Belebungsanlagen ab 5000 EW. DWA, Hennef, Germany [*in German*].

Henze M., Gujer W., Mino T. and van Loosdrecht M. (2000): Activated sludge models ASM1, ASM2, ASM2D and ASM3. *IWA Scientific and Technical Report No.9*. IWA Publishing, London, UK.

Koch, G., Kühni, M., Gujer, W., Siegrist, H. (2000): Calibration and Validation of Activated Sludge Model no. 3 for Swiss municipal Wastewater. *Wat.Res.* 34(14), 3580-3590.

Langergraber, G, Alex, J., Weissenbacher, N., Woerner, D., Ahnert, M., Frehmann, T., Halft, N., Hobus, I., Plattes, M., Spering, V., Winkler, S. (2007): Generation of diurnal variation for influent data for dynamic simulation. Poster presentation at the 10th IWA Specialised Conference on *"Design, Operation and Economics of Large Wastewater Treatment Plants"*, 10-13 September 2007, Vienna. Austria, this conference.