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Efficiency of the Activated Sludge Model no. 3 for German wastewater on six different WWTPs

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Abstract In 1999, the Activated Sludge Model No. 3 by the IWA Task Group on Mathematical Modelling for the Design and Operation of Biological Wastewater Treatment was presented. The model is used for the simulation of nitrogen removal. The simulations in this paper were done on the basis of a new calibration of the ASM 3 by Koch *et al.*, with the easily degradable COD measured by respiration. For modelling of EBPR the BioP-Module of Rieger *et al.*, was used.

Six German wastewater treatment plants were simulated during this research to test the existing set of parameters of the models on various large scale plants. It was shown that changes for nitrification and enhanced biological phosphorus removal in the set of biological parameters were necessary. Sensible parameters and recommended values are presented in this article. Apart from the values of the changed biological parameters, we will in our examination discuss the modelling of the different activated sludge systems and the influent fractioning of the COD. Two plants with simultaneous denitrification in the recirculation ditch (EBPR) are simulated, one with preliminary dentrification, one with intermittent denitrification (EBPR), one with cascade denitrification (EBPR), and one pilot plant according to the Johannesburg-process (EBPR) which was simulated over a period of three months.
Keywords Activated sludge model No. 3; EBPR; full scale plant data; simulation

Activated Sludge Model No. 3

The Activated Sludge Model No. 3 was published in 1999 by the IWA task Group on Mathematical Modeling for Design and Operation of Biological Wastewater Treatment (Gujer *et al.*, 1999). Better understanding of the biological processes have resulted in ASM3 to simulate nitrification, denitrification and degradation of COD. The new model describes storage of organic substrates, decay of heterotrophic organisms by endogenous respiration and smaller anoxic yields for the heterotrophic organisms were used. Hydrolysis of slowly degradable COD (XS), that is now independent from aerobic, anoxic or anaerobic situations has a smaller importance because the lysis process (with the production of slowly degradable COD) has been replaced by endogenous respiration. The decay rates for endogenous respiration of heterotrophic and autotrophic organisms are reduced under anoxic conditions (Nowak, 1996; Siegrist *et al.*, 1999). The calibrated version of ASM 3 by Koch *et al.* (2000) has been used in this research. The main difference to the original publication (Gujer *et al.*, 1999) is the fact that readily degradable COD is not measured by filtration but by respiration. Slowly degradable COD (X_S) includes soluble and particulate components.

The EAWAG-Bio-P-Module

Simulation of enhanced biological phosphorus removal is integrated in the ASM3 by the EAWAG Bio-P Module (Rieger *et al.*, 2001). The main structure and ideas from ASM3 have been supplemented. Endogenous respiration replaces lysis, different yields for aerobic and anoxic conditions are used and anaerobic decay was also neglected for the PAOs. The model adds 11 additional processes to the ASM 3 to describe the EBPR. Glycogen as an additional substrate pool for growth is not taken into consideration as there could not be found a significant influence on the enhanced biological P-removal or for the fermentation process in municipal wastewater. The processes of chemical precipitation have been integrated additionally in SIMBA 3.3+ (SIMBA 3.3+, 1999) in the way they are used in ASM2d (1999).

Pilot plant Gümmerwald

The pilot plant at Gümmerwald is run with the Johannesburg-Process. Therefore we have a first anaerobic tank for EBPR (6.3 m^3), then a denitrification (19 m^3) and nitrification zone (25 m^3) and a denitrification tank in the return sludge stream (7.3 m^3). The plant is operated with a pre-treatment tank (0.5 h) at a sludge age of 15.5 days. The influent fractioning in % of total COD was as follows: 54.8% XS, 12% XI, 10% XBH, 4.2% SI. For the readily degradable COD then exists measured data that shows that this fraction was 19% of total COD (measured by respiration) in the influent to the denitrification tank. The inflow is characterised by a high amount of sludge water and a very good nitrification.

Some simulation results of a specific period for ASM 3 including EAWAG BioP-Module and ASM2d are shown in Figure 1 for ammonia, nitrate and phosphate. As can be seen, nitrogen effluent values of ASM3 are of very good quality. Calculated nitrate effluent values are nearer to the snap sample measurements than the online data. For PO_4-P removal it could be seen that the EAWAG-BioP-Module in the used calibration reacts very dynamically.

The saturation coefficient of oxygen $K_{O2,Aut}$ has been decreased and μ_{Aut} increased to 1.6 d^{-1} to establish nitrification at the plant in Gümmerwald. As could be seen from the picture the simulation results compared with measured data are very good. To increase P removal K_{max} has been raised to 1 mg/l. Typical maximum values of 0.2–0.34 gP/gCOD in the PAO biomass haven't been reached in simulation, so this change of k_{max} is a possible calibration parameter. Gümmerwald was the only investigated plant, where phosphorus removal was simulated well with a storage rate value of $q_{PP} = 1.5\ d^{-1}$.

In Gümmerwald denitrification in the secondary clarifier was modelled. In contrast to other modelled plants measured data showed that denitrification was not only done in the thickening zone but also in the higher parts, as both effluent values of the SST and return sludge stream concentration of nitrate were reduced to influent SST values. So in the model an additional tank was installed in the main stream to the SST.

Wastewater treatment plant Neumünster

The WWTP at Neumünster (Figure 2) uses biological, chemical and mechanical treatment of the wastewater. It is built for 240,000 PE, but is loaded now with only 90,000 PE. Nitrogen and phosphorus is eliminated mainly biologically. EBPR is done with the ISAH-process, which means nitrate is eliminated in a return sludge tank that is fed with an additional stream of substrate, which in Neumünster comes from the influent of the pretreatment tank. This stream is 10% of the total influent to the PT. The influent wastewater runs through an anaerobic tank to establish EBPR and later through a recirculation ditch. The recirculation ditch was modeled as several aerated and unaerated tanks in line. Oxygen was only measured at one point with an average 1.7 mgO_2/l in the tank. Additional aerators are operated at the ditch, when NH_4-N is higher than 4 mg/l. The WWTP Neumünster is operated with chemical precipitation. Fe(III) is used as precipitation agent, which is dosed in the influent of the secondary clarifier.

Measured data was available for total and filtrated COD, BOD_5, NH_4-N, TKN, PO_4-P and NO_3-N. After the pretreatment tank BOD/TKN was quite low at 4; COD/BOD was 1.8 in the simulation period in April 2001. Sludge retention time was about 17 days, temperature 13°C. The influent fractioning in % of total COD was as follows after the PT: 48% X_S, 10% X_I, 15% X_{BH}, 8% S_I and 19% S_S.

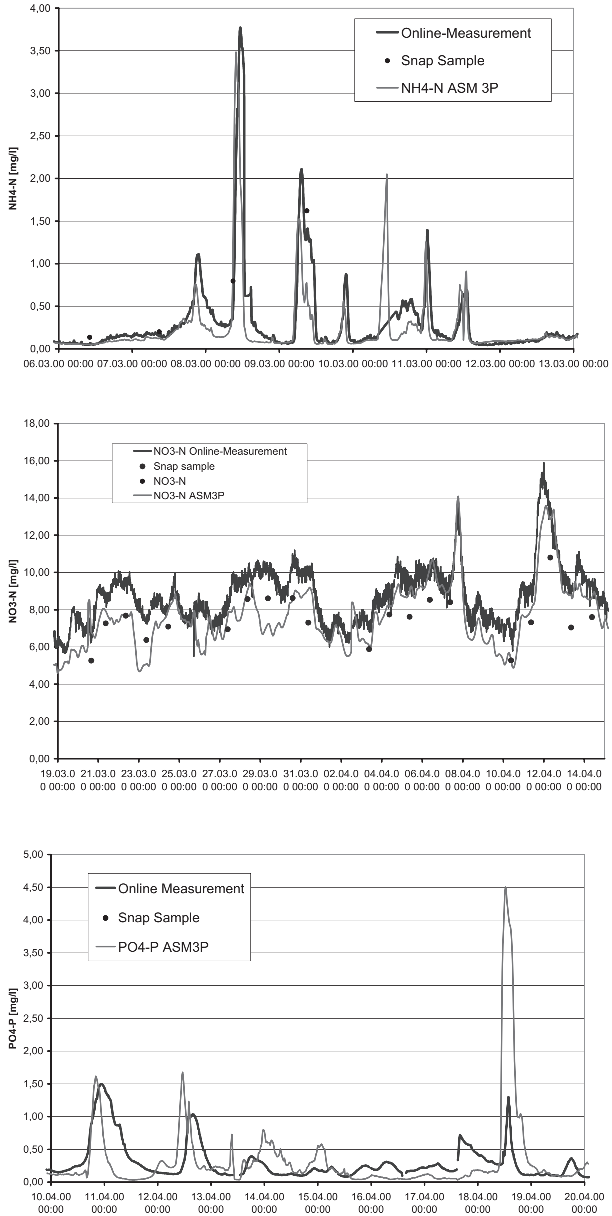

Figure 1 Examples of measured and simulated effluent concentrations [g/m^3] of the full-scale pilot plant at Gümmerwald (upper: ammonia from 6th to 13th of March, middle: nitrate for the 19th of March to 14th of April, bottom: phosphate for 10th to 20th of April 2001)

The simulation results for NH_4-N NO_3-N and P_{total} can be seen in Figure 3. Simulation results for Nitrate and PO_4-P are very good, ammonia is simulated satisfactorily. Measured data could be simulated again by an increase of nitrification and phosphorus removal. For nitrification the saturation coefficient for oxygen was reduced to the value of 0.13 gO_2/m^3, phosphorus elimination was achieved by increasing k_{max} to 1 mg/l and q_{PP} to the value of 1.95 1/d. Both values of the parameters have been used to established PAO in other German wastewater treatment plants with the EAWAG-BioP-Module.

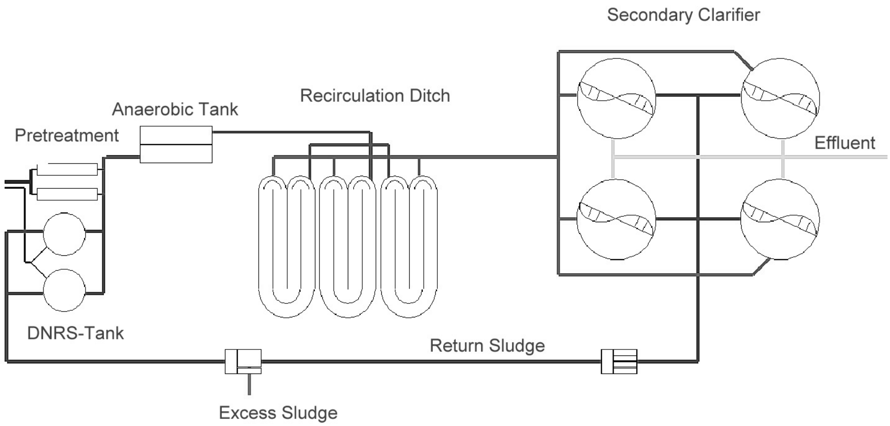

Figure 2 Flow sheet of the wastewater treatment plant at Neumünster

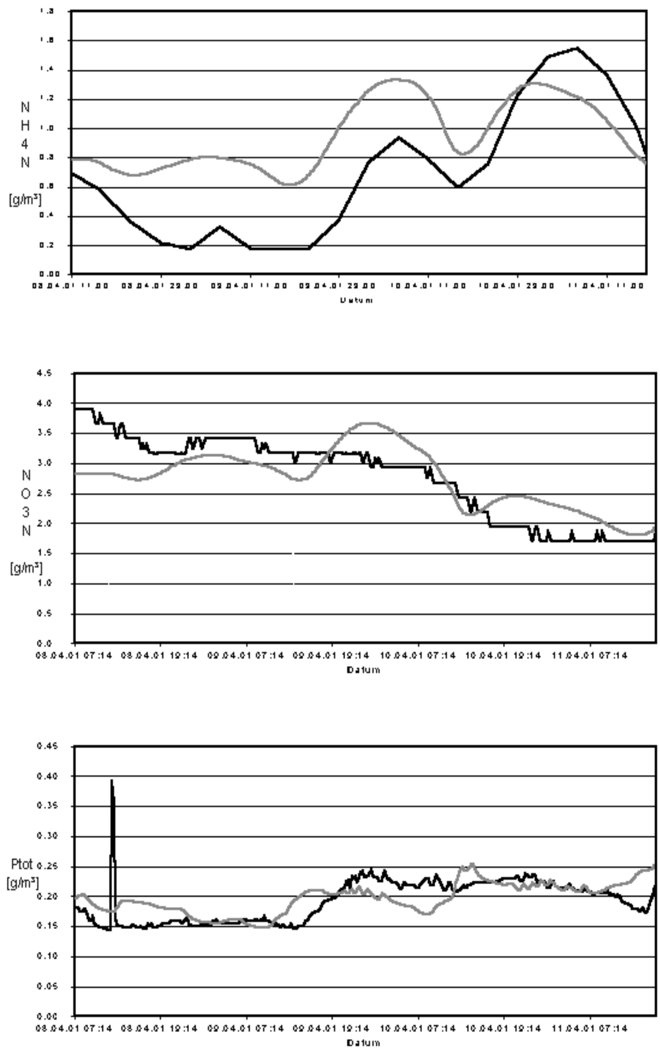

Figure 3 NH_4-N, NO_3-N and PO_4-P-effluent curves simulated (light colour) and measured (8.4. 2001–11.4. 2001) at the WWTP Neumünster

Wastewater treatment plant Lage

The existing plant at Lage is run according to the Johannesburg-process (Figure 4). The required effluent values of the municipal WWTP must be kept for a capacity of 125,000 PE. Internal process flows from the filter washing water, the mechanical surplus sludge thickening, and the sludge-treatment get into the influent of the activated sludge plant. After the grit chamber, the wastewater stream can be divided by a circumvention of the preliminary treatment. The two-line plant is characterised by a preliminary biological stage consisting of a cascade anaerobic tank and a recirculation sludge denitrification tank, the cascade denitrification, and a round secondary treatment tank with horizontal flow. The activated sludge tank is a two-street-unit. In each street, there are two lines with a denitrification/nitrification cascade and a preliminary cassette with facultative aeration which can be run either anoxically or aerobically. Between the two lines of a street, there is the middle flow, through which the denitrification tanks can be fed with bit-streams of the influent wastewater. There are internal recirculations from the nitrification tanks into the respective preliminary denitrification tanks and into the facultative aerated cassette.

The calibration and validation of the plant was run on the basis of two measuring periods in spring and autumn 1999. After warranting the data quality by balance calculations of the activated sludge tank and secondary treatment tanks as well as regression calculations, the

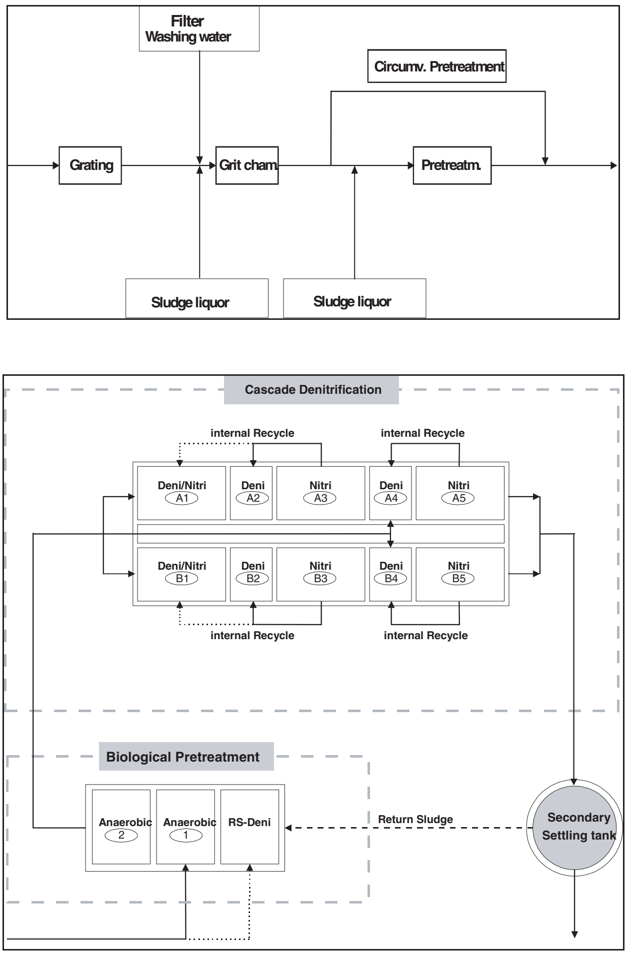

Figure 4 System of pre-treatment with process waters (above) and activated sludge tank with anaerobic zones (below) at the WWTP at Lage

calibration and validation of the plant model was successfully achieved with the help of the following influent fractionation (% of the COD_{total}): 7% SI, 17% SS, 12% XI, 45% XS, 19% XH. The fractionation of COD in the influent of the activated sludge tank depends on the plant operation due to the dosage of the process waters with different COD-fractions. Biological parameters have been changed compared with the original publications of Koch *et al*. (2000) and Rieger *et al*. (2001) for the increase of the nitrification ($K_{O2,Aut}$ = 0.13 gO_2/m^3, μ_{Aut} = 1.6 d^{-1}) and the phosphorus elimination (q_{PP} = 2.25 d^{-1}, $K_{Max,PAO}$ = 1.0 g/m^3). Some results of the simulation could be seen in Figure 5. Although it is quite typical for the investigated plants it could be said that nitrification here is really good, which results in a high autotrophic growth rate. Simulation results for ammonia are not shown because verification was done on only average values as dynamic data was missing.

Wastewater treatment plants of Koblenz, Hildesheim and Duderstadt

As the plants in Koblenz, Hildesheim and Duderstadt have been described already in Wichern *et al*. (2001) only some short information is given about the WWTPs here.

Koblenz

The wastewater treatment plant Koblenz was built for 320,000 populations equivalents. The plant uses primary treatment, a first biological stage with trickling filter and pre-denitrification. Rectangular tanks with horizontal flow are used for final clarification. The plant has two parallel lines that show a strong gradient of concentrations caused by the long tanks and these were simulated with several tanks in line. For the readily degradable COD there exists measured data that shows that this fraction was 10% of total COD in the influent to the denitrification tank. The retention time is about 11 days. The WWTP at Koblenz is not operated with enhanced biological phosphorus removal. Denitrification in the secondary

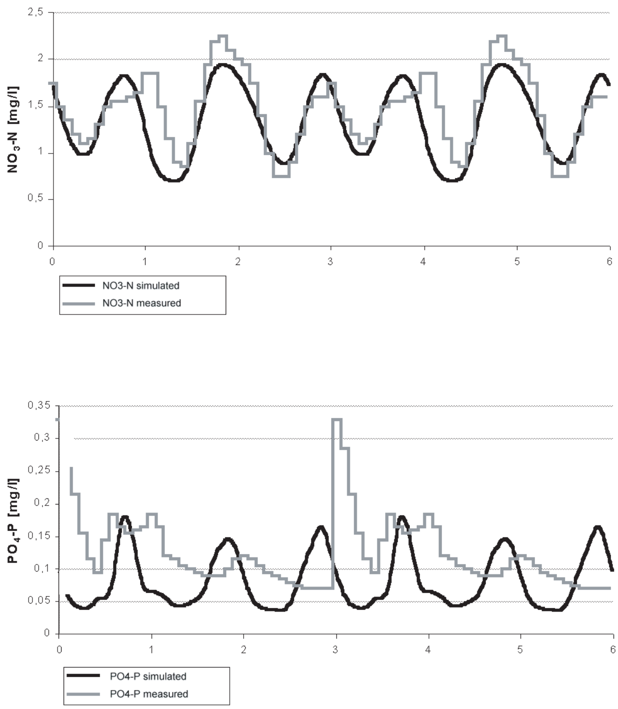

Figure 5 NO_3-N and PO_4-P-effluent curves simulated (dark line) and measured (11.10.–15.10. 1999) at the WWTP Neumünster

clarifier was integrated into the model with an additional tank of 20% of the total SC volume in the return sludge stream.

Hildesheim

The wastewater treatment plant at Hildesheim is built with nitrification, denitrification and biological phosphorus removal. The plant is run using the ISAH-process with EPBR, which means the return-sludge is denitrified in a separate anoxic tank in order to prevent an inhibition with nitrate in the anaerobic tank. If necessary, additional substrate can be fed from the anaerobic tank. The WWTP at Hildesheim is operated as simultaneous denitrification. The plant is modelled with the two layer approach of Alex *et al.* (1999). Readily degradable COD was about 16% of the total COD. The plant has been simulated with data of a high loading before the extension of the plant in 1995 (SRT = 11 d) and additionally after upgrading the plant and much lower loading rates (SRT = 38 d).

Duderstadt

The wastewater treatment plant at Duderstadt was designed as an intermittent denitrification one with a pre-anaerobic volume to establish enhanced biological phosphorus removal. The plant is operated with a high sludge retention time of about 29 d and without a primary settling tank. Readily degradable COD was about 16% of total COD in the influent. The intermittent aerated tanks are operated by a control of oxygen and ammonia. Denitrification in the secondary settling tank was taken into account with an additional tank in the return sludge stream.

Changed biological parameters

In Table 1 the values for the stoichiometric and kinetic parameters, which have been changed during simulation are presented. Basic are the parameter values of Koch *et al.*, (2000) for ASM 3 and Rieger *et al.* (2001) for the EAWAG-BioP-Module.

Five WWTPs and one pilot plant were simulated with the new models. With all investigated plants nitrification and EBPR were increased. To come to a better description for nitrification the saturation coefficient for oxygen for autotrophic biomass has been decreased. The change of this parameter resulted from the problems to model well the recirculation ditches in Neumünster and Hildesheim. Futhermore the maximum growth rate for the autotrophs was raised within the parameter range given by the new models.

Enhanced biological P-removal was increased in all EBPR plants. Two coefficients were adapted: the polyphosphate storage rate q_{PP} and the maximum storage constant of

Table 1 Changed biological parameters for different German WWTPs compared with published values

	Gujer 1999	Koch, 2000+Rieger 2001	Hildesheim '95 / '97	Duderstadt '94	Kobl. '94	Gümm. '01	Lage '99	Neumünster '01
Nitrification								
μ_{Aut} [1/d]	1.0	0.9–1.8	1.0	1.0	1.0	**1.6**	**1.6**	**1.15**
$K_{O2,Aut}$ [g_{O2}/m^3]	0.5	0.5	**0.13/0.13**	**0.18**	**0.13**	**0.13**	**0.13**	**0.13**
Denitrification								
K_{O2} [g_{O2}/m^3]	0.2	0.2	0.2/0.2	0.2	**0.5**	0.2	0.2	**0.5**
$\eta_{N03,end,Het}$[–]	0.5	0.5/0.33	0.33/0.33	0.33	0.5	0.5	0.33	0.5
P-Elimination								
$K_{max,PAO}$ [g_P/g_{CSB}]	–	0.2	**1.0/1.0**	**1.0**	–	**1.0**	**1.0**	**1.0**
q_{PP} [1/d]	–	1.5	**2.3/2.3**	**2.5**	–	1.5	**2.25**	**1.95**
$K_{PO4,PP}$ [gP/m^3]	–	0.2	0.2/**0.11**	0.2	–	0.2	0.2	0.2

polyphosphate K_{max} to 1.0. Although the maximum storage of polyphosphate was increased the simulated polyphosphate contents of PAO in simulation did not exceed normal maximum contents of of 0.2–0.34 gP/gCOD, so K_{max} could be recommended as an easy calibration parameter for EBPR.

Conclusions

In this paper different large scale treatment plants have been modelled with the Activated Sludge Model No. 3 (Gujer *et al.*, 1999) in the calibrated version of Koch *et al.* (2000) and the EAWAG-BioP-Module (Rieger *et al.*, 2001). Two plants with simultaneous denitrification in the recirculation ditch (EBPR) are simulated, one with preliminary dentrification, one with intermittent denitrification (EBPR), one with cascade denitrification (EBPR), and one pilot plant according to the Johannesburg-process (EBPR) which was simulated over a period of three months. Altogether eight loading situations were modelled with sludge ages from 11 to 38 days. It was obvious that in the investigated cases for German wastewater, nitrification and P removal had to be increased. Within this paper the parameters that worked well for calibrating the models, their recommended values and typical influent fractioning of COD were presented. ASM 3 and the EAWAG-BioP-Module can be used very well for modelling different municipal WWTPs.

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