MODELLING START-UP AND OPERATION OF AN ANAMMOX SEQUENCING BATCH REACTOR

STIJN W.H. VAN HULLE[1], ANA DAPENA-MORA[2], JOSÉ L. CAMPOS[2], R. MENDEZ[2], MIKE S.M. JETTEN[3] & PETER A. VANROLLEGHEM[1]

[1]Department for Applied Mathematics, Biometrics and Process Control (Biomath), Ghent University, Coupure Links 653, B-9000 Gent, Belgium

[2]Chemical Engineering Department, ETSE, University of Santiago de Compostela. E-15782. Spain

[3]Department of Microbiology. University of Nijmegen. Toernooiveld 1, 6525 ED Nijmegen. The Netherlands

INTRODUCTION

Biological nitrogen removal in wastewater with high nitrogen contents can become a major cost factor, in particular when the wastewater contains only small amounts of biologically degradable carbon compounds (Seyfried *et al*., 2001). A new way to remove nitrogenous compounds is the Anammox process. In this process ammonium is oxidised using nitrite as electron acceptor:

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2\,H_2O$$

Application of this process together with systems for partial nitrification (e.g. SHARON (Van Dongen *et al.*, 2001)) would reduce the required oxygen input by 60% and would alleviate the need for addition of external COD for nitrification (and concomitant increased sludge production).

The isolation and enrichment of Anammox biomass from a mixture of bacteria populations requires the optimisation of the conditions, favouring the Anammox process while limiting the growth of any other kind of microbial population. Especially the absence of oxygen is essential, because the Anammox process is completely inhibited by it (Jetten *et al*., 1999). So far few studies have been conducted towards modelling start-up and dynamic behaviour of the Anammox process, although this is an efficient way to optimize this novel process. Hao *et al.* (2002a,b) performed a thorough simulation study on the behaviour of a partial nitrification-Anammox system under different process conditions, such as varying temperature and dissolved oxygen concentration. However no verification with real data was performed and no start-up dynamics were included in the study. Koch *et al.* (2000) performed simulations with a similar system, but also did not include any start-up or long-term dynamic effects. Furthermore it can be noted that in both studies total nitrogen concentration amounted to about 150 mgN/l, while in a real Anammox reactor this concentration would be tenfold higher.

The purpose of this study was to interpret the results of an Anammox enrichment in an SBR system with the Activated Sludge Model nr. 1 (ASM1, Henze *et al.*, 2000) extended with submodels for 2 step nitrification-denitrification and the Anammox process. Simulation results of both start-up and dynamic operation of the reactor will be compared to the measured values. Total nitrogen concentrations in the reactor will amount up to 900 mgN/l as will be the case in a real reactor.

MATERIALS AND METHODS

Extension of ASM1

All modelling was performed in the modelling and simulation environment WEST® (Vanhooren *et al.*, 2002). Since the enrichment of Anammox was performed in an SBR, a standard SBR model in the WEST® modelbase was used to describe the SBR behaviour. In view of the size of the experimental reactor (1 litre) and the presence of a stirrer system the SBR reactor was assumed to be ideally mixed. Although settling was ideal, the fraction of biomass withdrawn with the effluent was set to 0.5 % to take the effect of sampling into account (Dapena *et al.*, 2003). For modelling purposes the Activated Sludge Model nr. 1 (ASM1, Henze *et al*., 2000) was extended with a 2 step nitrification-denitrification model and with the Anammox process (Hao *et al*., 2002a; Sin *et al.*, 2001; Liebig *et al.*, 2001). Monod kinetics were used to describe the dependency of the growth rate of Anammox on ammonium and nitrite. It should however be noted that nitrite is not only a substrate, but is also inhibiting the Anammox process (Strous *et al*., 1999). Therefore, Haldane kinetics are perhaps more appropriate then the Monod kinetics applied, but the measured nitrite concentrations in the reactor were never high enough (< 20 $mgNO_2$-N/l) to show an inhibiting effect, which prevented to calibrate the inhibition constant.

In previous simulation studies (Hao *et al*., 2002a,b; Koch *et al.*, 2002) endogenous respiration was used to describe decay. However in this study the death-regeneration concept was preferred, because the behaviour of Anammox under substrate limmiting conditions is not completely clear yet and because heterotrophs were found active in the reactor. Only the use of this death-regeneration concept can explain this activity, since no COD was added in the influent.

In the extended ASM1 model ammonium is oxidised to nitrite by ammonium oxidisers (X_{NH}). This nitrite can be further oxidised to nitrate by nitrite oxidisers (X_{NO}). Both nitrite and nitrate as well as oxygen can be used as electron acceptor by heterotrophs (X_H) for growth, while readily degradable substrate (S_S) is used as electron donor. This substrate can either be supplied in the influent or formed through hydrolysis of slowly degradable substrate (X_S). This slowly degradable substrate is formed during decay of biomass, along with inert biomass.

The complete stoichiometric matrix in Peterson matrix format (Henze *et al.*, 2000), together with the kinetic expressions and the values for the different parameters are given in Dapena *et al.* (2003).

RESULTS AND DISCUSSION

Influent concentrations to the enrichment SBR are shown in Figure 1. Ammonium and nitrite concentrations are gradually increased as the Anammox biomass consumes these components. After 4 months of operation the influent composition was kept constant and the reactor was operated for another 2 months at an influent ammonium and nitrite concentration of 410 mgN/l and 500 mgN/l respectively.

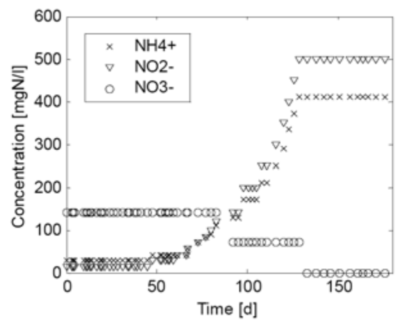

Figure 1. The influent ammonium, nitrite and nitrate concentrations to the reactor

In Figure 2 the simulated effluent concentrations are depicted. It can be seen from this Figure 2 that there is a good agreement between measured and simulation results. Also the effluent concentrations are low, indicating the possibility of the Anammox reactor to treat nitrogen rich streams.

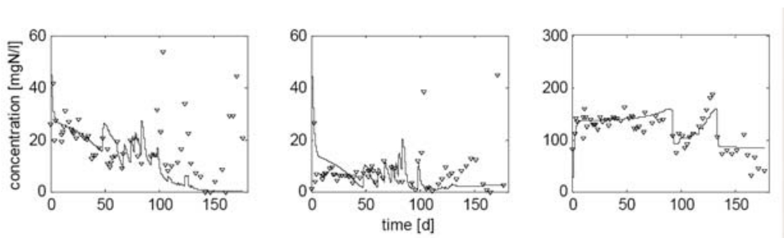

Figure 2. The calculated (—) and measured (∇) ammonium (left), nitrite (middle) and nitrate (right) concentrations in the effluent of the reactor

In Figure 3 the simulated Anammox and inert biomass concentrations are presented. From day 100 a gradual colour change from brownish to reddish was observed. This colour change can be explained by the gradually increasing Anammox biomass concentration. This shows the successful enrichment of Anammox organisms over the experimental period.

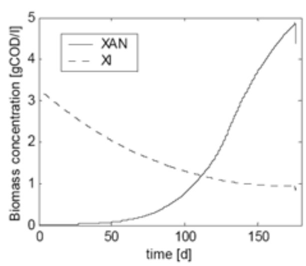

Figure 3. The calculated Anammox (—) and inert biomass (--) concentrations in the SBR

CONCLUSION

Simulation results of both start-up and dynamic operation of an Anammox SBR reactor were compared to the measured values, using ASM1 extended with a 2 step nitrification-denitrification model and with the Anammox process. Simulations were in very good agreement with the experimental data. The Anammox biomass concentration increased gradually over the experimental period, showing the successful enrichment of Anammox organisms in an SBR reactor.

ACKNOWLEDGMENTS

This study was supported by the EU by means of the ICON project, no. EVK1-CT2000-00054.

REFERENCES

DAPENA-MORA, A., VAN HULLE, S.W.H., CAMPOS, J.L., MENDEZ, R., VANROLLEGHEM, P.A. & JETTEN, M.S.M. (2003). Enrichment of ANAMMOX biomass from municipal activated sludge: experimental and modelling results and their implications towards full-scale applications. *Submitted to WR.*

HAO, X., HEIJNEN, J.J. & VAN LOOSDRECHT M.C.M. (2002a). Model-based evaluation of temperature and inflow variations on a partial nitrification-ANAMMOX biofilm process. *Water Research*, **36**, 4839-4849.

HAO, X., HEIJNEN, J.J. & VAN LOOSDRECHT, M.C.M. (2002b). Sensitivity analysis of a biofilm model describing a one-stage completely autotrophic nitrogen removal (CANON) process. *Biotechnology & Bioengineering*, **77**, 266-277.

HENZE, M., GUJER, W., MATSUO, T. & VAN LOOSDRECHT, M. (2000). *Activated Sludge Models ASM1, ASM2, ASM2d and ASM3.* IWA, Scientific and Technical Reports. London, UK.

KOCH, G., EGLI, K., VAN DER MEER, J.R. & SIEGRIST, H. (2000). Mathematical modeling of autotrophic denitrification in a nitrifying biofilm of a rotating biological contactor. *Water Science & Technology*, **41**(4-5), 191-198

LIEBIG, T., WAGNER, L., BJERRUM, L. & DENECKE, M. (2001). Nitrification performance and nitrifier community composition of a chemostat and a membrane-assisted bioreactor for the nitrification of sludge reject water. *Bioprocess and Biosytems Engineering*, **24**, 203-210.

JETTEN, M.S.M., STROUS M., SCHOONEN, K.T., SCHALK, J., VAN DONGEN, L.G.J.M., VAN DE GRAAF, A.A., LOGEMANN, S., MUYZER, G., VAN LOOSDRECHT, M.C.M. & KUENEN, J.G. (1999). The anaerobic oxidation of ammonium. *FEMS Microbiology Reviews*, **22**, 421-437

SEYFRIED, C.F., HIPPEN, A., HELMER, C., KUNST, S. & ROSENWINKEL K.-H. (2001). One-stage deammonification: nitrogen elimination at low costs. *Water Science & Technology*: *Water Supply*, **1**(1), 71–80.

SIN, G., VAN HULLE, S.W.H., VOLCKE, E.I.P., & VANROLLEGHEM, P.A. (2001). *Activated Sludge Model No. 1 Extended with Anammox and Sharon Processes.* Biomath Technical report. Ghent University, Belgium.

STROUS, M., KUENEN, J.G. & JETTEN, M.S.M. (1999). Key physiology of anaerobic ammonium oxidation. *Applied and Environmental Microbiology*, **65**(7), 3248–3250

VAN DONGEN, L.G.J.M., JETTEN, M.S.M. & VAN LOOSDRECHT M.C.M. (2001). *The combined SHARON/Anammox process.* IWA Publishing, London, UK.

VANHOOREN, H., MEIRLAEN, J., AMERLINCK, Y., CLAEYS, F., VANGHELUWE, H. AND VANROLLEGHEM, P.A. (2003) WEST: Modelling biological wastewater treatment. *Journal of Hydroinformatics*, 5, 27-50.