Generation of Anammox-optimal nitrite:ammonium ratio with SHARON process: usefulness of process control?

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Abstract

The combined SHARON-Anammox process for treating wastewater streams with high ammonia load, is discussed. Partial nitrification in the SHARON reactor should be performed to such an extent that an Anammox-optimal nitrite:ammonium ratio is generated. A simulation study for realistic influent conditions (sludge digestion reject water) reveals that the nitrite:ammonium ratio obtained in a SHARON process operated without control might deviate significantly from the ideal ratio and might endanger operation of the subsequent Anammox reactor. It is further examined how this ratio might be optimized through cascade feedback control by adding acid or base to the SHARON reactor. The results are quantified by means of an operating cost index.

Keywords

Anammox, operating cost index (OCI), partial nitrification, process control, SHARON, simulation

INTRODUCTION

In the SHARON process, partial nitrification of ammonium to nitrite is achieved by working at high temperature (30-40°C) and neutral pH (about 7.5). An appropriate sludge retention time (SRT) is maintained, in order to wash-out the nitrite oxidizing biomass, realizing significant aeration cost savings in comparison with conventional nitrification to nitrate. The SHARON process is applied to treat sludge digestion reject water in order to relieve the main wastewater treatment plant (WWTP) to which this stream is subsequently recycled. A full-scale SHARON process is operational since January 1999 at the Rotterdam Sluisjesdijk sludge treatment plant. In the last few years, the coupling of the SHARON process with a so-called Anammox process, in which ammonium and nitrite are converted to nitrogen gas under anaerobic conditions by autotrophic micro-organisms, has gained a lot of interest (van Dongen *et al.*, 2001). With the combined SHARON-Anammox process, low nitrogen effluent concentrations can be obtained, while aeration costs are further reduced, no additional carbon source is needed and sludge production is very low.

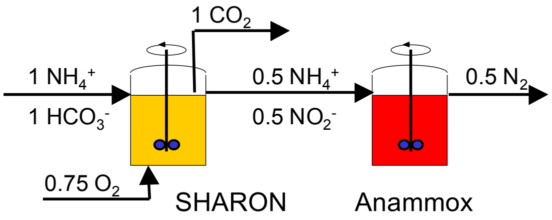

Figure 1 Simplified scheme of the SHARON-Anammox process

Theoretically, in case the SHARON influent contains equimolar amounts of ammonium and bicarbonate, which can be reasonably assumed for sludge digestion reject water, its effluent will contain the required nitrite:ammonium ratio of 1:1 that is needed to feed the Anammox reactor. This simplified reasoning, neglecting among others biomass growth, is represented in Figure 1.

In practice, the actual nitrite:ammonium ratio *needed* by the Anammox process will depend on the biomass yield and is typically somewhat higher. The nitrite:ammonium ratio *produced* by the SHARON process depends upon a number of factors, e.g. influent alkalinity. In this contribution, the nitrite:ammonium ratio produced by the SHARON process, as well as its effect on the subsequent Anammox process, in particular with respect to nitrite inhibition of the latter, is examined for realistic influent conditions by means of a simulation study. Cascade feedback control by adding acid or base to the SHARON reactor is proposed to optimize this ratio and is evaluated through an operating cost index (OCI).

THE SHARON AND ANAMMOX MODELS

The SHARON reactor model, implemented in Matlab-Simulink, has been described by Volcke *et al.* (2002b). The model takes into account the pH effects that occur during nitrification of highly concentrated streams. pH dependency of the biomass growth rate is taken up explicitly by pH dependency of μ_{max} as well as implicitly through the concentrations of the uncharged ammonia and nitrous acid, that are pH dependent. The Anammox reactor model, implemented in WEST® (Hemmis N.V., Kortrijk, Belgium), consists of a continuously stirred tank reactor with almost complete (99.5%) biomass retention. Anammox kinetics are based on the model proposed by Dapena *et al.* (2003). Inhibition of Anammox growth by nitrite was incorporated by a Haldane dependency, with an inhibition coefficient of 1 mole/m^3, in accordance with Strous *et al.* (1999).

SIMULATION RESULTS

The behaviour of the SHARON reactor is simulated over a period of a year under realistic influent conditions. An operating mode without process control is compared to one with cascade feedback control of the nitrite:ammonium ratio produced in the SHARON process.

Influent conditions

In order to obtain a realistic influent file, daily averaged on-line measurements for flow rate and ammonium concentrations, as well as weekly lab analyses for bicarbonate alkalinity and pH from the full-scale SHARON process in Rotterdam were used. Figure 2 gives the resulting load profiles for ammonium and bicarbonate. The influent flow rate varies between 0 and 921 m^3/day (mean 422), the influent bicarbonate:ammonium molar ratio varies between 0.16 and 3.59 (mean 1.1), the influent pH varies between 7.6 and 8.3 (mean 8.0). The simulation study has been performed for a continuously aerated SHARON reactor with a constant volume of 528 m^3, corresponding with a mean aerobic retention time of 1.25 days. The volume of the Anammox reactor was set to 400 m^3. Both reactors were operated at 35°C.

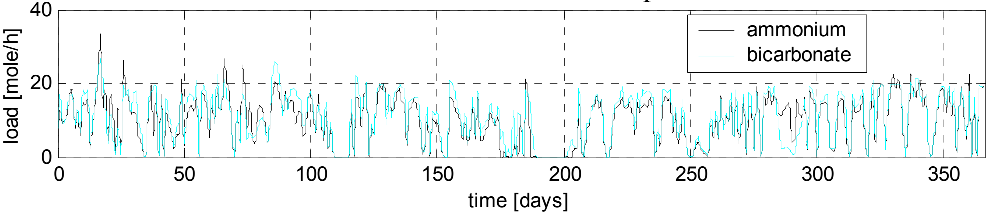

Figure 2: Typical yearly SHARON influent characteristics: ammonium and bicarbonate loads

Operation mode 1: continuously aerated SHARON reactor, no control

Figure 3 (top) shows the simulation results for the SHARON reactor operated without process control. For the assumed value of the nitrite inhibition constant, the Anammox reaction is strongly inhibited because of the unfavourable nitrite:ammonium ratio produced in the SHARON reactor. It seems strongly recommendable to control the nitrite:ammonium ratio produced by the SHARON reactor to avoid toxic nitrite concentrations.

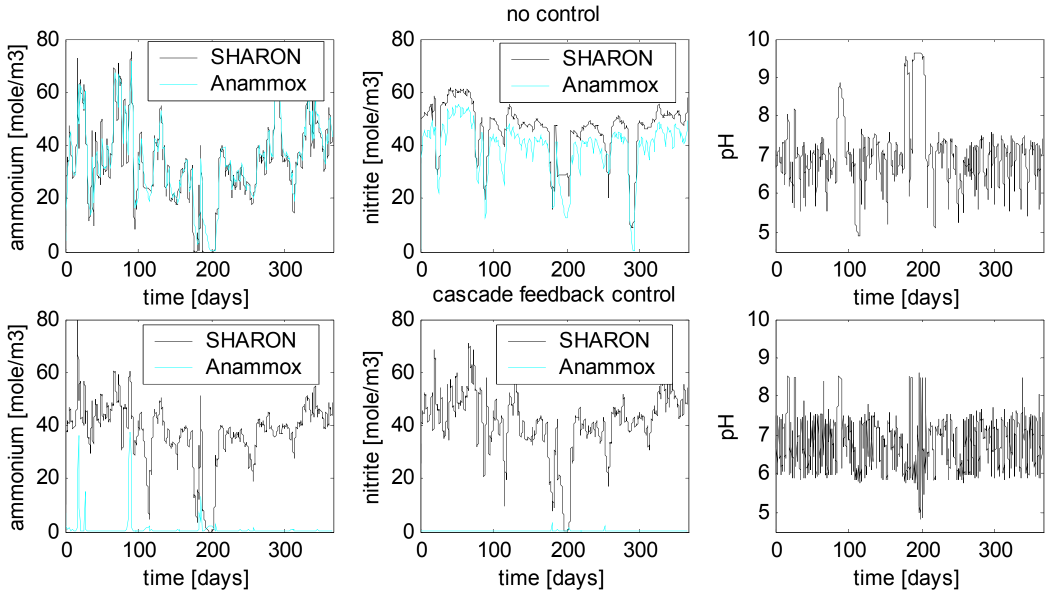

Figure 3: Simulation results for the operation modes without control (top) and with cascade feedback control (bottom). Concentration profiles of ammonium (left), nitrite (middle) in SHARON reactor and in subsequent Anammox reactor, pH in SHARON reactor (right).

Operation mode 2: continuously aerated SHARON reactor, cascade feedback control of produced nitrite:ammonium by acid/base addition

The proposed cascade feedback controller (Figure 3) consists of a primary controller, maintaining the desired nitrite:ammonium setpoint by adjusting the desired pH-value that has to be set by the secondary controller by means of acid or base addition. The Anammox-optimal nitrite:ammonium ratio (R^{sp}) is set to 1.32, according to the stoichiometry determined by Strous *et al.* (1998).

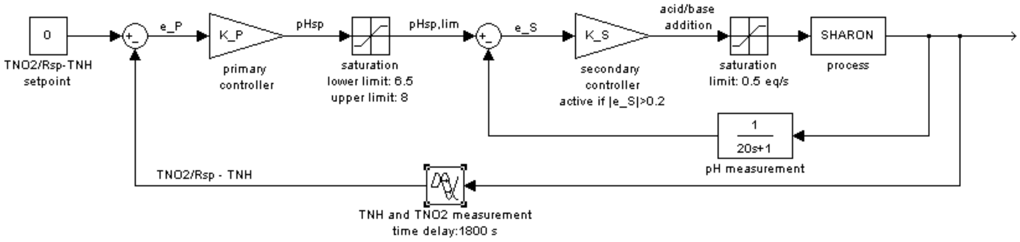

Figure 4: Structure of the proposed cascade feedback controller

Figure 3 (bottom) gives the simulation results. Although individual nitrite and ammonium concentrations in the SHARON reactor still vary, the produced nitrite:ammonium ratio remains quite constant with a slight stoichiometric excess of ammonium. As a result, the Anammox reactor performs very well.

EVALUATION PROCEDURE:USE OF AN OPERATING COST INDEX (OCI)

An operating cost index (OCI) is defined, that includes the operating cost factors that are different for the two operating modes under study:

$$\mathrm{OCI} = \gamma_1 \cdot \mathrm{EQ} + \alpha_{\mathrm{acid}} \cdot \Phi_{\mathrm{acid}} + \alpha_{\mathrm{base}} \cdot \Phi_{\mathrm{base}} \qquad [€/\mathrm{year}]$$

The effluent quality term EQ (in kg Pollution Units/day) is calculated as in the COST benchmark approach (Volcke *et al.* 2002a), and in this study covers ammonium in the Anammox effluent, that is recycled to the main WWTP and ends up in the effluent stream for plants with a lack of aeration capacity, as can be reasonably assumed here. The OCI further takes into account the cost of acid and base addition for the operation mode with control. The cost coefficients for the pollution units and acid and base additions are reported in Table 1 and are found in Volcke *et al.* (2002a) and http://ed.icheme.org/costchem.html respectively.

Table 1. Cost multiplication factors.

cost factor (€/year)	economic weight	value	unit
effluent fines	γ_1	50	€/EQ/year (EQ in kgPU/d)
acid addition	α_{acid}	0.00318	€/molar equivalent
base addition	α_{base}	0.00747	€/molar equivalent

Table 2. OCI economic evaluation

cost factor (€/year)	no control	cascade FB control
effluent fines	222032	7794
chemical addition	0	39993
OCI – aeration limitation (€/year)	222032	47787

Table 2 summarizes the results. The OCI indicates possible cost savings of 174245€/year by implementing the cascade feedback control strategy. This value is equivalent to the yearly investment costs that can be supported and certainly warrants the investment costs for the nitrite and amonium measuring system (assumed to cost 2x25.000 Euro).

CONCLUSIONS

Control of the nitrite:ammonium ratio produced by the SHARON reactor is crucial to avoid toxic nitrite concentrations, that inhibit the Anammox conversion. The authors also want to stress the importance for research on the nitrite inhibition of the Anammox reaction.

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