A modified ASM1 for nitritation/denitritation for the treatment of sludge reject water in a sequencing batch reactor

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Abstract

A modified ASM1 model was developed to simulate nitritation/denitritation in a sequencing batch reactor (SBR) treating sludge reject water. The model was validated using real data from a pilot SBR. The effect of a number of operating parameters on the nitritation/denitritation efficiency was tested including, among others, the volumetric nitrogen loading rate (vNLR), the solids retention time (SRT) and the number of cycles. Both the vNLR and the number of cycles critically affected the processes. Specifically, very high nitritation (>90%) was accomplished for vNLR <0.5 KgN/m^3d for an SRT of 10 d and 0.75 KgN/m^3d for SRTs between 15-20d. When vNLR>0.9 KgN/m^3d for an SRT of 10 d and vNLR>1.4KgN/m^3d for SRTs between 15-20 d nitritation was practically inhibited. The increase in the number of cycles of the SBR from 1 to 4 significantly improved the denitritation process. However, at 5 cycles and SRT=10 days the nitritation process was inhibited due to the decrease of the duration of the process time.

Keywords

ASM1; nitritation-denitritation; sludge reject water

1. INTRODUCTION

Nitritation/denitritation is increasingly being applied for the treatment of highly nitrogenous effluents including the sludge reject water. The latter is produced after the anaerobic digestion of sewage sludge and the subsequent dewatering processes and is characterized by very high ammonia-nitrogen (typically above 500 mg/L). Nitritation/denitritation results in reduced aeration requirements, lower organic carbon source needs and less sludge production compared to the conventional nitrification/denitrification process (Malamis et al., 2014). To achieve effective nitrogen removal via nitrite, the nitrite oxidizing bacteria (NOB) should be inhibited or washed out, while the growth of ammonia oxidizing bacteria (AOB) must be favoured. The most common way to inhibit NOB is by maintaining a high free ammonia concentration (> 1 $mgNH_3/L$) in the mixed liquor. Sequencing batch reactors (SBRs) are often applied to treat the sludge reject water since they are characterized by flexibility in operation which is required to favour the development of AOB over NOB.

So far, only a few attempts have been made to simulate a nitritation – denitritation process, by modifying existing models such as ASM1 and ASM3 in order to describe the phenomenon. Some of the most remarkable efforts of modifying existing models to perform nitritation – denitritation are those of Iacopozzi et al (2006) and Kaelin et al., (2009), developing an extended ASM3 model and of Ostace et al (2011), developing and extended ASM1 model. The aim of this work was to simulate the nitritation/denitritation process for an SBR treating sludge reject water. This was based on a modification of the ASM1 model, while real data from a pilot SBR were used to validate the model.

2. MATERIALS AND METHODS

Activated sludge model No.1 was modified in order to account for two step nitrification – denitrification. Two model components of ASM1 were further divided in four new elements and thus the total number components of the extended version of ASM1 are 15 instead of 13.

More specifically autotrophic biomass of ASM1 (X_{BA}) was divided in two components: i) X_{AOB} which represents the AOB which perform the oxidation of ammonia-nitrogen to nitrite-nitrogen and ii) X_{NOB} which represent the NOB which are responsible for the oxidation of nitrite-nitrogen to nitrate-nitrogen.

Furthermore, the nitrate-nitrogen component of ASM1 (S_{NO}) was divided in the nitrite-nitrogen fraction (S_{NO2}) and the nitrate-nitrogen fraction (S_{NO3}). Based on these modifications the total number of processes in the extended model were increased to 11 (from 8 in ASM1). Table 1 presents the processes rate equations of the extended model.

Different processes were assigned to the growth of heterotrophic microorganisms (X_{BH}) with nitrite-nitrogen and nitrate-nitrogen as the electron acceptor (processes 2-3). Accordingly, different rate equations were used of the growth and decay of X_{AOB} and X_{NOB}.

In order to account for the possible inhibition of free ammonia-nitrogen (S_{NH3}) on the growth of AOBs and NOBs, a simple inhibition model based on the concentration of S_{NH3} was used. The calculation of pH was not included in the model explicitly, but the fate of alkalinity was calculated and a switching factor for alkalinity was adopted in the model in order to account for the effect of low alkalinity to the growth of all type of microorganisms (Table 1).

Appropriate values for the kinetic and stoichiometric parameters of the model were adopted based on values reported in literature and through calibration with the results of pilot-scale experiments. Application of the extended model was performed for the simulation of a pilot-scale unit used for the treatment of sludge liquors originating from a wastewater treatment plant.

The pilot-scale unit consisted of a sequential batch reactor tank (SBR) with a total effective volume of 2.8 m^3, a pH adjustment unit and an external carbon source dosing unit. According to the operational data the feeding of easily degradable organic carbon source (i.e. acetic acid) was taking place during the first 5 min of the anoxic phase in each cycle at a feeding rate of 2 kgCOD/kgNO_2-N (Frison et al., 2014). Average COD and total nitrogen concentrations in the sludge reject water were equal to 140 mg/L and 640 mg/L respectively.

3. RESULTS AND DISCUSSION

The extended ASM1 model, after being calibrated, was initially applied for validation. Based on its first application with the aforementioned conditions, effluent ammonia-nitrogen and nitrite-nitrogen concentrations were equal to 157 mg/L and 54 mg/L respectively, values which were very close to the experimental ones (165 mg/L and 50 mg/L respectively). Following validation, a series of applications of the extended model took place in order to assess the effect of several operating parameters on system's performance. Two of these applications were related to the assessment of the effect of the number of cycles of SBR and of the volumetric nitrogen loading rate (vNLR) on the system's performance. Indicative results from these applications are presented in Figures 1-2. Figure 1 illustrates the dependence of effluent ammonia-nitrogen and nitrite-nitrogen concentration on the vNLR, whereas Figure 2 presents the effect of different number of operating cycles on the effluent nitrite and ammonia nitrogen concentration.

Table 1. Processes rate equations of the modified ASM1.

j	Process	Process rate equation ρj
1	Aerobic growth of heterotrophs	$\mu_H \frac{S_S}{K_S + S_S} \frac{S_O}{K_{OH} + S_O} \frac{S_{ALK,H}}{K_{ALK,H} + S_{ALK,H}} X_{BH}$
2	Anoxic growth of heterotrophs on S_{NO2}	$\mu_H \frac{S_S}{K_S + S_S} \frac{K_{OH}}{K_{OH} + S_O} \frac{S_{NO3}}{K_{NO3} + S_{NO2}} \frac{S_{NO3}}{S_{NO2} + S_{NO3}} \frac{S_{ALK}}{K_{ALK,H} + S_{ALK}} X_{BH} \cdot ng_1$
3	Anoxic growth of heterotrophs on S_{NO3}	$\mu_H \frac{S_S}{K_S + S_S} \frac{K_{OH}}{K_{OH} + S_O} \frac{S_{NO3}}{K_{NO3} + S_{NO2}} \frac{S_{NO3}}{S_{NO2} + S_{NO3}} \frac{S_{ALK}}{K_{ALK,H} + S_{ALK}} X_{BH} \cdot ng_2$
4	Aerobic growth of AOBs	$\mu_{AOB} \frac{S_{NH}}{K_{NH} + S_{NH}} \frac{S_O}{K_{OA,AOB} + S_O} \frac{K_{i,NH3,AOB}}{K_{i,NH3,AOB} + S_{NH3}} \frac{S_{ALK}}{K_{ALK,AOB} + S_{ALK}} X_{AOB}$
5	Aerobic growth of NOBs	$\mu_{NOB} \frac{S_{NO2}}{K_{NO2,NOB} + S_{NO2}} \frac{S_O}{K_{OA,NOB} + S_O} \frac{K_{i,NH3,NOB}}{K_{i,NH3,NOB} + S_{NH3}} \frac{S_{ALK}}{K_{ALK,NOB} + S_{ALK}} X_{NOB}$
6	Decay of heterotrophs	$b_H X_{BH}$
7	Decay of AOBs	$b_{AOB} X_{AOB}$
8	Decay of NOBs	$b_{NOB} X_{NOB}$
9	Ammonification of soluble organic nitrogen	$K_A S_{ND} X_{BH}$
10	Hydrolysis of entrapped organics	$K_H \frac{X_S / X_{BH}}{K_X + X_S / X_{BH}} \left[\frac{S_O}{K_{OH} + S_O} + n_H \frac{K_{OH}}{K_{OH} + S_O} \frac{S_{NO2} + S_{NO3}}{K_{NO} + S_{NO2} + S_{NO3}} \right] X_{BH}$
11	Hydrolysis of entrapped organic nitrogen	$\rho_{10} \left(\frac{X_{ND}}{X_S} \right)$

The model's results show that for vNLR less than 0.50 KgN/m^3d for SRT equal to 10 d and 0.75 KgN/m^3d for SRTs in between 1-20 d, almost complete nitritation can be achieved with nitrite effluent concentration ranging between 15-85 mgN/L (depending upon solids retention time (SRT) of the system and the exact value of the vNLR). On the other hand for vNLR greater than 0.9 KgN/m^3d for a SRT of 10 d and 1.4 KgN/m^3d for SRTs between 15-20 d, nitritation deteriorates significantly. Furthermore, the number of operating cycles greatly affects the quality of the final effluent along with the oxygen and organic carbon demand of the system. More operating cycles (up to 4/day) lead in an improvement of the final effluent with higher nitritation and denitritation rates, while at the same time they increase the oxygen and organic carbon demand of the system

(35% increase of organic carbon demand and 6% increase in oxygen demand between 1 and 4 operating cycles). This increase is reasonable since more nitrogen load is nitrified (i.e. oxygen requirement) and denitrified (i.e. carbon source demand).

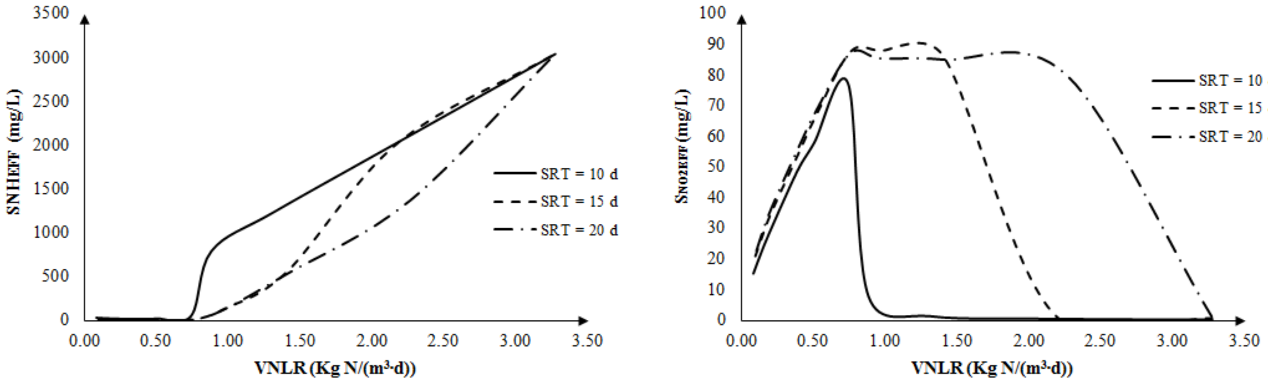

Figure 1 Dependence of the treated effluent ammonia-nitrogen and nitrite-nitrogen concentration with respect to the vNLR for different SRTs

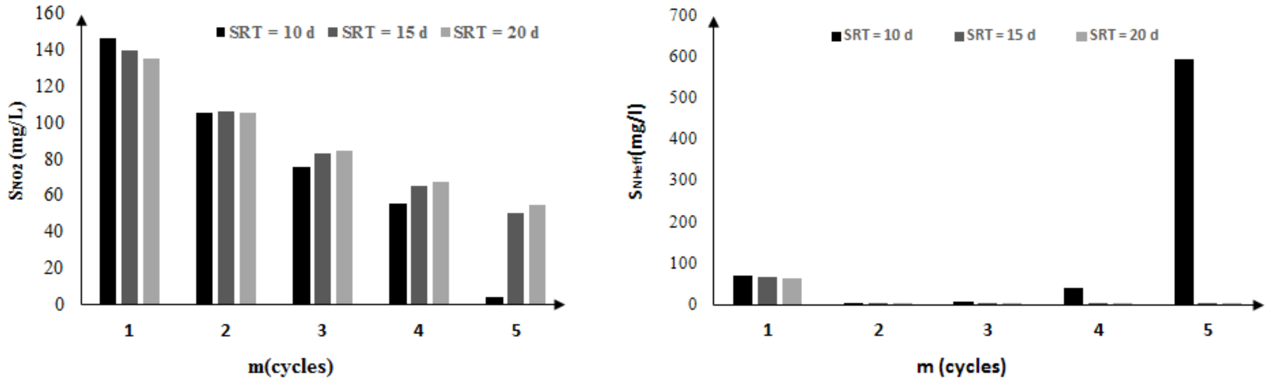

Figure 2 Dependence of effluent nitrite-nitrogen and ammonia-nitrogen concentration on the number of operational cycles of SBR

4. CONCLUSIONS

The objective of this study was to develop a mathematical model for the simulation of the operation of a sludge liquors treatment system. ASM1 model was employed after significant modifications to provide for the simulation of nitritation/denitritation processes taking place in a sequencing batch reactor (SBR) treating sludge reject water. The model was validated using real data from a pilot SBR. Based on the results of the mathematical modelling it was found that both the volumetric nitrogen loading rate (vNLR) and the number of cycles critically affected process performance.

Very high nitritation (>90%) was accomplished for vNLR <0.5 KgN/m^{3}d for an SRT of 10 d and 0.75 KgN/m^{3}d for SRTs between 15-20d. When vNLR>0.9 KgN/m^{3}d for an SRT of 10 d and vNLR>1.4KgN/m^{3}d for SRTs between 15-20 d nitritation was practically inhibited. The increase in the number of cycles of the SBR from 1 to 4 significantly improved the denitritation process. However, at 5 cycles and SRT=10 days the nitritation process was inhibited due to the decrease of the duration of the process time.

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