

Technical Report

Comparison of quasisteady-state performance of the DEAMOX process under intermittent and continuous feeding and different nitrogen loading rates

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The recently developed denitrifying ammonium oxidation (DEAMOX) process combines the anammox reaction with autotrophic denitrifying conditions using sulfide as an electron donor for the production of nitrite from nitrate within an anaerobic biofilm. This paper compares a quasisteady-state performance of this process for treatment of baker's yeast wastewater under intermittent and continuous feeding and increasing nitrogen loading rate (NLR) from 300 till 858 mg N/L/d. The average total nitrogen removal slightly decreased on increasing the NLR: from 86 to 79% (intermittent feeding) and from 87 to 84% (continuous feeding). The better performance under continuous feeding was due to a more complete nitrate removal in the former case whereas the ammonia removal was similar for both feeding regimes under the comparable NLR. A possible explanation can be that, during continuous feeding (simultaneous supply of nitrate and sulfide), there were less mass transfer limitations for sulfide oxidizing denitrifiers presumably located in the outer layer of sludge aggregates. On the contrary, the ammonia oxidisers presumably located inside the aggregates apparently suffered from nitrite mass transfer limitations under both the feedings. The paper further describes some characteristics of the DEAMOX sludge.

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1 Introduction

Recently [1], a new biological nitrogen removal process called denitrifying ammonium oxidation (DEAMOX) for treatment of strong nitrogenous wastewater was developed. It combines the anaerobic ammonium oxidation

(anammox) reaction [2–4] with autotrophic denitrifying conditions using sulfide as an electron donor for the production of nitrite from nitrate within an anaerobic biofilm (reactions 3 and 4, Table 1). The concept of the DEAMOX process was experimentally proved [1] using such a strong nitrogenous wastewater as baker's yeast effluent and the laboratory setup consisted of three reactors (Fig. 1) which is briefly described below. To generate sulfide and ammonia, the upflow anaerobic sludge bed (UASB) reactor was used as a pretreatment step (reaction 1, Table 1). The anaerobic effluent thus produced was partially fed to the nitrifying reactor (to generate mainly nitrate, reaction 2, Table 1) and the remaining part was directly fed to the DEAMOX reactor. There both the streams were mixed together for realization of reactions 3 and 4 (Table 1). Stable process performance with a total nitrogen removal above 85% and a volumetric nitrogen loading rate (NLR) of the DEAMOX reactor of about 1000 mg

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Abbreviations: Anammox, anaerobic ammonium oxidation; CM-1S, cultivation medium from the first yeast separation process; COD, chemical oxygen demand; DEAMOX, denitrifying ammonium oxidation; HRT, hydraulic retention time; NLR, nitrogen loading rate; UASB, upflow anaerobic sludge bed (reactor); VFA, volatile fatty acids

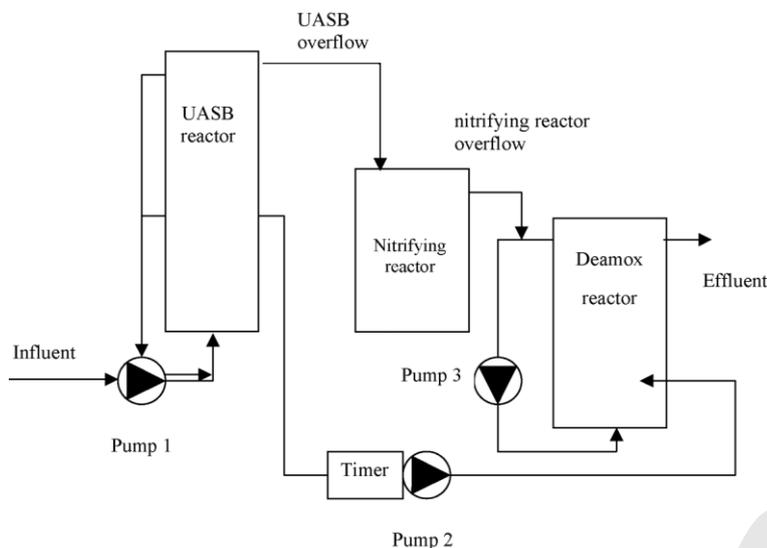


Figure 1. Process flow diagram of the DEAMOX process.

N/L/d were achieved after a long-term (410 days) optimization of the process [1]. It should be noted that these results were obtained under the intermittent (0.5 h for each flow) supply of nitrified and anaerobic effluents to the DEAMOX reactor (for details see Section 2 and Fig. 1). Such a discontinuous feeding regime, resembling the sludge selection/enrichment approach [3], was applied for a better startup of this reactor because the DEAMOX sludge just did not exist as matter before the start of our experiments [1]. Since, after that study [1], such a sludge became available, the objective of the current paper was to compare the quasisteady-state performance of the process for intermittent and continuous supply of nitrified and anaerobic effluents to the DEAMOX reactor under variation of hydraulic retention time (HRT) (and thus NLR) using baker's yeast wastewater as the primary influent to the system. Some characteristics of the DEAMOX sludge are presented as well.

2 Materials and methods

2.1 Wastewater

Baker's yeast wastewater was simulated by tap water dilution of cultivation medium from the first yeast separation process (CM-1S) representing the major and the most concentrated wastewater stream from yeast factories [5]. The variation of some characteristics of CM-1S taken from Moscow baker's yeast factory during the end of 2005 and the first half of 2006 and used in this study are presented below (mg/L, except pH): total chemical oxygen demand (COD) – 20.500–34.020; soluble COD – 17.330–21.500; total N – 1.000–2.861; total P – 12–58; sulfate – 3.050–5.892; pH = 4.6–5.5.

Table 1. Major biochemical conversions involved in the setup of DEAMOX process

Reactor	Schematic reaction
UASB reactor	$\text{N-organics} + \text{SO}_4^{2-} \rightarrow \text{NH}_4^+ + \text{HCO}_3^- + \text{CH}_4 + \text{HS}^-$ (1)
Nitrifying reactor	$\text{NH}_4^+ + \text{O}_2 \rightarrow \text{NO}_3^- + \text{NO}_2^-$ (2)
DEAMOX reactor	$4\text{NO}_3^- + \text{HS}^- \rightarrow 4\text{NO}_2^- + \text{SO}_4^{2-}$ (3)
	$\text{NH}_4^+ + \text{NO}_2^- \rightarrow \text{N}_2 + 2\text{H}_2\text{O}$ (4)

2.2 UASB reactor

The laboratory UASB reactor (rectangular cross-section 54 cm², height 94 cm, total working volume 5.08 L, with recycle) made from transparent plastic material was kept in the thermostat (under 35 ± 1°C), and seeded with the granular sludge (~1.5 L) from the previous study [1].

2.3 Nitrifying activated sludge reactor

As a nitrifying unit, the laboratory activated sludge reactor with internal settler was used. It had rectangular cross-section 283 cm², height 12 cm, and total working volume 3.42–4.35 L (depending on the height of outlet). This reactor was operated under ambient temperature of the laboratory (20 ± 3°C) and was fed by a fraction of the anaerobic effluents from the UASB reactor (~60% flow). Dissolved oxygen (DO) concentration sensor (Datchik, Russia) was inserted in the middle of this reactor for continuous monitoring of this parameter. The DO concentrations were maintained above 4 mg/L throughout the study. The nitrifying sludge from the previous study [1] was used as a seed. The excess of sludge produced was periodically (usually 40–60 mL per 2–3 wk) withdrawn from the reactor.

2.4 DEAMOX reactor

The laboratory upflow reactor (UASB-type, rectangular cross-section 33.1 cm², height 77 cm, total working volume 2.53 L) was used, which was made from transparent plastic material and equipped with an effluent recycle for better mixing (the upflow liquid velocity was maintained at around 15 cm/h). The anaerobic effluents were fed into the bottom of the DEAMOX reactor, while the nitrified effluents were fed to the recirculation line of this reactor. Temperature inside the reactor was controlled around 35 ± 1°C by using a thermostat. The reactor was seeded with the DEAMOX sludge (~1 L) from the previous study [1]. Some characteristics of this sludge (appeared as a flocculent one) at the start of the experiments are presented in Table 2.

Table 2. Some characteristics of the sludge from the DEAMOX reactor (mean ± SD of three assays)

Parameters	Start (day 0)	End (day 151)
TSS, g/L	26.7 ± 1.1	35.5 ± 2.7
VSS, g/L	20.4 ± 0.5	25.7 ± 2.1
VSS/TSS	0.77 ± 0.02	0.72 ± 0.02
Denitrifying activity (sulfide), mg N-NO ₃ /g VSS/d	82 ± 3	107 ± 19
Anammox activity in the DEAMOX conditions (NO ₃ ⁻ + H ₂ S + NH ₄ ⁺), mg N-NH ₄ ⁺ /g VSS/d	19 ± 1	24 ± 2

2.5 Process flow diagram for intermittent and continuous loading of the DEAMOX reactor

A detailed process flow diagram of the process under investigation is given in Fig. 1. Starting points for the design were as follow:

- (i) To run the process with only three pumps and failure free as much as possible.
- (ii) To avoid as much as possible the introduction of oxygen into the DEAMOX reactor, where it might give problems.
- (iii) To realize a discontinuous loaded gradient in the DEAMOX reactor, which was presumed to be essential for running the denitrification process *via* nitrite (*e.g.*, during the startup).

Thus, the UASB reactor was fed with the first feeding pump *via* its first channel, while a recycle was organized *via* its second channel, so the recycle ratio was 1:1. This recycle was taken from a point (~20 cm below the water level) where the potential entrance of oxygen can be excluded. The overflow from the UASB reactor was running by gravity into the nitrifying activated sludge reactor. The second feeding pump was connected to the recycle line from the UASB reactor and was pumping directly into the

bottom of the DEAMOX reactor. For intermittent loading, this pump was connected with the timer which was “on” during 0.5 h and then “off” during 0.5 h. The flow rate of the second pump was set at about 85% of the flow of the influent feed pump of the UASB reactor (in order to fulfil stoichiometric requirements of the DEAMOX process, see below). This means that the nitrifying reactor was loaded also discontinuously but it was not a problem for its performance (see Section 3). Operated like this, a gradient from anaerobic to nitrate/nitrite containing water was realized in the DEAMOX reactor; furthermore, this gradient was loaded discontinuously. For continuous loading, the timer was removed and the flow rate of the second pump was set at about 40% of the flow of the influent feed pump of the UASB reactor. The overflow from the nitrifying reactor was flowing by gravity into the recycle pump of the DEAMOX reactor for both the feeding regimes investigated.

2.6 Sludge characteristics

Assessment of the DEAMOX sludge specific activities (denitrifying and anammox) was performed as described previously [1]. Electronic scanning microscopy of granules was carried out as described elsewhere [6].

2.7 Analyses

All the analyses were performed by standard methods [7] or as described previously [1, 6]. All the gas measurements were recalculated at 1 atm and 0°C. Statistical analysis of data was performed using Microsoft Excel.

3 Results and discussion

3.1 Performance of the UASB reactor

Taking into account an auxiliary role of this reactor, only the most important data on its functioning throughout an entire period of this experimentation (151 days) are discussed here. In short, this mineralization reactor demonstrated a stable performance in the range of the COD loading rates applied (3.9–9.5 g COD_{tot}/L/d) giving the average total COD removal of 71 ± 2% (including sulfide produced) and almost complete conversion of sulfate into sulfide (99 ± 1%) by the accompanying process of biological sulfate reduction. The volatile fatty acid (VFA) concentrations were negligible (<15 mg COD/L) in the UASB effluents where sulfide represented a major part (>90%) of easily biodegradable biological oxygen demand (BOD). The remaining COD (after subtraction of sulfide and VFA) was hardly biodegradable that is typical for baker's yeast wastewater due to the presence of melanoidins, *etc.* [8]. Generally, the reactor produced the effluents with ammonia and sulfide concentrations of 222 ± 14 mg N/L and

264 ± 14 mg S/L, respectively. Thus, the S/N ratio in these effluents (~1.19 mg S/mg N) was more than sufficient to fulfil denitrification requirements for the DEAMOX process (reaction 3, Table 1), i.e., ~1.5 times higher than the balance required (0.79 mg S/mg N under 58:42 split of anaerobic effluent between the nitrifying and the DEAMOX reactor). The excess of sulfide was also useful for ensuring anaerobic conditions in the DEAMOX reactor under occasional oxygen penetrations sometimes happening in laboratory scale reactors.

3.2 Performance of the nitrifying reactor

Since this reactor also played an auxiliary role in this research, its performance data are summarized as follows. The activated sludge reactor also functioned without problems throughout an entire study showing near 100% ammonia conversion efficiency under the ammonia loading rates of 111–350 mg N/L/d with nitrate as a prevailing product over nitrite. Besides nitrification, some additional total COD removal (41 ± 2%, data not shown) occurred there mainly due to complete oxidation of sulfide and VFA traces (data not shown). The remaining COD

(0.85–1.05 g/L) was quite recalcitrant in both anaerobic and aerobic conditions [8].

3.3 Quasisteady-state performance of DEAMOX reactor

Since a true steady state is practically impossible to reach for reactors with high sludge retention times (like in our case), the quasisteady-state conditions were assumed (and the collection of data started) after passing of at least five reactor volumes of feed through the DEAMOX reactor after each changing of operational regime.

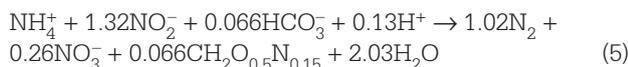
3.3.1 Intermittent supply of nitrified and anaerobic effluents

The quasisteady-state data for the performance of the DEAMOX reactor fed in this regime are generalized in Table 3. It is seen that, in spite of decrease of the HRT from 0.67 to 0.27 days, and, hence, increase of the NLR from 300 to 748 mg N/L/d, the reactor demonstrated only a slight trend in deterioration of its performance: the average ammonia, nitrate, and total inorganic nitrogen removals (nitrite was completely consumed) decreased by only a few percents to 72, 83, and 79%, respectively (Table 3). As a result, the average ammonia and nitrate con-

Table 3. Quasisteady-state data of the DEAMOX reactor performance under the intermittent supply of nitrifying and anaerobic effluents (mean ± SD)

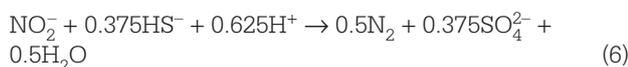
HRT (days)	0.65	0.51	0.36	0.27
Sampling period, days	20	18	12	6
Number of samples analyzed	7	7	6	5
% of anaerobic effluent fed	42.3 ± 1.6	42.7 ± 0.7	42.5 ± 0.0	40.7 ± 1.0
Influent pH	~8.0	~8.0	~8.0	~8.0
Effluent pH	8.29 ± 0.10	8.22 ± 0.06	8.18 ± 0.04	8.18 ± 0.06
Influent total COD, g/L	1.09 ± 0.03	1.11 ± 0.02	1.19 ± 0.02	1.3 ± 0.08
COD loading rate, g COD _{tot} /L/d	1.67 ± 0.05	2.17 ± 0.05	3.26 ± 0.05	4.76 ± 0.29
Effluent total COD, g/L	0.77 ± 0.02	0.80 ± 0.02	0.83 ± 0.01	0.93 ± 0.06
Total COD removal, %	29 ± 1	28 ± 2	30 ± 0	29 ± 1
Influent N-NH ₄ ⁺ , mg N/L	85 ± 3	96 ± 4	104 ± 11	94 ± 5
Ammonia loading rate, g N/L/d	132 ± 4	188 ± 7	286 ± 32	343 ± 18
Effluent N-NH ₄ ⁺ , mg N/L	19 ± 2	22 ± 2	23 ± 2	26 ± 3
N-NH ₄ ⁺ removal, %	77 ± 3	77 ± 1	76 ± 2	72 ± 2
Influent N-NO ₂ ⁻ , mg N/L	6 ± 4	10 ± 2	15 ± 7	13 ± 8
Effluent N-NO ₂ ⁻ , mg N/L	~0	~0	~0	~0
N-NO ₂ ⁻ removal, %	100	100	100	100
Influent N-NO ₃ ⁻ , mg N/L	102 ± 4	105 ± 3	103 ± 7	97 ± 8
Effluent N-NO ₃ ⁻ , mg N/L	7 ± 2	12 ± 2	15 ± 5	17 ± 1
N-NO ₃ ⁻ removal, %	93 ± 1	88 ± 2	86 ± 4	83 ± 2
Consumed N-NO _x ⁻ /consumed N-NH ₄ ⁺	1.53 ± 0.03	1.39 ± 0.04	1.33 ± 0.15	1.39 ± 0.04
N _{inorg} loading rate, mg N/L/d	300 ± 14	413 ± 10	588 ± 8	748 ± 22
Total N _{inorg} removal, %	86 ± 1	84 ± 2	83 ± 3	79 ± 1
N _{inorg} removal rate, mg N/L/d	259 ± 14	344 ± 4	477 ± 27	592 ± 16
Influent S-SO ₄ ²⁻ , mg S/L	141 ± 6	127 ± 11	118 ± 2	125 ± 3
Effluent S-SO ₄ ²⁻ , mg S/L	232 ± 8	220 ± 17	203 ± 4	211 ± 1
Influent S-H ₂ S, mg S/L	118 ± 7	114 ± 9	109 ± 2	108 ± 2
Effluent S-H ₂ S, mg S/L	1 ± 1	~0	5 ± 3	1 ± 1
S-H ₂ S recovery as S-SO ₄ ²⁻ , %	78 ± 5	82 ± 4	81 ± 3	79 ± 1
Influent S-H ₂ S/N-NO ₃ ⁻ , mg S/mg N	1.12 ± 0.10	1.11 ± 0.06	1.06 ± 0.09	1.11 ± 0.07

centrations slightly increased to 26 and 17 mg N/L, correspondingly, under the highest NLR applied. The ratio of consumed N-NO_x/consumed N-NH₄ was (except the run with the lowest NLR) in the range of 1.33–1.39 (Table 3), *i.e.*, very close to the stoichiometry of metabolic anammox reaction deduced in [3]:



■Eq.5■check Eq nos.■

This observation indicates that almost all nitrogen removal in the system was accomplished through ammonia oxidation and only a minor part through denitrification of nitrite by sulfide (which was present in excess, *e.g.*, the influent S-H₂S/N-NO₃ ratio was >1 mg S/mg N (Table 3) compared to the theoretically required one (0.57 mg S/mg N) according to reaction 3):



■Eq.6■

The last statement is indirectly supported by small pH differences between the effluent and influent (~0.2 U,

Table 3), *i.e.*, they were smaller than those expected under a substantial occurrence of high proton-consuming reaction 6.

The impact of heterotrophic denitrification was marginal due to miserable concentrations of VFA and biorecalcitrant nature of other organic COD [8] entering the DEAMOX reactor. This statement is supported by relatively high effluent COD concentrations leaving this reactor (Tables 3 and 4). Their decrease (~0.3 g/L) was mainly due to consumption of sulfide (1 g S-H₂S is stoichiometrically equal to 2 g COD).

It should be noted that the recovery of sulfide as soluble sulfate in the DEAMOX reactor accounted for ~80% throughout all the NLR applied for both the feeding regimes (Tables 3 and 4). The remaining 20% of sulfide could end up as elementary sulfur (white color precipitation was sometimes observed in the effluent pipe) or sulfide and sulfate precipitates of metals (Fe, Ca, Mg, *etc.*) presented in the baker's yeast wastewater. The latter process is facilitated under pH >8 as observed in our case (Tables 3 and 4).

Thus, in spite of apparent absence of stoichiometric limitations (at least for reaction 3), the removal of ammo-

Table 4. Quasisteady-state data of the DEAMOX reactor performance under the continuous (simultaneous) supply of nitrifying and anaerobic effluents (mean ± SD)

HRT (days)	0.64	0.53	0.34	0.27
Sampling period, days	11	5	13	8
Number of samples analyzed	5	5	7	6
% of anaerobic effluent	40.9 ± 1.7	40.5 ± 0	40.3 ± 1.3	38.3 ± 1.6
Influent pH	~8.0	~8.0	~8.0	~8.0
Effluent pH	8.23 ± 0.09	8.21 ± 0.12	8.17 ± 0.11	8.23 ± 0.09
Influent total COD, g/L	1.13 ± 0.02	1.14 ± 0.02	1.20 ± 0.03	1.22 ± 0.02
COD loading rate, g COD _{tot} /L/d	1.76 ± 0.04	2.15 ± 0.04	3.51 ± 0.39	4.44 ± 0.08
Effluent total COD, g/L	0.80 ± 0.01	0.83 ± 0.01	0.87 ± 0.03	0.89 ± 0.01
Total COD removal, %	29 ± 1	27 ± 0	27 ± 1	27 ± 1
Influent N-NH ₄ ⁺ , mg N/L	93 ± 5	89 ± 1	95 ± 6	114 ± 6
Ammonia loading rate, g N/L/d	145 ± 8	169 ± 2	280 ± 37	415 ± 21
Effluent N-NH ₄ ⁺ , mg N/L	21 ± 4	20 ± 4	22 ± 3	34 ± 5
N-NH ₄ ⁺ removal, %	77 ± 3	77 ± 5	76 ± 2	71 ± 3
Influent N-NO ₂ ⁻ , mg N/L	8 ± 9	10 ± 7	10 ± 5	27 ± 12
Effluent N-NO ₂ ⁻ , mg N/L	~0	~0	~0	~0
N-NO ₂ ⁻ removal, %	100	100	100	100
Influent N-NO ₃ ⁻ , mg N/L	103 ± 11	104 ± 8	102 ± 6	95 ± 17
Effluent N-NO ₃ ⁻ , mg N/L	5 ± 6	10 ± 3	8 ± 4	5 ± 6
N-NO ₃ ⁻ removal, %	96 ± 6	91 ± 2	93 ± 4	96 ± 5
Consumed N-NO _x ⁻ /consumed N-NH ₄ ⁺	1.51 ± 0.03	1.52 ± 0.14	1.45 ± 0.04	1.46 ± 0.02
N _{inorg} loading rate, mg N/L/d	318 ± 5	384 ± 5	611 ± 76	858 ± 22
Total N _{inorg} removal, %	87 ± 2	85 ± 1	86 ± 2	84 ± 2
N _{inorg} removal rate, mg N/L/d	275 ± 7	328 ± 7	522 ± 59	719 ± 14
Influent S-SO ₄ ²⁻ , mg S/L	118 ± 5	125 ± 1	119 ± 5	132 ± 3
Effluent S-SO ₄ ²⁻ , mg S/L	203 ± 1	207 ± 1	203 ± 3	215 ± 6
Influent S-H ₂ S, mg S/L	105 ± 5	101 ± 2	101 ± 2	103 ± 4
Effluent S-H ₂ S, mg S/L	2 ± 1	2 ± 1	0	0
S-H ₂ S recovery as S-SO ₄ ²⁻ , %	80 ± 1	84 ± 1	84 ± 1	80 ± 5
Influent S-H ₂ S/N-NO ₃ ⁻ , mg S/mg N	1.03 ± 0.14	0.92 ± 0.09	0.99 ± 0.07	1.11 ± 0.18

nia and nitrate was incomplete (Table 3). The reasons of this can be related to the intermittent supply of nitrifying and anaerobic effluents to the DEAMOX-reactor as well as to the mass-transfer limitation inside of it. To illustrate this, in the end of run with the HRT of 0.36 days, the detailed monitoring of ammonia and nitrate concentrations in the effluent was performed (Fig. 2). It is seen that, in the end of feeding of either nitrifying (0, 60, 120 min) or anaerobic (30, 90, 150 min) effluents, the increases of concentrations of either nitrate or ammonia, respectively, were observed. This means that the DEAMOX sludge was unable to fully accommodate such a variable feeding pattern. An absence of electron donor limitations was further revealed during a stop of feeding starting from 150 min (Fig. 2). It is seen that, during the subsequent 120 min, the sludge was able to decrease the nitrate and (partially) ammonia concentrations in the unfed reactor. Thus, apparently, there were some mass-transfer limitations for the flocculent DEAMOX sludge in the running reactor under the bulk nitrogen species concentrations around 20 mg N/L. Similar mass transfer limitations were documented, for example, for flocculent methanogenic sludges [9, 10].

3.3.2 Continuous supply of nitrified and anaerobic effluents

The quasisteady-state data for the performance of the DEAMOX reactor fed continuously are generalized in Table 4. It is seen that, similar to the intermittent feeding, the decrease of HRT from 0.64 to 0.27 days (accompanied by increase of the NLR from 318 to 858 mg N/L/d) led to only a slight decrease of the average ammonia and total inorganic nitrogen removals, whereas the average removal of nitrate and nitrite was almost unaffected (Table 3). However, generally the continuous (simultaneous) supply of anaerobic and nitrifying effluents to the DEAMOX reactor seems to be slightly better than the intermittent one in terms of average total nitrogen removal (Fig. 3). This was due to a more complete nitrate removal in the former case whereas the ammonia removal was similar for both the feeding regimes applied under the comparable NLR (Fig. 3). These data correlate with the in-

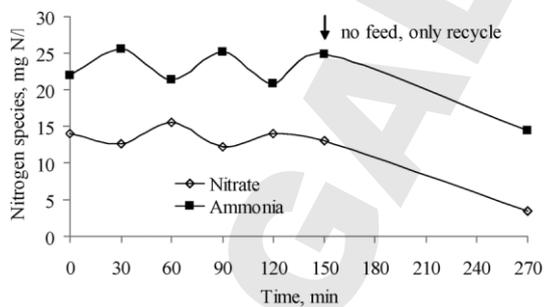


Figure 2. Concentration of nitrogen species in the DEAMOX effluent during the special monitoring period at the end of run with the HRT of 0.36 days. End of feeding by nitrifying effluent – 0, 60, 120 min; end of feeding of anaerobic effluent – 30, 90, 150 min; starting from 150 min, all feeding stopped – only mixing by recycle.

creased ratio of consumed $\text{N-NO}_x/\text{consumed N-NH}_4$ accounting for 1.45–1.51 under continuous feeding (Table 4), i.e., somewhat higher than in the previous regime (Table 3), witnessing, in turn, about a higher extent of realization of reaction 6. The possible explanation can be that, during the simultaneous supply of the anaerobic and nitrified effluents to the DEAMOX reactor, there were less mass transfer limitations for either nitrate or sulfide around the sludge aggregates. However, this was not a case for anammox reaction apparently suffering from nitrite mass transfer limitations. This is also seen from Fig. 2 when the consumption of ammonia was incomplete after the stop of feeding. Such a pattern can be explained by the formation of joint aggregates with the outer layers of sulfide oxidizing denitrifiers and the inner layers of anaerobic ammonia oxidisers. A close location of these bacterial groups with interspecies transfer of nitrite was shown for marine sediments [11]. The similar aggregate structure was found in the environments with a limited oxygen supply, where anammox bacteria were surrounded by aerobic ammonium oxidizers [12–14]. Thus, the anammox bacteria presumably located inside the aggregates probably not always could outcompete the denitrifiers for nitrite, especially under the negligible concentrations of the latter, as it was observed for both the feeding regimes (Tables 3 and 4).

3.3 Some characteristics of the DEAMOX sludge

The determination of specific denitrifying and anammox activity of the DEAMOX sludge performed at the end of study showed their 26–30% increase compared to the start (Table 2). It is likely that the steady state operation of the reactor further enhances a selection of key bacterial populations in the system. The overall content of VSS in the reactor increased by 26% while that of TSS by 33% resulting in some decrease of VSS/TSS ratio of the sludge till 0.72 (Table 2). This fact supports our supposition (revealed

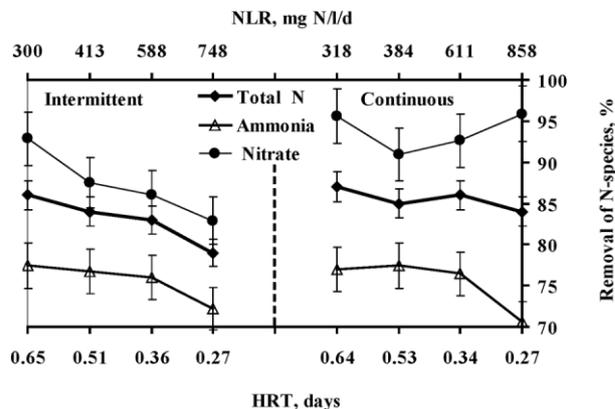


Figure 3. The average removal of nitrogen species by the DEAMOX reactor in quasisteady-state conditions under the intermittent and continuous supply of nitrifying and anaerobic effluents and variation of HRT (NLR).

from material balances of soluble sulfur species) about a precipitation of some sulfates and sulfides as well as elementary sulfur in the reactor.

4 Concluding remarks

Thus, the results described above show that the continuous supply of anaerobic and nitrifying effluents to the DEAMOX reactor seems to be better than the intermittent one in terms of total nitrogen removal (Fig. 3). Some enhancement of the latter parameter was due to a more complete nitrate removal under continuous feeding, whereas the ammonia removal was similar for both the feeding regimes applied under the comparable NLR (Fig. 3). A possible explanation of these observations can be related with the structure of sludge aggregates which are presumably formed with the outer layers of sulfide oxidizing denitrifiers and the inner layers of anaerobic ammonia oxidisers. Thus, during continuous feeding (simultaneous supply of nitrate and sulfide), there were less mass transfer limitations for denitrification. In contrast, ammonia oxidation presumably occurring inside the aggregates apparently suffered from nitrite mass transfer limitations under both the feeding regimes. Future research has to disclose the real reason(s).

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5 References

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