LABORATORY-SCALE STUDY ON TREATMENT OF HIGH-STRENGTH AMMONIUM WASTEWATER

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ABSTRACT
The paper presents evaluation of biological nitrogen conversions during deammonification process studied in the laboratory-scale pilot plant. The control of different parameters (pH, temperature, dissolved oxygen and conductivity) and analysis of nitrogen compounds (ammonium, nitrite and nitrate nitrogen) were executed in two reactors of pilot plant over the operational period of three months. The laboratory-scale studies focused on the mechanisms controlling the deammonification process performance. Supernatant from dewatering of digested sludge taken from Bromma Wastewater Treatment Plant (WWTP) was used as a substrate for the process and was pumped to the system continuously. Kaldnes rings were carriers on which the biofilm microorganisms were growing. Experiment on the influence of increase in ammonium surface load was planned and conducted. The experiment was performed with the stepwise increasing influent ammonium nitrogen concentration from 230, through 280, 330 to 380 mg NH_4-N/l. Nitrogen removal efficiency in reactor 1 was dropping during the experiment from 54% to 21% (as average values) for the periods with influent ammonium nitrogen concentration of 230 mg NH_4-N/l and 330 mg NH_4-N/l, respectively. Average ammonium surface load (ASL) for these periods was equal to 1.16 g NH_4-N/m^2·d and 1.42 g NH_4-N/m^2·d. At the influent ammonium nitrogen concentration of 330 mg NH_4-N/l ASL to reactor 2 (0.98 g NH_4-N/m^2·d) was doubled comparing to the initial value and coincided with highest average efficiency of the process in reactor 2 (46%). The pilot plant was operated in a stable way and gave 70% of overall nitrogen removal as an average value for the whole experimental period with maximum value of 92%.

KEYWORDS
ammonium surface load (ASL), Anammox, deammonification, high-strength ammonium wastewater, nitritation, supernatant from digested sludge

INTRODUCTION

Wastewater effluents are commonly discharged into a recipient that has a subsequent municipal, commercial and recreational use. The presence of inorganic forms of nitrogen may have adverse effects on these uses. In sludge digestion process ammonium nitrogen is not removed and therefore dewatering of digested sludge generally yields an ammonium nitrogen rich effluent (supernatant) with low content of biodegradable organic compounds. This effluent is usually fed to the inlet of wastewater treatment plant (WWTP). Treatment of supernatant is often considered as solution for decreasing the nitrogen load to the WWTP.

A range of new technologies for handling of nitrogen rich wastewater, often with low content of biodegradable organic material, has been recently proposed and investigated by research groups in many countries (Hellinga et al., 1998; Helmer et al., 2000, 1999, 1998; Hippen et al., 2000; Jetten et

al., 2002; Mulder et al., 1995; Siegrist et al., 1998; van de Graaf et al., 1995). In order to make use of Anammox process in the wastewater technology a preliminary nitritation stage is needed (van Dongen et al., 2001). It was named SHARON (Mulder and van Kempen, 1997) and was followed by the Anammox conversion in the separate reactor. To go further, results from investigations both in technical and semi-industrial scale as well as detailed analysis (Helmer et al., 2000, 1999) indicate that at low oxygen concentrations ammonium nitrogen can be eliminated even in one reactor when biofilm technology is used. That process was patented (Van Loosdrecht and Jetten 1997; Dijkman and Strous 1999) and named CANON (Completely Autotrophic N-removal Over Nitrite). CANON refers to the way the two groups of bacteria interact performing two sequential reactions simultaneously. Moreover, Laboratory of Microbial Ecology (Gent, Belgium) proposed one-step process of oxidative-reductive nitrogen removal carried out by straightforwardly enriched autotrophic nitrifiers as biocatalysts and without addition of COD. It was called Oxygen Limited Autotrophic Nitrification Denitrification (OLAND). This process is not yet fully understood and the ammonium loading rates are low. It seems possible that OLAND will be based on the CANON concept (a combination of aerobic and anaerobic ammonia oxidizers). Presented possibilities were researched and initially were considered under the term "aerobic deammonification" (Hippen et al., 2001). To be exact, "aerobic/anoxic deammonification" is a combination of preceding nitritation and succeeding oxidation of the remaining ammonium nitrogen with nitrite as electron acceptor to give gaseous nitrogen (Helmer et al., 1998, 1999).

New process options of the new nitrogen removal systems are compared in Table 1 to a conventional nitrogen removal system based on autotrophic nitrification and heterotrophic denitrification (Jetten et al., 2002; Schmidt et al., 2003; Verstraete et al., 1998).

Most of the reported experiments with deammonification process (Table 2) were run with ammonium surface load (ASL) in the range 4-5 g NH_4-N/m^2·d (Seyfried et al., 2001).

Mathematical model to evaluate the influence of ASL and temperature on a fully autotrophic N-removal process (CANON) in an aerated biofilm reactor was used by Hao et al. (2002). ASL was associated with the biofilm thickness. Simulations with different ASL (0.25-4 g NH_4-N/m^2·d) were run at a constant temperature of 20^0C and a fixed biofilm depth of 0.7 mm. It was proved that a thin biofilm has a limited capacity for the activity of the Anammox process. At a defined biofilm thickness a lower temperature needs a lower ASL and a lower DO for an efficient nitrogen removal. On the other hand, at the defined ASL, a lower temperature needs a thicker biofilm and a higher DO to maintain the nitrogen removal efficiency at a high level.

Evidently, lowering the ASL largely benefits nitrogen removal, since smaller amount of ammonium nitrogen needs to be eliminated. However, it is difficult to properly control very low DO level in large-scale reactors. If the oxygen variations are small, i.e. ±0.2 mg O_2/l, and remain around the optimal set point, there is no significant influence on the process performance. A variable diurnal ammonium load has more negative influence on the process performance, at both a constant and a variable DO level profile caused by changes in ASL. If in practice it is feasible to control the DO exactly on the requirement of the momentary ammonium load, this might lead to relative high nitrogen removal efficiency along with the variable ASL. For practical full-scale applications careful control of dissolved oxygen along with a variable ammonium load is obligatory to obtain high nitrogen removal efficiency.

Table 1. Qualitative and quantitative comparison of several processes of nitrogen removal technology (*Schmidt et al., 2003)

SYSTEM	Conventional nitrification/ denitrification	Sharon	Anammox	CANON	OLAND	Aerobic deammonification
Number of reactors	2	1	1	1	1	1
Discharge	NO_3^-, N_2O, N_2	NH_4^+, NO_2^-	N_2, NO_3^-	N_2, NO_3^-	N_2	N_2, NO_3^-
Conditions	Oxic; anoxic	Oxic	Anoxic	Oxygen limited	Oxygen limited	Oxygen limited
Oxygen requirement	High	Low	None	Low	Low	Low
pH control	Yes	None	None	None	None	None
Biomass retention	None	None	Yes	Yes	Yes	Yes
COD requirement	Yes	None	None	None	None	None
Sludge production	High	Low	Low	Low	Low	Low
NH_4^+ loading* (kg N m^{-3} day^{-1})	2-8	0.5-1.5	10-20	2-3	0.1	1-2
N-removal efficiency* (%)	95	90	90	90	85	60
Biofilms or suspension	Biofilms /suspension	Suspension	Biofilms	Biofilms	Biofilms	Biofilms
Bacteria	NH_4^+ and NO_2^- oxidizers, Various heterotrophs	Aerobic NH_4^+ oxidizers, N.eutropha	Planctomycetes, Aerobic NH_4^+ oxidizers: B.anammoxidans, K.stuttgartiensis	Aerobic NH_4^+ oxidizers, Planctomycetes	Autotrophic nitrifiers	Unknown salt tolerant ammonia oxidizers, anaerobic ammonia oxidizers K.stuttgartiensis
Process complexity	Separate oxic and anoxic compartments or periods, methanol dosing	Separate oxic and anoxic compartments or periods, methanol dosing	Preceding partial nitrification/ nitritation needed	Aeration needs to be tuned to ammonia loading	Aeration needs to be tuned to ammonia loading	Ammonia needs to be tuned to ammonia loading
Application status	Established	Two full-scale plants	Full scale initiated	Laboratory	Laboratory	Two full-scale plants
Investment costs	Medium	Medium	Low	Medium	Medium	Medium
Operational costs	High	Low	Very low	Low	Unknown	Low

Table 2. Survey of various nitrogen removal systems operating on different ASL

System	Source of ammonium	ASL (g NH_4-N/m^2·d)	Reference
Rotating biological contractor	Leachate	1.4 – 3.2	Siegrist et al. 1998
Moving-bed pilot plant	Supernatant	7.8 – 11.9	Helmer et al. 2001
Moving-bed pilot plant	Supernatant	4 -8	Seyfried et al. 2001
Laboratory-scale pilot plant	Supernatant	4.7 – 4.9	Hippen et al. 2001
Laboratory-scale pilot plant	Supernatant	4.6	Beier et al. 1998

MATERIALS AND METHODS

Design and operation of the laboratory-scale pilot plant

The laboratory-scale pilot plant studies were carried out during a 3-month period at the Department of Land and Water Resources Engineering, Royal Institute of Technology (KTH), Stockholm, Sweden. The laboratory-scale pilot plant consisted of two reactors. As biofilm carriers Kaldnes rings were used. There was a stable culture used during experiment. The stirrers assured both mixing in the reactors and avoidance of sedimentation. In addition, the temperature was maintained stable in both reactors thanks to the thermostats. The pH was corrected with a continuous dosage of Na_2CO_3 solution to the first reactor. There was also peristaltic pump that was pumping supernatant from a container to the first reactor. Wastewater was flowing into second reactor and then to the outlet container by gravity. Pilot plant was earlier described in Plaza et al. (2003) and Szatkowska et al. (2003).

The operation of laboratory-scale pilot plant consisted in observation and control of values of temperature, pH, dissolved oxygen (DO) concentration and conductivity. The parameters describing laboratory-scale pilot plant are shown in Table 3.

Table 3. Design and operational parameters of laboratory-scale pilot plant

Parameter	R1	R2
Volume (dm^3)	8	7.5
Influent flow rate (l/d)	4.0	4.0
HRT (days)	1.6	1.5
Influent NH_4-N concentration (mg/l)	224 - 480	71 - 295
Kaldnes filling (%)	20	20
DO concentration* (mg O_2/l)	0.46 ± 0.27	0.35 ± 0.21
pH* (-)	8.28 ± 0.13	8.19 ± 0.08
Temperature* (ºC)	32.0 ± 0.45	29.8 ± 0.45

* mean ± S.D.

Reactors were continuously supplied with the supernatant from dewatering of digested sludge on centrifuges that was taken from Bromma Wastewater Treatment Plant (WWTP). Bromma WWTP is treating municipal wastewater from central and western part of Stockholm region. Through an increase in the influent ammonium nitrogen concentration required ammonium surface load was obtained (Table 4). Constant flow of wastewater through the system (4 l/d) resulted in stable HRT (3.1 days). At the end of the operational period problems with a pump occurred and consequently the HRT increased.

Table 4. Schedule for increase in influent ammonium nitrogen concentration in the laboratory-scale pilot plant

Period	Dates	Duration (days)	Planned strategy NH_4-N (mg NH_4-N/l)	Average NH_4-N (mg NH_4-N/l)
I	1^{st} – 11^{th} July	11	230	231.1
II	12^{th} July – 6^{th} August	25	280	288.0
III	7^{th} August – 5^{th} September	29	330	320.3
IV	6^{th} – 30^{th} September	24	380	380.5

Operational parameters

During operational period weekdays measurements of parameters were executed. These parameters were: temperature, pH value, dissolved oxygen concentration and conductivity value. The conductivity measurements were introduced in the middle of the operational period and were conducted using Conductivity Meter model 115 ORION in both reactors and in the inlet and outlet containers. The temperature was measured directly using an electrical thermometer in both reactors. The pH was kept within optimal range due to measurements made by a pH-meter Orion model 210A. The dissolved oxygen concentration was measured with DO-meter ATI Russell, model RL 425, based on polarized and temperature compensated electrodes.

Analytical procedures

Under three months of experimental period samples collected twice a week were analysed for NH_4-N, NO_2-N and NO_3-N concentration using DrLange spectrophotometer Type LPG 378 (method based on Vis-spectrophotometry). The samples of 25 ml each were taken from the inlet and outlets from two reactors (In, Out1 and Out2), filtrated with a 25 mm prefilter and 0,45 μm filter and put into the freezer afterwards. In addition, supernatant from Bromma WWTP was analysed for Chemical Oxygen Demand (COD) with HACH DR/2010 (Vis–spectrophotometry method) and for NH_4-N concentration on the collection day.

RESULTS AND DISCUSSION

Operational parameters

In general, pH fluctuations did not affect the process and pH values were in the optimal range of 8.1-8.3 (Figure 1 and 2). As the pH value was continuously corrected in reactor 1, the pH value in reactor 2 was less variable.

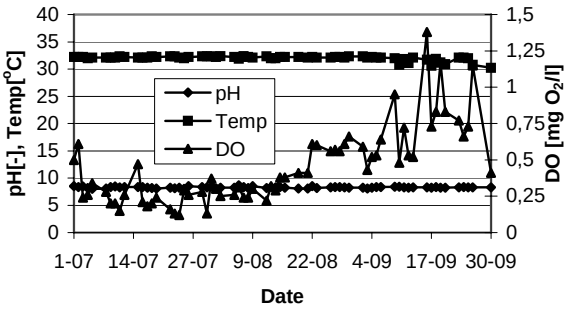

Figure 1. Parameters of pH, temperature and DO in reactor 1

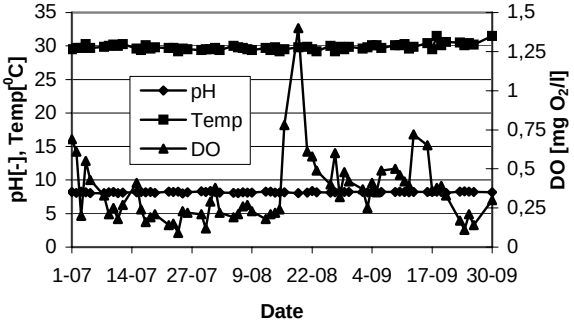

Figure 2. Parameters of pH, temperature and DO in reactor 2

Temperature was the most stable parameter (Figure 1 and 2). Due to usage of thermostats no significant problems in maintenance of the required temperature occurred. Generally, the temperature of the inflowing wastewater from the first reactor affected the temperature in the second reactor. Some decrease of temperature in reactor 1 in the end of the operational period was associated with dissolved oxygen variations and necessity of turning off mixers. The temperature in reactor 2 was changing only to a small degree. Contrary to the temperature parameter, the dissolved oxygen concentration (Figure 1 and 2) appeared to be the most sensitive parameter. Even though it was supposed to be maintained lower than 1 mg O_2/l in reactor 1 and 0.5 mg O_2/l in reactor 2 there were difficulties in holding DO level in an invariable way in both reactors. Higher values of DO in reactor 1 were desirable for proper process performance.

Nitrogen compounds variations

Along with the increase in the influent concentration of ammonium nitrogen to both reactors of the laboratory-scale pilot plant (Figure 3 and 4) the biofilm microorganisms were utilizing higher amount of ammonium nitrogen. Decline in concentration of NH_4-N at the outlet from reactors was observed some time after an increase in ASL. After increasing influent ammonium nitrogen concentration the deammonification process was more reliant on the second reactor.

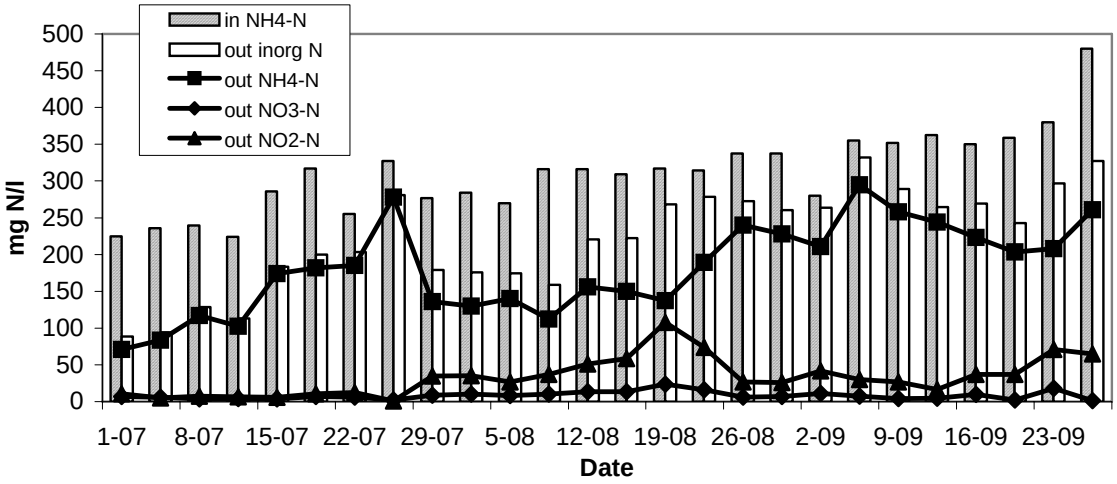

Figure 3. Nitrogen variations in reactor 1

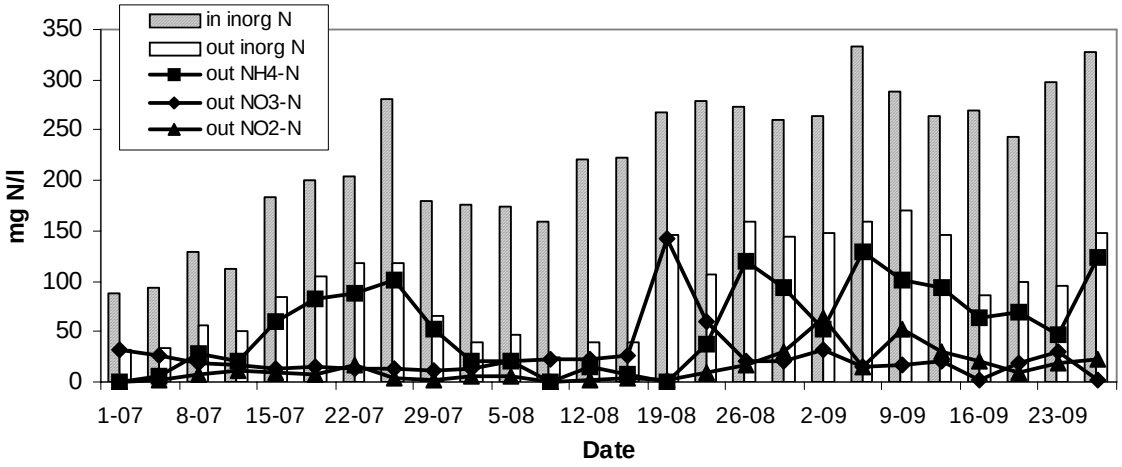

Figure 4. Nitrogen variations in reactor 2

Low values of the effluent nitrite nitrogen concentration in both reactors (Figure 3 and 4) indicate its almost total uptake in the system of reactors. However, much higher amounts of nitrite nitrogen were produced in reactor 1 and therefore bacterial culture in reactor 2 had access to both substrates (NO_2-N and NH_4-N) to perform Anammox process. It was proved that reactor 2 was prepared to handle much higher concentrations of either ammonium or nitrite nitrogen to perform the Anammox process, whereas reactor 1 was switching more into the nitritation process. The more nitrite nitrogen was produced in reactor 1 the highest was efficiency of the system. Such biofilm microorganisms' behaviour in reactor 1 is favourable as long as the process does not result in nitratation. Simultaneous low levels of nitrate nitrogen and decrease in ammonium nitrogen concentration at the outlets indicate that no nitratation occurred and the process of

deammonification was sustained. Moreover, an assumption of parallel nitritation and Anammox processes in reactor 1 can be made. Difficulty in maintaining DO level below 0.5 mg O_2/l was one of the factors that caused peak nitrite nitrogen concentrations in both reactors.

There was regularity in response of the first reactor to increase in influent NH_4-N concentration to 280 and 330 mg NH_4-N/l. Initially, ammonium nitrogen utilization was increasing to some extent. However, later on the NH_4-N removal was dropping and reactor 2 was forced to sustain the deammonification process. Behaviour of bacterial culture in reactor 1 was different when switching to 380 mg NH_4-N/l in the influent. Satisfactory performance of reactor 1 was due to enlarged HRT. Longer HRT enabled bacterial culture to consume a considerable part of influent ammonium nitrogen. At that time utilization of ammonium nitrogen in reactor 2 was kept stable.

Total amount of inorganic nitrogen in the influent was equal to the NH_4-N concentration. Due to predominance of partial nitrification in reactor 1, reactor 2 was receiving liquor that already had three inorganic nitrogen forms: ammonium, nitrite and nitrate nitrogen. The major goal of reduction in total inorganic nitrogen concentration was achieved. The amount of inorganic nitrogen at the outlet from reactor 1 was increased stepwise due to rise in NH_4-N concentration in the influent. As a consequence removal of ammonium nitrogen in reactor 1 decreased.

Evaluation of the results

The operational time was divided into four periods in order to evaluate the results of nitrogen compounds analysis (Table 4 and 5). Low concentrations of nitrate nitrogen at the outlets from both reactors were observed. High NO_2-N concentration was expected at the outlet from reactor 1 due to nitritation process. Such a tendency occurred along with the increase in influent ASL. The efficiency of the deammonification process decreased with increased influent ASL but on average the nitrogen removal efficiency was maintained high (70%). The results of both ammonium removal rate and nitrogen removal rate confirmed the dissimilarities in the process paths in both reactors. In reactor 1 average ammonium removal rate (0.56 g NH_4-N/m^2·d) exceeded the nitrogen removal rate (0.38 g N/m^2·d) as a result of nitritation reaction dominance. The same mean value of ammonium removal rate and nitrogen removal rate (0.58 g NH_4-N or N/m^2·d) in reactor 2 proved that the Anammox process was responsible for ammonium nitrogen removal. ASL results are in agreement with results reported by others (Hao et al., 2002; Siegrist et al., 1998). The ASL curves representing both reactors of the laboratory-scale pilot plant (Figure 5) run parallel for most of the experimental period. The closer the curves run the bigger are discrepancies within the processes and between both reactors. The decline in performance of reactor 1 results in higher ASL in reactor 2. The influent ASL was substantially decreased during the period with influent concentration of 380 mg NH_4-N/l due to doubled HRT.

Generally, an exchange between reactors in carrying on the deammonification process occurred. Initially, reactor 1 was responsible for as much as 60% of overall process efficiency. Along with the increase in ASL reactor 2 turned out to be prepared to remove higher amount of nitrogen compounds with a maximum value amounting to 59% of overall efficiency. During periods of low efficiency of nitrogen removal in reactor 1 the ammonium removal rate in this reactor was maintained high, around 0.5 g NH_4-N/m^2·d. It indicates that reactor 1 was functioning satisfactory despite small contribution to the overall efficiency of the deammonification process. Even though some fluctuations in nitrogen removal efficiency occurred reactor, 2 took over the responsibility for process maintenance until the end of the experimental period.

Table 5. Performance data (mean ± S.D.)

	Period I		Period II		Period III		Period IV		Experiment		
	R1	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**overall**
ASL ($g\ NH_4\text{-}N/m^2 \cdot d$)	1.16 ±0.11	0.50 ±0.09	1.40 ±0.09	0.90 ±0.22	1.42 ±0.25	0.98 ±0.39	1.15 ±0.72	0.75 ±0.48	1.35 ±0.39	0.83 ±0.36	1.35 ±0.39
Ammonium removal rate ($g\ NH_4\text{-}N/m^2 \cdot d$)	0.70 ±0.14	0.43 ±0.03	0.56 ±0.20	0.59 ±0.12	0.59 ±0.29	0.71 ±0.16	0.44 ±0.33	0.47 ±0.24	0.56 ±0.23	0.58 ±0.19	0.57 ±0.16
Nitrogen removal rate ($g\ N/m^2 \cdot d$)	0.63 ±0.13	0.34 ±0.04	0.43 ±0.14	0.61 ±0.12	0.29 ±0.14	0.74 ±0.19	0.30 ±0.23	0.48 ±0.27	0.38 ±0.20	0.58 ±0.22	0.48 ±0.14
N removal Efficiency (%)	54.2 ±7.3	27.4 ±2.5	30.9 ±9.6	40.7 ±8.0	21.0 ±13.8	45.7 ±9.7	25.7 ±5.8	41.6 ±9.0	29.8 ±15.0	40.6 ±10.0	70.4 ±13.3

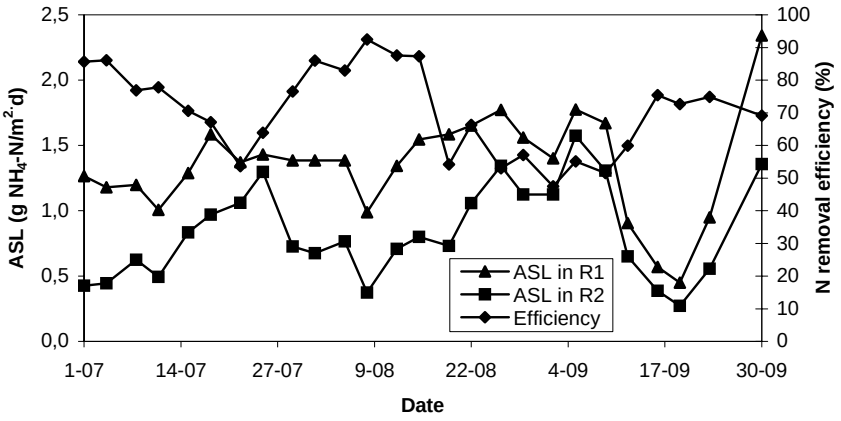

Figure 5. ASL in reactor 1, 2 and nitrogen removal efficiency

Average ASL to reactor 1 from period I to period III was increased by amount of 0.26 g NH_4-$N/m^2 \cdot d$ (Table 5). During that time nitrogen removal efficiency was decreasing in reactor 1 to reach an average 33% drop. Both ammonium removal rate and nitrogen removal rate decreased in reactor 1. However, in reactor 2 increase in ammonium removal rate and nitrogen removal rate was obtained, what corresponded to 18% increase in nitrogen removal efficiency. The highest average ASL (influent 330 mg NH_4-N/l) was calculated in parallel with maximum average nitrogen removal efficiency in reactor 2 (45.7%). To the contrary, in reactor 1 enlarged ASL during period III (average value of 1.42 g NH_4-$N/m^2 \cdot d$) resulted in lower nitrogen removal efficiency (21%).

In Figure 6 the correlation coefficient indicates a relation between overall ammonium removal rate and ASL. The experiment on increase in the influent ammonium nitrogen concentration proved higher capability of the bacterial culture to utilize ammonium nitrogen as a result of processes similar to nitritation/CANON in reactor 1 and Anammox in reactor 2. Focusing on the performance of the deammonification process in the laboratory-scale pilot plant, the overall nitrogen removal rate was plotted with the influent ASL (Figure 7). Due to lower removal of total inorganic nitrogen in the reactor 1 the overall nitrogen removal rate did not strongly depend on the influent ASL.

Removal of total inorganic nitrogen depended more on the NO_2^-/NH_4^+ ratio (it should oscillate around 1.3) in the influent to the reactor 2, what was important for the efficiency of the Anammox process. In general, the system performance was limited by the efficiency of the nitritation process in the reactor 1.

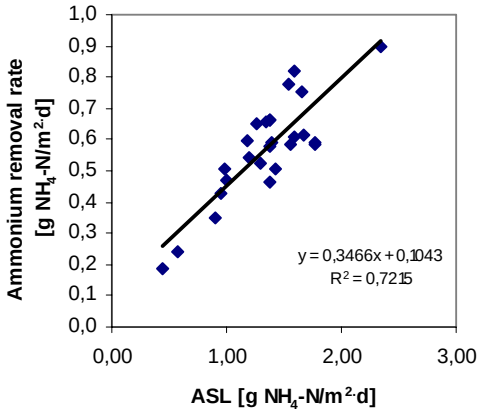

Figure 6. Calculated ammonium removal rate as function of ASL

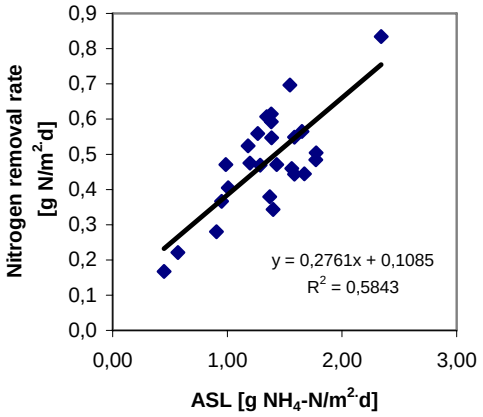

Figure 7. Calculated nitrogen removal rate as function of ASL

CONCLUSIONS

Based on experience from different studies it can be stated that in order to successfully operate the deammonification process low oxygen concentrations (below 0.5 mg O_2/l) in combination with the optimum pH values around 8.2 – 8.3 and temperature of 30ºC are required. Results from performed experiment showed that:

- pH and temperature parameters are easy to maintain. Even if some fluctuations in temperature occurred, it did not influence greatly the process performance.
- dissolved oxygen concentration (average value of 0.46 mg O_2/l in reactor 1 and 0.35 mg O_2/l in reactor 2) was a very sensitive parameter. It was proved that deammonification process is impaired by high DO concentration and its increase was one of the main reasons for the periods of bad performance of the laboratory-scale pilot plant. High dissolved oxygen concentration influence on the deammonification process seemed to be reversible and it caused only transient increase in the nitrate nitrogen concentration. Under oxygen-limited conditions, only 1-10% of the consumed ammonium nitrogen was converted to nitrate nitrogen during nitrification process in reactor 1.

It was possible to obtain long-term and stable nitrogen removal efficiency for the deammonification process. The overall efficiency of the deammonification process was in the range from 47% to 92% with the average of 70% of nitrogen removal. There were considerable discrepancies in the efficiency of the process between both reactors. The average nitrogen removal efficiency in reactor 1 amounted to 29.8% whereas in reactor 2 it was calculated as 40.6%.

The overall process efficiency depended on initial NH_4-N concentration. During the following periods of the experiment average efficiency of nitrogen removal in reactor 2 was gradually increasing whereas in reactor 1 it was decreasing. Increase in the influent ammonium nitrogen concentration from 230 mg NH_4-N/l to 280 mg NH_4-N/l caused an average 10% decrease in overall

nitrogen removal efficiency. When influent NH_4-N concentration of 330 mg NH_4-N/l was introduced the average system efficiency decreased by 15% in comparison to the initial value. Despite higher influent ammonium nitrogen concentration (380 mg NH_4-N/l), the efficiency of the deammonification process did not decrease further due to increased HRT (as a consequence of lower rate of flow).

Due to differences in the performance of both reactors it can be concluded that different reactions are present. Reaction kinetics was evaluated by calculations of ammonium removal rate and nitrogen removal rate for both reactors and for the whole system (0.57 g NH_4-N/m^2·d and 0.48 g N/m^2·d as average overall removal rates). For the periods of secure operation of the laboratory-scale pilot plant during the increase of influent ammonium nitrogen concentration from 230, through 280 to 330 mg NH_4-N/l both rates were dropping in reactor 1 whereas increasing in reactor 2. Higher overall ammonium removal rate (0.56 g NH_4-N/m^2·d) than nitrogen removal rate (0.38 g N/m^2·d) in reactor 1 identify domination of nitritation process in this reactor. Comparable mean values of both rates (0.58 g NH_4-N or N/m^2·d) calculated for reactor 2 proved that the Anammox process was responsible for nitrogen removal. On the other hand, the reaction paths in the first reactor show similarity to the CANON process, where in one reactor partial nitrification and Anammox process occur in parallel. It proves possibility to perform deammonification process even in one single reactor.

In general, system performance was limited by nitritation process efficiency in reactor 1. The system has a high potential for application, when laboratory-scale studies are fulfilled. An extended programme for a proper DO control along with the variable ammonium load is needed.

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