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Nitrogen and Phosphorus Removal from Low Carbon/Nitrogen Wastewater in an Anaerobic/Oxic/Anoxic Process with Endogenous Denitrification at Different DO Concentrations

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Abstract

The effect of selected dissolved oxygen (DO) concentrations (DO ≥ 2 mg l^{-1} and DO ≈ 1 mg l^{-1}) on nitrogen (N) and phosphorus (P) removal was investigated in the treatment of wastewater with a low C/N ratio using an anaerobic/oxic/anoxic (A/O/A) process with endogenous denitrification. The selected DO significantly influenced the efficiency and rate of N removal. The N loss of 43 and 71 %, due to simultaneous nitrification and denitrification in the oxic phase of the A/O/A process, were observed at ≥ 2 mg DO l^{-1} and ≈ 1 mg DO l^{-1}, respectively. The NH_4-N removal rate of 11.2 mg NH_4-N l^{-1} h^{-1} and the PO_4-P uptake rate of 9 mg PO_4-P l^{-1} h^{-1}, and NH_4-N removal rate of 9.4 mg NH_4-N l^{-1} h^{-1} and PO_4-P uptake rate of 9.4 mg PO_4-P l^{-1} h^{-1} at ≥ 2 mg DO l^{-1} and ≈ 1 mg DO l^{-1}, were determined. P removal of 78.5 % and N removal of 76.6 % (in the A/O/A process at DO ≥ 2 mg l^{-1}), and P removal of 77.9 % and N removal of 95.3 % (in the A/O/A process at DO ≈ 1 mg l^{-1}) were achieved.

Keywords

Nitrification, denitrification, phosphorus removal, endogenous denitrification, dissolved oxygen, wastewater with low C/N ratio

1 Introduction

Excessive nitrogen (N) and phosphorus (P) in receiving waters can cause eutrophication, posing potential risks to human health and the environment.[1–5] Strict discharge standards for N and P[6] require the addition of an external carbon source for N removal as well as chemicals for P removal to achieve enhanced N and P removal, which significantly increases wastewater treatment costs.[7–9] Biological nutrient removal (BNR) is the most sustainable and cost-effective approach for N and P removal. Biological N removal is achieved through processes of nitrification, aerobic oxidation of ammonia to nitrate over nitrite by nitrifiers, and denitrification, an anoxic/anaerobic reduction of nitrate with organics as electron donor by denitrifiers.[1,4,5] Biological P removal is mediated by polyphosphate-accumulating organisms (PAOs), which take up and intracellularly store P in the form of polyphosphate (poly-P), under alternating anaerobic and oxic/anoxic conditions in the enhanced biological phosphorus removal (EBPR) process. Under anaerobic conditions, PAOs take up volatile fatty acids (VFA) and store them intracellularly as polyhydroxyalkanoate (PHA) through poly-P hydrolysis and glycogen glycolysis. Under subsequent oxic/anoxic conditions, PAOs oxidise PHA, take up P, restore poly-P reserves, and replenish glycogen reserves. The only difference between aerobic and anoxic PAO metabolism is the electron acceptor: dissolved oxygen (DO) under oxic conditions and nitrate and/or nitrite under anoxic conditions.[2,3,5]

Recent studies have shown that simultaneous nitrification, denitrification, and phosphorus removal (SNDPR) combined with endogenous denitrification (ED) are a promising strategy for nutrient removal with low carbon and energy requirements.[10–15] Simultaneous nitrification, denitrification, and phosphorus removal with endogenous denitrification from wastewater with low C/N ratio, with no external carbon addition, depends on several factors:[11,12,15–17] (i) functional microorganisms, including PAOs, denitrifying phosphorus-accumulating organisms (DPAOs), glycogen-accumulating organisms (GAOs), denitrifying glycogen-accumulating organisms (DGAOs), nitrifiers, denitrifiers); (ii) anaerobic stage duration to ensure the intracellular carbon storage and provide sufficient carbon sources for phosphorus uptake and denitrification, and (iii) oxic stage duration and oxygen concentration to ensure a nitrification, denitrification, phosphorus uptake, and endogenous denitrification.

The aim of this study was to investigate the effect of dissolved oxygen concentration on the efficiency of N and P removal from wastewater with a low C/N ratio in an anaerobic/oxic/anoxic (A/O/A) process with endogenous denitrification, with a focus on potential operational cost savings.

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2 Experimental

2.1 Experiment design

A laboratory-scale sequencing batch reactor (SBR) with a working volume of 6 l, inoculated with sludge enriched with PAOs from a parent SBR reactor, was used to study the effect of DO concentration on N and P removal from low C/N wastewater (C/N $\approx$ 4) in an A/O/A process with endogenous denitrification. The system operated for 30 days for each configuration, with an influent of 30 ± 2 mg NH_4-N l^{-1}, and a mixed liquor suspended solids (MLSS) concentration of 3.0 ± 0.2 g MLSS l^{-1}. During the anaerobic phase (2 h), 2 l of synthetic wastewater was added in the first 10 min. The oxic phase of the process (3 h) was conducted under two DO regimes: $\geq$ 2 mg l^{-1} and $\approx$ 1 mg l^{-1}. This was followed by the anoxic phase (3 h) during which endogenous denitrification occurred. Mixing during the anaerobic and anoxic phases was achieved using a mechanical mixer, while DO in the oxic phase was maintained using an air pump (compressor, HIBLOW HP 40, Germany) with a flowmeter and a stone diffuser positioned at the base of the reactor. The SBR operated at room temperature without pH control or correction. Temperature, DO concentration, and pH value were monitored continuously using a WTW Multi 3420 SET KS1 (pH electrode SenTix 940-3, Germany, and dissolved oxygen electrode WTW FDO 925, Germany). Samples were taken at certain time intervals, filtered through a glass filter (Lab Logistic Group GmbH, Meckenheim, Germany), and an aliquot was used for the analytical determination of chemical oxygen demand (COD), NH_4-N, NO_2-N, NO_3-N, PO_4-P, and total N. Filter paper with precipitates was used for MLSS and PHA determination.

2.1 Synthetic wastewater composition

Synthetic wastewater was prepared by dissolving salts (Merck, Germany) in tap water as follows: 2 g l^{-1} $(NH_4)_2SO_4$; 0.4 g l^{-1} $FeSO_4$; 0.5 g l^{-1} $MgSO_4$; 0.4 g l^{-1} NaCl; 1 g l^{-1} $MgCO_3$; 1 g l^{-1} $CaCO_3$. Sodium acetate and KH_2PO_4 were used as carbon and PO_4-P sources, respectively. In addition, 0.3 ml l^{-1} of trace element solution was added, comprising EDTA 10 g l^{-1}, $FeCl_3$ 1.5 g l^{-1}, H_3BO_3 0.15 g l^{-1}, $CoCl_2 \cdot 7H_2O$ 0.15 g l^{-1}, $CuSO_4 \cdot 5H_2O$ 0.03 g l^{-1}, $MnCl_2 \cdot 4H_2O$ 0.06 g l^{-1}, $Na_2MoO_4 \cdot 2H_2O$ 0.06 g l^{-1}, $ZnSO_4 \cdot 7H_2O$ 0.12 g l^{-1}, KI 0.18 g l^{-1}.

2.2 Analytical methods

MLSS, COD, NH_4-N, NO_3-N, NO_2-N, PO_4-P, and total N were measured according to Standard Methods.[18] PHA was determined based on the method by *A. Oehmen et al.*[19]

3 Results and discussion

The challenge of N and P removal from low C/N wastewater lies in maintaining the activity of functional microorganisms by regulation of the process parameters to ensure the competitiveness of microbial clusters of PAOs, DPAOs, GAOs, DGAOs, ammonia-oxidising bacteria (AOB), and nitrite-oxidising bacteria (NOB).[11,12,15–17] The A/O/A process with endogenous denitrification ensures the intracellular carbon storage during the anaerobic phase, providing carbon sources for phosphorus uptake and denitrification, and in the oxic phase, it ensures phosphorus uptake, nitrification, and denitrification, and/or simultaneous nitrification and denitrification (SND), and endogenous denitrification in the anoxic phase.[11,12,15]

The results of N and P removal from low C/N wastewater in the A/O/A process with endogenous denitrification at different DO concentrations are presented in Fig. 1 ($\geq$ 2 mg DO l^{-1}), and Fig. 2 ($\approx$ 1 mg DO l^{-1}). Each configuration was tested over 30 days. To gain further insight into the microbial processes involved into each phase of the A/O/A process, batch experiments were conducted at day 21 (DO $\geq$ 2 mg l^{-1}, Fig. 3) and at day 24 (DO $\approx$ 1 mg l^{-1}, Fig. 4).

The A/O/A regime at DO $\geq$ 2 mg l^{-1} and DO $\approx$ 1 mg l^{-1} achieved average COD removal efficiencies of 91.6 and 91.8 %, respectively, with average COD effluent concentrations of 19.7 mg COD l^{-1} and 19.2 mg COD l^{-1}, respectively (Figs. 1 and 2). During the anaerobic phase, organics were used by DPAOs and DGAOs, which compete for the carbon source, and by ordinary heterotrophic organisms (OHOs) for denitrification when nitrate/nitrite was present in the anaerobic phase. Research by other authors highlights the importance of a prolonged anaerobic phase to ensure carbon consumption for intracellular PHA storage.[10,13–15] In this study, during the anaerobic phase of 2 hours, available carbon was used for PHA formation by DPAOs and DGAOs, later consumed during the oxic phase for N and P removal, as well as to improve NO_x-N removal in endogenous denitrification (Figs. 3 and 4). The beneficial effect of a longer anaerobic phase on PHA storage in A/O/A with endogenous denitrification, with a duration of 3 h was reported by *Wang et al.*[14] and 3.1 h by *Zhao et al.*[13]

The selected DO concentrations ensured complete ammonia oxidation (Figs. 1 and 2) without stoichiometric nitrate accumulation (Figs. 1 and 2). The DO $\geq$ 2 mg l^{-1} resulted in an average NO_3-N effluent concentration of 7.4 mg NO_3-N l^{-1}, which affected NO_3-N concentration in the influent in the anaerobic phase (average 4.8 mg NO_3-N l^{-1}), and an average nitrite effluent concentration of 0.8 mg NO_2-N l^{-1}. The average TN removal efficiency was 76.6 % with the average effluent TN concentration of 8.2 mg TN l^{-1} (Fig. 1). The lower DO concentration (DO $\approx$ 1 mg l^{-1}) was more beneficial for N removal, achieving an average TN removal efficiency of 95.3 % (and an average TN effluent concentration of 1.5 mg TN l^{-1}). The average effluent NO_3-N concentration of 1.1 mg NO_3-N l^{-1} led to an average influent NO_3-N concentration of 0.9 mg NO_3-N l^{-1} in the anaerobic phase. The average nitrite concentration in the effluent was low, 0.4 mg NO_2-N l^{-1} (Fig. 2). The results of the effect of DO concentration (Figs. 1 and 2 align with previous studies, which indicate that reduced DO concentrations in the oxic phase of the process promote N removal.[10,13–15]

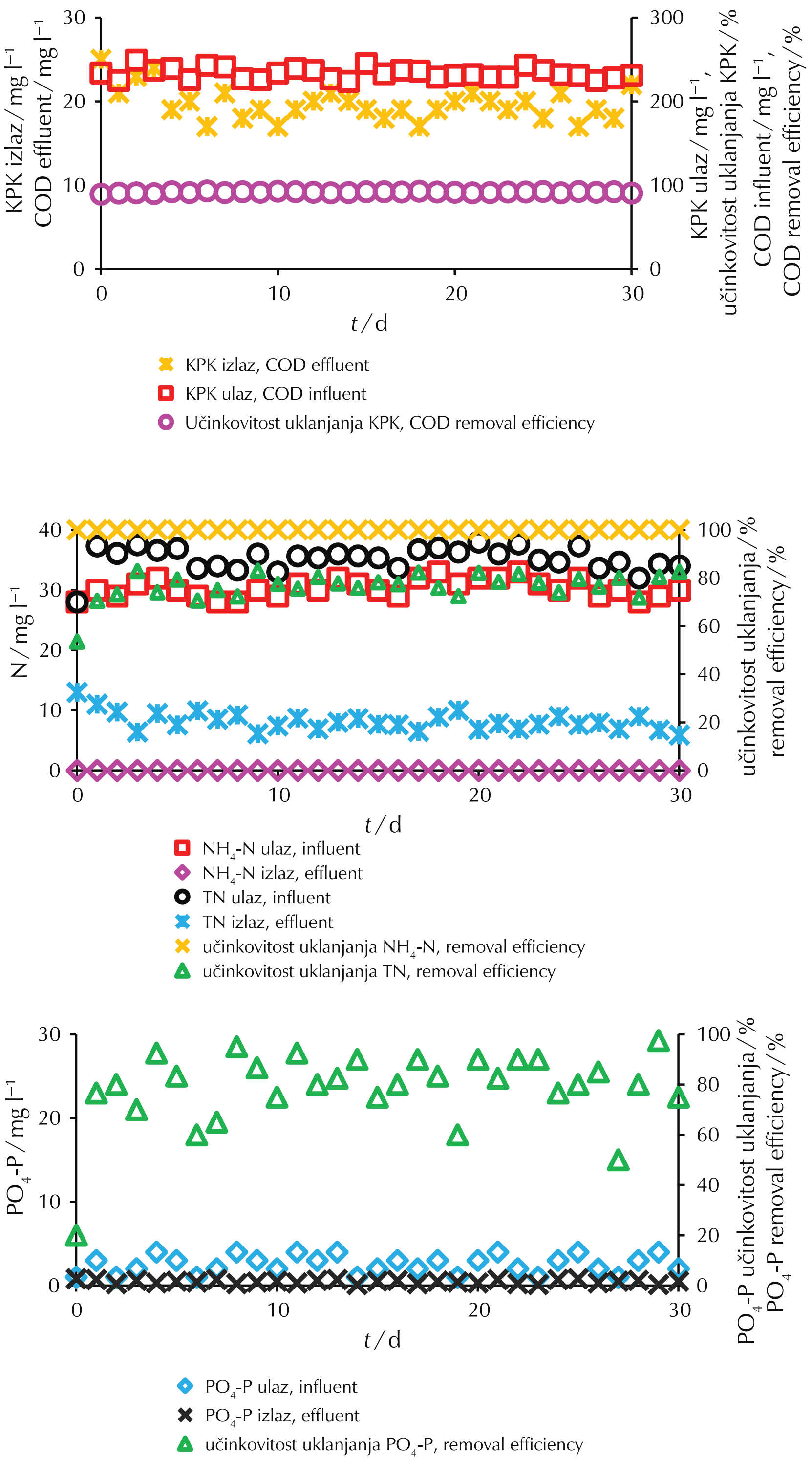

Fig. 1 – Influent, effluent, and removal efficiency of COD, NH_4-N, total N (TN), and PO_4-P in the A/O/A process with endogenous denitrification at DO ≥ 2 mg l^{-1}

Slika 1 – Ulaz, izlaz i učinkovitost uklanjanja KPK, NH_4-N, ukupnog dušika (TN) and PO_4-P u A/O/A procesu uz endogenu denitrifikaciju pri DO ≥ 2 mg l^{-1}

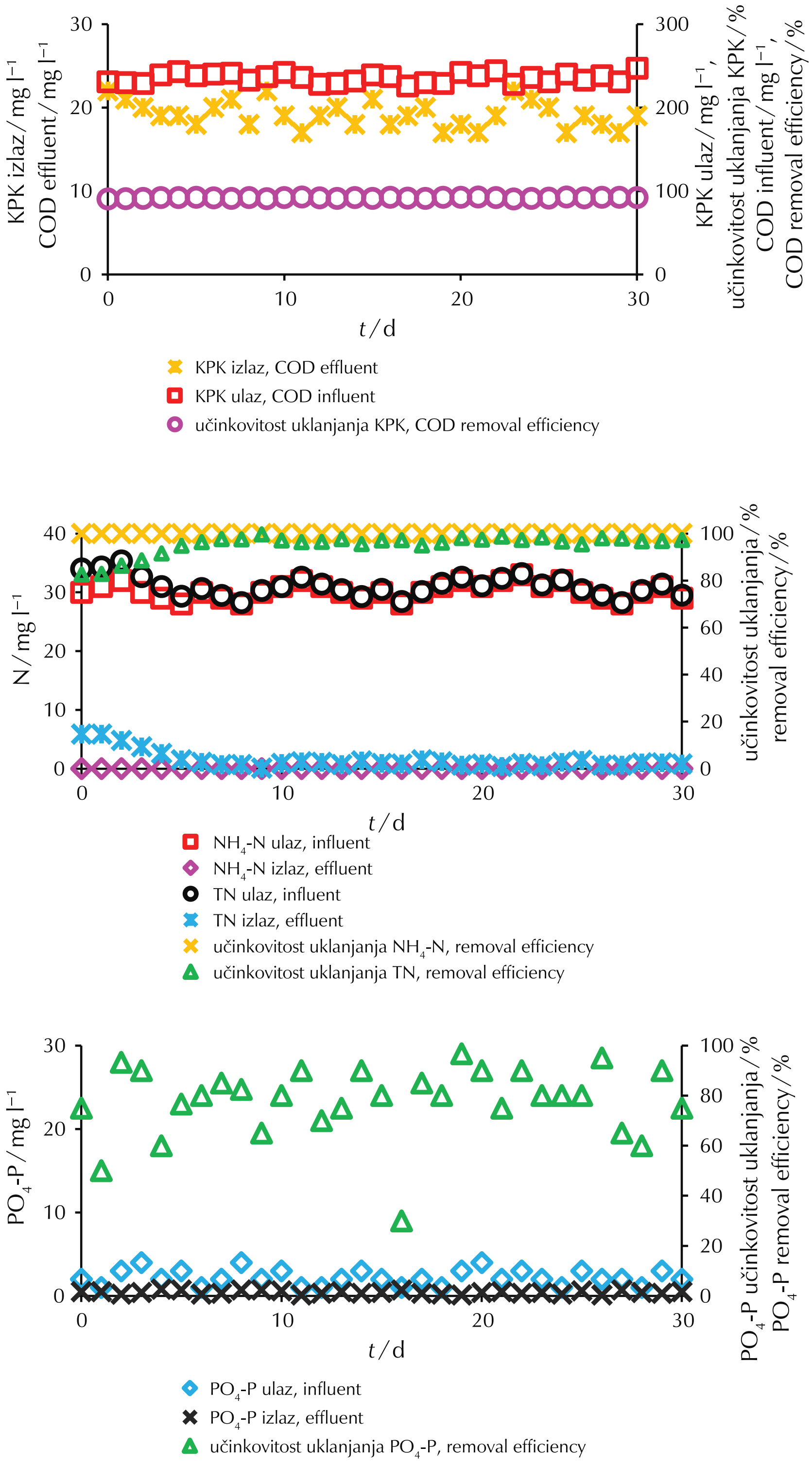

Fig. 2 – Influent, effluent, and removal efficiency of COD, NH_4-N, total N (TN), and PO_4-P in the A/O/A process with endogenous denitrification at DO ≈ 1 mg l^{-1}

Slika 2 – Ulaz, izlaz i učinkovitost uklanjanja KPK, NH_4-N, ukupnog dušika (TN) and PO_4-P u A/O/A procesu uz endogenu denitrifikaciju pri DO ≈ 1 mg l^{-1}

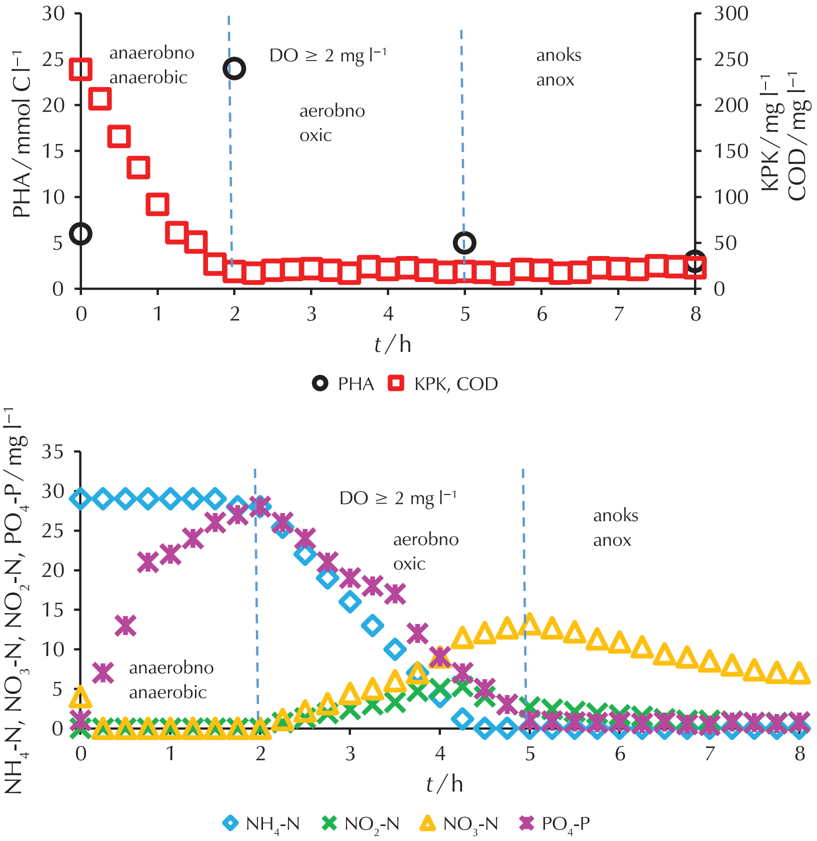

Fig. 3 – Batch experiment of the A/O/A process with endogenous denitrification at DO ≥ 2 mg l^{-1}, at day 21

Slika 3 – Šaržni pokus A/O/A procesa uz endogenu denitrifikaciju pri DO ≥ 2 mg l^{-1}, 21. dana pokusa

A slightly higher average of PO_4-P removal efficiency was observed under the A/O/A configuration at DO ≥ 2 mg l^{-1}, of 78.5 % compared to average PO_4-P removal efficiency at A/O/A configuration at DO ≈ 1 mg l^{-1}, of 77.9 % (Figs. 1 and 2). The average effluent PO_4-P concentrations at both tested DO concentrations were below 0.5 mg PO_4-P l^{-1}. Other authors have also reported low effluent PO_4-P values of 0.4 mg PO_4-P l^{-1}[14], ≤ 0.2 mg PO_4-P l^{-1}[13], 0.2 mg PO_4-P l^{-1}.[15] In addition, the majority of the investigated WWTPs cannot achieve total P in effluent < 0.5 mg l^{-1}, mainly due to the high influent ratio of COD/P (28.6–196.2).[20]

The batch experiment performed at day 21 (Fig. 3) under the A/O/A configuration at DO ≥ 2 mg l^{-1} revealed complete COD removal during the anaerobic phase and the conversion of the majority of COD to the PHA and a small part of COD was used for denitrification of the returned-influent NO_3-N and/or NO_2-N. The COD oxidation rate amounted to 110 mg COD l^{-1} h^{-1}. Most of the PHA was consumed during the oxic phase with consumption of 19 mmol C l^{-1}, and some of the PHA was consumed by endogenous denitrification in the anoxic phase. The batch experiment in A/O/A configuration at DO ≈ 1 mg l^{-1} (Fig. 4) showed very similar behaviour regarding the COD consumption and PHA accumulation as in experiments conducted at DO ≥ 2 mg l^{-1}. The COD oxidation rate amounted 104 mg COD l^{-1} h^{-1}. The PHA degradation was slightly more pronounced in A/O/A configuration at DO ≥ 2 mg l^{-1} during the oxic phase (Fig. 3) compared to DO ≈ 1 mg l^{-1} (PHA consumption of 15.4 mmol C l^{-1}) (Fig. 4), which could be the reason for lower TN removal at DO ≥ 2 mg l^{-1} (Fig. 3). The production of PHA is the conformation of DPAOs and DGAOs activity.[10–14,20]

During the anaerobic phase in both regimes of the A/O/A process with endogenous denitrification, a negligible NH_4-N decrease was detected (Figs. 3 and 4). Complete NH_4-N oxidation was observed during the oxic phase at DO ≥ 2 mg l^{-1} with the NH_4-N oxidation rate of 11.2 mg NH_4-N l^{-1} h^{-1} (Fig. 3). The DO concentration of approximately 2 mg l^{-1} is beneficial for complete ammonia oxidation with no inhibition to either AOB or NOB.[4,5] Ammonia oxidation resulted in 2.7 mg NO_2-N l^{-1} and 13.2 mg NO_3-N l^{-1} with N loss of 43 % in the oxic phase (Fig. 3) as a result of SND. Since organics were consumed during the anaerobic phase, intracellular PHA served as an electron donor for nitrate and nitrite reduction (Fig. 3), consistent with other studies.[11,12,17,21] SND is favourable for N removal, among others, because of pH regulation. During nitrification, especially during the oxidation of NH_4-N to NO_2-N, the production of H^+ ions occurs, leading to pH decrease. Both AOB and NOB are sensitive to pH oscillations, and nitrification is slowed down and inhibited at pH below 7, with optimal pH value for nitrification in range of

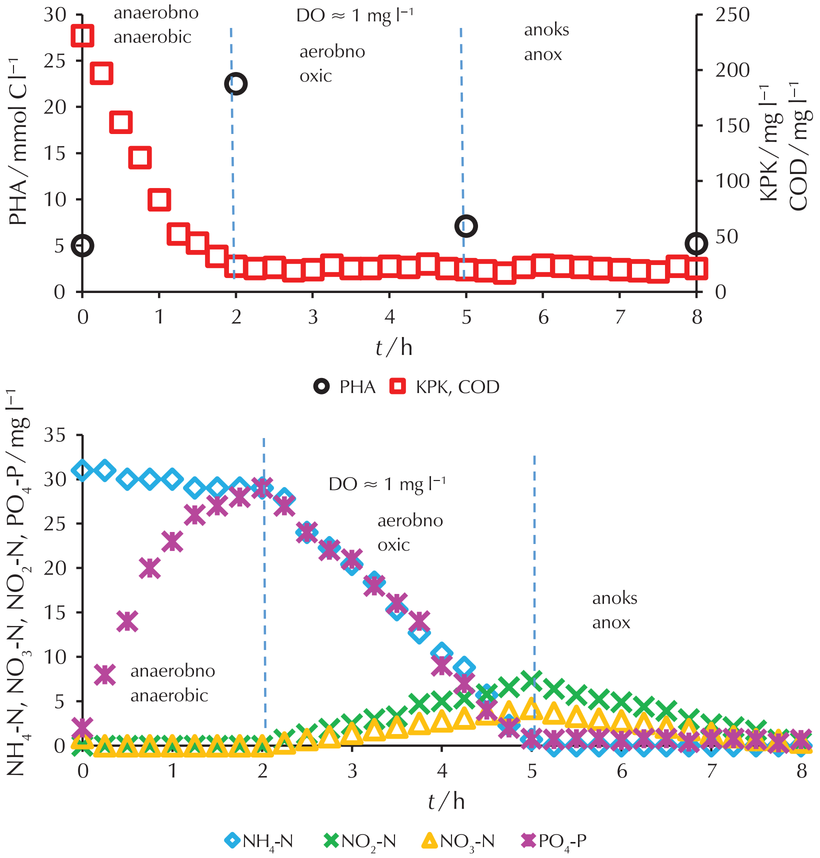

Fig. 4 – Batch experiment of the A/O/A process with endogenous denitrification at DO ≈ 1 mg l^{-1}, at day 24
Slika 4 – Šaržni pokus A/O/A procesa uz endogenu denitrifikaciju pri DO ≈ 1 mg l^{-1}, 24. dana pokusa

7.2–8.0[4,5] and for denitrification 7–9.[22] Denitrification, on the other hand, recovers the alkalinity lost during nitrification, and leads to an increase in pH value. In addition, pH value affects the molecular and ionic form of NH_3/NH_4-N and HNO_2/NO_2-N. Both molecular forms are inhibitors for nitrifiers and DPAOs.[4,5] In this research, due to the SND process, there was no detrimental effect of pH on nitrification, denitrification, and PAOs/DPAOs activity (Figs. 3 and 4). Ammonia oxidation was also complete at DO ≈ 1 mg l^{-1} with the ammonia oxidation rate of 9.4 mg NH_4-N l^{-1} h^{-1} and resulted in 7.3 mg NO_2-N l^{-1} and 4.2 mg NO_3-N l^{-1}, *i.e.,* the N loss amounted to 71 % at the end of the oxic phase (Fig. 4). The DO concentration of ≈ 1 mg DO l^{-1} is favourable for nitritation (oxidation of NH_4-N to NO_2-N), so in this case, the ammonia oxidation resulted with higher nitrite than nitrate concentration. Also, DO concentration of approximately ≈ 1 mg DO l^{-1} is beneficial for SND because higher DO concentrations inhibit denitrification reductases, and denitrifiers switch enzymes to DO instead of NO_2-N and NO_3-N as electron acceptors because the amount of energy obtained over oxic respiration of organics is higher than over anoxic respiration of organics.[4,5,23–26] For the NO_2-N and NO_3-N denitrification, PHA was used (Fig. 4). For microbial activity of competitive organisms, it is important to ensure a long anaerobic phase for intracellular carbon storage by PAOs/DPAOs and DGAOs, a not too long an oxic phase to prevent the stored PHA's excessive consumption under oxic conditions, which would potentially reduce the availability of PHA for endogenous denitrification, a long post-anoxic endogenous phase since ED is a slower process than heterotrophic denitrification.[10–15,20] The A/O/A process with endogenous denitrification (at DO 1 mg l^{-1} in the oxic phase) with anaerobic phase duration of 150 min, oxic phase 180 min, and anoxic phase of 120 min, achieved the removal efficiency of 80.9 % COD, 96.6 % NH_4-N, 77.2 % TN, 95.1 % PO_4-P, 46.7 % SND, in treatment of low C/N (≤ 4) wastewater.[14] In the A/O process (at DO 1 ± 0.3 mg l^{-1} in the oxic phase) with anaerobic phase duration of 180 min, short oxic phase 150 min, the removal efficiency of 77.7 % TN, 49.3 % SND and effluent P 0.2 mg l^{-1}, in treatment of low C/N (≤ 3.5) wastewater, was achieved.[15] In the A/O/A process with endogenous denitrification (at DO 1–2 mg l^{-1} in the oxic phase) with anaerobic phase duration of 3.1 h, oxic phase 3.9 h, and long anoxic phase of 7 h, the removal efficiency of 92.15 % TN, and 92.67 % PO_4-P, in treatment of low C/N (4.4) wastewater, was achieved.[13]

The anoxic phase in both regimes (Figs. 3 and 4) contributed to additional nitrate and nitrite reduction, and resulted with 73 % total N loss (Fig. 3), and 97 % total N loss (Fig. 4), due to the endogenous denitrification with PHA as electron donor, at DO ≥ 2 mg l^{-1} and DO ≈ 1 mg l^{-1}, respectively. The endogenous denitrification rate is lower

(0.2–0.6 mg N g^{-1} VSSh^{-1}) than denitrification with external carbon sources[27] and therefore requires longer anoxic phase duration.[28,29] Recent studies[30] have shown that in A/O/A process with endogenous denitrification, the efficiency of endogenous denitrification can be improved by two scenarios[27]: long anaerobic phase, enhancing the intracellular carbon storage of GAOs[13–15,31], or increasing biomass concentration.[27,30,32]

The dynamics of PO_4-P changes are very similar in both regimes, at DO ≥ 2 mg l^{-1} and DO ≈ 1 mg l^{-1}, and under anaerobic conditions, the PO_4-P release occurred together with the acetate uptake and PHA accumulation (Figs. 3 and 4). PAOs/DPAOs break down intracellular polyP and release PO_4-P from the cells. At the same time, PAOs/DPAOs take up VFAs, acetate, and store it as PHA.[11,12,15–17] Since the nitrification during the oxic phase at DO ≥ 2 mg l^{-1} and denitrification during anoxic phase resulted with an average NO_3-N effluent concentration of 7.4 mg NO_3-N l^{-1}, influent NO_3-N concentration in the anaerobic phase was on average 4.8 mg NO_3-N l^{-1}, thus, denitrification occurred during the first cca. 10 min in the anaerobic phase, and therefore, part of the COD was used for denitrification with no effect on the PAOs/DPAOs activity for the PHA accumulation and PO_4-P release (Fig. 3). Almost complete PO_4-P removal in the oxic phases at DO ≥ 2 mg l^{-1} and DO ≈ 1 mg l^{-1} was achieved, with PO_4-P uptake rate of 9 mg PO_4-P l^{-1} h^{-1} (Fig. 3) and 9.4 mg PO_4-P l^{-1} h^{-1} (Fig. 4). Different PAOs possess different capabilities – some PAOs can use DO as electron acceptor, some DPAOs can use NO_3-N and/or NO_2-N as electron acceptors.[11,12,17,33–35] In comparison to oxic P uptake, the anoxic P uptake is usually lower since the energy production efficiency with nitrates as electron acceptor is around 40 % lower compared to energy production efficiency with dissolved oxygen as electron acceptor.[36–38] Under oxic conditions, PAOs use DO as electron acceptor and take up PO_4-P and store it as intracellular polyP with simultaneous PHA degradation. It is possible that, due to the diffusion limitation, the DO concentration in flocs was low and therefore the DPAOs used some nitrates and nitrites as electron acceptors together with PHA degradation, which could have contributed to the N removal. Flocs larger than 100 µm are large enough to create the dissolved oxygen gradient through the floc radius. In case of dissolved oxygen gradient through the floc radius, the aerobic organisms are placed on the outer layers of the floc, and use DO for respiration, while organisms that require nitrite and/or nitrate for respiration are placed in deeper floc layers.[4]

4 Conclusion

In the anaerobic/oxic/anoxic (A/O/A) process with endogenous denitrification for the treatment of wastewater with a low C/N ratio, the selected DO concentration significantly influenced the efficiency and rate of N removal. The A/O/A process at ≈ 1 mg DO l^{-1} demonstrated significantly higher nitrogen removal efficiency compared to the process at ≥ 2 mg DO l^{-1}. This outcome can be attributed to the combined activity of PAOs/DPAOs and endogenous denitrifiers (DGAOs). Experiments at ≥ 2 mg DO l^{-1} in the oxic phase of the process resulted in N loss of 43 %, whereas at ≈ 1 mg DO l^{-1}, N loss reached 71 %, primarily due to the SND process. During the anaerobic phase in both regimes of the A/O/A process with endogenous denitrification, negligible NH_4-N reduction was observed alongside almost complete COD consumption and PHA accumulation. The COD oxidation rates were 110 mg COD l^{-1} h^{-1} and 104 mg COD l^{-1} h^{-1} at DO ≥ 2 mg l^{-1} and DO ≈ 1 mg l^{-1}, respectively. In the oxic phase at DO ≥ 2 mg l^{-1}, complete NH_4-N oxidation occurred with an NH_4-N oxidation rate of 11.2 mg NH_4-N l^{-1} h^{-1}, while the PO_4-P uptake rate was 9 mg PO_4-P l^{-1} h^{-1}. At DO ≈ 1 mg l^{-1}, the NH_4-N oxidation rate was 9.4 mg NH_4-N l^{-1} h^{-1}, and the PO_4-P uptake rate was 9.4 mg PO_4-P l^{-1} h^{-1}. P removal of 78.5 % and N removal of 76.6 % (in the A/O/A process at DO ≥ 2 mg l^{-1}), and P removal of 77.9 % and N removal of 95.3 % (in the A/O/A process at DO ≈ 1 mg l^{-1}) were achieved. Future research should focus on investigating the effect of lower DO concentrations in the oxic phase and optimising the duration of both the anaerobic and anoxic phases of the process.

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List of symbols and abbreviations
Popis kratica i simbola

A/O/A	– anaerobic/oxic/anoxic – anaerobno/aerobno/anoksično
AOB	– ammonia oxidation bacteria – amonijak oksidirajuće bakterije
BNR	– biological nutrient removal – biološko uklanjanje nutrijenata
COD/ KPK	– chemical oxygen demand – kemijska potrošnja kisika
DGAOs	– denitrifying glycogen-accumulating organisms – denitrificirajući glikogen akumulirajući organizmi
DO	– dissolved oxygen – otopljeni kisik
DPAOs	– denitrifying phosphorus-accumulating organisms – denitrificirajući fosfor akumlirajući organizmi
EBPR	– enhanced biological phosphorus removal – napredno biološko uklanjanje fosfora
GAOs	– glycogen-accumulating organisms – glikogen akumulirajući organizmi
MLSS	– mixed liquor suspended solids – suspendirane čestice miješane tekućine
N	– nitrogen – dušik
NOB	– nitrite oxidation bacteria – nitrit oksidirajuće bakterije
OHOs	– ordinary heterotrophic organisms – uobičajeni heterotrofni organizmi
P	– phosphorus – fosfor

PAOs – phosphorus-accumulating organisms
– fosfor akumulirajući organizmi

PHA – polyhidroxyalkanoates
– polihidroksialkanoati

polyP – polyphosphate
– polifosfati

SBR – sequencing batch reactor
– šaržni reactor koji radi u fazama

SND – simultaneous nitrification and denitrification
– istovremena nitrifikacija i denitrifikacija

SNDPR – simultaneous nitrification, denitrification, and phosphorus removal
– istovremena nitrifikacija, denitrifikacija i uklanjanje fosfora

TN – total nitrogen
– ukupni dušik

VFAs – volatile fatty acids
– hlapljive masne kiseline

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SAŽETAK

Uklanjanje dušika i fosfora iz otpadne vode niskog omjera ugljik/dušik u anaerobno/aerobno/anoksičnom procesu s endogenom denitrifikacijom pri različitoj koncentraciji otopljenog kisika

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U obradi otpadnih voda s niskim omjerom C/N u anaerobno/aerobno/anoksičnom (A/O/A) procesu s endogenom denitrifikacijom istražen je učinak odabrane koncentracije DO (DO ≥ 2 mg l^{-1} i DO ≈ 1 mg l^{-1}) na uklanjanje N i P. Učinak odabranog DO reflektira se na učinkovitost i brzinu uklanjanja dušika. Određen je gubitak dušika od 43 i 71 %, kao rezultat istodobne nitrifikacije i denitrifikacije, u aerobnoj fazi A/O/A procesa pri ≥ 2 mg DO l^{-1} odnosno ≈ 1 mg DO l^{-1}. Brzina uklanjanja NH_4-N od 11,2 mg NH_4-N l^{-1} h^{-1} i brzina unosa PO_4-P od 9 mg PO_4-P l^{-1} h^{-1}, i brzina uklanjanja NH_4-N od 9,4 mg NH_4-N l^{-1} h^{-1} i brzina unosa PO_4-P od 9,4 mg PO_4-P l^{-1} h^{-1} određeni su pri ≥ 2 mg DO l^{-1} odnosno pri ≈ 1 mg DO l^{-1}. Postignuto je uklanjanje P od 78,5 % i uklanjanje N od 76,6 % (u A/O/A procesu pri DO ≥ 2 mg l^{-1}) te uklanjanje P od 77,9 % i uklanjanje N od 95,3 % (u A/O/A procesu pri DO ≈ 1 mg l^{-1}).

Ključne riječi
Nitrifikacija, denitrifikacija, uklanjanje fosfora, endogena denitrifikacija, otopljeni kisik, otpadna voda niskog omjera C/N

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