EKOLOGIJA. 2007. Vol. 53. No. 1. P. 80–88

Effect of nitrogen on phosphate reduction in biological phosphorus removal from wastewater

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Conventional schemes of biological nitrogen removal can be combined with phosphorus removal schemes. One of the common technology schemes for biological nitrogen removal is the aeration zone and the anoxic zone in one tank. The nitrification and denitrification are carried out during the aeration switching on and off. The anaerobic zone is equipped behind the nitrification/denitrification tank for biological phosphorus removal. Exchange of the anaerobic and aerobic conditions is necessary for biological phosphorus removal. The concentration of oxygen must be sufficient in the aerobic zone for microorganisms that have accumulated phosphorus for complete or near complete nitrification.

The aim of the work was to evaluate the effect of biological nitrogen removal from wastewater on biological phosphorus removal. The evaluation of ammonia nitrogen quantity in the aeration zone was carried out before complete nitrification and the moment of phosphates split from microorganisms to the wastewater, and the time when the phosphates split is complete, if the aerobic phase is extended and the mixture temperature varies.

Dependence between partial nitrification and phosphate release in the aerobic zone and the impact of the aerobic phase prolongation on phosphate release in the aerobic zone was estimated in warm and cold seasons.

Key words: total nitrogen (TN), total phosphorus (TP), biological active potential (BPA), ratio of biochemical oxygen demand and total phosphorus (BOD_7/TP), phosphates, nitrates

INTRODUCTION

Phosphorus and nitrogen are two most important elements helping the growth of algae and aquatic plants in rivers, lakes, and shallow embayed areas of the marine environment. For this reason, they are termed eutrophic or life-giving elements. In quiescent surface waters, excessive growth of algae and other aquatic vegetation reduces the sunlight penetration into the water body, thereby inducing stratification and causing oxygen depletion in the lower levels. This discourages the growth of fish and other natural aquatic life, causes undesirable tastes and odours, and generally reduces the value of water for domestic, industrial, agricultural and recreational use.

Attempting to protect the surface water quality, nitrogen and phosphorus have been identified as the limiting nutrients for algae growth. Limiting the discharge of phosphorus, however, has been recognized as the more effective method of these two to prevent eutrophication. The ratio of nutrient substances should be C : N : P = 106 : 16 : 1 for the algae growth. Sludge growing is being limited by the substance whose concentration in the water is minimal in the case of breaking the above ratio. The algae growing limit has been determined by the nitrogen concentration of 0.3 mg/l and the phosphorus concentration of 0.01–0.03 mg/l (Beržinskienė, 1999).

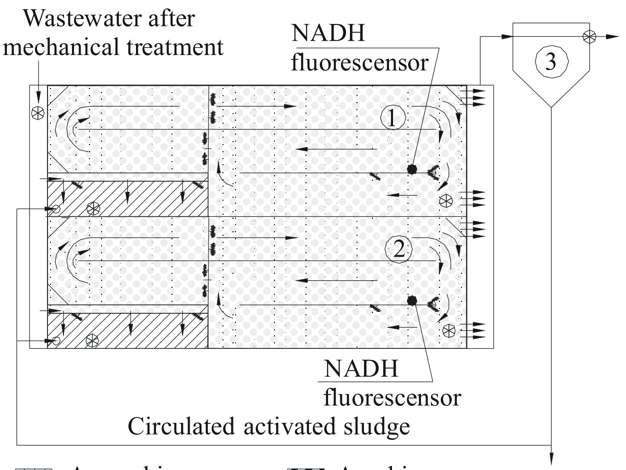
Municipal and industrial wastewater contains significant quantities of phosphorus and nitrogen and therefore the removal of these nutrients has become an important facet of wastewater treatment. Biological removal of these nutrients is preferred to the chemical removal as it results in a lower waste sludge production and has the public perception that biological processes are more "environmentally friendly" than chemical processes (Oldham, 2002).

Biological nitrogen removal from wastewater is based on the nitrification and denitrification processes at the biological treatment plant with the activated sludge. Biological phosphorus removal is based on special microorganisms – polyphosphate accumulating organisms with accumulate phosphate in excess to their metabolic requirement for growth. Usually, schemes of nitrogen removal are combined with phosphorus removal schemes. Biological phosphorus and nitrogen removal are closely linked, both in a positive and negative sense. Nitrates are usually considered to have an adverse effect on phosphorus removing capacity of activated sludge (Bitton, 1994; Jenicek, 2004). Exchange of the anaerobic and aerobic conditions is necessary for biological phosphorus removal. The concentration of oxygen must be enough in the aerobic zone for microorganisms that have accumulated phosphorus for complete or near complete nitrification.

The concentration of oxygen must be 2–6 mg l^{-1}, no less than 1 mg/l in the aerobic zone, because otherwise the phosphates will split from the microorganisms to wastewater (Henze, 1995; Droste, 1997). Phosphates' emission from microorganisms to wastewater is possible in the sludge sedimentation phase.

Phosphate release may also take place in fully aerobic conditions if the aerobic phase is prolonged. The reason for this can be that the carbon store in the cells becomes depleted before the sludge reaches the end of the aerobic zone, and degradation of polyphosphates results in the beginning of a new carbon store build-up (Casey, 1997; Matuzevičius, 1998). One of the common technology schemes for biological nitrogen removal is the aeration zone and the anoxic zone in one tank. Nitrification and denitrification are carried out during the aeration switching on and off. The anaerobic zone is equipped behind the nitrification / denitrification tank for biological phosphorus removal.

The aim of the present work was to evaluate the effect of biological nitrogen removal from wastewater on biological phosphorus removal. The evaluation of ammonia nitrogen quantity in the aeration zone was carried out before complete nitrification and the moment of phosphates split from microorganisms to wastewater, i.e. the time when phosphates split is complete, if the aerobic phase is extended and the mixture temperature varies.



Anaerobic zone — Aerobic zone

1 – Aeration tank No. 1 — *3* – Secondary clarifiers

2 – Aeration tank No. 2 — ⊛ – sampling points

Fig. 1. Basic scheme of biological treatment plant

MATERIALS AND METHODS

The research was carried out at the Utena Wastewater Treatment Plant with biological phosphorus and nitrogen removal. Two aeration tanks were used for biological wastewater treatment. The inlet part of each aeration tank was used as an anaerobic zone for biological phosphorus removal. The remaining part was used as an aeration tank (Fig. 1). Microorganisms that have accumulated polyphosphates grow at the anaerobic zone. They can accumulate a large quantity of phosphates in their own cells. Nitrogen removal according to the BioBalance Symbio technology was carried out in a simultaneous way of nitrification and denitrification; the oxygen supply was controlled by a NADH sensor according to sludge activity.

Commonly, there exist co-ferments that function as suppliers of hydrogen and electrons and are nicotinamideadeninedinucleotide NAD^+ and its phosphoresced compound derivative $NADP^+$. The reduced NAD(P)H form can be oxidised once more during the formation of ATP. During the processes of metabolism, the co-ferments NADH and NADPH are produced in all microorganisms. NAD(P)H quantity in the microorganisms depends on their activity. The above-mentioned activity depends on sludge loads supplied in the form of nutritive matters. This means that, for example, NAD(P)H quantity will remain stable under the conditions of constant quantity of nutritive matters supplied to the active sludge system, constant load and sludge activity. The sludge activity and NAD(P)H production increase gradually simultaneously with an increase of the sludge load because of a more intensive supply of nutritious matters. Differently, NAD(P)H production decreases with a decrease of nutritive matter supply in a linear dependence (Norgard, 1996).

The BioBalance measuring equipment NADH fluorescensor is based on the process mentioned above. The fluorescensor fixes only NADH that gives information on how much energy the microorganisms possess. The information on energy is defined as the biologically active potential (BPA). The NADH fluorescensor controls denitrification and nitrification process according to sludge activity in a single aeration tank. Ammonia is oxidised to nitrates by nitrifying bacteria during the nitrification phase. The nitrates are reduced to molecular nitrogen (N_2) by denitrifying bacteria during the denitrification phase. These processes are carried out periodically. Organic matter is oxidised bacterially during both the nitrification and denitrification phases, with oxygen and nitrates, respectively, as the oxidising agents, and phosphorus is absorbed by special microorganisms. A NADH fluorescensor and an oxygen meter are mounted in each aeration tank.

The low oxygen concentration (0.1–0.5 $mgO_2\,l^{-1}$) was kept until denitrification was carried out, and a higher oxygen concentration (0.5–1 $mgO_2\,l^{-1}$) was kept for the nitrification processes to carry out periodically. Conditions for the nitrification to be carried out were kept approximately for 2–4 h, and after that 2–3.5 h were spent on denitrification. The duration of nitrification and denitrification had varied depending on the concentration of ammonium nitrogen, nitrates and BPA in the aeration tank.

The study was carried out in two periods (January–June and July–September 2005) to estimate changes during the warm and the cold seasons. First, wastewater was taken after mechanical treatment and the following data were analysed: temperature, pH, BOD_7, TP, TN, BOD_7/TN and BOD_7/TP ratios. Investigations were carried out during the cold season first, and the temperature of wastewater being 12.4–17 °C, average 14 °C. Subsequent investigations were done during the warm season when the temperature of wastewater was 17.7–20.8 °C, average 19.4 °C. The pH of wastewater after mechanical treatment did not fluctuate significantly and was within 7.4–7.5. The characteristics of wastewater also did not fluctuate significantly during the cold and warm seasons (Table 1). The BOD_7/TP ratio of wastewater after mechanical treatment was 10.2–26.4, average 19.4, and the BOD_7/TN ratio was 2.5–4.8, average 3.7.

Wastewater was supplied to two aeration tanks: in the anaerobic and the aerobic zones. The concentrations of phosphates and nitrates were estimated in wastewater from the anaerobic zone. The concentrations of phosphates and ammonium nitrogen were estimated in wastewater from the aerobic zone. Two aeration tanks worked at the same time. The wastewater flow after mechanical treatment was divided into both aeration tanks simultaneously. However, the regime of aeration in each aeration tank was different. Aeration can be carried out in one aeration tank; in the meantime, no aeration can be carried out in the other tank. The term of aeration and switched off aeration can be different in the aeration tanks. For the above-mentioned reasons, the results were analysed as in similar aeration tanks.

Wastewater samples were taken after secondary clarifiers and the following characteristics were estimated: BOD_7, TP and TN concentration and the biological treatment effect on BOD_7, TP and TN (Table 1).

The tests were repeated on several occasions after the estimated time when the NADH sensor fixes BPA changes. When the data showed that only partial nitrification had been carried out in the aeration tank (a high concentration of ammonium nitrogen in the aeration tank was found), the aeration was prolonged and the tests were repeated after a special aeration time. After that the data indicated only partial denitrification in the aeration tank (high concentrations of nitrates in the aeration tanks was estimated); the slowed down aeration was prolonged and the research tests were repeated after the estimated no aeration time. The active sludge load was low (45–55 mgBOD_7/g MLVSS*d) in the aeration tanks. The active sludge concentration fluctuated at 3.4–4.6 g l^{-1} in the aeration tanks. In the warm season, the active sludge concentration was about 3.6 g/l, and in the cold season about 4.3 g l^{-1}. The active sludge age fluctuated within 11–20 days. All analyses in wastewater were conducted in accordance with the current Lithuanian Standards.

Experimental data are statistically reliable, if the likelihood is from 92.5% to 97.5%. For the gathered data, checking of statistical reliability was done: the arithmetical means (X), the parameter of the Student repartition (t_{95}), standard deviation (S). Reservation of statistically faithful data was checked: $[X_i - X] < 2s$. The data the dissonant reservation of which different from statistically reliable ones were eliminated and the calculation was repeated. The maximum and minimum means of the data with a 95% probability were calculated according to the formula: $X_{max} = X + 2 \cdot S$, $X_{min} = X - 2 \cdot s$, respectively (Martinėnas, 2004; Matuzevičius, 1999).

RESULTS AND DISCUSSION

First, the statistically faithful results obtained during the warm season were analysed. The concentration of phosphates and nitrates in the anaerobic zone in both aeration tanks were similar and fluctuated within 34–61 mg l^{-1} and 0.00–1.01 mg l^{-1}, respectively. The average concentrations of phosphates and nitrates were 48 and 0.4 mg l^{-1}, respectively (Tables 2, 3). The concentration of phosphates and nitrates in the aerobic zone in both aeration tanks was different because of the different aeration regimes. In the first aeration tank, the concentration of phosphates, ammonium nitrogen and nitrates in the aerobic zone fluctuated within 0.00–1.61 mg l^{-1}, 0.00–2.17 mg l^{-1} and 0.00–1.23 mg l^{-1}, respectively. The average concentrations of phosphates, ammonium nitrogen and nitrates were 0.59, 1.01 and 0.61 mg l^{-1}, respectively (Table 2).

The concentration of phosphates, ammonium nitrogen and nitrates in the aerobic zone was 0.00–0.96 mg l^{-1}, 0.00–1.30 mg l^{-1}, 0.31–1.11 mg l^{-1} respectively in the second aeration tank. The average concentrations of phosphates, ammonium nitrogen and nitrates were 0.3, 0.47 and 0.71 mg l^{-1}, respectively (Table 3).

Analysis of the above-mentioned data showed that there was an increased concentration of phosphates in the aerobic zone in the warm season when complete nitrification was not carried out in the aeration zone and a major concentration of ammonium nitrogen remained. A dependence between phosphates and ammonium nitrogen in the aeration zone was sought to prove this suggestion.

However, there are many factors that have a negative or positive impact on biological phosphorus removal. These factors are the composition of wastewater, oxygen supply, active sludge load / active sludge age, the concentration of nitrates, etc. (Ywang, 2004; Dauknys, 2000; Casey, 1997; Pauli, 1994).

The composition of wastewater is an important factor for biological phosphorus removal, because products of organic fermentation are a nutrient for microoganisms that accumulate phosphorus. So, higher ratios of BOD_7/TP and BOD_7/TN are very important for biological phosphorus removal. Our earlier study showed the BOD_7/TP ratio in the influent to impact the effect of phosphorus removal. This ratio is different and uses different technologies (Vabolienė, 2005; Seldak, 1999; Matuzevičius, 1999; Heather, 1998). In the present study, it was determined that when the BOD_7/TP ratio in the influent fluctuated within 15–30, the concentration of total phosphorus in the effluent was not higher than 1 mg l^{-1}, using a different technology.

Therefore, analyses were eliminated (this analysis was not shown in Tables 2, 3) when the BOD_7/TP ratio in the influent was above 15. In these cases phosphates could increase in the aeration zone because there was not enough organic matter in the wastewater.

The active sludge load and age do not directly affect biological phosphorus removal. A direct parameter is the concentration of nitrates. Biological phosphorus removal is effective when the concentration of nitrates is not

Table 1. **Wastewater characteristics**

	Wastewater after mechanical treatment, mg l^{-1}			Wastewater after secondary clarifiers, mg l^{-1}			Biological treatment effect addressed, %		
	BOD_7	TN	TP	BOD_7	TN	TP	BOD_7	TN	TP
Max value, x_{max}	212	56	12.4	11.3	10.2	1.2	96.9	94.1	100
Min value, x_{min}	177	33	6.6	3.9	2.7	0.1	95.7	76.7	87.9
Average value, x	195	45	9.5	7.6	6.4	0.6	96.3	85.4	94.1
Amplitude	36	23	6	7	8	1.0	1.2	17.4	12.0
Median	200	45	9.7	7.2	6.5	0.6	96.3	86.1	94.3
Dispersion, s^2	79	33	2.1	3.4	3.6	0.1	0.1	19.0	9.7
Standard deviation, s	9	6	1.5	1.8	1.9	0.3	0.3	4.4	3.1

Table 2. **Concentrations of phosphates, ammonium nitrogen and nitrates in aeration tank No. 1 during warm season**

No.	Anaerobic zone, mg l^{-1}		Aeration zone, mg l^{-1}		
	$P\text{-}PO_4$	$N\text{-}NO_3$	$P\text{-}PO_4$	$N\text{-}NH_4$	$N\text{-}NO_3$
1	57	0.34	0.57	1.40	0.62
2	54	0.70	0.07	0.40	0.54
3	61	0.91	0.11	0.78	0.86
4	87	0.11	0.98	1.40	0.23
5	41	0.11	4.10	4.70	0.08
6	50	0.24	2.38	2.10	0.13
7	56	0.38	0.34	0.63	0.65
8	45	0.32	0.05	0.61	1.80
9	42	1.60	1.41	1.30	4.80
10	54	0.28	0.50	0.82	1.78
11	48	0.31	0.08	0.25	1.02
12	49	0.09	1.42	2.00	0.81
13	51	0.47	0.06	0.58	0.69
14	50	0.35	0.07	0.66	0.62
15	42	0.18	1.00	1.50	1.20
16	36	0.59	0.58	0.64	2.00
17	51	0.12	0.08	0.23	0.47
18	48	0.29	1.20	1.00	0.58
19	27	0.52	0.30	0.40	0.71
20	50	1.80	1.90	1.80	4.30
21	44	0.59	1.20	1.70	6.10
22	50	1.20	1.10	1.10	4.90
Max value, x_{max}	*58.5*	*0.64*	*1.61*	*2.17*	*1.23*
Min value, x_{min}	*39.5*	*0.00*	*0.00*	*0.00*	*0.00*
Average value, x	*49.0*	*0.31*	*0 .59*	*1.01*	*0.61*
Amplitude	*18.9*	*0.65*	*2.05*	*2.31*	*1.23*
Median	*50.0*	*0.31*	*0.50*	*0.82*	*0.62*
Dispersion, s^2	*22.4*	*0.03*	*0.26*	*0.33*	*0.09*
Standard deviation, s	*4.7*	*0.16*	*0.51*	*0.58*	*0.31*

Table 3. **Concentrations of phosphates, ammonium nitrogen and nitrates in aeration tank No. 2 during warm season**

No.	Anaerobic zone, mg l^{-1}		Aeration zone, mg l^{-1}		
	$P\text{-}PO_4$	$N\text{-}NO_3$	$P\text{-}PO_4$	$N\text{-}NH_4$	$N\text{-}NO_3$
1	72	0.25	1.54	2.00	0.47
2	64	0.51	0.57	0.84	0.68
3	59	0.78	0.62	0.91	0.31
4	78	0.48	0.14	0.77	0.62
5	35	0.35	0.15	0.08	0.57
6	42	0.74	0.08	0.04	0.91
7	56	0.84	0.01	0.09	0.54
8	47	0.78	0.04	0.29	1.05
9	40	1.04	1.01	1.17	2.89
10	52	0.36	0.48	0.81	1.05
11	49	0.31	0.09	0.03	0.84
12	46	0.41	0.83	0.92	0.64
13	52	0.05	0.92	1.30	0.38
14	49	0.25	0.09	0.41	0.63
15	44	0.28	0.05	0.28	0.71
16	38	0.57	0.06	0.28	0.95
17	51	0.11	2.10	2.30	0.54
18	51	0.23	0.04	0.38	0.62
19	27	0.48	0.33	0.29	0.84
20	40	1.5	2.00	2.10	9.80
21	47	0.58	0.14	0.02	1.20
22	55	0.77	0.09	0.10	9.90
Max value, x_{max}	*60.5*	*1.01*	*0.96*	*1.30*	*1.11*
Min value, x_{min}	*34.2*	*0.00*	*0.00*	*0.00*	*0.31*
Average value, x	*47.4*	*0.48*	*0.30*	*0.47*	*0.71*
Amplitude	*26.3*	*1.01*	*0.96*	*1.65*	*0.80*
Median	*48.0*	*0.48*	*0.14*	*0.29*	*0.64*
Dispersion, s^2	*43.2*	*0.07*	*0.11*	*0.17*	*0.04*
Standard deviation, s	*6.6*	*0.26*	*0.33*	*0.41*	*0.20*

Table 4. **Concentrations of phosphates, ammonium nitrogen and nitrates in aeration tanks during warm season**

No.	Anaerobic zone, mg l^{-1}		Aeration zone, mg l^{-1}		
	$P\text{-}PO_4$	$N\text{-}NO_3$	$P\text{-}PO_4$	$N\text{-}NH_4$	$N\text{-}NO_3$
1	61	2.00	2.40	0.29	13.0
2	39	2.60	3.50	0.18	6.60
3	42	1.60	1.41	1.30	4.80
4	50	1.80	1.90	1.80	4.30
5	50	1.20	1.10	1.10	4.90
6	67	3.20	4.10	0.18	3.60
7	50	2.20	2.80	0.01	17.0
8	35	2.10	2.70	0.00	5.40
9	40	1.04	1.01	1.17	2.89
10	40	1.50	2.00	2.10	9.80
11	37	2.20	3.50	0.89	7.50
12	45	2.40	3.40	1.20	9.30
Max value, x_{max}	*54.1*	*3.20*	*4.53*	*2.30*	*10.58*
Min value, x_{min}	*31.5*	*0.77*	*0.44*	*0.00*	*1.23*
Average value, x	*42.8*	*1.99*	*2.49*	*0.82*	*5.91*
Amplitude	*22.5*	*3.20*	*4.53*	*2.96*	*9.35*
Median	*41.0*	*2.05*	*2.55*	*0.89*	*5.15*
Dispersion, s^2	*31.7*	*0.37*	*1.04*	*0.55*	*5.47*
Standard deviation, s	*5.6*	*0.61*	*1.02*	*0.74*	*2.34*

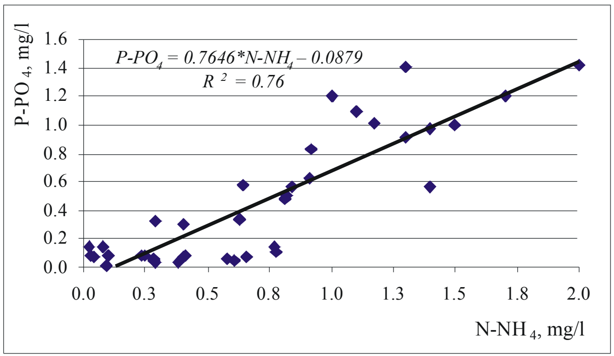


Fig 2. Phosphate concentration dependence on ammonium nitrogen concentration in aeration zone during warm season

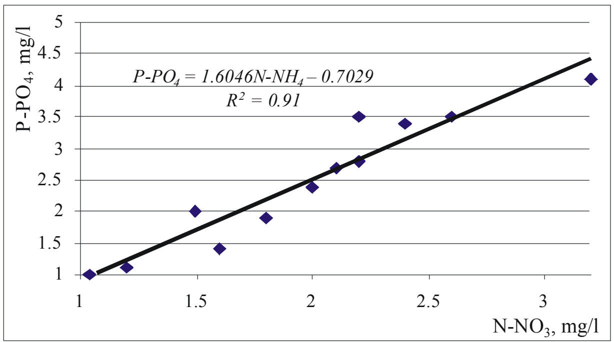


Fig 3. Phosphate concentration dependence in aeration zone on nitrate concentration in anaerobic zone during warm season

higher than 2 mg l^{-1} in the anaerobic zone (Dauknys, 2000; Hatziconstantinou, 2002). High active sludge load and short active sludge age mean the low nitrification degree and a low concentration of nitrates.

The active sludge load and age did not have a negative impact on phosphorus removal. Nitrate content was not higher than 2 mg l^{-1} in the anaerobic zone, so the negative impact on phosphorus removal was eliminated.

Hydraulic retention time in the anaerobic zone should be longer than 1 h. Hydraulic retention time in the anaerobic zone was 2.25–1.2 h in our study.

A regressive correlation analysis of statistically reliable data (without the negative impact of factors mentioned above) was carried out to estimate the correlation between the concentration of phosphates and ammonium nitrogen in the aerobic zone. The analysis showed the concentration of phosphates depended on ammonium nitrogen concentration in the aeration zone. The model correlation index $R^2 = 0.76$; in the data dissemination diagram, the data are arranged along the regression line (Fig. 2).

Nitrates in the anaerobic zone are an important factor to be taken into consideration especially in the phosphorus removal activated sludge during domestic wastewater treatment. One explanation could be that in the presence of nitrates the substrates are metabolized through oxidative rather than fermentative pathways. The latter suggestion means that the formation of volatile fatty acids required by the polyphosphate accumulating organism in the anaerobic zone is limited. Another explanation could be that an anaerobic zone containing nitrates favors denitrifiers which compete for fermentation products with the polyphosphate accumulating organism. It should, however, be noted that this reasoning includes the assumption that the polyphosphate accumulating organism does not denitrify.

When only partial nitrification was carried out in the aeration tank (a high concentration of ammonium nitrogen in the aeration zone was estimated), the aeration was prolonged. After that the tests were repeated and showed that when the concentration of ammonium nitrogen and phosphates degreased, the aeration was not stopped. Therefore, the concentration of nitrates increased in the anaerobic zone. At the same time the concentration of phosphates increased in the aerobic zone.

Phosphate release may also take place in fully aerobic conditions if the aerobic phase is prolonged. The reason for this could be that the carbon store in the cells becomes depleted before the sludge reaches the end of the aerobic zone, and a new carbon store begins to build up, resulting in the degradation of polyphosphates.

The regressive correlation analysis of the data (without the negative impact of factors mentioned above, except nitrate) was carried out to estimate the correlation between the concentration of phosphates in the aeration zone and nitrates in the anaerobic zone. The concentration of nitrates fluctuated from 1 to 3.20 mg l^{-1}. When the concentration of nitrates was low (1 mg l^{-1}), there was no negative impact on phosphate removal.

The regressive data correlation analysis (Table 4) showed the concentration of phosphates in the aeration zone to depend on nitrate concentration in the anaerobic zone. The linear regression model is suitable following the received results. The model correlation index $R^2 = 0.91$; in the data dissemination diagram, the data are arranged along the regression line (Fig. 3).

With increasing ammonium nitrogen above 1 mg l^{-1} in the aerobic zone, the concentration of phosphates also increased and the concentration of total phosphorus in the effluent exceeded 1.5 mg l^{-1}. Similarly, with increasing nitrates to 3.2 mg l^{-1} in the anaerobic zone, the concentration of phosphates increased and the concentration of total phosphorus in the effluent exceeded 1.8 mg l^{-1}.

Then, data received in the cold season were investigated. The tests were carried out in one aeration tank. The concentration of phosphates and nitrates in the anaerobic zone fluctuated within 17–69 mg l^{-1} and 0.16–0.76 mg l^{-1}, respectively. The average concentrations of phosphates and nitrates were 43 and 0.46 mg l^{-1}, respectively (Table 5). The concentration of phosphates, ammonium nitrogen and nitrates in the aerobic zone fluctuated within 0.00–0.02 mg l^{-1}, 0.00–2.3 mg l^{-1} and 0.00–1.26 mg l^{-1}, respectively. The average concentrations of phosphates, ammonium nitrogen and nitrates were 0.01, 0.9 and 0.58 mg l^{-1}, respectively (Table 5).

Table 5. **Concentrations of phosphates, ammonium nitrogen and nitrates in aeration tanks during cold season**

No.	Anaerobic zone, mg l^{-1}		Aeration zone, mg l^{-1}		
	P-PO_4	N-NO_3	P-PO_4	N-NH_4	N-NO_3
1	17	0.27	0.01	0.68	5.70
2	24	0.53	0.02	1.30	2.40
3	27	0.30	0.03	1.70	3.00
4	29	0.31	0.01	0.10	1.20
5	29	0.67	0.02	0.17	2.80
6	48	0.67	0.01	0.22	3.50
7	44	0.24	0.01	0.70	0.59
8	53	0.51	0.01	0.19	0.30
9	55	0.46	0.01	1.20	0.67
10	55	0.37	0.01	0.30	0.30
11	49	0.46	0.01	0.03	0.79
12	53	0.71	0.01	1.00	1.20
13	39	1.10	0.01	2.20	1.20
14	49	0.68	0.00	1.70	0.28
15	43	0.35	0.22	2.00	0.23
16	37	0.53	0.03	0.08	0.28
17	40	0.48	0.01	1.10	0.29
18	59	0.59	0.31	1.90	0.33
19	65	0.28	0.00	0.10	0.58
20	27	0.34	0.00	0.01	0.40
21	28	0.65	0.00	0.90	0.53
22	35	0.27	0.01	1.00	0.31
23	55	0.55	0.40	1.10	1.10
24	55	0.43	0.01	1.00	0.42
25	60	0.35	0.13	1.80	0.54
Max value, x_{max}	*69*	*0.76*	*0.02*	*2.30*	*1.26*
Min value, x_{min}	*17*	*0.16*	*0.00*	*0.00*	*0.00*
Average value, x	*43*	*0.46*	*0.01*	*0.90*	*0.58*
Amplitude	*53*	*0.60*	*0.02*	*2.30*	*1.26*
Median	*44*	*0.46*	*0.01*	*1.00*	*0.48*
Dispersion, s^2	*175*	*0.02*	*0.00*	*0.49*	*0.12*
Standard deviation, s	*13*	*0.15*	*0.00*	*0.70*	*0.34*

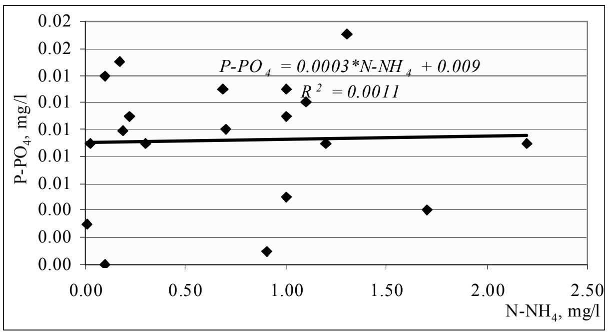


Fig 4. Phosphate concentration dependence on ammonium nitrogen concentration in aeration zone during cold season

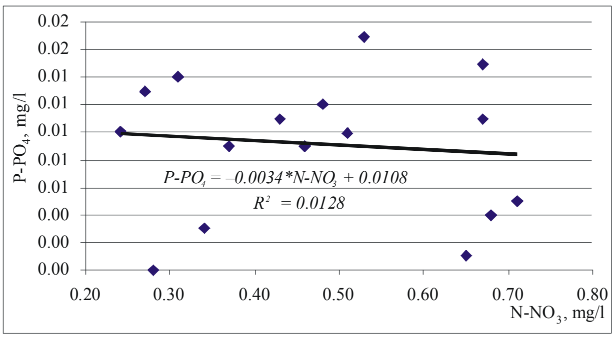


Fig 5. Phosphate concentration dependence in the aeration zone on nitrate concentration in anaerobic zone during cold season

During the increase of ammonium nitrogen above 2.2 mg l^{-1} in the aerobic zone, the concentration of phosphates did not increase.

The regressive correlation analysis did not show the concentration of phosphates in the aeration zone to depend on ammonium nitrogen concentration in the anaerobic zone. The model correlation index was close to zero (Fig. 4). No negative impact of nitrates on phosphates was found, because the concentration of nitrates did not exceed 1.1 mg l^{-1}. Neither did the regressive correlation analysis show the concentration of phosphates in the aeration zone to depend on nitrate concentration in the anaerobic zone (Fig. 5). The model correlation index was close to zero, too.

CONCLUSIONS

The temperature of treated wastewater was 17.7–20.8 °C (mean, 19.4 °C), and dependence of phosphates and ammonium nitrogen in the aerobic zone in the aeration tanks was estimated. Analysis of the warm season data showed that with the increase of ammonium nitrogen above 1 mg l^{-1} in the aerobic zone, the concentration of phosphates was increasing, and the concentration of total phosphorus in the effluent exceeded 1.5 mg l^{-1}. The dynamics of phosphates in the aerobic zone and of nitrates in the anaerobic zone in the warm season, in fully aerobic conditions (if the aerobic phase was prolonged) was estimated. Similarly, with the increase of nitrates above 1 to 3.2 mg l^{-1} in the anaerobic zone, the concentration of phosphates was increasing, and the concentration of total phosphorus in the effluent exceeded 1.8 mg l^{-1}. The reason for this phenomenon could be that the carbon store in the cells becomes depleted before the sludge reaches the end of the aerobic zone, and a new carbon store begins to build up, resulting in polyphosphate degradation.

However, when the temperature of wastewater was 12.4 to 17 °C (mean, 14 °C), no interrelation of phos-phates and ammonium nitrogen in the aerobic zone of the aeration tanks was estimated. With increasing of ammonium nitrogen level above 2.2 mg l^{-1} in the aerobic zone, the concentration of phosphates did not increase, and the concentration of total phosphorus in the effluent did not exceed 0.71 mg l^{-1}. This fact could indicate the impact of other unknown factors, which need further research.

Thus, in the warm season, to ensure wastewater total phosphorus concentration up to 1.5 mg l^{-1}, nitrate concentrations in the anaerobic zone and ammonium nitrogen concentrations in the aerobic zone should not exceed 1 mg l^{-1}.

Received 11 November 2006
Accepted 10 February 2007

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BIOLOGINIO AZOTO ŠALINIMO IŠ NUOTEKŲ ĮTAKA FOSFORO ŠALINIMUI

Santrauka

Siekiant išvengti eutrofikacijos vandens telkiniuose, būtina iš nuotekų šalinti azotą ir fosforą. Biologinis azoto šalinimas iš nuotekų dažniausiai derinamas su fosforo šalinimu. Anaerobinės ir aerobinės fazės kaitaliojimasis yra būtina sąlyga biologiškai šalinant fosforą. Kad mikroorganizmai optimaliai pasisavintų fosforą, turi būti pakankamai deguonies aerobinėje zonoje. Šį kiekį nurodo visiška arba beveik visiška nitrifikacija. Šio darbo tikslas buvo nustatyti azoto šalinimo įtaką fosforo šalinimui, esant suderintai biologinio azoto ir fosforo šalinimo technologinei schemai. Tam tikslui nagrinėta, kokioms amonio azoto reikšmėms esant aeracinėje zonoje, neįvykus visiškai nitrifikacijai, fosfatai pradeda išsiskirti iš organizmų į nuotekas ir kada fosfatai išsiskiria, jei aerobinė fazė prailginta. Nustatytas dalinės nitrifikacijos ir fosfatų išsiskyrimo aerobinėje zonoje ryšys bei aerobinės fazės prailginimo poveikis fosfatų išskyrimui aerobinėje zonoje. Esant valomų nuotekų temperatūrai nuo 17,7 iki 20,8°C, o vidutinei 19,4°C, nustatyta fosfatų koncentracijos priklausomybė nuo amonio azoto koncentracijos aeracinėje kameroje. Gauti rezultatai parodė, kad pakilus amonio azoto koncentracijai per 1 mg/l aeracinėje kameroje, fosfatai pradeda išsiskirti iš organizmų į nuotekas. Tuomet liekamasis bendrojo fosforo kiekis valytose nuotekose yra didesnis nei 1,5 mg/l. Taip pat nustatyta fosfatų koncentracijos aeracinėje kameroje priklausomybė nuo nitratų koncentracijos anaerobinėje kameroje šiltuoju metų laikotarpiu. Esant visiškoms aerobinėms sąlygoms, kai aerobinės fazės trukmė prailginta, padidėjus nitratų kiekiui anaerobinėje kameroje per 1 mg/l, daugiau fosfatų išsiskyrė aeracinėje kameroje ir kartu pablogėjo išvalymo efektas pagal bendrąjį fosforą. Tuo metu išleidžiamose nuotekose bendrojo fosforo koncentracija didesnė kaip 1,8 mg/l. Priežastis galėtų būti tai, kad anglies atsargos ląstelėse išeikvojamos dar dumblui nepasiekus aerobinės zonos pabaigos ir todėl, skaidant polifosfatus, pradedamos kaupti anglies atsargos. Tačiau toliau nagrinėjant tyrimų, atliktų šaltuoju metų periodu, tiriamų valomų nuotekų temperatūrai kintant nuo 12,4 iki 17°C, o vidutinei esant 14°C, rezultatus, paaiškėjo, kad amonio azoto koncentracijai net viršijus 2,2 mg/l, fosfatai iš organizmų į nuotekas nepradėjo išsiskirti. Tuomet liekamasis bendrojo fosforo kiekis valytose nuotekose yra ne didesnis kaip 0,71 mg/l. Tam galėjo turėti įtakos kiti dar nežinomi veiksniai, kurių ištyrimas yra tolesnių eksperimentų tikslas.