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EFFECTS OF SHORT SLUDGE RETENTION TIME ON ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL IN AN SBR SYSTEM

The behaviour of a fill-and-react activated sludge system operating at short solid retention time (SRT) was observed. Enhanced biological phosphorus removal (EBPR) was established and sludge phosphorus content was above 4.0%. It was proved that EBPR could be sustained even at very short SRT. Phosphate accumulating organisms (PAO) were washed-out for SRT shorter than 1.5 d. The best system performance and phosphorus capacity were for SRT = 2 d. The results presented in the paper confirm previous findings and literature data.

ABBREVIATIONS

SBR – sequencing batch reactor,
SRT – solids retention time,
EBPR – enhanced biological phosphorus removal,
PAO – phosphate accumulating organisms,
VFA – volatile fatty acids,
MLSS – mixed liquor suspended solids,
P_{MLSS} – phosphorus content in mixed liquor suspended solids.

1. INTRODUCTION

Due to increasing eutrophication of rivers, lakes and coastal waters as well as the need to comply with the European Union legislation, the interest in high-efficient methods of phosphorus removal has increased dramatically in recent years in Poland. In order to fulfil the requirements for EU membership, Polish legislation system has to be adapted to European Union by the year 2000. The former Polish law permitted the phosphorus concentration in effluent from wastewater treatment plant as high as 5 mg/dm^3 and this will have to be lowered to 1.5 mg/dm^3 after 2000. Not all of Polish wastewater treatment plants are equipped with adequate facilities to achieve such high phosphorus removal capacity.

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Probably the best known and most popular method for removal of phosphorus excess quantities is chemical precipitation. Although the process is very reliable it brings about construction of additional technological lines (chemical storage, dilution and dosage installations) and enlarges the volume of sludge generated, contributing to the increase of operational costs.

Enhanced biological phosphorus removal process (EBPR) seems to be a very good alternative to chemical precipitation. The principle of EBPR process is that the bacterial population is alternately subjected to anaerobic and aerobic conditions enabling development of a specialised population. The mechanisms of the EBPR process are still being discussed and are not fully understood. It was shown that under anaerobic–aerobic conditions bacteria that are capable of storing energy in the form of polyphosphates inside their cells prevail. During the anaerobic phase these microorganisms hydrolyse stored polyphosphates and obtain energy for the uptake of carbon compounds such as volatile fatty acids (VFA) or other easily accessible carbon source. Hydrolysed polyphosphates are released to supernatant as orthophosphates, and taken up carbon compounds are stored as polyhydroxyalkanoates (PHA), primarily polyhydroxybutyrate (PHB), inside the microbial cells. During the aerobic phase poly-P bacteria (phosphate accumulating organisms – PAO) regain poly-P level by the excess uptake of orthophosphates and use stored PHA as carbon and energy source [5], [8]. Therefore under anaerobic–aerobic conditions this type of metabolism is preferred and poly-P bacteria prevail in such a system. Thus, during treatment the shape of phosphorus concentration curve typical of enhanced populations is that the increase of soluble phosphorus concentration in the supernatant during an anaerobic phase is followed by its rapid decrease during the subsequent aerobic phase. The more phosphorus is released during the anaerobic phase, the more of it will be taken up during the aerobic phase, provided that there is enough (and not in excess) easily accessible organic matter in the anaerobic phase (to prevent the phenomenon of secondary release) [5]. The excess quantities of the organic matter may lead to a situation where not all of the substrates are utilised during the anaerobic phase and their passing on to the aerobic phase will cause a phosphorus uptake inhibition [15]. In the system without EBPR process, the phosphorus content typical of activated sludge on mixed liquor suspended solids (MLSS) basis ranges between 1.5% and 2.3%, while that in EBPR system may be as high as 8–10% or even more.

Despite the high variability of the process there are a few full-scale installations taking advantage of EBPR. Numerous tests were carried out in order to understand and comprehensively assess the influence of different factors and agents on the process. PAO seem to be very sensitive to the process conditions. It is known that VFA have definitely stimulatory effect on the EBPR process, but as shown they may be inhibitory in very high doses [9]. Oxygen present in anaerobic zone has high inhibitory effect on the process. The same effect have all nitrogen oxides. It was also proved that in order to observe EBPR process, metal ions such as Mg^{2+} and K^{+} were necessary in the influent [2], [10].

Such technical parameters as temperature, aeration intensity, solids' retention time (SRT) or pH also affect the EBPR process. It is generally accepted that the intensity of EBPR process does not change in the SRT ranging from 3 to 7 d. Increasing of sludge age results in nitrate formation and may deteriorate EBPR due to competition with nitrifying bacteria, while too short SRT may result in washout of BAP population [15]. In different studies it was shown that depending on the system operation the washout SRT varied. SHAO et al. [13] reported the decrease in the efficiency of phosphorus removal from 94.6% to 62.0% with lowering sludge age from 2.5 to 1.8 days. The same author observed lack of phosphorus release in the anaerobic phase (no EBPR process) in the system with SRT equal to 1.5 d [13]. According to some authors washout SRT was heavily dependent on the temperature and systems were more prone to washout at lower temperatures. At the temperature of 10 °C the washout SRT was 5 days, but other authors claimed that EBPR was possible even at very low temperatures (5 °C) [6]. MAMAIS and JENKINS [6] reported that at the temperature between 10 and 37 °C the changes in SRT above 2.9 d did not influence EBPR. At the SRT shorter than 2.9 d systems were susceptible to PAO washout, and washout SRT depended on the temperature [6]. Some authors claim that the best overall efficiency of the system (on P-removal basis) is achieved for SRT = 10 d [11]. In the treatment systems operating in longer or shorter SRT the phosphorus removal is worse. However, these results were not confirmed by other researchers. Generally the scientists are agreed that phosphorus removal efficiency is not changed drastically with changing SRT in the range of 3–25, provided that there are no inhibitory substances (e.g. nitrogen oxides) and the washout SRT is heavily dependent on ambient temperature.

2. OBJECTIVES

The objective of this study was to observe the behaviour of activated sludge system and removal efficiencies (especially enhanced biological phosphorus removal) during shortening the activated sludge solid retention time. The secondary aim was to observe the washout SRT for a specific wastewater under ambient conditions. The experiments were conducted on synthetic wastewater of characteristics adequate to municipal wastewater in sequencing batch reactor system.

3. METHODS AND MATERIALS

Activated sludge used for seeding the system was taken from municipal wastewater treatment plant not revealing EBPR during sample collection. The system configuration was SBR. In the moment of sampling no EBPR was observed. The laboratory system was seeded and during early days of experiment no phosphorus release was observed. The system was considered adapted when phosphorus release appeared at the end of the anaerobic phase, i.e. after 4 weeks of seeding the reactors.

Experimental set-up. The experimental set-up consisted of two laboratory-scale sequencing batch reactors, each of 3.3 dm^3 volume (working volume of 2.7 dm^3). The reactors were glass jars with plastic covers. They were equipped with aeration and excess sludge removal facilities glued with silicon glue to the jar walls. The excess sludge facility could be adjusted to different sludge volumes discharged to allow SRT changes. The reactors were operated at 3 cycles/day (8 hours per cycle). Each cycle consisted of four phases: the operation began with an anaerobic phase lasting for 2 hours and 45 minutes, with filling of the reactors at the beginning of the phase (13 minutes), followed by an aerobic phase (4 hours and 15 minutes) and settling phase (45 minutes). Settling was followed by drawing lasting about 12 minutes and idle time of about 2–3 minutes. The raw wastewater was prepared daily by mixing and solubilizing adequate quantities of ingredients in tap water and stored in 30 dm^3 tank from which it was pumped out. Peristaltic pumps were used to fill and draw the reactors, and mechanical stirrers to mix the sludge during anaerobic phases (set at about 150 rot/minute). An air pump enabled drawing excess sludge. All operations were performed automatically and controlled by 5 timers.

Wastewater. The wastewater used for the experiments was a synthetic medium. The medium was prepared daily by dissolving 200 mg of broth, 310 mg of gelatine peptone, 60 mg of NH_4Cl, 2 mg of $MgSO_4$, 50 mg of NaH_2PO_4, 20 mg of KH_2PO_4, 70 mg of NaCl and 30 mg of NaH_2CO_3 in 1 dm^3 of tap water. No suspended matter was added to the medium (MLSS ≈ 0). The synthetic wastewater was used in order to avoid inevitable wastewater composition variations when municipal wastewater was applied. The synthetic wastewater was characterised by a relatively high phosphorus content (22 g P/m^3), which prevented phosphorus shortage. A detailed characteristics of the synthetic medium is shown in table 1.

Table 1

Raw synthetic wastewater characteristics

Parameter	Unit	Value
pH		7.0
Alkalinity	val/m^3	5.0
Total organic carbon (TOC)	g C/m^3	170
BOD_5	g O_2/m^3	300
Ammonium nitrogen ($N-NH_4$)	g N_{NH_4}/m^3	22
Organic nitrogen ($N-N_{org}$)	g N_{org}/m^3	45
Nitrogen (N_{total})	g N_{tot}/m^3	67
Phosphates ($P-PO_4$)	g P_{PO_4}/m^3	22
Phosphorus	g P_{tot}/m^3	20

Technological factors. The volume flowing into the system at the beginning of an anaerobic phase was 1.2 dm^3. The appropriate volume was drawn as excess sludge at the end of the aerobic phase and the rest was drawn at the end of the settling period. The systems were operated for SRT = 0.76 d (18 h). The acclimatisation time was at least 4 SRT, no analysis had been carried out beforehand. All effluent wastewater analyses were carried out during the following week, one analysis set per day, six days in row. Arithmetical means were calculated for every parameter measured.

This paper presents the results of the experiments run on activated sludge systems of SRT ranging from 1.45 to 6.0 days. The results are presented in terms of arithmetical means. Influent wastewater was analysed at the beginning of the experiments and it was assumed that its quality did not change in time. Spot sample analyses were carried out from time to time and they proved that none of the parameters changed.

Analytical methods. All analyses were carried out in accordance with the Polish Standards. Basic parameters of the wastewater treated (pH, temperature, alkalinity, concentrations of phosphates, nitrites and ammonium nitrogen) were measured daily. Certain analyses were carried out every second day during the measuring period (MLSS and mixed liquor volatile suspended solids, TOC, sludge phosphorus content (P_{MLSS})), while some only once to ensure the correctness of technological parameters (concentrations of nitrates and total phosphorus in the influent and effluent). Dissolved oxygen and redox potential were also measured during one full cycle to confirm technological correctness of the process.

4. RESULTS AND DISCUSSION

System start-up. The laboratory system was seeded and during the first weeks of experiment no phosphorus release was observed. Both SBRs were initially set for SRT = 4 d. It can be assumed that the time needed for the system adaptation is about 3–5 times longer than SRT lasting 4 d. Phosphorus concentration was frequently measured during the first month after seeding and significant phosphorus release could be observed only after 4 weeks from the seeding. The systems were considered adapted after 4 weeks and at that time the experiments started. Despite a very short SRT of the system, EBPR did not appear before one month of the operation. This could indicate that PAO needed a relatively long time to appear in the system, if the system was not inoculated with an appropriate bacterial culture. This observation is confirmed by some other authors' investigations carried out on enhanced bacterial cultures [8].

General operating conditions. The experimental results are presented in figures 1–4 and in table 2. The temperature varied in the range of 20.3–23.0 °C during whole experimental period. Such a small temperature fluctuations are not considered to cause significant EBPR changes. The oxygen concentration decreased approaching zero in approx. 10 min after the mixing was started at the beginning of anaerobic phase. At the beginning of aerobic phase 10 min aeration of the system resulted in the increase of oxygen concentration to 6–8 g/m^3. Analogously, the redox potential dropped below zero during 30 min of anaerobic phase and further down to about –120 mV during another 30 min, and it rose to 100 mV during the first 30 min of aerobic phase. These measurements ensure technological correctness of the experiments. As expected, the longer SRT, the better organic fraction removal effectiveness. For a very short SRT organic nitrogen can be found in the effluent, but it is completely eliminated for SRT = 6 days. The decrease of alkalinity and pH for SRT ≈ 6 d is caused by quantitative formation of nitrites.

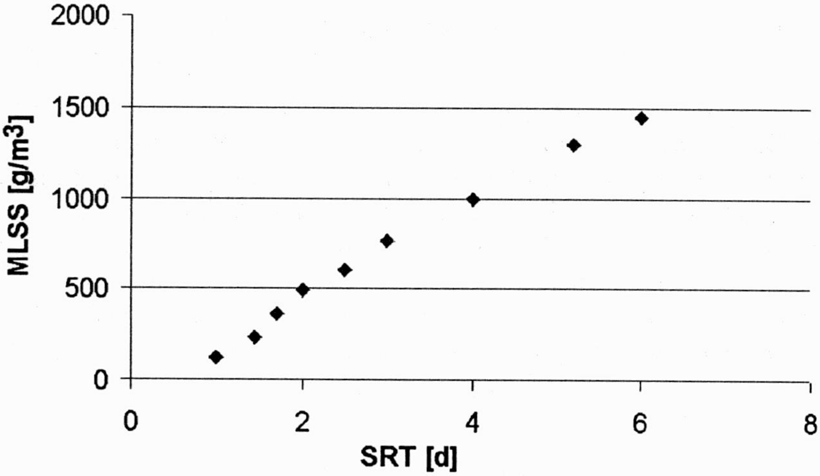

Fig. 1. Mixed liquor suspended solids

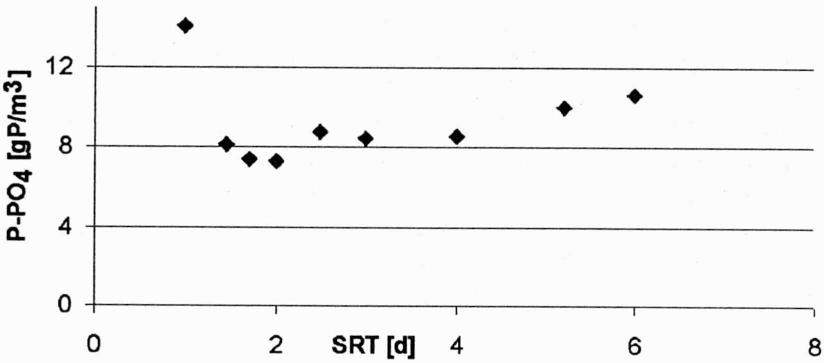

Fig. 2. Effluent phosphates

Mixed liquor suspended solids (MLSS) content in the whole system was between 120 and 1450 g/m^3 for SRT equal to 1.0 and 6.0 days, respectively. The content of MLSS is relatively low (compared to the content of typical wastewater from treatment plants facilities or industrial installations operating in similar SRT) because there is no suspended matter in the influent to the reactors, hence its accumulation is not possible. The experiments were also conducted for SRT = 7 d, but MLSS was deteriorated by mass reproduction of *Rotatoria* and therefore the results are not presented in the article. SRT = 7 d seems to be long enough to enable a rapid *Rotatoria* reproduction. These micro-organisms tended to eat-up the bacterial content of activated sludge which reduced the content of suspended solids. In the SRT range between 2.0 and 6.0 days, MLSS changed linearly and the quantity of excess sludge (on MLSS basis) discharged daily was approximately the same. The content of suspended solids in the system versus SRT is presented in figure 1.

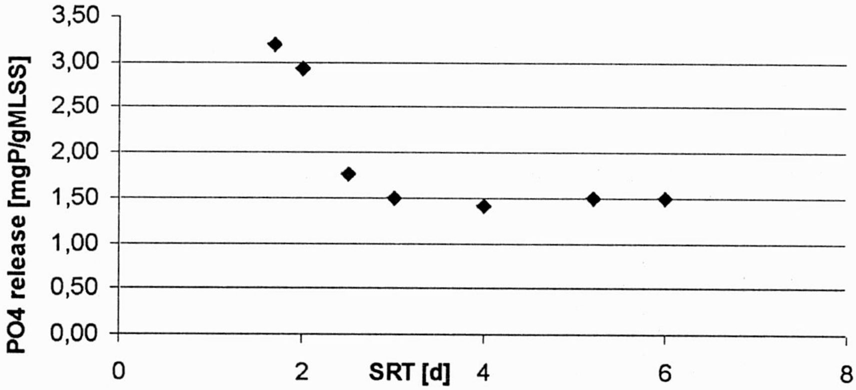

Fig. 3. Phosphorus release per gram of MLSS during 2.5 hour anaerobic phase

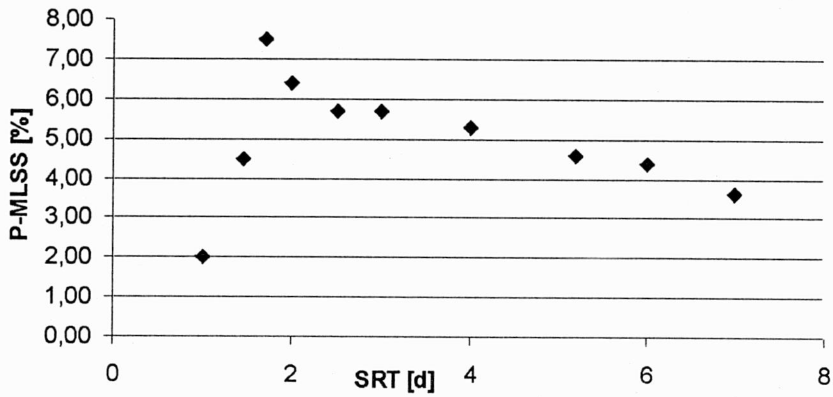

Fig. 4. MLSS phosphorus content

Phosphorus removal. The influent total phosphorus consisted of phosphates (in mineral fraction of the wastewater, 20 g/m^3 as phosphorus) and organic phosphorus (added as organic compounds, 2 g/m^3). Effluent phosphorus consisted of phosphates only.

Table 2

The effects of wastewater treatment in SBR system with varying SRT

Parameter	Unit	Solid retention time [d]								
		SRT = 1.0	SRT = 1.45	SRT = 1.7	SRT = 2.0	SRT = 2.5	SRT = 3.0	SRT = 4.0	SRT = 5.2	SRT = 6.0
pH		8.0	7.2	7.5	7.9	7.7	8.0	8.1	8.0	6.7
Temperature	°C	23.0	21.5	21.3	21.5	20.3	21.5	22.0	22.0	21.7
Alkalinity	g/m^3	4.8	3.8	3.8	5.0	5.6	5.7	5.3	5.2	1.4
TOC	$g\ C_{org}/m^3$	24.8	21.5	16.0	20.3	21.8	18.3	15.2	13.8	11.8
Phosphates	$g\ P_{PO_4}/m^3$	14.1	8.1	7.4	7.3	8.8	8.4	8.5	10.0	10.6
Nitrates	$g\ N_{NO_3}/m^3$	nd	nd	nd	nd	nd	0.1	nd	0.1	0.2
Nitrites	$g\ N_{NO_2}/m^3$	1.0	1.0	1.1	1.8	1.0	1.0	2.0	3.5	26.0
Ammonium nitrogen	$g\ N_{NH_4}/m^3$	35.7	45.0	43.0	45.0	36.0	45.0	45.0	43.0	20.0
Organic nitrogen	$g\ N_{org}/m^3$	18.3	3.5	–	2.0	3.2	traces	traces	traces	traces
Total nitrogen	$g\ N_{tot}/m^3$	55.0	49.0	46.6	48.8	40.3	48.8	47.0	46.6	46.2
MLSS	g/m^3	120	230	360	490	600	760	1000	1300	1450
MLVSS	% MLSS	65	70	73	70	72	75	75	72	76
P_{MLSS}										
measured	%	2.0	4.5	7.5	6.4	5.7	5.7	5.3	4.6	4.4
from mass balance	%	6.5	9.7	7.7	6.8	6.1	6.0	5.8	5.6	5.2
PO_4 release/MLSS	$mg\ P_{PO_4}/g\ MLSS \cdot 2.5\ h$	–	–	3.19	2.93	1.76	1.50	1.40	1.50	1.50

All values are arithmetical means of 6 measurements conducted during one week (unless different in *Methods and Materials*).
nd – not detected.
Traces – very close to detection limit (0.7 g/m^3).

The lowest concentration of phosphate effluent (7.3 g P_{PO4}/m^3) is found when SRT approaches 2 days. Phosphate effluent concentration increases gradually as the SRT increases (to 10.6 g P_{PO4}/m^3 for SRT = 6.0 d) and very rapidly when the SRT is decreased (to 14.1 g P_{PO4}/m^3 for SRT = 1.0 d). Detailed data on effluent quality are presented in table 2. The particular SBR system has the highest phosphorus removal capacity for this SRT due to superposition of two factors: a) very high phosphorus-to-total solids ratio, b) relatively high amount of activated sludge discharged as excess sludge. Activated sludge discharged daily for SRT = 2.0 d amounted to 660 mg MLSS/d and it is nearly as much as for the systems operated for SRT = 5.0 or 6.0 days. The phosphorus content of 2.0 d sludge was 6.4% (as measured, 6.8% from mass balance). When SRT was longer, the content of phosphorus in sludge was lower, i.e. 4.4% (or 5.2% from mass balance) for 6.0 d sludge. For the shorter SRT the amount of excess sludge (as MLSS) was significantly lower, i.e. ΔTS = 430 and 325 mg MLSS/d for SRT = 1.0 and 1.45 days, respectively. This is why the capacity of phosphorus removal reaches its maximum for a very short SRT. For a longer SRT, this capacity decreases and according to WENTZEL and EKAMA [16] such a decrease should be asymptotic. Analysing the experimental results and figure 2 it can be observed that the concentration of effluent phosphorus tends to approx. 11.4 g P_{PO4}/m^3 for a longer SRT. The decrease in the excess sludge production reduces the capacity of phosphorus removal in the system for longer SRT.

The possibility of partial precipitation of phosphates induced by phosphorus release during an anaerobic phase as described by MAURER et al. [7] was investigated (the so-called biologically-induced precipitation). The experiments proved that the phosphates' precipitation occurred and approached no more than 7% of total phosphorus removal even at the highest pH (8.1). In general, the amount of phosphates being precipitated depended on pH, but in some cases no precipitation could be measured even at pH = 8.0. The phosphates' precipitation does not seem to influence considerably the results of the experiments for a defined wastewater.

Phosphorus release. Phosphorus release was observed during 2.5 hours of an anaerobic phase. The concentration of supernatant phosphorus was measured after the reactor was filled and then by the end of the anaerobic phase. Phosphorus release per gram of suspended solids was then calculated.

It was observed that the shorter the SRT, the greater the phosphate release per gram of MLSS. This release exceeded the value of 1.3 mg P_{PO4}/g MLSS×2.5 h for SRT longer than 4 days, while it was as high as 3.2 mg P_{PO4}/g MLSS×2.5 h for SRT = 1.7 d. Phosphate release per gram of MLSS is closely related to the content of suspended phosphorus in solids. The higher P_{MLSS}, the more phosphates released to the supernatant. This is a logical relationship, because in the shorter SRT, PAO may contribute to a large fraction of activated sludge biocenosis, which is confirmed by very high concentration of P_{MLSS} and also by microscopic analyses (only bacteria occur in very short SRT). This is why phosphorus release per gram of MLSS is higher in shorter SRT. The quantities of phosphorus released per gram of the activated sludge dry matter are typical of municipal wastewater and comparable to the values reported in literature [3], [4], [6].

The fact that phosphorus release and luxury uptake were observed even for a very short SRT (even for 1.7 d) proved that PAO population was not washed-out until SRT was shortened to less than 1.5 d and:

• Substrates used under laboratory conditions satisfied the PAO population needs.

• Laboratory conditions were appropriate for the PAO succession and dominance (in shorter SRT).

• Relatively high temperature (20–23 °C) enabled an intense PAO population reproduction. PAO washout did not occur until the SRT was shorter than 1.5 d. It should be stressed that in the designs of wastewater treatment plants such high temperature is not taken into account.

Content of sludge phosphorus. The contents of sludge phosphorus (P_{MLSS}) measured and calculated from mass balance are different. Precipitation of some phosphates is probably responsible for these differences. The calculated P_{MLSS} is higher than the measured P_{MLSS} by up to 8% for SRTs equal to 1.7, 2.0, 2.5, 3.0 and 4.0 days. This is associated with phosphates' precipitation – up to 7% of phosphates are precipitated at the highest pH. This difference is much higher for SRTs equal to 1.45 and 1.0 days, which can be attributed to biofilm growth and mass balance difficulties (as described below). Also for SRTs equal to 5.2 and 6.0 days the differences are bigger and in the case of SRT = 5.2 d this phenomenon may be partially explained by apparently higher precipitation (relatively high pH = 8.0). However, such an explanation cannot be accepted for SRT = 6.0, as pH in this case is the lowest (6.7). The author is unable to explain this discrepancy. Despite these differences, the general tendency towards the changes in sludge phosphorus content is easily seen and clear.

The content of total solid phosphorus is higher for shorter SRT. The P_{MLSS} typical of 5- and 6-day sludge is ca. 4–5% and it exceeds the value of 7% when SRT is shorter than 2 days. For the very short SRT (ca. 2 days) PAO are a significant fraction of activated sludge mass. For this low SRT a great deal of other microorganisms are washed-out and only various kinds of bacteria remain. As microscopic examinations proved there were no other microorganisms observed (*Vorticella, Opercularia, Euplotes*, *Nemathoda, Rotatoria*) but bacteria for SRT shorter than 2 days. The content of MLSS phosphorus decreases asymptotically to a value of approx. 4.0% for a longer SRT. For SRT longer than 4 days, activated sludge microbial population is very diversified, different kinds of *Vorticela, Opercularia* and other higher microorganisms appear contributing to higher MLSS content and relatively lower bacterial content. Microorganisms other than PAO have phosphorus content of 1.5–2.3%, which decreases an overall content of sludge phosphorus. The shortest operational SRT for this system was 1 day, since it was not possible to operate in shorter time because of technological and hydraulic restrictions of the system. For this short SRT, the PAO washout, together with washout of the majority of microorganisms, was observed. Those results are also reported by other researchers [6], [10]. Most authors observed the PAO washout when SRT was shorter than 2 d, which was also confirmed by these experiments. EBPR was still observed for SRT = 1.7 d. When SRT was reduced to

1.45 d, the beginning of BAP washout could be observed, which could be deduced from the lower content of phosphorus in the sludge. For SRT = 1 d the content of phosphorus decreased to 2% which indicated that PAO were washed-out from the system. Even for the shortest SRT, phosphorus release could be observed and EBPR took place.

This phenomenon can be explained as follows: There was a significant difference between phosphorus content (P_{MLSS}) measured in sludge and phosphorus content calculated from mass balance for SRT shorter than 1.7 d. This may be attributed not only to the precipitation contribution, but also to the fact that for very short SRT (1.45 and 1.0 d) the amount of mixed liquor suspended solids was comparable to the amount of a sludge growing on jar walls, hence MLSS would have to be calculated as a sum of both fractions. Additionally, the biofilm growing on the jar wall released some amount of phosphorus, even in the shortest SRT. This inconvenience can be taken into account in future experiments when SRT will be very short: bigger reactors should be used to avoid problems with mass balance.

As postulated by WENTZEL and EKAMA [16] the amount of volatile solids (MLVSS) in suspended solids is dependent on the phosphorus content in sludge – the higher the P_{MLSS} content, the lower the MLVSS fraction. This relationship is vaguely observed in the experiments. Volatile solids contribute to 75% of MLSS when the phosphorus content in sludge is approx. 4%. MLVSS contribute up to 70% for shorter SRT and phosphorus content in sludge above 6%.

5. CONCLUSIONS

The experiments were carried out in order to assess the effectiveness of phosphorus removal in SBR, depending on the sludge retention time of the system. The results obtained can be presented as follows:

• Sludge adaptation to enhanced biological phosphorus removal process did not occur before one month has elapsed since the seeding of the system.

• Enhanced biological phosphorus removal was observed in a wide range of the SRT investigated (1.7–7 d). PAO washout was observed for SRT shorter than 1.5 d, which confirmed results found in literature.

• The maximal phosphorus capacity was obtained for SRT = 2 d (effluent phosphates P = 7.3 g P_{PO_4}/m^3). This capacity decreased asymptotically with longer SRT.

• The phosphorus content in sludge was highest (almost 8%) for SRT = 1.7 d and decreased asymptotically to approx. 4% for SRT longer than 5 days.

• The phosphorus release was observed in the wide range of SRT (for sludge age above 1.45 d). In the system operating for SRT = 2.0 d, the release of phosphorus per gram of TS was twice as high as that in the system where SRT was longer than 4 d.

• Due to biofilm growth it was not possible to eliminate completely phosphorus release even for the shortest SRT. For this short SRT bigger reactor should be employed to minimise mass balance discrepancy.

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WPŁYW KRÓTKIEGO WIEKU OSADU NA NADMIAROWE BIOLOGICZNE USUWANIE FOSFORU W MODELU SBR

Zbadano zachowanie tłokowego układu oczyszczania ścieków metodą osadu czynnego (SBR) podczas utrzymywania krótkiego wieku osadu. Układ zaszczepiono osadem czynnym pochodzącym z komunalnej oczyszczalni ścieków i po około miesiącu uzyskano nadmiarowe wbudowywanie fosforu (EBPR) w biomasę; zawartość fosforu w biomasie przekraczała 4%. Dowiedziono, że można uzyskać EBPR nawet wtedy, gdy wiek osadu (WO) jest bardzo krótki. Organizmy nadmiarowo wbudowujące fosfor w biomasę zostały wymyte z układu, gdy WO był krótszy niż 1,5 d. Najlepszy efekt usuwania fosforu zaobserwowano, gdy WO wynosił 2 d. Otrzymane wyniki potwierdzają wcześniejsze doniesienia literaturowe.

osad czynny usuwanie fosforu
oczyszczalnie ścieków
biomasa