USE OF HYDROLYZED PRIMARY SLUDGE AS CARBON SOURCE FOR DENITRIFICATION. A CASE STUDY.

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Abstract The aim of this work was to evaluate the possibility to improve nitrogen removal efficiency by use of hydrolyzed primary sludge as carbon source for denitrification. Activated sludge model No. 2d was chosen as a basis for simulation experiments. The model was calibrated then used to compare several control strategies. High concentration of phosphorus in the digested primary sludge thickener supernatant transported to secondary anoxic reactor results in the increase of phosphorus concentration in the WWTP effluent. The optimal scenario was found as a compromise between N and P removal, which suggested 7% decrease in nitrogen concentration.

Keywords wastewater treatment, nutrient removal, simulation, ASM2d

INTRODUCTION

Many of municipal wastewater treatment plants in Poland were built in period of very dynamic socioeconomic changes. After few years of exploitation, it can be clearly seen that expected flow of raw sewage received by plants is significantly lower and pollution load is much higher than expected. The amount of municipal sewage to be processed in many wastewater treatment plants is nowadays at the level of 50% of their hydraulic capacity. On the other hand, unitary load of contamination that can be found in wastewater is so high that many objects are beyond their processing capacity. Increase of nitrogen compounds in raw sewage was shown to occur in many plants. For Ostrów Wielkopolski wastewater treatment plant the increase is considerable - from designed 48 g/m^3 to about 75 g/m^3 and above. Content of nitrogen compounds limits the amount of raw sewage that a plant can accept. Under designed hydraulic capacity of 26 000 m^3/day, average flow of raw sewage to plant at level of about 13 000 m^3 seems to be problematic to meet legal regulations for the discharge of total nitrogen.
In this work some simulation experiments were made to find the best control strategy for the plant. The aim of this study was to investigate the possibility to improve denitrification process efficiency by use of hydrolyzed primary sludge as carbon source for denitrification.

MATERIALS AND METHODS

Description of the Ostrow Wielkopolski WWTP

The wastewater treatment plant considered in this paper is located near the Ostrow Wielkopolski city in Poland. The plant is designed to receive 26 000 $m^3 \cdot d^{-1}$. There are two identical technological lines. Primary treatment is composed of screens and grit chamber followed by primary clarifier and primary sludge digester and thickener. All the primary sludge thickener's outflow is directed into anaerobic reactor R1.
Secondary treatment is designed to enhanced biological nutrient removal and it is comprising:

- anaerobic reactor (R1), $V_{R1} = 800\ m^3$,
- anoxic reactor (R2), $V_{R2} = 3200\ m^3$,
- aerobic reactor (R3), $V_{R3} = 6000\ m^3$,
- secondary anoxic reactor (R4), $V_{R4} = 1600\ m^3$,
- secondary aerobic reactor (R5), $V_{R5} = 400\ m^3$.

There is an additional small anoxic reactor placed in return activated sludge line. The reactor is used to improve biological phosphorus removal process by eliminating nitrate nitrogen in return activated sludge.
Total volume of each reactor series is 12400 m^3. Each technological line ends with secondary clarifier. Currently, only one technological line remains active, while the second one is unused due to wastewater inflow rate which is about two times smaller than planned.
The data collected for this study consists of 23 datasets (daily mean values) gathered in 2007. This data were used for model calibration and verification. Then, the data were averaged assuming that this can mimic steady state (Table 1 and 2).

Table 1 Average values of technological parameters used in simulation. Data collected in Ostrow Wielkopolski WWTP, 2007

Parameter	Unit	Value
Influent flow rate	$m^3 \bullet d^{-1}$	13600
Return sludge flow rate	$m^3 \bullet d^{-1}$ %	10800 79
Nitrate recycle rate	$m^3 \bullet d^{-1}$ %	40600 298
Waste sludge flow rate	$m^3 \bullet d^{-1}$ $kg \bullet d^{-1}$	312 2506
Primary sludge flow rate	$m^3 \bullet d^{-1}$ $kg \bullet d^{-1}$	250 2729
Hydraulic retention time in reactors R1-R5	h	22,4
MLSS concentration	$g \bullet L^{-1}$	3,84
Sludge age (R1-R5)	d	17,7
Sludge age (R3, R5)	d	9,2
Wastewater temperature	^oC	15,8

Table 2 Characteristics of the wastewater. Data collected in Ostrow Wielkopolski WWTP, 2007

Parameter	Unit	Raw wastewater	Settled wastewater	Effluent
TSS	$g \bullet m^{-3}$	410	159	5,5
COD	$g \bullet m^{-3}$	770	503	55
BOD_5	$g \bullet m^{-3}$	352	263	2,5
$N\text{-}NH_4$	$g \bullet m^{-3}$	50	49,1	0,17
$N\text{-}NO_3$	$g \bullet m^{-3}$	x	x	10,8
TKN	$g \bullet m^{-3}$	75	67,6	14,1
Total phosphorus	$g \bullet m^{-3}$	10,3	x	1,8

Model configuration

The simulations were based on the Activated Sludge Model No. 2d (ASM2d) (Henze et al., 1999) and carried out using the BioWin software. The ASM2d is a model for biological phosphorus removal with simultaneous nitrification-denitrification in activated sludge systems.

BioWin is a Microsoft Windows-based simulator used world-wide in the analysis and design of wastewater treatment systems.
The model of the WWTP investigated in this study is shown on Figure 1 below.

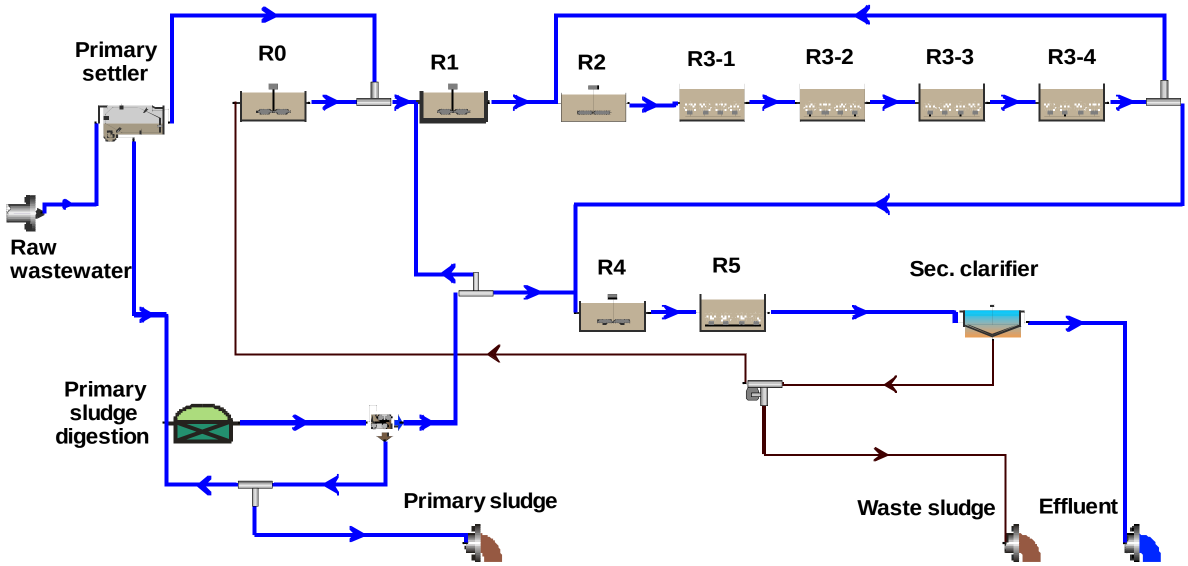

Figure 1 Configuration of the Ostrow Wielkopolski WWTP model used in simulation environment "BioWin". R1 - anaerobic reactor ; R2 anoxic reactor ; R3 - aerobic reactor divided into four parts; R4 - secondary anoxic reactor; R5 - final aerobic reactor; R0 - additional anoxic reactor to remove nitrate nitrogen from return sludge.

Determination of influent wastewater COD fractions

As mentioned above, the ASM2d model was used to simulate organic matter and biogenous substances removal in activated sludge process. An application of ASM family models requires dividing COD into a number of fractions (Henze et al., 2000). Several methods have been developed for wastewater characterization (Sin et al., 2005; Pasztor et al., 2009). The raw wastewater samples were analyzed mostly according to STOWA (Dutch foundation for applied water research) protocol (Hulsbeek et al., 2002). Some of the results of the raw wastewater fractioning are shown in Table 3.

Table 3 Selected values from the raw wastewater composition.

COD fraction		Value
BioWin software variables		
Fraction of total influent COD which is readily biodegradable (f_{BS})	%	24
Fraction of total influent COD which is acetate readily biodegradable (acetate) (f_{AC})	%	21
Fraction of total influent COD which is unbiodegradable particulate (f_{UP})	%	21
Fraction of total influent COD which is unbiodegradable soluble (f_{US})	%	6
Fraction of slowly degradable COD which is particulate (f_{XSP})	%	73
ASM2d variables, as part of total COD		
Readily biodegradable substrate, dissolved (S_S)	%	24
Inert, non-biodegradable organics, dissolved (S_I)	%	6
Slowly biodegradable substrate, particulate (X_S)	%	49
Inert, non-biodegradable organics, particulate (X_I)	%	21

RESULTS AND DISCUSSION

Model calibration

To obtain proper simulation results, some of the model variables must be calibrated. The model predictions for effluent quality, activated sludge concentration in the biological reactors and volatile fatty acids (VFA) in primary sludge thickener effluent were used to calculate prediction errors. The model calibration was performed by comparing calculation results with the measured data and manually adjusting model variables. Based on this expert-approach (Insel et al., 2006) the calibration was obtained changing only four parameters, as depicted in Table 4.

Table 4 Model variables changed during calibration.

Parameter	Unit	Default value	Calibrated value
Maximum growth rate of autotrophic organisms, μ_{AUT}	d^{-1}	0,9	0,8
Maximum growth rate of phosphorus-accumulating organisms (PAO), μ_{PAO}	d^{-1}	1	0,9
Hydrolysis rate constant, K_H	d^{-1}	0,1	0,16
Suspended solids removal efficiency (secondary clarifier)	%	99,8	99,2

The calibration results are shown in Figure 2. It shows that model's prediction exactness is good enough to achieve reasonable simulation accuracy.

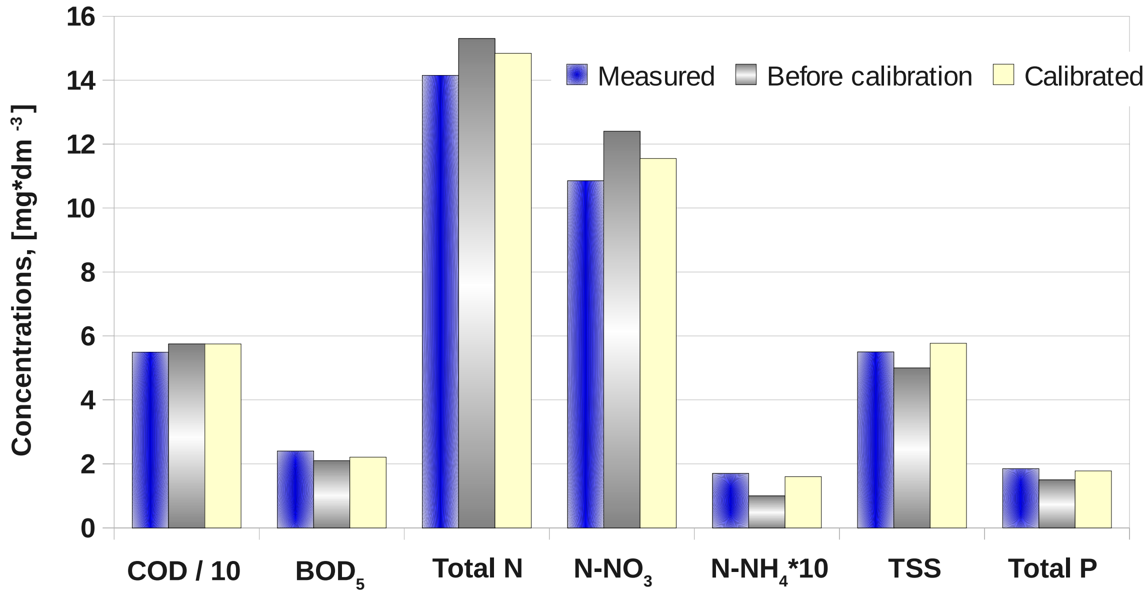

Figure 2 The model calibration results. Comparison of measured and calculated concentrations (effluent from secondary clarifier).

Effect of VFA addition on nitrogen removal

The aim of this work was to study the possibility of use of the hydrolyzed primary sludge as carbon source for denitrification. To achieve this aim, various simulation experiments were conducted. The simulations differed in the amount of VFA-rich primary sludge supernatant transported to final anoxic reactor (R4). It was achieved by the primary sludge thickener outflow partitioning between the two reactors: R1 and R4 as shown on Figure 1. The amount of the VFA changed from 100% to reactor R1 and 0% to reactor R4 to 0% to R1 and 100% to R4, incrementing by 5%. This resulted in 21 simulation experiments. During each of the simulations nitrogen and phosphorus removal efficiency were calculated as shown on Figure 3.

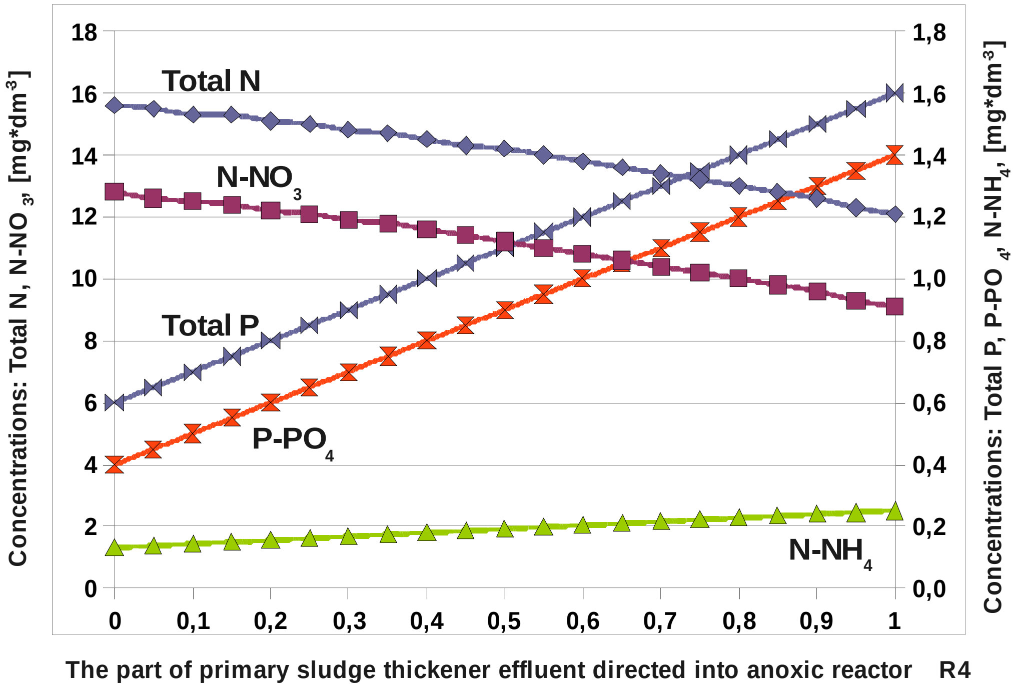

Figure 3 The results of the simulation experiments. Nitrogen and phosphorus concentrations in the WWTP effluent as a function of the primary sludge thickener outflow partitioning.

The readily degradable COD affects the rate of denitrification which influence the nitrogen removal. The total Kiejdahl nitrogen (TKN) decreased from 15,6 mg•dm^{-3} to 12,1 mg•dm^{-3}, but simultaneously total phosphorus concentration increased from 0,6 mg•dm^{-3} to 1,6 mg•dm^{-3}. This is due to two effects. First, there is a big amount of phosphorus in the primary sludge thickener effluent (Table 5). It results in the increase of phosphorus concentration in the reactors R4, R5, secondary clarifier and, of course, in the WWTP effluent. Second, the enhanced phosphorus accumulation efficiency is expected to decrease due to lack of readily biodegradable COD in the anaerobic reactor R1.

Table 5 The primary sludge thickener effluent concentrations. The mean values of the data collected in Ostrow Wielkopolski WWTP, 2007.

Parameter	Unit	Value
COD	mg•dm^{-3}	4500
BOD_5	mg•dm^{-3}	3130
TKN	mg•dm^{-3}	190
$N\text{-}NH_4$	mg•dm^{-3}	182
Total soluble phosphorus	mg•dm^{-3}	59
VFA	mg•dm^{-3}	2120

The increased phosphorus concentration in the WWTP effluent exceeds limits (which are 1 mg P•dm^{-3}). Thus, it is not possible to transport all the VFA-rich supernatant from digested primary sludge thickener to final anoxic reactor R4. The optimal scenario is to transport 40% of supernatant to anoxic reactor R4 and 60% to anaerobic reactor R1.

CONCLUSIONS

The improvement of nitrogen removal by use of hydrolyzed primary sludge as carbon source for denitrification was investigated using a model-based approach.
The ASM2d model employed in this study is able to predict the Ostrow Wielkopolski WWTP plant behaviour with acceptable accuracy.
It is possible to increase nitrogen removal efficiency without dosing of an external carbon source (i.e. methanol). The optimal scenario was found as a compromise between N and P removal, which suggested 7% decrease in nitrogen concentration. Phosphate, however, had to be sacrificed to achieve this nitrogen removal performance (increase from 0,6 mg P•dm^{-3} to 1 mg P•dm^{-3}).

REFERENCES

Henze M.; Gujer W.; Mino T.; Matsuo T.; Wentzel M.C.; Marais G.v.R.; Van Loosdrecht M.C.M., (1999). Activated Sludge Model No.2d, ASM2D, *Water Sci. Technol.*, 39, No. 1, pp. 165-182

Henze, M., Gujer, W., Mino, T., van Loosdrecht, M.C.M., (2000). Activated Sludge Models ASM1, ASM2, ASM2d, and ASM3. IWA Scientific and Technical Report n. 9. IWA Publishing, London, UK.

Hulsbeek J.J.W., Kruit J., Roeleveld P.J., van Loosdrecht M.C.M., (2002). A practical protocol for dynamic modelling of activated sludge systems, *Water Sci. Technol.* 45 (6), pp. 127–136.

Insel G., Sin G., Sung Lee D., Nopens I., Vanrolleghem P.A., (2006). A calibration methodology and model-based systems analysis for SBRs removing nutrients under limited aeration conditions, *Journal of Chemical Technology & Biotechnology*, Vol. 81 (4), pp. 679 - 687

Pasztor I., Thury P., Pulai J., (2009). Chemical oxygen demand fractions of municipal wastewater for modeling of wastewater treatment, *Int. J. Environ. Sci. Tech.*, 6 (1), pp. 51-56

Sin G., Van Hulle S.W.H., De Pauw D.J.W., van Griensven A., Vanrolleghem P.A., (2005). A critical comparison of systematic calibration protocols for activated sludge models: A SWOT analysis, *Water Research*, 39, pp. 2459–2474