Environment Protection Engineering

Vol. 37 2011 No. 4

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TREATMENT OF SLUDGE WATER WITH REVERSE OSMOSIS

Considering the increasingly stringent requirements on the quality of treated wastewater introduced into surface or ground water, it is reasonable to reduce the loads of biogenic compounds produced already at wastewater treatment plants in sludge treatment processes because sludge water produced in such treatment brings into the process cycle up to 20% more of nitrogen and phosphorus load. The paper presents the results of sludge water treatment in a reverse osmosis process. The concentration of biogenic compounds in sludge water was successfully reduced by 95%. The tests were made using a pilot installation and laboratory installation. The concentrate produced in the reverse osmosis was treated by precipitating nitrogen and phosphorus compounds in form of struvite $(NH_4)Mg(PO_4)\times 6H_2O$ that can be next used as a fertiliser.

1. INTRODUCTION

Removal of biogenic compounds containing nitrogen and phosphorus from wastewater for many years has been at the focal point of both, researchers and end users. The issue has become especially vital after Poland's accession into the European Union and the adaptation of sewage treatment legislation with the EU standards. The Ordinance of the Minister of Environment valid from 2006 (and earlier from 2004) on the conditions to be fulfilled for discharging sewage to surface or ground water and on the substances especially harmful for the aquatic environment is setting forth that the permitted quantity of total nitrogen discharged to the environment with treated sewage for wastewater treatment plants with the ENI value of over 100 000 is only 10 mg N/dm^3 or that the achieved reduction level should be at least 85%. The permitted value for wastewater treated at such plants was laid down at 1.0 mg/dm^3 for phosphorus. The requirements were the consequence of adaptation Polish legislation with the EU solutions, in particular Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment and Directive 98/15/EC of 27 February 1998 amending

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Directive 91/271/EEC with respect to certain requirements established in Annex I thereof.

One should underline that the previous national requirements in this field provided that the permitted total nitrogen content in treated wastewater should not exceed 30 mg/dm^3 and 5 mg/dm^3 for phosphorus (Ordinance of the Minister of Environmental Protection, Natural Resources and Agriculture of 5.11.1991, Jol No. 116, item 503). Considering such low permitted concentration thresholds for N and P elements, it has become necessary to find efficient methods of removing biogenic compounds from sewage by methods other than conventional nitrification-denitrification systems.

Significant amounts of sludge are produced as a result of implementing new, advanced sewage treatment technologies. Sludge undergoes, respectively, the stabilisation and dewatering process at the treatment plant. The sludge water produced in such processes is in most cases recycled directly to the process cycle. Many researchers, therefore, have become interested in seeking alternatives to reduce nitrogen and phosphorus loads generated already at the treatment plants as the removal of biogenic compounds from the internal process streams substantially decreases the nitrogen and phosphorus load flowing into the treatment plant's main process [1].

Studies at wastewater treatment plants have revealed that the nitrogen and phosphorus load returned with the sludge water produced in sludge treatment processes may account for up to 20–30% of the general load of biogenic compounds directed to biological reactors [2–4]. The C/N ratio is improved in the main process by removing nitrogen from the side streams, thus enhancing denitrification efficiency. It is an especially attractive solution for the existing plants that are being upgraded for the purpose of carrying out or intensifying the biological removal of biogenic compounds.

There are significant issues involved in the treatment of water from digested sewage sludge dewatering such as: very high concentration of total nitrogen (occurring predominantly in the form of ammonium nitrogen), high concentration of phosphorus compounds and suspended solid and marked variations in the concentration of contaminants.

High concentrations of nitrogen and phosphorus compounds is the effect of processes occurring in mesophile sludge digestion – a hydrolysis of polyphosphates gathered in the cells of the bacteria responsible for the biological sewage dephosphatation process and the intensive proteins ammonification process.

2. CHARACTERISTICS OF SLUDGE WATER AND ITS TREATMENT METHODS

The following are the key parameters evaluated for sludge water [5]

- COD 500–10 000 mg O_2/dm^3,
- BOD_5 150–1000 mg O_2/dm^3,
- ammonium nitrogen 300–1000 mg N– NH_4^+/dm^3 (TKN typically 966 mg/dm^3 [2]),

- phosphorus 30–100 mg P/dm^3,
- suspended solid = 400–13000 mg/dm^3,
- dissolved gases, including H_2S,
- heavy metals.

Irrespective of the broad range of potential contaminant concentrations in sludge water of various treatment plants, one should be aware that its composition in one particular plant may vary from day to day. The loads introduced with recirculated sludge water for particular plants may also differ, what is shown in a list provided as an example in Table 1 for several treatment plants in Poland [6].

Table 1

Average estimated loads of contaminants introduced with recirculated sludge water at wastewater treatment plants [5]

Parameter	Loads [%]				
	Białystok	Ełk	Łomża	Suwałki	Olsztyn
BOD_5	3.5	26.0	0.47	erv	3.5
COD	6.5	31.0	4.8	2.4	1.0–4.5
Total nitrogen	9.7	43.3	5.8	19.6	4.1–8.6
Ammonium nitrogen	12.0	40.0	6.9	16.7	4.4–10
Total phosporus	4.8	28.6	6.8	15.8	4.0–6.6
Phosphates	5.7	27.8	7.2	15.3	3.9–7.8
Suspended solid.	6.0	42.7	0.06	6.7	0.6–4.1

In connection with the above, when analysing the operation of a specific plant it becomes necessary to identify how much such composition may vary, or alternatively, which determinations may exhibit the highest fluctuations of results as such data is indispensable for deciding what treatment process for such water will be most appropriate in a particular case.

In general, sludge water can be treated with methods falling into two groups: biological processes and physiochemical processes. The following methods are most widespread for physiochemical processes:

- chemical precipitation,
- hot air degassing,
- stripping,
- ion exchange.

Each of the methods – both biological and physiochemical one, has its advantages and disadvantages and many factors are decisive in choosing a specific one. Choosing the right method depends on the quality and variation of the treated water composition, available funds as well as the conditions existing at the site. For instance, ammonia stripping with water steam will prove cost-effective if waste heat is available, whereas such costs will be substantial if such heat has to be produced particularly for this method. If the high concentrations of ammonium nitrogen are also accompanied by the high concentrations of phosphorus compounds, the precipitation method (e.g. struvite crystallisation) may offer more benefits as compared to stripping because it allows one to remove both biogenic elements at the same time.

On the other hand, a certain disadvantage of new, unconventional biological methods is, most generally, that they focus more on removing nitrogen compounds, and their goal at the same time is not to remove phosphorus. The fact is also weighty that such methods are not conventional; therefore wastewater treatment plant researchers and environmental engineering designers are not familiar with them too well. The physiochemical methods, though, have been in use at the chemical industry for many years and are well known.

The paper focuses on the feasibility of reducing a load of biogenic compounds in sludge water using a combined method – reverse osmosis (RO) and then the precipitation of struvite from a concentrate in reverse osmosis. In practise, the RO process has been employed for treating run-offs from landfill sites (so-called leachates). Up till now the process has not, however, been used for sludge water at treatment plants. This is because the further handling of the concentrate has not been solved yet (in the case of leachate it is recycled to landfill sites where it gradually concentrates as water is evaporating naturally). Precipitation of ammonium and magnesium phosphate allows one not only to treat a concentrate from biogenic contaminants but also supplies a product usable as a fertiliser [7]. The advantage of concentrating contaminants before their precipitation in such case is that the tanks and equipment used will require smaller volumes and throughputs. Moreover, the precipitation of the struvite sludge itself from the tanks should also be easier as compared to the precipitation method used directly for raw sludge water. It was also expected when choosing this method that the struvite crystals produced would be more regular than when precipitating this compound from unconcentrated solutions, and hence the struvite sludge will feature better sedimentation properties. A simple operation of a reverse osmosis installation and resistance to any installation startups and shutdowns was also of importance when choosing such a method. In addition, the installation is also easy to operate as the driving force of the process is pressure gradient. Similarly, any change in the amount of the medium treated is not any problem – modular design of the device enables changes to its processing capacity by increasing or decreasing the area of the membrane applied (by adding or removing the installation modules).

3. CHARACTERISTICS OF REVERSE OSMOSIS

Reverse osmosis, also referred to as hyperfiltration, serves for separating water (solvent) from the solute having small molecular mass. Single- and multivalent ions and low-molecular organic compounds are separated in this process. RO process is the opposite of natural osmosis phenomenon where the solvent is spontaneously passing through a semipermeable membrane. If the membrane separates the solution from the solvent or separates two solutions with different concentration, then the solvent is flowing towards the solution having a higher concentration. External pressure equalising the osmotic flow is called osmotic pressure characteristic of a specific solution. If a hydrostatic pressure builds up at the solution side exceeding the osmotic pressure, the solvent will permeate from the more concentrated solution to the more diluted one, therefore in the direction opposite than in the osmosis process. This process has been termed reverse osmosis [8].

The amount of water (solvent – F_w) passing through a semipermeable membrane characterised by L_p permeability ($cm^3/(cm^2 \cdot s \cdot Pa)$) can be calculated from the following formula [8]:

$$F_w = L_p\,(P - \pi).$$

The hydraulic performance of the process is directly proportional to the difference between the external pressure P and the osmotic pressure π [9].

The amount of the solute (F_s) passing through the membrane depends on the constant permeability of the solute B (cm/s) though, and the difference in concentrations ΔC for the solutions separated with the membrane:

$$F_s = B\Delta C.$$

The hydraulic performance of the process is measured with so-called membrane permeability (L_p) determined with the following formula:

$$L_p = \frac{V_r}{tS_m\Delta P},$$

where V_r – solution volume, t – time, S_m – membrane surface area, ΔP – pressure drop at both sides of the membrane [10].

Transmembrane pressure (TMP) used in reverse osmosis is higher than in an ultrafiltration (UF) and microfiltration (MF) processes (3,5-10 MPa) [11], and the solvent (water) affinity to the membrane material plays a predominant role for choosing a membrane, whereas membrane pores are much less important as the separation mechanism is of the solving and diffusion nature [12,13].

4. EXPERIMENTAL

Sludge produced in the Central Wastewater Treatment Plant in Gliwice is introduced to mezophilic methane fermentation and next the dewatering process on Roediger–Pasavant belt filter presses is performed. The sludge water produced during the dewatering is recycled to the biological part of the plant and directed to the activated sludge chambers. The following parameters were evaluated for investigated sludge water: pH, COD, BOD_5, ammonium nitrogen, nitrate nitrogen, total nitrogen, total phosphorus, phosphates, suspended solid, conductivity, calcium, magnesium. All analyses were made according to standards presented in Table 2. Studies were carried out between January 2005 and March 2009.

Table 2

Variations in sludge water composition in January 2005–March 2009

Parameter	Method of determination (Norm)	Average	Minimum	Maximum
pH	PN–C-04540/01:1990	7.58	7.3	8.0
COD, mg O_2/dm^3	PN–ISO 15705:2005	435.5	79.5	869.0
BOD_5, mg O_2/dm^3	PB-5.4-01/23 publ. 02. 02.01.07	99.8	40	220
Ammonium nitrogen, mg $N–NH_4/dm^3$	PN–ISO 5664:2002	603.3	416	887
Nitrates nitrogen, mg $N–NO_3/dm^3$	PB-5.4-01/09 publ. 02. 02.01.07	5.48	0.5	24.3
Total nitrogen, mg N/dm^3	PB-5.4-01/04 publ. 04. 02.02.09 PB-5.4-01/09 publ. 02. 02.01.07 PN–EN 25663:2001 PN–C-04576/14:1973	652.9	438.0	896.7
Total phosphorus, mg P/dm^3	PB-5.4-01/08 publ. 02. 02.01.07	27.8	4.67	114.0
Phosphates, mg PO_4^{3-}/dm^3	PB-5.4-01/08 publ. 02. 02.01.07	194.5	13.8	349.0
Suspended solids, mg/dm^3	PN–EN 872:2005 +Apl:2007	91.5	14.4	292.4
Conductivity, µS/cm	PN EN 27888:1999	5863	4299	9699
Calcium, mg Ca^{2+}/dm^3	PB-5.4-01/32 publ. 03. 02.02.09	55.0	21.8	130.0
Magnesium, mg Mg^{2+}/dm^3	PB-5.4-01/32 publ. 03. 02.02.09	20.0	12.5	57.8

The next step of the studies focused on the treatment of sludge water by the reverse osmosis process. The studies were performed using two installations: Osmonics' laboratory installation and a pilot installation supplied by the Pall Poland with a disk tube (DT) module mounted. Composite membranes were used for the studies in both cases marked with BW 30 symbol by the Pall Poland. The final step of the studies covered the treatment of the condensate from RO process via struvite crystallization.

The evaluation of produced crystals was made with the use of a Novex optic microscope magnified 40 and 100 times.

Pilot installation. The membrane cushions of the pilot installation comprised two composite membrane disks with a spacing inner layer. They were sealed with a patented technique so as the filtered medium did not contact other materials (e.g. bonding agents for membrane). The total surface area of membranes in the installation was 6.8 m^2 (160 “cushion” membranes with the surface area of 0.0425 m^2 each).

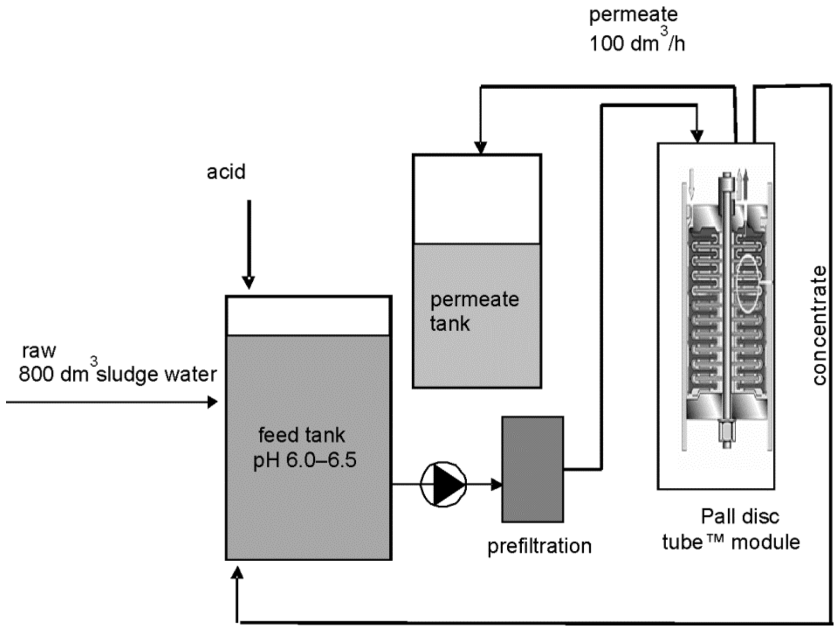

Fig. 1. Simplified working principle of the pilot installation

A sample of 800 dm^3 of sludge water was tested (Fig. 1). It was directed onto the membrane module under an initial pressure of 1.6–1.8 MPa, thus reaching the permeate flow of 100 dm^3/h. The RO concentrate was returned to the feed tank and its concentration gradually increased. The studies were continued until 75% of the initial volume of feed was purified (i.e. for approx. 8 h). A constant intensity of permeate flow was maintained during the experiment and the intensity was adjusted by increasing operating pressure. When the feed concentration reached 25% of its initial volume, the working pressure had to be increased to 2.1–2.2 MPa to maintain the permeate stream of 100 dm^3/h.

After ca. 5–10 min, as only the condensation process was stabilized, the feed and permeate samples were collected in order to determine their physicochemical composition.

Osmonics laboratory installation. The surface area of the tested membrane was 0.013m^2, being much smaller than that for the pilot installation. Nevertheless, the efficiency of retention of the ammonium nitrogen turned out to be comparable to that in the pilot installation. As the area of the tested membrane was small, the intensity of permeate flow was much smaller as compared to that in the pilot installation. Thus the sample was not concentrated in this case and instead the experiment was focused on seeking optimum process parameters such as:

- pH (in the range of 5.5–7.2, adjusted by addition of 0.1 M HCl)
- temperature (from 22 °C to 39 °C, its self-heating was obtained by shutting off the feed cooling)
- pressure (2.0, 2.5 and 3.0 MPa),
- water flow rate through the module (1.2 and 3 m/s).

Pressure and feed flow rate were adjusted by using a pump and appropriate RO module valves opening.

Most of experiments (except from the part focused on the influence of pressure on the process efficiency) were carried out under the pressure of 2.0 MPa. Permeate samples for physicochemical analysis were collected after stabilization of the process conditions, i.e. ca. 15 minutes after every change in the process set up.

The volume of the feed introduced to every process was equal to 10 dm^3 and it was decreasing during the process run by the amount of collected permeate (depending on the number of collected permeate samples, the final volume of the concentrate varied from 8 to 9 dm^3). The initial concentration of ammonium nitrogen in the feed varied insignificantly within 580–615 mg/dm^3.

Condensate treatment. The premliminary tests of struvite precipitation from sludge water (feed) and from concentrated water (concentrate) were made. The tests were made in two series:

- for samples prepared with distilled water, $NH_4H_2PO_4$ and $MgCl_2 \cdot 6H_2O$,
- for actual raw and concentrated sludge water.

The same quantities of $NH_4H_2PO_4$ and $MgCl_2 \cdot 6H_2O$ were dissolved in different amounts of water in the first case, thus producing solutions with the same load but different concentrations. 2 dm^3 of water for the diluted solution was used and 0.5 dm^3 for the concentrated one.

The content of ammonium nitrogen, phosphates and magnesium in raw and concentrated sludge water was determined in the first case. Next, K_2HPO_4 and $MgCl_2 \cdot 6H_2O$ were added in stoichiometric amounts, necessary for struvite precipitation.

Precipitation was performed after adjusting pH of the solutions to 9.0 with NaOH [14]. The results of such preliminary studies are given in Table 3.

Table 3

Results of preliminary tests for struvite precipitation efficiency[a]

Parameter	Prepared sludge water					
	Prepared sludge water (feed)			Concentrated sludge water		
	Series 1					
	P1	P2	Red %	P1	P2	Red %
PO_4	2830	69	97.6	11350	151	98.7
$N–NH_4$	420	42	90	1630	170	89.6
	Series 2					
	P1	P2	Red %	P1	P2	Red %
PO_4	2850	15	99.5	11340	11	99.9
$N–NH_4$	450	40	91.1	1635	187	88.6
	Actual sludge water					
	Sludge water (feed)			Concentrated sludge water		
	Series 3					
	P1	P2	Red. %	P1	P2	Red %
PO_4	241	5	97.9	10085	10	99.9
$N–NH_4$	665	322	51.6	1456	192	86.8
	Series 4					
	P1	P2	Red. %	P1	P2	Red %
PO_4	3792	12	99.7	11428	10	99.9
$N–NH_4$	769	271	64.8	1578	232	85.3
	Series 5					
	P1	P2	Red. %	P1	P2	Red %
PO_4	6013	39	99.4	14245	279	98
$N–NH_4$	735	107	85.4	1542	136	91.2

[a]P1 – solutions prior to adding $MgCl_2·6H_2O$, P2 – solutions after adding $MgCl_2·6H_2O$ and struvite crystallisation

5. DISCUSSION OF RESULTS

The results of the study of the composition of sludge water (Table 2) show very strong fluctuations in concentrations of contaminants affected by the seasons of the year as well as the procedures taken in the sludge treatment process. Slightly higher concentrations of phosphorus compounds are observed during the biomass growth of filamentous bacteria (e.g. in spring). This, most likely, is caused firstly by efficient biological dephosphatation induced by this group of bacteria in a biological reactor and, secondly, by a release of phosphates collected in the bacterial cells during sludge digestion. When the higher doses of coagulant for phosphorus precipitation from wastewater (e.g. PIX) are used at the plant, however, the quantity of this element in sludge water is lower, as well. The loading of digestion chambers with sludge significantly affects ammonium nitrogen concentrations in sludge water. The above findings point out that the concentrations of contaminants in sludge water are not constant parameters even for one specific plant, which makes it even more difficult to choose a single optimum treatment process. The results of studies of the pilot installation are given in Table 4. Results of selection of optimum parameters such as pH, temperature, pressure and water flow speed through the module are presented in Figs. 2–4.

Table 4

Results of studies of the pilot installation

Parameter	Method of determination (Norm)	I series		II series		III series	
		N	P	N	P	N	P
pH	PN–C-04540/01:1990	6.5	5.1	6.9	5.7	7.1	5.9
COD, mg O_2/dm^3	PN–ISO 15705:2005	444	13.9	204	8.8	320	8.7
BOD_5, mg O_2/dm^3	PB-5.4-01/23 publ.02, 02.01.07	240	4	95	2	140	14
N–NH_4, mg/dm^3	PN–ISO 5664:2002	490	12	474	22	533	28
N–NO_3, mg/dm^3	PB-5.4-01/09 publ.02, 02.01.07	8.4	1.5	3.15	1.5	10.9	0.55
Total N, mg N/dm^3	PB-5.4-01/04 publ.04, 02.02.09 PB-5.4-01/09 publ.02, 02.01.07 PN–EN 25663:2001 PN–C-04576/14:1973	541	15	477	26	555	32
Total P, mg P/dm^3	PB-5.4-01/08 publ.02, 02.01.07	19.5	0.6	15.1	0.64	17.0	1.4
PO_4^{3-}, mg/dm^3	PB-5.4-01/08 publ.02, 02.01.07	61.7	1.7	46.4	2.0	49.7	4.4
Suspended solids, mg/dm^3	PN–EN 872:2005 +Apl:2007	51	2.0	36	0.8	49	1.6
Conductivity, μS/cm	PN EN 27888:1999	6701	153	3109	264	5282	371
Calcium, mg Ca^{2+}/dm^3	PB-5.4-01/32 publ.03, 02.02.09	53	0.5	28	1.1	42	2.3
Magnesium, mg Mg^{2+}/dm^3	PB-5.4-01/32 publ.03, 02.02.09	21	2.1	5	1.4	14	1.7
Chrome, μg Cr/dm^3	PN EN ISO 15586:2005	10.7	<2	3.3	<2	3.1	<2
Zinc, μg Zn/dm^3	PN ISO 8288:2002	120	7.4	32.3	3.6	57.1	8.2
Cadmium, μg Cd/dm^3	PN EN ISO 15586:2005	2.62	<0.4	<0.4	<0.4	0.45	<0.4
Manganese, μg Mn/dm^3	PN EN ISO 15586:2005	328	4.55	118	2.20	150	10.2
Copper, μg Cu/dm^3	PN EN ISO 15586:2005	10.1	<1.5	6.3	1.5	6.8	<1.5
Nickel, μg Ni/dm^3	PN EN ISO 15586:2005	56.5	3.2	26.2	3.9	27.1	4.7
Lead, μg Pb/dm^3	PN EN ISO 15586:2005	2.61	1.35	1.07	1.01	0.50	0.36

It was confirmed that sludge water can be treated by the method of reverse osmosis. The process efficiency was very high, as 95% reduction in biogenic compounds was achieved. The reduction level for N and P compounds differed insignificantly according to the feed quality.

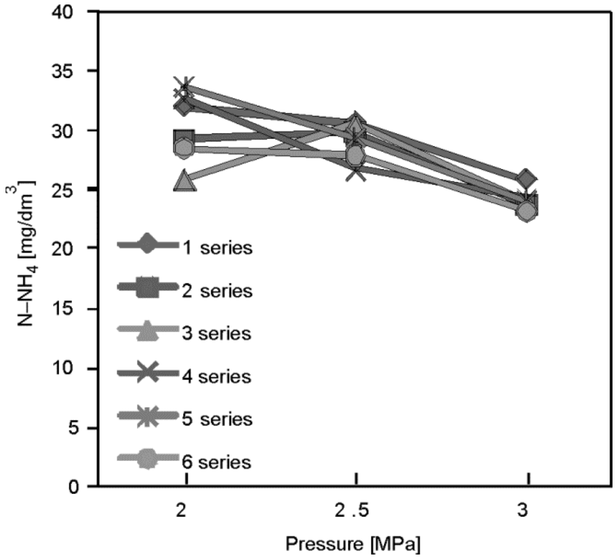

Fig. 2. Pressure dependence of the $N–NH_4$ content in permeate
using the Osmonics module and BW 30 membranes;
T = 22 °C, flow speed 2 m/s, $N–NH_4$ in feed: 600 mg/dm^3

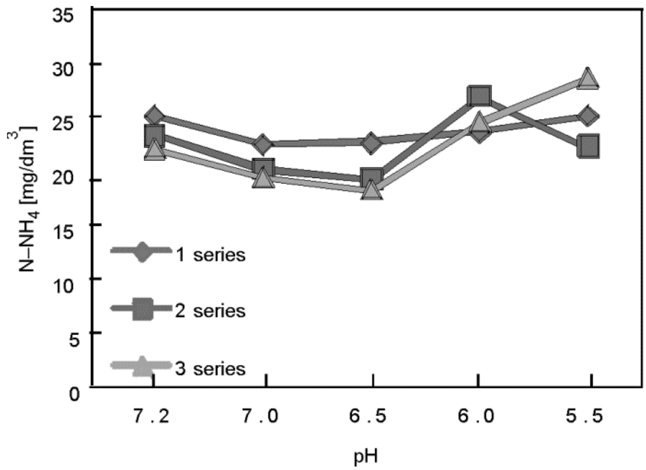

Fig. 3. Dependence of the $N–NH_4$ content in permeate on pH of feed
using the Osmonics module and BW 30 membranes;
ΔP = 2 MPa, T = 22 °C, flow speed 2 m/s, $N–NH_4$ in feed 605 mg/dm^3

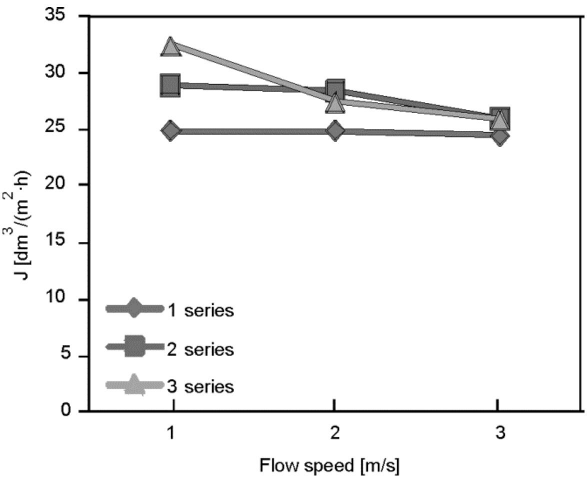

Fig. 4. Dependence of the volumetric flux of permeate on the flow rate through the Osmonics module in the RO process using the BW 30 membrane; ΔP = 2 MPa, pH = 7.0, T = 22 °C, N–NH_4 in feed 590 mg/dm^3

The content of ammonium nitrogen in the permeate however, never exceeded 30 mg/dm^3, and 1.5 mg/dm^3 for general phosphorus, i.e. the permeate composition was similar in this respect to standard urban sewage (Table 4). Additional load brought to the treatment plant with permeate will, therefore, not be significant from the process point of view.

Optimum working conditions for the reverse osmosis were identified: the highest reduction in ammonium nitrogen content was reached for the feed with pH of 6.5 (Fig. 3) under the pressure of 3 MPa. (Fig. 2). However, considering the energy consumption and fouling intensity observed for the higher pressure, its the lower value, i.e. 2 MPa was found to be efficient enough to provide satisfactory treatment effect.

A higher intensity of permeate flow was accomplished for feed flowing via the membrane at a lower flow rate (Fig. 4). The reasons would be both turbulent flow for higher flow rate disturbing the convection motion to the membrane and/or torrential growth of flow losses under higher flow rate leading to the decrease of the process driving force.

The concentrate produced in the reverse osmosis was purified by precipitating ammonium and phosphorus compounds in a form of struvite $(NH_4)Mg(PO_4)\times 6H_2O$ (Table 4). The appropriate amount of magnesium ions and phosphates had to be added to the concentrate for this purpose. It is also important that by concentrating the contaminants, the tank and the equipment to be used in actual conditions will feature dimensions and capacities much smaller than when using this technology straightforward for untreated sludge water.

Sedimentation properties of the sludges precipitating from concentrated solutions were better than those of the sludges precipitating from raw sludge water: the precopitates were falling quicker and the occurence of other types of crystals produced in sludges was found in the microscopic image (optical microscope Novex, magnified 40× and 100×). Sludges from the concentrated samples were drying quicker than the those from the samples imitating raw sludge water. Similar reduction values for ammonium nitrogen were obtained from the concentrated and diluted solution. The tests made for actual solutions also differed with regard to the composition of crystals, however, it is necessary to select appropriate process conditions to intensify struvite precipitation considering unsatisfactory reduction in ammonium nitrogen content as compared to the prepared solutions.

Regular, romboidally-shaped crystals along with thin needles and X-shaped forms occured in all the cases. The proportions of various crystal forms in sludges differed, however: forms with regular shapes were prevalent in respect of X-shaped forms for the concentrated solutions and regular forms for the actual solutions were lower in numbers.

The admixtures of other compunds, disturbing the struvite crystallisation process, were probably present in the actual solutions. It is therefore recommened to determine the elemental composition of the sludges produced, which could help to conclude if other crystals than struvite occur in sludges.

The studies have not been completed, yet and they are being continued to produce a series of repeatable results and to select appropriate parameters for the process performed.

6. CONCLUSIONS

The studies have shown that the treatment of sludge water with the reverse osmosis method is feasible and its efficiency is very high. The concentrate produced in the process can be treated by the precipitation of struvite sludge. The sludge can be used in agriculture as a good quality fertiliser. The RO module is simple to operate and its installation is resistant to changes in contaminant concentrations in the feed. Breaks in the module usage do not affect the efficiency of the method. There is an opportunity to implement this process for wastewater treatment plants where it can be used for limiting the concentration of biogenic loads from external process streams, thereby achieving higher efficiency of nitrogen and phosphorus removal in biological reactors.

REFERENCES

[1] STROUS M., VAN GERVVEN E., ZHENG P., KUENEN J.G., JETTENM S.M., Water Res., 1997, 31 (8), 1955.

[2] CONSTANTINE T., SHEA T., JOHNSON B., *Newer approaches for treating return liquors from anaerobic digestion*, IWA Spec. Conf. Nutrient Management in Wastewater Treatment Processes and Recycle Streams, Cracow, 2005, 455–464.

[3] CAFFAZ S., LUBELLO C., CANZIANI R., SANTIANNI D., A*utotrophic nitrogen removal from anaerobic supernatant of Florence's WWTP digesters, Newer approaches for treating return liquors from anaerobic digestion*, IWA Spec. Conf. Nutrient Management in Wastewater treatment Processes and Recycle Streams, Cracow, 2005, 397–406.

[4] MASŁOŃ A., TOMASZEK J.A., Environ. Prot. Eng., 2007, 33 (2), 175.

[5] MALEJ J., MAJEWSKA A., BOGUSKI A., Rocznik Ochr. Środ., 2002, 4, 11.

[6] MYSZOGRAJ S., Inż. Ochr. Środ., 2008, 11 (2), 219.

[7] BRIDGER G., CEEP Scope Newsletter, 2001, 43, 3.

[8] KOŁTUNIEWICZ A.B., DRIOLI E., *Membranes in Clean Technologies. Theory and Practice*, Wiley, Weinheim, 2008.

[9] MAJEWSKA-NOWAK K., Ochr. Środ., 2007, 2, 21.

[10] KOWAL A., ŚWIDERSKA-BRÓŻ M., *Purification of Water*, PWN, Warsaw, 2009, p. 311–312 (in Polish).

[11] CHERYAN M., *Ultrafiltration and Microfiltration Handbook*, Technomic Publ. Comp., Lancaster, 1998.

[12] NOWORYTA A., TRUSEK-HOŁOWNIA A., *Membrane Separations*, Agencja Wyd. ARGI, Wrocław, 2001 (in Polish).

[13] NARĘBSKA A., *Membrany i membranowe techniki rozdziału*, Wyd. Uniw. Mikołaja Kopernika, Toruń, 1997.

[14] JAFFER Y., CLARK T.A., PEARCE P., PARSONS S.A., Water Res., 2002, 36, 1834.