18. *Ibanez J.A., Litter M.I., Pizarro R.A..* Photocatalytic bactericidal effect of TiO2 on Enterobacter cloacae: Comparative study with other Gram (“) bacteria//J. Photochem. Photobiol. A Chem. – 2003. –Vol. 157. – P. 81-85.

Надійшло до редакції 16.11.2015

УДК 628.35

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THE ROLE OF DEAMMONIFICATION TECHNOLOGY IN THE NEW CONCEPT OF WASTEWATER TREATMENT

Наведено короткий огляд сучасних тенденцій з модернізації систем очищення міських стічних вод. Описані швидко розвиваються інноваційні технології автотрофной денітрифікації. Обговорено сучасні тенденції в застосуванні процесів часткової нітрифікації ("nitritation / anammox process") як з точки зору успіхів, так і невирішених проблем. Виконано прогнозний аналіз перспективних напрямків у розвитку систем очищення стічних вод в найближчому майбутньому.

Ключові слова: часткова нітрифікація; "nitritation / anammox process"; надійне очищення стічних вод.

Приведен краткий обзор современных тенденций по модернизации систем очистки городских сточных вод. Описаны быстро развивающиеся инновационные технологии автотрофной денитрификации. Обсуждены современные тенденции в применении процессов частичной нитрификации ("nitritation/ anammox process") как с точки зрения успехов, так и нерешенных проблем. Выполнен прогнозный анализ перспективных направлений в развитии систем очистки сточных вод в ближайшем будущем.

Ключевые слова: частичная нитрификация; "nitritation/ anammox process"; надежная очистка сточных вод.

In the paper a short review of current trends in development of municipal sewage treatment systems are introduced. In that context a quickly-spreading, innovative technology of autotrophic deammonification is described. Current achievements of partial nitritation/ anammox process for reject water treatment as well as challenges and successes of its mainstream application are discussed as well. Layouts of probable sewage treatment systems of the future are presented.

Keywords: partial nitritation, anammox, sustainable sewage treatment

Introduction

Most of currently operated wastewater treatment plants are large energy consumers. We need about 1 kWh of energy for collecting, treating and discharging wastewater (Szetela (2014)). The share of electric power that is allocated for water supply and sewage handling is reaching up to forty percent (40%) of the whole electrical energy demand in the Polish municipal communities. In the rural areas that contribution may be even higher (Wójtowicz (2014), Szetela (2014)). At the same time in the sole organic matter (COD) inflowing to a wastewater treatment plant, a significant amount of energy is accumulated. It is estimated that in every cubic meter can be stored 1,4…2,8 kWh of energy in the form of organic carbon (COD) (Szetela (2014)) (for comparison Polish household consumes about 5.6 kWh of electric power per day (GUS (2012)). It is about seven times more than electric power – and about three times more than total energy – demand for sewage treatment (Szetela (2014)). In other words we utilize 1 unit of energy to waste of 3 units of energy in the course of sewage treatment.

Aeration of the wastewater is an essential part of biological organic carbon, nitrogen and phosphorous removal processes. About 60% of energy consumption at wastewater treatment plant is connected with sewage aeration. The other 40% of energy is required mostly for pumping operations, running of sewage treatment devices and heating of anaerobic digesters and buildings (Szetela (2014), Stinson et al. (2013)). We might say that the present concept of sewage treatment consists in inputting large amounts of energy into wastewater and as the return we receive hardly manageable solid wastes, greenhouse gases (CO_2, CH_4, N_2O) and effluent containing hazardous substances (micro contaminants, pathogenic bacteria and viruses).

This way of thinking is being changed at the moment and we start looking at inflowing wastewater stream as at the new source of energy. It seems that anaerobic processes replace the oxidation of organic carbon in the near future. As the result most of organic matter will be transformed into biogas. It would allow energy self-sufficiency of wastewater treatment or even net energy production. Just now we can produce about 1 m^3 of biogas per every kilogram of sludge that was anaerobically digested. It equals about 6…7 kWh of energy that can be utilized with combined heat and power (CHP) gas engines (Dymaczewski (2011)). Stabilized and dried sewage sludge can be thermally utilized and energy recovered with CHP units (about 2.8 kWh per kilogram of dried mass of digested sewage sludge) (Szetela (2014)). There are also other possibilities to recover energy from wastewater connected with application of heat pumps and water micro turbines.

Furthermore valuable resources could be recovered from wastewater. The most obvious and precious is water. Reclaimed wastewater would be used for irrigation or sanitary purposes, and it is also possible to produce potable water from sewage (PUB (2015)). There is only one condition – application of advanced treatment processes for sewage disinfection and micro pollutants (e.g. pharmaceutical residuals) removal. Phosphorus can be recycled from wastewater in the form of magnesium ammonium phosphate (MAP, struvite). Right now it is possible to produce from about 500 kg to 8000 kg of MAP weekly (Remy et al. (2013), Thelin (2014)). Other resources that are in focus of researchers and could be recovered from sewage sludge are metals (among them are gold, silver, copper and rare earth elements). Westerhoff et al. (2015) has estimated their value at up to US$ 13 million annually for a community of 1 million people.

The future wastewater treatment plants are to be energy neutral and turned into “water resources recovery facilities”.

Deamonification – key process for innovative wastewater treatment

The problem with the organic matter conversion into biogas is that organic carbon is also needed for conventional nitrogen removal from wastewater. The organic carbon shortage is often the main limiting factor for efficient denitrification and addition of external carbon source (e.g. methanol) is required. Fortunately there is available innovative technology for fully autotrophic nitrogen removal from sewage. It is called deammonification. Deammonification is based on two autotrophic processes: partial nitritation and anammox (PN/A). In the course of partial nitritation about fifty percent of total ammonium load is oxidized to nitrites (NO_2^-).

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + 2H^+$$

Nitrites are then utilized by anammox bacteria for oxidizing ammonium ions (NH_4^+) into gaseous nitrogen (N_2). The anammox process’ by products are nitrates (about 11% of nitrogen is transformed into this form). The stoichiometry of the anammox process is shown below (Kartal (2013)).

$$1NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.26NO_3^- +$$
$$+ 0.066CH_2O_{0.5}N_{0.15} + 2.03H_2O$$

Advantages of deammonification derive from reduction of oxygen amount that is required for ammonium nitrogen oxidation, and from the fact that organic carbon is not necessary for this process. What’s more, due to the fact that anammox bacteria are slow growers with small yield coefficient the amount of excess biomass is low. As the result the following benefits might be achieved in comparison to conventional nitrogen removal process:

- reduction of energy consumption for aeration by 60%,
- reduction of surplus sludge production by 90%,
- reduction of demand for organic carbon by 100%,
- reduction of emission of CO_2 by 90 -104% (result above 100% is possible due to the assimilation of bicarbonates by autotrophs) (Van Loosdrecht and Salem 2006)).

Partial nitritation/ anammox process (PN/A) for reject-water treatment

The move towards energy neutrality of wastewater treatment plants has been already made in many of the currently operated systems. The first step was application of anaerobic stabilization of sewage sludge and biogas production. Then biogas started being utilized for energy production (initially heat and subsequently also electric power with CHP gas engines). It allowed cover the energy demand of WWTP up to about 70% (electrical energy) and to about 50% (heat). However dewatering of digested sludge (with belt press or centrifuge) is the source of a wastewater stream (called “reject water” “side-stream wastewater” or “filtrate”). The reject water contain significant amount of nitrogen. The concentration of ammonium nitrogen ($N\text{-}NH_4^+$) in the reject water can be 10-20 times higher than in the influent. Although reject water flow rate is a small proportion of total inflow (about 1-2%), the nitrogen loading rate from this source can achieve 15…20% of total nitrogen load into wastewater treatment plant (Dosta et al. (2007), Cema (2009)). The reject water which entering bioreactor disturb its operation by lowering ratio between organic carbon and ammonium nitrogen (COD/ $N\text{-}NH_4^+$) in the wastewater. The surplus nitrogen load requires also additional amount of oxygen for nitrification. Consequently higher electric power consumption for aeration occurs. Treatment of side-stream wastewater with deammonification reactors allows ammonium nitrogen removal by about 80% (nitrogen load from this source is reduced to about 3% of the total daily load) (Cema (2009), Szatkowska et al. (2007), Gut et al. (2006)). What’s important the process is run without any addition of external carbon and with significantly reduced power consumption. Because of this it brings closer present wastewater handling systems to energy self-sufficiency. Experiences of first sewage treatment plants with net energy production (Strass and Glarnerland) show that application of deammonification technology for reject water treatment was the key factor which allowed them achieved this success (WERF (2010)).

The technology being described was implemented for the first time in the technical-scale about ten years ago. The innovation has been wide- and fast-spreading over the last decade. By the end of 2014 about 100 full-scale systems for reject water deammonification was in operation worldwide (mainly in Europe and North America) (Lackner et al. (2014)). Three most frequently applied reactor types are sequencing batch reactors (SBR – more than 50% of all deammonification systems), bioreactors based on granular biomass and moving bed biofilm reactors (MBBR) (Lackner et al. (2014)). In the table 1 ranges of operational and applied technological parameters are presented. In “figure 1b” the location of PN/A reactor in technological setup of sewage treatment system is shown.

Mainstream deammonification

Deammonification of reject water does not cover the whole range of potential application of this technology. As it was mentioned before the current goal is to remove organic carbon from the influent via anaerobic route with increase of biogas production. In the “figure 2a”, a conventional layout of sewage treatment system is presented. The goal of increasing production of biogas could be gained by diverting of organic matter (COD), in the form of sewage sludge, from the influent into anaerobic digesters. In such a technological setup we want to increase production of sewage sludge. The application of high-rate activated sludge (HRAS) reactors makes it possible. Biomass organic loading rate (F/M) in HRAS systems is one or even two orders of magnitude higher than in a conventional activated sludge chambers (1…10 [kgCOD kg_{TSS}^{-1} d^{-1}]).

Table 1

Ranges of operational and applied technological parameters of PN/A systems for "side-stream" nitrogen removal (based on the review of Lackner et al.(2014))

Parameter	Reactor type	
	SBR	MBBR&granular
Influent N concentration [$mgN\text{-}NH_4^+ L^{-1}$]	from <500 to >1500	
Reactor volume [m^3]	134 – 2400	200 – 1800
Hydraulic retention time (HRT) [h]	26 – 114	5 – 42
Total suspended solids (TSS) [g L-1]	1.0 – 4.5	5 – 25
Volumetric loading rate (VLR) [$kg_N m^{-3} d^{-1}$]	0.04 – 0.65	1.0 – 2.3
Biomass loading rate (F/M) [$gN kg_{TSS}^{-1} d^{-1}$]	35 – 155	64 – 238
Dissolved oxygen concentration (DO) [$mgO_2 L^{-1}$]	0.3 – 1.5	
Temperature [^oC]	20 – 25	
Process control parameters (*on-line* sensors)	pH, DO, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$	
Energy demand [$kWh kg_N^{-1}$]	0.8 – 1.92	1.05 – 1.86

Consequently, other features of those bioreactors are: very short hydraulic retention time (HRT about 30 minutes) and sludge age (SRT = 0,5…1 d). Furthermore the process is run under anoxic conditions in order to prevent the oxidation of COD. As the result the energy demand for the process is minimal (0,02 kWh/m^3) (Bunce et al. (2013)). It was found that under described conditions both suspended solid's, colloidal and soluble fraction of COD is removed from wastewater mainly via adsorption on the surface of activated sludge flocks. The sludge from HRAS is moved into sludge thickeners and anaerobic digesters. This first stage of the new technological setup is called "A – process" (where "A" stands for "adsorption"). Alternatively to HRAS, an upflow anaerobic sludge blanket (UASB) reactor might be applied (see figure 2e). Then direct biogas production from inflowing sewage would be possible (Malovanyy et al. (2015)). Sewage stream after "A-stage" treatment still contains ammonium nitrogen. Its removal could be conducted with common nitrification/denitrification pathway (N/DN). This phase of sewage treatment is called "B-process" (where "B" stands for "biooxidation"). However, the process has to be run at low "COD:$N\text{-}NH_4^+$" ratio of about 2:1 or lower. Due to this it is proposed to aerate uniformly the whole N/DN chamber instead of dividing it into anoxic and aerobic compartments. Then aeration control must be subordinated to a major goal: oxidizing of $N\text{-}NH_4^+$ with simultaneous suppression of COD oxidation with oxygen. The entire load of COD is to be utilized for denitrification. Dissolved oxygen concentration's level below 1 mgO_2/L must be kept.

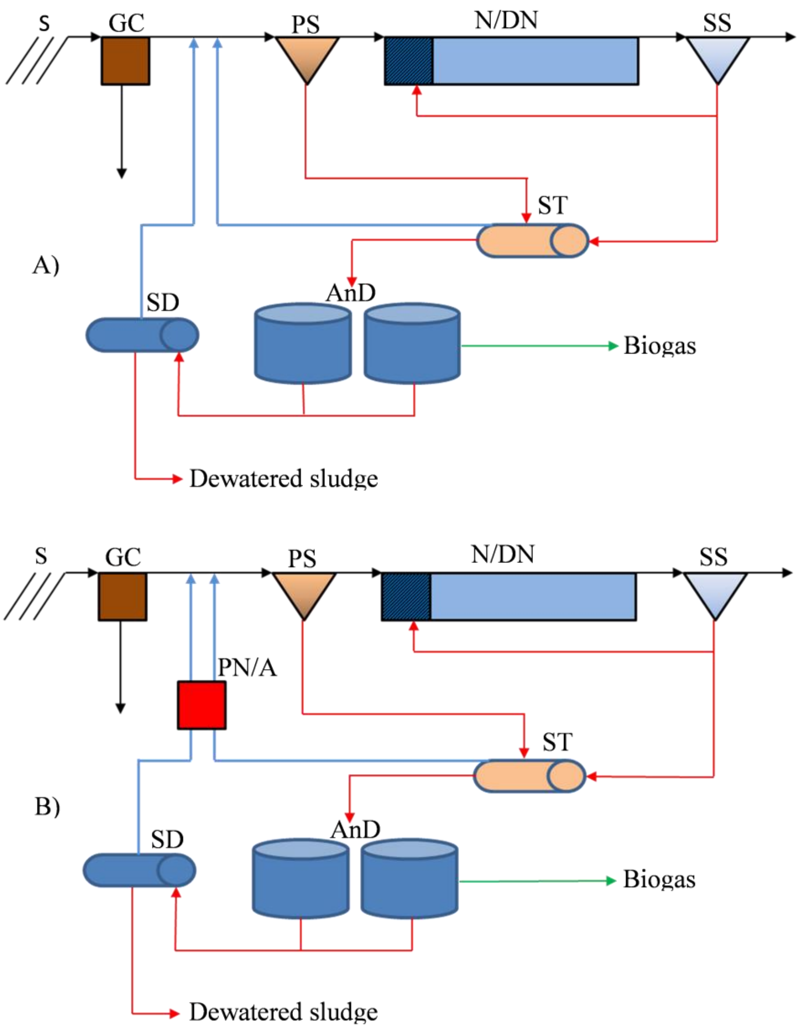

Figure 1. Layout of: **A**) conventional system of municipal wastewater treatment with reject water stream from sludge dewatering device (SD) entering directly the mainstream technological line; **B**) innovative system with reject water treatment with PN/A process. Nomenclature: S – screens, G – grit chamber, PS – primary settler, N/DN – nitrification/denitrification, SS – secondary settler, ST – sludge thickener, AnD – anaerobic digester, SD – sludge dewatering, PN/A – partial nitritation/anammox

The exact value of DO concentration is controlled with programmable logic controllers (PLC), linked with DO and N-NH_4^+ "*on-line*" sensors (Bunce et al. (2013)). Sometimes strategy of intermittent aeration is applied.

Under low concentration of DO, simultaneous denitrification can occur in the core layer of activated sludge flocks (Bunce et al. (2013), Regmi et al. (2013)). What's more it is also possible to oxidize N-NH_4^+ to nitrites (N-NO_2^-) and subsequently reduced them with COD. In such scenario the conventional nitrification-denitrification process is replaced by "nitritation-denitritation" scheme. It is called also as "nitrite-shunt" (see figure 2 b, c). It turns out that nitrogen removal process leading through that route is more efficient and at the same time energy consumption for aeration is reduced (Bunce et al. (2013), Regmi et al. (2013)).In order to achieve "denitrification through nitrites" NOB (nitrite oxidizing bacteria) have to be suppressed in the system. It is usually hard to accomplish under mainstream wastewater conditions because of low concentrations of substrates and low temperature in the reactor. However getting it under control would give foundations for even further development of the sewage treatment system. The purpose is to turn it from "A/B – process" described above, into "A/Deammonification" system (see figure 2 d).

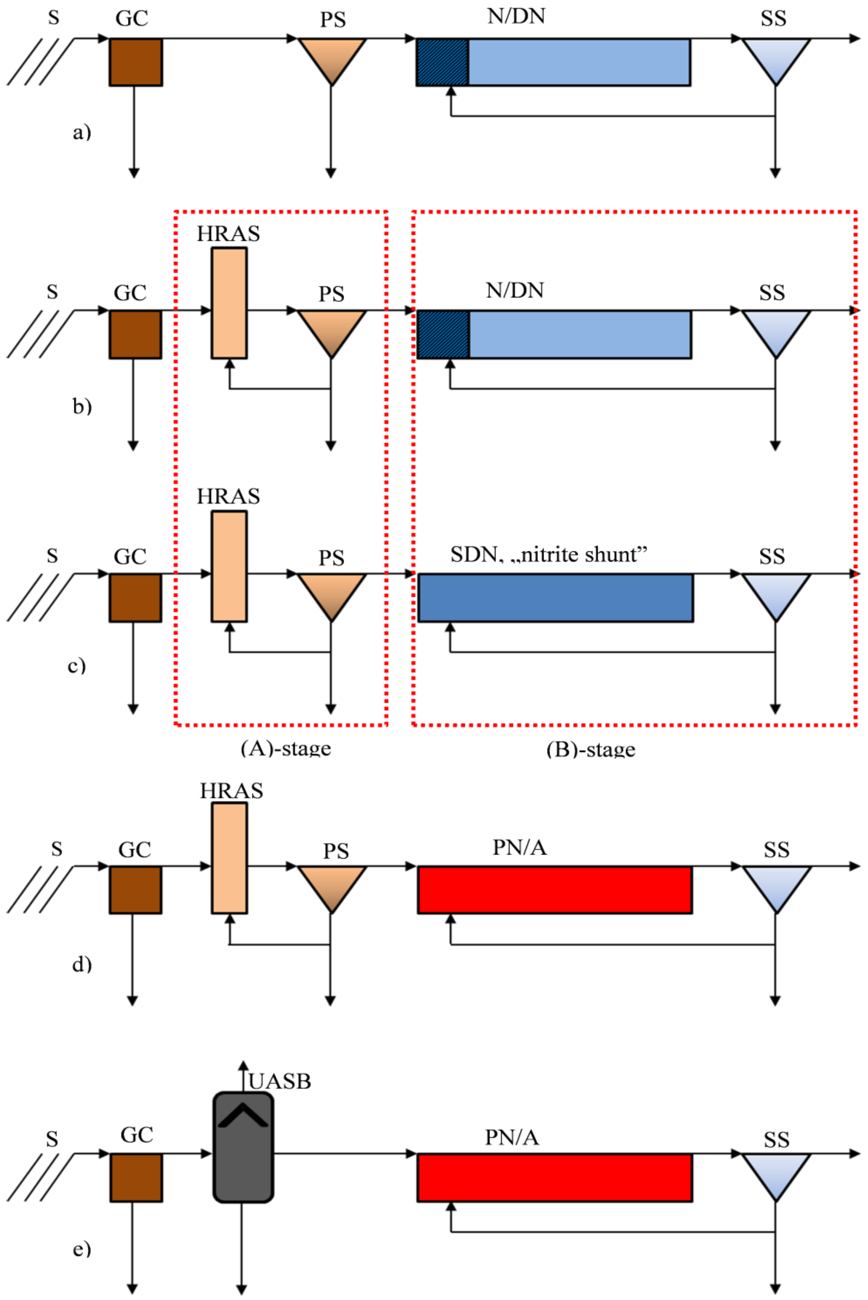

Figure 2. Layout of: **a**) conventional municipal wastewater treatment system; **b**) and **c**) innovative "A&B - stage" system; **d**) innovative system with "A-stage" and mainstream deammonification (PN/A); **e**) innovative system of mainstream wastewater treatment with UASB and deammonification reactors. Nomenclature: SDN – simultaneous denitrfication PN/A – partial nitritation/anammox, HRAS – high rate activated sludge, UASB – upflow anaerobic sludge blanket

It will be possible if we have measures to suppress NOB's growth and a source of anammox biomass is available. That source (of anammox biomass) could be deammonification reactors for reject water treatment. Having in mind that vision it justifies even more investments in side-stream deammonification and modern aeration control system for presently operated conventional nitrogen removal reactors.

Successful mainstream deammonification will be linked with substantial reduction of energy consumption. This, in turn will bring us closer towards net energy production in the sewage treatment system. Results published in the available literature showed that it is possible to remove nitrogen from mainstream wastewater via PN/A process both in a combined granular-activated sludge system (Wett et al. (2013)) and MBBR (Sultana (2014)). Malovanyy et al. (2014, 2015) proved the suitability and high capacity of IFAS (integrated fixed-film activated sludge reactor) run at 25^{o}C for deammonification of mainstream wastewater pretreated in UASB (upflow anaerobic sludge blanket) reactor. IFAS was presented as the most promising system also for mainstream deammonification at low temperatures (Trojanowicz et al.(2015)). To the best of authors' knowledge, at the moment two wastewater treatment plants are operated in the layout which was described above (Wett et al. (2013)). In the figure 3 the diagram of the future, sustainable wastewater treatment system is shown (where the reject- and mainstream wastewater deammonification reactors are interconnected).

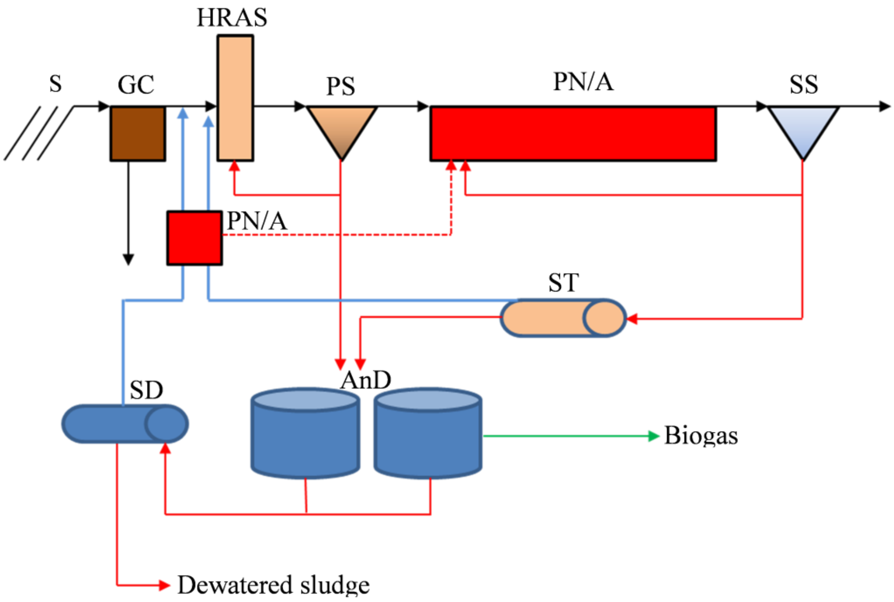

Figure 3. Layout of municipal wastewater treatment plant of the future with interconnected deammonification reactors for reject water and mainstream wastewater treatment

Conclusion

In order to achieve energy neutrality of the sewage treatment systems of the future, increase of biogas production from organic matter inflowing to the system is necessary. That will be possible if an autotrophic technology of nitrogen removal from the wastewater is available. The partial nitritation/anammox process fulfill that requirement. Mainstream application of PN/A at low temperature will be possible only if a robust method for suppression of NOB bacteria will be developed and anammox biomass will be accessible. The first step towards described in the paper concept of sustainable wastewater treatment plant is application of deammonification technology for reject water treatment.

References

1. *Bunce R.W., Miller M.W., Regmi P., Hingley D.M., Kinnear D., Bott C.B*., 2013. Modification of a B-stage MLE to Take Advantage of SND and Nitrite Shunt in an A/B Process Pilot Study. *WEF/IWA Nutrient Removal and Recovery Conference* – July 28-31, 2013, Vancouver, Canada.

2. *Cema G*., 2009. Comparative Study On Different Anammox Systems. *Ph.D. Thesis*, TRITA-LWR PhD Thesis 1053. Royal Institute of Technology, Stockholm – Sweden.

3. *Central Statistical* Office (GUS), „Energy Consumption in Households in 2012", Warsaw 2014.

4. *Dosta J., Galí A., Benabdallah El-Hadj T., Macé S., Mata-Álvarez J*., 2007. Operation and model description of a sequencing batch reactor treating reject water for biological nitrogen removal via nitrite. *Bioresource Technology*, 98, 2065 – 2075.

5. *Dymaczewski Z*. Poradnik eksploatatora oczyszczalni ścieków. PZITS Poznań 2011

6. Gunar Thelin – Ekobalans, 2014. Sustainable nutrient recycling. *Euroslam Conference, Helsingborg, Sweden.*

7. *Gut L., Płaza E., Trela J., Hultman B., Bosander J*., 2006. Combined partial nitritation/Anammox system for treatment of digester supernatant. *Water Science & Technology*. 53 (12), 149–159.

8. *Kartal B., Van Niftrik L., Keltjens J.T., Op den Camp H.J.M., Jetten M.S.M*., 2012. *Anammox—Growth Physiology, Cell Biology,and Metabolism*. Advances in Microbial Physiology. pp. 211- 262.

9. *Lackner S., Eva M. Gilbert E.M., Vlaeminck S.E., Joss A., Horn H., van Loosdrecht M.C.M*., 2014. Full-scale partial nitritation/anammox experiencese An application survey. *Water research* 55, 292-303.

10. *Malovanyy A., Plaza E., Rajkowski M., Trela J*. 2014. Deammonification process combined with UASB reactor for treatment of mainstream wastewater. In *Proceedings of 11th IWA Leading Edge Conference on Water and Wastewater Technologies*, May 26-30, 2014 Abu-Dhabi, United Arab Emirates.

11. *Malovanyy A., Yang J., Trela J., Plaza E*. 2015. Combination of upflow anaerobic sludge blanket (UASB) reactor and partial nitritation/anammox moving bed biofilm reactor (MBBR) for municipal wastewater treatment. *Bioresource Technology* 180, 144–153.

12. *Malovanyy A., Yang J., Trela J., Plaza E*. 2015. Combination of upflow anaerobic sludge blanket (UASB) reactor and partial nitritation/anammox moving bed biofilm reactor (MBBR) for municipal wastewater treatment. *Bioresource Technology* 180, 144–153.

13. *PUB (2015-11-10):* (*http://www.pub.gov.sg/water/newater/Pages/default.aspx*) Singapore's national water agency.

14. *Regmi P., Holgate B., Miller M.W., Bunce R., Park H., Chandran K., Wett B., Murthy S., Bott C.B*., 2013. NOB out-selection in mainstream makes two-stage deammonification and nitrite-shunt possible. *WEF/IWA Nutrient Removal and Recovery Conference* – July 28-31, 2013, Vancouver, Canada.

15. *Remy M., Kruit J., Hendrickx T., Haarhuis R., van Loosdrecht M*., 2013. Phospaq: Full scale experience with phosphorus recovery via controlled struvite precipitation. *WEF/IWA Nutrient Removal and Recovery Conference* – July 28-31, 2013, Vancouver, Canada.

16. *Stinson B., Murthy S., Bott C., Wett B., Al-Omari A., Bowden G., Mokhyerie Y., De Clippeleir H*., 2013. Roadmap Toward Energy Neutrality & Chemical Optimization at Enhanced Nutrient Removal Facilities. *WEF/IWA Nutrient Removal and Recovery Conference* – July 28-31, 2013, Vancouver, Canada.

17. *Sultana R*., 2014. Partial Nitritation/Anammox process in a moving bed biofilm reactor operated at low temperatures. *Licentiate thesis, TRITA-LWR LIC-2014:05*, Royal Institute of Technology, Stockholm, Sweden.

18. *Susanne Lackner S., Gilbert E.M., Vlaeminck S.E., Joss A., Horn H., van Loosdrecht M.C.M*, 2014. Full-scale partial nitritation/anammox experiences. An application survey. Water Research 55, 292 – 303.

19. *Szatkowska B., Cema G., Plaza E., Trela J., Hultman B*., 2007. A one-stage system with partial nitritation and Anammox processes in the moving-bed biofilm reactor. *Water Science & Technology*, 55 (8–9), 19–26.

20. *Szetela R*., 2014. Bilans energetyczny oczyszczalni ścieków. *Gaz Woda i Technika Sanitarna* 4, 143-147.

21. Trojanowicz K., Plaza E., Trela J., 2015. Pilot Scale Studies on Nitritation-Anammox Process for Mainstream Wastewater at Low Temperature. *Water Science & Technology – in press.*

22. *Van Loosdrecht M.C.M., Salem S*., 2006. Biological treatment of sludge digester liquids. *Water Sci. Technol.* 53, 11.

23. *WERF (2010)* Strass im Zillertal WWTP Case Study Sustainable Treatment: Best Practices from the Strass im Zillertal Wastewater Treatment Plant. (http://brownfields-toolbox.org/download/office_of_water/Strass%20WWTP%20Energy%20Case%20Study.pdf)

24. *Westerhoff P., Lee S., Yang Y., Gordon GW., Hristovski K., Halden RU., Herckes P.,* 2015. Characterization, Recovery Opportunities, and Valuation of Metals in Municipal Sludges from U.S. Wastewater Treatment Plants Nationwide. *Environ. Sci. Technol.* 49 (16), 9479–9488.

25. *Wett B*., 2013. Application of Mainstream Deammonification. *WEF/IWA Nutrient Removal and Recovery Conference* – July 28-31, 2013, Vancouver, Canada.

26. *Wett B., Omari S. M., Podmirseg M., Han O., Akintayo M., Gómez B., Murthy S., Bott C., Hell M., Takács I., Nyhuis G., O'Shaughnessy M.,* 2013. Going for mainstream deammonification from bench to full scale for maximized resource efficiency. *Water Science & Technology,* 68(2), 283-289.

27. *Wójtowicz A*., 2014. Kierunki rozwoju gospodarki osadowej. *Gaz Woda i Technika Sanitarna* 4, 148-153.

Надійшло до редакції 15.11.2015

УДК 628.17:628.194

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ВОДОПОСТАЧАННЯ НАСЕЛЕНИХ ПУНКТІВ В УМОВАХ ЗНАЧНОГО ЗНИЖЕННЯ ВОДОСПОЖИВАННЯ

Запропоновані сучасні заходи підвищення ефективності водопровідних систем в умовах значного зниження водоспоживання

Ключові слова: підвищення ефективності, зниження водоспоживання, вторинне забруднення води.

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Стрімке зниження водоспоживання в Україні простежується з початку її незалежності та триває до теперішнього часу. Надто помітним стає потреба зниження виробничих потужностей очисних споруд, зростання питомих витрат електроенергії насосних станцій, потужні витрати на утримання системи подачі та розподілу води. Особливо гостро ця проблема постає для систем водопостачання населених пунктів з середньою та значною чисельністю населення.

За оцінками фахівців потенціал енергозбереження у секторі водопостачання становить 25…30%, що в масштабі країни відповідає 1,2…1,5 млрд кВт год/рік [1].