Chapter 11

Beata Tomczuk, Wojciech Dąbrowski

New Applications of Hydrophyte Method in Environmental Protection

1. Introduction

The problem of proper sewage treatment becomes more current because of increasing needs for water and its limited resources. Sewage treatment is commonly considered as a one of key activities of environmental protection.

The concept of environmental protection is understood as taking or holding off actions that lead to the maintenance or restoration of environmental balance. This is put forward in particular by means of shaping the environment and managing its resources according to the rules of sustainable development. It is also done by combating atmospheric pollution as well as by restoring proper conditions of environmental elements (Dz.U. 2001 Nr 62 poz. 627 2001).

The rules of sustainable development were defined in 1987 by The World Commission
of Environment and Development in the report “Our Common Future”; approved in 1992 under “Agenda 21” act. As a result, methods of ecological engineering gained importance, amongst which were natural methods which minimize interference into the environment (Cooper 2009).

The hydrophyte method of water and sewage treatment is an example of ecological engineering method applied in environmental protection. It uses natural processes which occur in marshy ecosystems by taking them under intensification and control. The method is a biological process utilizing heterotrophic microorganisms and hydrophytes which inhabit properly designed constructed wetlands and ponds (Vymazal 2005, Obarska-Pempkowiak et al. 2010).

The prevalence of hydrophyte method results from a wide range of processes taking place in constructed wetlands. Among them the most important are: oxidation and reduction, sorption, sedimentation and assimilation. They enable efficient removal of organic and biogenic compounds, as well as specific pollutants such as selected heavy metals (Obarska – Pempkowiak et al. 2010). There are three types of constructed wetlands: free water surface flow (FWS-CW), subsurface vertical flow (VF-CW) and subsurface horizontal flow (HV-CW).

The usefulness of free water surface flow constructed wetland is limited in moderate climate because of significant decrease in the effectiveness during cold seasons (Ozimek, Renman 1995). Moreover, its application involves some odour nuisance and sanitary risk.

Therefore, subsurface flow constructed wetlands are used more commonly. Research indicates that subsurface horizontal flow constructed wetlands provide sufficient decomposition of organic compounds and denitrification. Vertical flow constructed wetlands provide suitable conditions for organic compounds mineralization and efficient nitrification (Gajewska, Obarska – Pempkowiak 2005).

A lot of processes taking place in constructed wetlands enable their wide application. These are commonly used for domestic sewage treatment in non-urbanized areas, where there are no economic and technical conditions for construction of sewerage systems (Brix, Arias 2005, Sadecka 2003, Soroko 2001). The examples of constructed wetlands applications on rural areas are presented in the photograph 1 and 2.

Phot. 1. Vertical flow constructed wetland (phot. Ekoprom 2011)

Phot. 2. Vertical flow constructed wetland (phot. Dąbrowski 2010)

Another known application of hydrophyte method is treatment of landfill reject water (Birkbeck et al. 1990, Bulc 2006, Wojciechowska et al. 2010, Johansson-Westholm 2004), rain waters (Greenway et al. 2006, Obarska-Pempkowiak et al. 2008, Shutes et al. 1999), selected industrial wastewater (Dunbabin et al. 1992, Dąbrowski 2011), sewage sludge dewatering and stabilization (Nielsen 2003, Uggetti et al. 2010) as well as treatment of reject water from aerobic and anaerobic stabilization (Dąbrowski 2010a, Gajewska 2011).

Current development of hydrophyte method focuses on extending its application. High potential was noticed at sewage treatment plants overloaded with pollutants. It is especially valid at diary sewage treatment plants that recycle reject water from sludge stabilization. The similar problem is observed at municipal sewage treatment plants with high rate of septage in the total load. In both cases, uncontrolled increase of the load of biological part can result in many disturbances in sewage treatment plant operation. The most important are disorders of activated sludge operation in biological chambers and problems with sedimentation in secondary settlement tanks. As a result, the risk of system breakdown increases. There are also observed difficulties in obtaining required quality of the effluent. It threatens natural environment.

Moreover, higher pollutant load causes the increase of the costs of sewage treatment (Miłaszewski 2003) and the necessity of a plant expansion or modernization. As a result, high and unreasonable investment expenditures and operational costs are incurred. The price of sewage treatment increases. That does not promote sustainable development rules.

Low investment and operational costs of hydrophyte systems have become a reason for widening their application for treatment of reject water from diary sewage treatment plants as well as for pretreatment of septage in municipal sewage treatment plants. The recommended use of vertical flow constructed wetlands comes out from its high removal efficiency of ammonium nitrogen, which is one of the major pollutants in both cases. It is also as effective in removal of organic compounds and total solids, which concentration is high in septage. In addition, vertical flow constructed wetlands require less space in comparison to the other types of wetlands.

The aim of the paper is to share conclusions from the application of hydrophyte method for treatment of reject water from aerobic stabilization of dairy sludge. It also presents the effectiveness of septage pretreatment in constructed wetlands.

2. Characteristic of the implemented installation in Bielsk Podlaski juxtaposed with the issue

The problem of the influence of reject water on biological treatment process is regarded to both municipal and industrial sewage treatment plant using activated sludge method. Application of intensive sewage treatment methods was forced by the implementation of stricter rules concerning quality of the effluent. As a result, the quantity of generated sludge and reject water has increased.

Reject water from sewage treatment plants which apply anaerobic sludge stabilization is characterized by higher values of pollution indicators in comparison with plants using aerobic sludge stabilization. The quantity of reject water in plants with aerobic sludge stabilization accounts for 2.7% to 7% of total sewage (Ryzińska 2006). Such reject water is characterized by high ammonium nitrogen pollution, reaching even 2000 mg $N·dm^{-3}$. Literature data confirms that plants are significantly loaded with ammonium nitrogen from anaerobic sludge treatment, which requires application of advanced and expensive treatment methods. References in foreign literature indicate that the load of reject water from anaerobic sludge stabilization accounts for 7% to even 25% of total load (Meyer, Wilderer 2004). Research studies conducted at sewage treatment plant utilizing separate aerobic sludge stabilization in Podlaskie province has indicated that the quantity of generated reject water accounts for 2.1% to 2.9% of treated sewage quantity. Mean values of the basic pollution concentrations were as follows: BOD_5 (Biochemical Oxygen Demand): 185-219 mg $O_2·dm^{-3}$, ammonium nitrogen: 56.4-96.5 mg $N\text{-}NH_4^+·dm^{-3}$, total phosphorus: 9.6-12.6 mg $P·dm^{-3}$ (Dąbrowski 2010a). According to the research conducted in 2008, the quantity of reject water from aerobic stabilization in dairy sewage treatment plants accounted for a few to several percent of raw sewage quantity. Pollution concentrations in reject water (mean values in Wysokie Mazowieckie) were at the level of: BOD_5: 106 mg $O_2·dm^{-3}$, ammonium nitrogen: 19.8 mg $N\text{-}NH_4^+·dm^{-3}$, total phosphorus: 6.9 mg $P·dm^{-3}$ (Dąbrowski 2008).

Reject water recycling to the beginning of treatment process, which is commonly used, has limitations in many individual dairy sewage treatment plants. It was necessary to search for new methods which would have enabled decreasing reject water influence on biological treatment. Therefore, it was suggested to enrich system with constructed wetland for separate reject water treatment.

Based on results of the research conducted between 2006 and 2009, full scale installation was constructed at Mlekovita Dairy Sewage Treatment Plant in Bielsk Podlaski. Vertical flow constructed wetland is the main element. It is built of three layers: sand, gravel, and stones. The total filter height is 0.65 m. Unused sludge drying beds were used as a structure of constructed wetlands. It has enabled to decrease costs of the installation. Sludge drying beds had been used for sludge dewatering at municipal and industrial sewage treatment plants. Therefore it is possible to utilize them at many sewage treatment plants. Vertical flow constructed wetland, which is one of the element of implemented installation is shown in the photograph 3 (June 2011).

Phot. 3. Part of implemented installation in Bielsk Podlaski (phot. Dąbrowski 2011)

Conducted research with the use of implemented installation in the framework of the project "Determination of constructed wetlands usefulness for treatment of reject water from aerobic sludge stabilization in dairy sewage treatment plants" proved high efficiency of reject water treatment. According to the research conducted after the installation start – up, mean removal efficiencies were as follows: BOD_5 – 71.2 %, COD (Chemical Oxygen Demand) – 60.3%, ammonium nitrogen – 72.5 % and total phosphorus – 30.2% (Dąbrowski 2010b). Apart from total phosphorus, the effluent parameters allowed the reject water to be discharged to the receiver. However, the composition and the quantity of reject water is going to change because of modernization of sewage treatment plant in Bielsk Podlaski. Therefore, it is planned to expand the installation adequately.

3. Conditions of the research on septage pretreatment process

The concept of the research on septage pretreatment process also comes out from the search for new application of simple, efficient and non-waste hydrophyte method.

A problem of overloading with pollutants contained in septage from individual cesspools regards mainly small sewage treatment plants located in non-urbanized areas. Septage quality is significantly different from sewage quality. According to author's research, mean values of pollutants concentration in septage were at the level of: BOD_5: 1080 mg $O_2 \cdot dm^{-3}$, COD: 1790 mg $O_2 \cdot dm^{-3}$, ammonium nitrogen: 84 mg $N\text{-}NH_4^+ \cdot dm^{-3}$, total phosphorus: 31.6 mg P $\cdot dm^{-3}$, whereas in sewage respectively: BOD_5: 250 mg $O_2 \cdot dm^{-3}$, COD: 790 mg $O_2 \cdot dm^{-3}$, ammonium nitrate: 26 mg $N\text{-}NH_4^+ \cdot dm^{-3}$, total phosphorus: 15 mg $\cdot dm^{-3}$ (Tomczuk 2011a). There are many reasons of observed differences. Cesspool leak or even their deliberate unsealing are the most important. As a result, only slight part of septage is delivered to plants and properly treated. However, in previous years, the quantity of treated septage increased slowly but systematically (GUS 2004-2007, US in Białystok 2003 – 2009). It is mainly thanks to control actions taken by municipalities and introduced legal regulations. A similar trend is observed in other European countries (Troesch et al. 2009). As a consequence, the problem of overloading of small sewage treatment plants with pollutants contained in septage is going to increase.

The septage receiving stations and equalization reservoir tanks are technical solutions used in Poland, which aim to decrease negative septage impact on biological treatment. Installation of septage receiving stations has enabled measuring septage quantity and its primary mechanical treatment, resulting in the decrease of total solids and organic compounds (Tomczuk 2010). Sewage treatment plant equipment in equalization reservoir tanks has enabled hydraulic regulation of septage flow. However, pollutant loading going to biological treatment has remained almost unchanged (Tomczuk 2011b, Tomczuk, Dąbrowski 2011). The research carried out by Grygorczuk-Peterson (2008), Jeleń and Wyrwik (2003) and Sadecka (2011) has proved that it can disturb biological treatment resulting in insufficient effluent quality.

In order to solve problems caused by septage completely, it is necessary to reduce load of organic and biogenic compound before it is added to biological treatment. Therefore, it was suggested to enrich the system with vertical flow constructed wetland for septage pretreatment. It is fed by mechanically treated septage.

There were not found any references to this application of hydrophyte method in the literature. Research on hybrid system (vertical flow constructed wetland and sand filter) application for total septage treatment and co-treatment of septage and sewage was conducted in France (Paing, Voisin 2005). There is also known application of reed bed filters for sewage sludge and septage stabilization and dewatering (Nielsen 2003, Koottatep et al. 2005, Troesch et al. 2009, Vincent et al. 2010). The aim of the mentioned studies conducted in France and Thailand was to find out the relationship between constructed wetland pollutant loading, impounding period and effectiveness of septage treatment or dewatering. The load of total solids given for square meter of constructed wetland per year was used as a load indicator. An extremely high concentration of total solids was the reason for using this parameter: in Thailand: 2202 - 67200 mg TS·dm^{-3} (Koottatep et al. 2005), in France: 6704 - 63970 SS mg·dm^{-3} (Troesch et al. 2009), in United Stated: 1132 - 130475 mg TS·dm^{-3} (US EPA 1994). The range and spread of these values significantly differ from values observed in Podlaskie province. The highest differences are observed in total solids concentration, which according to preliminary research was not as high (Tomczuk 2010, Tomczuk 2011a). That was the reason to base author's research on the organic load of constructed wetlands, not on the total solids load.

The aim of the research was to determine constructed wetlands effectiveness in municipal septage pretreatment. The paper presents results from installation start-up.

4. Object and methodology of the research on septage pretreatment process

A research object was an installation built at Municipal Sewage Treatment Plant in Sokółka. Vertical flow constructed wetland is the main element of the installation. It is built of three layers: sand 0-2 mm (15 cm), gravel 2-16 mm (35 cm) and stones 16-60 mm (15 cm). Total filter depth is equal to 65 cm. The filter surface amounts to 5 m^2. Bottom and sides were reinforced by wood plates and sealed by foil. Distribution system is placed on the upper layer. Drainage collecting system is placed on the bottom. Ventilation is provided by system of six vertical pipes connected with drainage, which prevent creation of anaerobic conditions. Constructed wetland construction is shown in the figure 1.

The constructed wetland was planted with common reeds (*Phragmites australis*). Seedlings, presented in the photographs 4 and 5, were specially prepared for the project, and proved very effective in the project of reject water treatment. Research started after full growth of plants.

Apart from the constructed wetland, the installation consists of sieve 5 mm, two equalization reservoir tanks of 1 m^3 capacity each, control well, measurement system and weather station. The research installation as of summer 2011 is presented in the photograph 6.

Septage used to feed installation was mechanically treated by means of sieve, which is commonly used device in septage receiving station. The reservoir tank was filled with septage discharged from vacuum tank truck (in equal portions during each: initial, medium and final phases of discharge). This methodology of sampling is recommended by American Environmental Protection Agency (US EPA 1994).

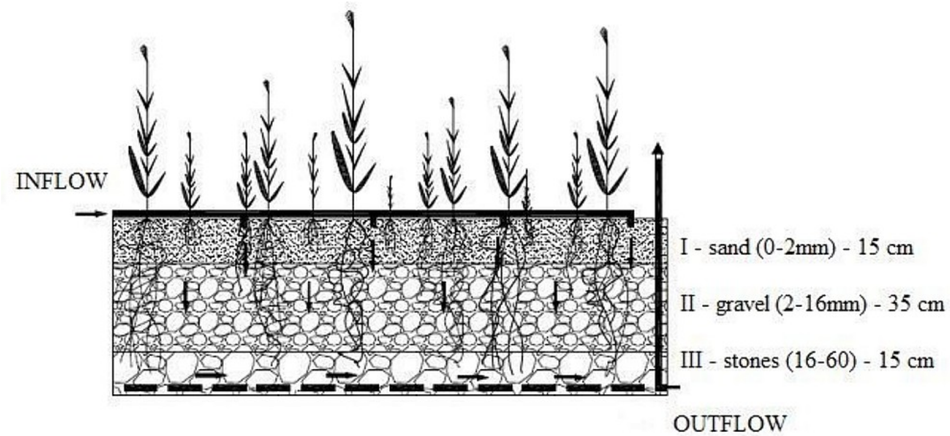
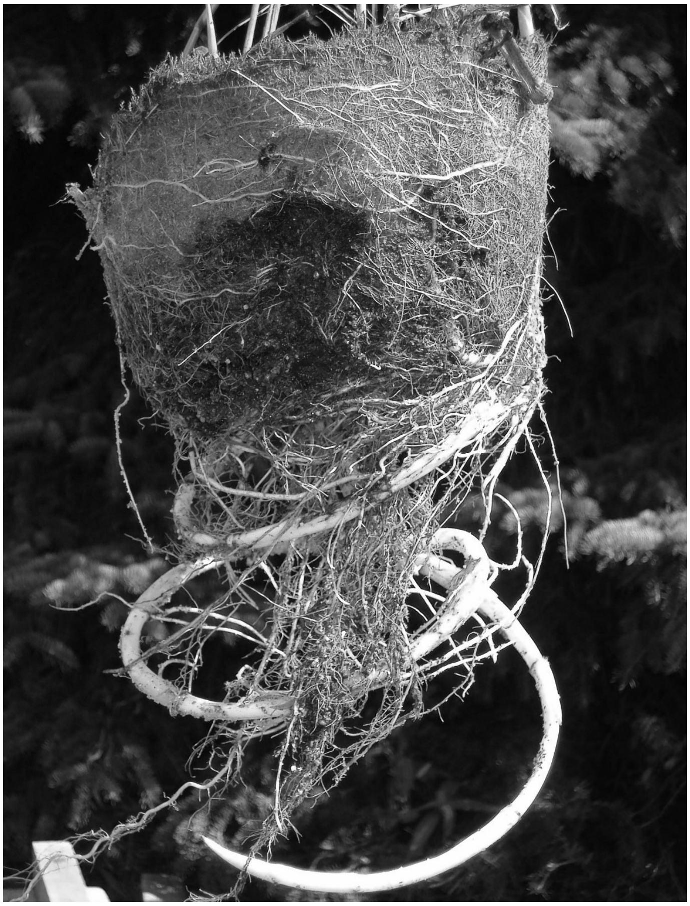


Fig. 1. Scheme of vertical flow constructed wetland (Tomczuk 2010)



Phot. 4. Seedling of common reed (*Phragmites australis*) used for constructed wetland planting (phot. Tomczuk 2010)

Phot. 5. Constructed wetland after planting (phot. Tomczuk 2010)

Phot. 6. Research installation (phot. Tomczuk 2011)

5. Results and discussion

A start-up of the installation described above took place in Autumn 2010. Hydraulic load was equal to 0,05 m·d-1 and 0,1 m·d-1. Samples of pretreated septage were taken 24 hours after initial loading of constructed wetland. All research series were conducted in rainless period. The following parameters of basic pollution indicators were determined: biochemical oxygen demand BOD_5, chemical oxygen demand COD, total solids, ammonium nitrogen $N\text{-}NH_4^+$, nitrate nitrogen (V) $N\text{-}NO_3^-$, nitrite nitrogen (III) $N\text{-}NO_2^-$, total phosphorus TP, reaction pH and conductivity. Analyses were conducted in compliance with Polish standards methodologies. The results are presented in the table 1.

Table 1

Effectiveness of septage pretreatment

Experimental conditions		T = 15°C Q = 0,05 $m \cdot d^{-1}$ Area per PE*= 2,3 m^2			T = 13°C Q = 0,1 $m \cdot d^{-1}$ Area per PE*= 0,8 m^2		
Parameter	**Unit**	**Inlet**	**Outlet**	**Efect.**	**Inlet**	**Outlet**	**Efect.**
BOD_5	mg $O_2 \cdot dm^{-3}$	660	120	82%	800	160	80%
COD	mg $O_2 \cdot dm^{-3}$	1325	281	79%	1532	384	75%
Total solids	mg$\cdot dm^{-3}$	309	5,5	98%	612	29	95%
Ammonium nitrogen	mg $N\text{-}NH_4^+ \cdot dm^{-3}$	51,4	10,3	80%	66,0	62,7	6%
Nitrate nitrogen (V)	mg $NO_3^- \cdot dm^{-3}$	1,6	0	-	2,2	6,0	-
Nitrite nitrogen (III)	mg $NO_2^- \cdot dm^{-3}$	0,40	0,11	73%	0,28	0,13	54%
Total phosphorus	mg $P \cdot dm^{-3}$	2,7	0,9	67%	33,2	14,1	58%
Reaction pH	-	7,2	7,2	-	6,8	7,0	-
Conductivity	$mS \cdot cm^{-1}$	1,86	1,6	-	1,77	1,42	-

*PE – person equivalent – loading of 60 g $O_2 \cdot d^{-1}$
Source: author's research

Values of standard pollution indicators observed in raw septage were significantly different from values noted in France (Paing, Voisin 2005, Troesch et al. 2009; Vincent et al. 2010), Argentine (Ingallinella et al. 1996), Thailand (Koottatep et al. 2005) and United States (US EPA 1994). Significant differences are allowed because of many different factors influencing septage composition. According to American Agency of Environmental Protection Climate the most important are: hygienic habits of inhabitants, frequency of cesspools emptying, their shape and geometry (US EPA 1994). In Polish literature, tank – tightness is considered as a principal factor (Maksymowicz, Opęchowski 2006). Moreover, discrepancy could be a result of the lack of differentiation between municipal and industrial septage. In the author's research only municipal septage was used.

In initial operational phase no significant relation was observed between pollutant loading and effectiveness of organic compounds removal. The lack of this relation was also proved by Koottatep et al. (2005) in application of constructed wetlands planted with Narrow Leaf Cattail *Typha angustifolia* for septage dewatering in tropical climate. An increase of treatment effectiveness with the increase of pollutant loading was observed by Gajewska and Obarska-Pempkowiak in multistage constructed wetland treating domestic sewage (2009).

There is no impact of hydraulic load on pollutant removal efficiency, except for removal of ammonium nitrogen. Research conducted by Paing and Voisin (2005) on constructed wetland application for full treatment of septage and co-treatment of sewage and septage also did not prove relation between hydraulic load and effectiveness of organic compounds removal. High hydraulic load decreases the effectiveness of ammonium nitrogen removal in nitrification process. It is confirmed by studies conducted by Gajewska and Obarska – Pempkowiak (2005). Results received by Koottatep et al. (2005) did not show significant influence of load on nitrogen compounds removal. However, a plan of the research was based on the annual global total solids load, not on hydraulic load, which influences constructed wetland aeration.

The efficiency of total phosphorus removal do not significantly changes with the increase of hydraulic and pollutant loading. Similar relation comes out from research conducted by Vincent et al. (2010) and Paing and Voisin (2005). The effectiveness of total phosphorus removal at the level of 58% and 67% is considered as a very high. It is probably caused by high sorption capacity of the filter material in the initial period of constructed wetland operation.

In order to assess effectiveness of septage pretreatment in vertical flow constructed wetland completely it is necessary to carry on research in a yearly cycle. Received results will enable the preparation of detail instructions for designing this type of installations in small sewage treatment plants located in non-urbanized areas.

6. Conclusions

1. Searching for new applications of natural, low-cost and efficient hydrophyte method is aimed at rationalization of the environment management and use of its resources according to the rules of sustainable development. It contributes to the broad field of environmental protection.
2. Application of the installation based on vertical flow constructed wetland for reject water treatment and septage pretreatment could resolve problems with unstable and inefficient operations of sewage treatment plants which are overloaded with pollutants. It may also prevent their costly modernization.
3. Hydraulic load of constructed wetland does not influence the effectiveness of organic compounds removal. However, its overloading beyond vegetation period decreases effectiveness of the nitrification process. Pollutant load also does not have impact on the effectiveness in the start-up phase of constructed wetland operation, but could have after reaching its maturity stage.

4. The load of constructed wetlands shall be determined individually for each sewage treatment plant, in accordance with economic effectiveness of septage pretreatment.

Acknowledgements

Research co-financed from funds of European Social Fund, budget of Poland and Podlaskie province in the frame of the project *„Podlaska Strategia Innowacji – budowa systemu wdrażania*”.

References

Birkbeck A.E, Reil D., Hunter R., 1990. Application of natural and engineering wetlands for treatment of low strength leachate. Constructed Wetlands in Water Pollution Control (Eds. P.F. Cooper, B.C. Findlater). Oxford, UK: Pergamon Press, 411-418.

Brix H., Arias C.A., 2005. The use of vertical flow constructed wetlands for on-site treatment of domestic waste water: New Danish guidelines. Ecological Engineering, 25: 491-500.

Bulc T.G., 2006. Long term performance of a constructed wetlands for landfill leachate treatment. Ecological Engineering, 26: 365-374.

Cooper P., 2009. What can we learn from old wetlands? Lessons that have been learned and some may have been forgotten over the past 20 years. Desalination, 246: 11-26.

Dąbrowski W., 2008. Oczyszczanie odcieków z przeróbki osadów w oczyszczalni ścieków mleczarskich. Inżynieria i Ochrona Środowiska, 11: 115-122.

Dąbrowski W., 2010a. Charakterystyka odcieków z tlenowej przeróbki osadów w komunalnych i przemysłowych oczyszczalniach województwa podlaskiego. Inżynieria i Ochrona Środowiska, 13: 43-51.

Dąbrowski W., 2010b. Wdrożenie systemu do oczyszczania odcieków z tlenowej przeróbki osadów w oczyszczalni ścieków mleczarskich. Monografia Komitetu Chemii Analitycznej PAN pt. Gospodarka odpadami Komunalnymi (red. Szymański K.): 153-163.

Dąbrowski W., 2011. Effectiveness of constructed wetlands for diary wastewater treatment. Ecological Chemistry and Engineering, 18: 175-181.

Dunbabin J., Bowmer K., H., 1992. Potential use of constructed wetlands for treatment of industrial waste containing metals. The Science of the Total Environment, 3: 151-168.

Gajewska M., Obarska – Pempkowiak H., 2009. 20 lat doświadczeń z eksploatacji oczyszczalni hydrofitowych w Polsce. Rocznik Ochrony Środowiska, 11: 875-88.

Gajewska M., Obarska – Pempkowiak H., 2005, Wpływ konfiguracji zasilania obiektów hydrofitowych na efektywność usuwania zanieczyszczeń, Ogólnopolska Konferencja Naukowa nt: Kompleksowe i Szczegółowe Problemy Inżynierii Środowiska, Ustronie Morskie.

Gajewska M., 2011. Oczyszczanie odcieków z mechanicznego odwadniania przefermentowanych osadów ściekowych w wielostopniowych złożach hydrofitowych. Inżynieria Ekologiczna, 25: 86-98

Główny Urząd Statystyczny, 2004, 2005, 2006, 2007. Ochrona środowiska. Warszawa.

Grygorczuk – Petersons E., 2008. Ocena efektywności oczyszczalni ścieków w gminie Narewka woj. podlaskie. Gaz, Woda i Technika Sanitarna, 9: 66-69.

Ingallinella A.M., Sanguinetti G., Vazquez H. P., Fernandez G.G., 1996. Treatment of wastewater transported by vacuum tanks. Water Science Technology, 33(3): 239-246.

Jeleń U., Wyrwik Sz., 2003. Wpływ ścieków dowożonych beczkowozami na prawidłową pracę małej oczyszczalni ścieków na podstawie eksploatacji oczyszczalni w Trzebini-Sierszy. Forum Eksploatatora, 3: 5-8.

Johansson-Westholm L., 2004. Constructed wetlands for treatment of landfill leachate – experiences from Sweden and Norway. Vatten Lund, 60: 7-14.

Koottatep T., Surinkul N., Polprasert C., Kamal A.S.M., Koné D., Montangero A., Heinss U., Strauss M., 2005. Treatment of septage in constructed wetlands in tropical climate: lessons learnt from seven years of operation, Water Science & Technology, 51, (9): 119-126.

Maksymowicz B., Opęchowski P., 2006. Zasady gospodarowania nieczystościami ciekłymi. Poradnik, Ośrodek Badawczo – Rozwojowy Ekologii Miast, Łódź.

Miłaszewski R., 2003. Ekonomika ochrony wód powierzchniowych. Fundacja Ekonomistów Środowiska i Zasobów Naturalnych. Wydawnictwo Ekonomia i Środowisko, Białystok, pp. 81-84.

Meyer S.S., Wilderer A., 2004. Reject Water: Treating of Process Water In Large Wastewater Treatment Plants In Germany - A Case study. Journal of Environmental Science and Health, 39 (7): 1645-1654.

Nielsen S., 2003. Sludge drying reed beds, Water Science & Technology, 48 (5): 101-109.

Obarska – Pempkowiak H., Gajewska M, Arendacz M., 2008. Oczyszczanie wód opadowych w obiektach hydrofitowych. Gaz, Woda, Technika Sanitarna, 9: 56-59.

Obarska – Pempkowiak H., Gajewska M., Wojciechowska E., 2010. Hydrofitowe oczyszczanie wód i ścieków, Wydawnictwo Naukowe PWN, Warszawa, pp. 1-28.

Ozimek T., Renman G., 1995. Wykorzystanie makrolitów w niekonwencjonalnych oczyszczalniach ścieków, Wiadomości Ekologiczne: 239-254.

Paing J., Voisin J., 2005. Vertical flow constructed wetlands for municipal wastewater and septage treatment in French rural area. Water Science & Technology, 51(9): 145-155.

Ryzińska J., 2006. Problem wód osadowych i możliwości ich oczyszczania w Polsce. Gaz Woda i Technika Sanitarna, 7-8: 58-62.

Sadecka Z., 2003. Ocena efektywności pracy wybranych oczyszczalni hydrobotanicznych. Ochrona Środowiska, 25, (1): 13-16.

Sadecka Z., 2011. Weryfikacja danych do modernizacji oczyszczalni ścieków. Forum Eksploatatora, 3: 58-62.

Shutes R.B.E., Revitt D.M., Lagerberg I.M., Barraud V.C.E.: 1999. The design of vegetative constructed wetlands for the treatment of highway runoff. The Science of the Total Environment, 235: 189-197.

Soroko M., 2001. Skuteczność usuwania substancji organicznych oraz związków biogennych w kilku oczyszczalniach hydrofitowych. Woda – Środowisko – Obszary wiejskie, 1: 175-186.

Troesch S., Liénard A., Molle P., Merlin G., Esser D., 2009. Treatment of septage in sludge drying reed beds: a case study on pilot-scale beds. Water Science & Technology, 60 (3): 643-653.

Tomczuk B., 2010. Skład ścieków dowożonych i efektywność ich podczyszczania w wybranej oczyszczalni komunalnej województwa podlaskiego, XXX Międzynarodowe Sympozjum im. Bolesława Krzysztofika AQUA 2010 – Problemy Inżynierii Środowiska, Oficyna Wydawnicza Politechniki Warszawskiej, Płock: 102-108.

Tomczuk B., 2011a. Zmienność ilości ścieków i nieczystości ciekłych oraz ładunku zanieczyszczeń na przykładzie Oczyszczalni Ścieków Komunalnych w Lipsku n. Biebrzą. Inżynieria Ekologiczna, 24:145-153.

Tomczuk B., 2011b. Metody oczyszczania i podczyszczania nieczystości ciekłych, XXXI Międzynarodowe Sympozjum im. Bolesława Krzysztofika AQUA 2011 – Problemy Inżynierii Środowiska. Oficyna Wydawnicza Politechniki Warszawskiej. Płock: 83-88.

Tomczuk B., Dąbrowski W., 2011. Podczyszczanie nieczystości ciekłych dowożonych do oczyszczalni komunalnej i układ do podczyszczania. Zgłoszenie patentowe nr P.394093.

Uggetti E., Ferrer I., Llorens E., García J., 2010. Sludge treatment wetlands: A review on the state of the art. Bioresource Technology, 101: 2905-2912.

Urząd Statystyczny w Białymstoku, 2003, 2004, 2005, 2006, 2007, 2008, 2009. Ochrona środowiska i leśnictwo w województwie podlaskim. Białystok.

U.S. Environmental Protection Agency, 1994. Guide to Septage Treatment and Disposal. EPA Office of Research and Development, Washington, D.C. EPA/625/R-94/002.

Ustawa z dnia 27 kwietnia 2001 r. Prawo ochrony środowiska (Dz.U. 2001 Nr 62 poz. 627)

Vincent J., Molle P., Wisniewski C., Liénard, 2010. Sludge drying reed beds for septage treatment: towards design and operation recommendation. 12th IWA International Conference on Wetland System for Water Pollution Control, 04/10/2010 – 09/10/2010. Venice, ITA, 10p.

Wojciechowska E., Gajewska M., Obarska – Pempkowiak H., 2010. *Treatment of landfill leachate by* constructed wetlands: three case studies. Polish Journal of Environmental Studies, 19 (3): 643-650.

Vymazal J., 2005. Constructed wetlands for wastewater treatment. Ecological Engineering, 25: 475-477.

Beata Tomczuk, Wojciech Dąbrowski

Białystok Technical University
Faculty of Civil & Environmental Engineering
Department of Technology in Engineering & Environmental Protection
ul. Wiejska 45a, 15-351 Białystok, Poland
E-mail: b.tomczuk@doktoranci.pb.edu.pl, dabrow@pb.edu.pl