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DEWATERING OF ANAEROBICALLY STABILIZED SLUDGE ON REED BEDS

ODWADNIANIE OSADÓW STABILIZOWANYCH W WARUNKACH BEZTLENOWYCH NA POLETKACH TRZCINOWYCH

Słowa kluczowe: Osady ściekowe, osady ściekowe stabilizowane beztlenowo (osady przefermentowane), odwadnianie osadów, trzcina, poletka trzcinowe.

Keywords: Sewage sludge, anaerobically stabilized sludge (fermented sludge), dewatering of sludge, reed, reed bed.

W pracy przedstawiono wyniki badań przeprowadzonych w okresie 1997–2005 nad odwadnianiem osadów ściekowych stabilizowanych w warunkach beztlenowych na poletkach trzcinowych zlokalizowanych na komunalnej oczyszczalni ścieków, w Polsce Centralnej.

Z istniejących na oczyszczalni poletek osadowych do badań wydzielono poletko o powierzchni 60 m^2. Po nasadzeniu trzciny rozpoczęto zalewanie poletka osadem przefermentowanym. W ciągu roku dokonywano 5–6 zalewów. Wysokość warstwy zalewu wynosiła od 0,1 do 0,2 m. Roczne obciążenie poletka suchą masą osadu wynosiło około 41,7 kg/m^2. Czas odwadniania w okresie wiosenno–letnim wynosił 39 dni, zaś w okresie jesienno-zimowym 176 dni.

Objętość osadu przefermentowanego po odwodnieniu zmniejszała się średnio o 91,8 %. Ogólna wysokość warstw zalewów wynosiła 9,15 m. Łączna wysokość nagromadzonego wysuszonego osadu w ciągu 9 lat eksploatacji poletka trzcinowego wynosiła 0,75 m.

W okresie badawczym był obserwowany wzrost trzciny. Plon trzciny w postaci suchej masy wynosił od 1978 do 3150 g/m^2. Badania wykazały, że poletka trzcinowe mogą być wykorzystywane do odwadniania osadów ściekowych stabilizowanych w warunkach beztlenowych.

1. INTRODUCTION

Sludge developed in the sewage treatment process must be a subject to stabilization and dewatering process, because of its characteristics and a large volume. Many sewage treatment plants, especially small ones, can dewater stabilized sewage treatment sludge utilizing sludge dewatering beds. Currently some European countries and USA utilize wetlands ecosystem plants, mainly common reeds (*Phragmites australis*), to intensify sludge dewatering process on sludge dewatering beds.

Reed is a plant capable of growing on various types of beddings including acid, alkaline and neutral environment. It easily accommodates to constant floods as well as extended drought periods. As all capillary aquatic plants, reed has substantial ability to transpiration, which is the ability to intake water and discharge water in a form of vapor. Reed extensive root system increases permeability and filtration abilities of the bedding through constantly growing root and rhizome system, which positively affects the dewatering process of stabilized sewage sludge. The dewatering process of stabilized sludge, in natural condition on reed beds is less expensive then dewatering of sludge utilizing mechanical methods.

Initial research related to reed utilization for dewatering of sewage sludge was carried out in Germany in the Nuclear Research Center in Karlsruhe [Beitmann and Seidel, 1967; Kickuth 1969]. The eighties brought an increased interest in this method of dewatering. At that time research on this problem begin in many Europeans countries such as Germany, France, Belgium, Denmark, Sweden, and Great Britain as well in the United States.

In the nineties some research results were published based on couple of years of usage of dewatering systems in European countries [Lienards et all.1990, 1999, Lienard and Payrastre 1996, Hoffman 1990, Nielsen 1999] and in the United States [Kim and Cardenas 1990, Burgon et al. 1996, Hastreiter 1996, Kim and Smith 1997, Beeg et all. 2001]. Towards the end of nineties wide research over utilization of reeds for the sewage sludge dewatering in aerobic and anaerobic conditions commenced in Poland [Kalisz and Sałbut 1998, 1999, 2001, Cytawa 1995, 1996, Kalisz et all. 2002, Kalisz and Sałbut 2003, Obarska-Pempkowiak and Zwara 1996, Obarska-Pempkowiak et al. 1997]. Different types of concrete tanks with drainage and aeration channels, lined ground tanks as well as conventional sludge beds with reeds planted over it were used for sludge dewatering with reeds utilization.

The goal of those researches was to establish sludge dewatering parameters, in particular an applied dry mass loading of the dewatering systems to be used. Published results indicate, that dry mass loading applications used by different researchers vary very significantly.

Based on research by Lienard et all. [1990] the applied dry mass loading for the systems operating in the 10 year period for the aerobically stabilized sludge varied from 30 to 40 kg·d.m./m^{2}year (d.m. = dry mass). Nielsen [1990] indicates that the aerobically stabilized sludge loading was 49 kg·d.m./m^{2}year, and fermented sludge loading was approximately 55 kg.d.m./m^{2}year. Research data provided by Maeseneer [1997] indicate, that the applied rate of the aerobically stabilized sludge was 20 to 30 kg·d.m./m^{2}year. Kim and Smith [1997] indicate, that the applied system rate of fermented sludge was 13 to 60 kg·d.m./m^{2}year. Based on Kalisz et all. [2002], Kalisz and Sałbut [2003] the loading of the reed bed over the 5 year usage was averaging 30 kg·d.m./m^{2}year for the aerobically stabilized sludge and was averaging 47 kg·d.m./m^{2}year for the fermented sludge. Those later results allowed establishing initial technological parameters for the dewatering process over the 5 year period of usage of reed beds, where stabilized aerobic sludge and fermented sludge was dewatered [Kalisz et all. 2002]. Nielsen [2003] indicates, that over 10 year usage period of the dewatering system, he applied the aerobically stabilized sludge loading at a rate of approximately 50 kg·d.m./m^{2}year.

Advantages of usage of reeds for dewatering of sewage sludge were confirmed during the practical use and resulted in continuous successful application of this method in many Europeans countries as well as in the United States [Kalisz 2001, Nielsen 2003, Nielsen 2005].

2. MATERIAL AND METHODS

The fermented sewage sludge was the research material. Tests were carried out at the Municipal Sewage Treatment Plant, where a 60 m^2 bed separated from the other existing sludge beds was planted with reeds (*Phragmites australis*) and was exposed to multi layer flooding of the fermented sludge. There were 50 drying bed flood applications with sludge during the research period between 1997 and 2005. The height of the flood level during the research period was between 0,1 to 0,2 m. The subject reed bed was in use for 106 months. The purpose of tests was to evaluate the sludge dewatering process on the dewatering bed, where reeds were planted to intensify the dewatering process.

Technological measurements during the test:

- Height of the flood level – meters.
- Bed flood loading – based on the dry mass of the applied sludge and height of the flood level.
- Daily bed loading – based on the bed sludge dry mass loading and time of the sludge dewatering to the time in reaches water contents of 65 %.

- Yearly height of the flood level-determined by height of each loading and the number of loadings per year.
- Yearly bed loading-determined from bed flood loading and the number of loads per year.

Samples of sludge are taken to regular determine of analytical methods like:
- pH – potentiometric method.
- Dry sludge mass – weight method.
- Minerals and organics substances – weight method.
- Sludge wetness- determined by weight difference between wet sludge and dry sludge (dried in 105^{o}C).
- Total nitrogen-Kjeldahl method.
- Total phosphorus-colorimetric method.
- Potassium, calcium, magnesium-atomic absorption spectrometry (ASA).

During the test at the end of each vegetation period (autumn) results of plants activity were noted as follows:
- Height of the reed plants – determined in meters.
- Number of individual reed plants – clusters of reed plants was counted and number of individual plants in a cluster was counted per the unit area of the drying bed.
- Estimated weight of plants – at the end of the vegetative season, during each year of drying bed usage, reeds were cud from a certain area of the bed and the harvest was weighted and then dried in temperature of 105 degrees C, and from the difference of the weight the dry weight of plants was computed per 1 m^2.

3. RESULTS

See table 1 for the physical-chemical characteristic of the stabilized sludge applied for the dewatering during usage of the bed. The results in this table indicate, that pH of the sludge over the entire testing period remain at the similar level and averaged at pH of 7,0. Sludge had a tar consistency and the water contents was 95,8% on average, which equaled to a dry sludge weight of 42 g/kg. There was an average of 61,5% d.m. of organic material. There was on average of 3,90% d.m. of total nitrogen and 1,76% of total phosphorus and 0,47 % potassium in the dry mass of sludge.

There were 50 flood applications with sludge on this bed during the research period (between 1997 and 2005), out of which the last flood was applied during the winter period. The height of the flood level during the research period was

Table 1. Parameters of fermented sludge during dewatering process over period 1997 to 2005
Tabela 1. Parametry osadu przefermentowanego podczas procesu odwadniania w okresie od 1997 do 2005

Parameters	Units	Parameter range		
		minimum	maximum	average
pH		6,3	7,6	7,0
Dry weight	g/kg	20	72	42
Mineral substances	% d.m.	29,1	53,0	38,5
Organic substances	% d.m.	47 0	70,9	61,5
Sludge water content	%	92,8	98,0	95,8
Total nitrogen	(N_{og}) % d.m.	1,42	7,10	3,90
Total fosforus	(P) % d.m.	0,70	3,50	1,76
Potassium	(K) % d.m.	0,38	0,56	0,47

between 0,1 to 0,2 m. The dry mass bed loading was changing within the range of 3,0 to 14,4 kg/m^2. Discharge of the drainage water was reduced to zero after 5 to 6 days. After several days of the dewatering process the sludge layer was breaking up. During the vegetation period the bed dry mass loading was between 0,085 to 0,489 kg/m^{2}day during the nine year period of the drying bed usage. During the fall/winter season the bed loading was lighter and was 0,033 to 0,077 kg/m^{2}day. The number of flood applications during the year was 5 to 6. During the spring/summer season the of the dewatering process was 39 days on average and during the fall/winter season was longer and was 176 days on average. Reduction of the sludge water contents was 34,7 % on average and sludge volume reduction was by 91,2 %.

Total loading of the drying bed with dry sludge mass during the exploitation period was 375,7 kg/m^2, which equaled to the total height of the flood level of 9,15 m (table 2).

Strong growth of plants (*Phragmites australis*) was observed on the drying bed. The reeds harvest in form of dry mass during each year of the bed exploration was 1978 to 3150 g/m^2. Water content in plants was from 39 to 50%. Ash content was 9,3% with organic substances at 90,7 %. Contents of total nitrogen discovered in the reeds varied from averaging 1,63 % d.m., of total phosphorus averaging 0,17 % d.m.

Average in underground parts of reeds amount to the following: dry mass 476 g/kg, organic substance 86,2 % d.m., ash contents 13,8 % d.m., water contents 52,4 %, total nitrogen 31,5 g N/kg d.m. (3,15 % d.m.), total phosphorus 3,9 g P/kg d.m. (0,39 % d.m.).

Table 2. Technological parametus of fermented sludge dewatering on a reed bed over period of 1997 to 2005

Tabela 2. Parametry technologiczne osadu odwodnionego na poletkach trzcinowych w okresie od 1997 do 2005

Parameters	Units	Parameter range		
		minimum	maximum	average
Dry mass bed loading				
- per flood	kg/m^2flood	3,0	14,4	7,6
- per day (spring–summer)	kg/m^2day	0,085	0,489	0,236
- per day (winter season)	kg/m^2day	0,033	0,077	0,056
Height of the flood	m.	0,10	0,20	0,10–0,20
Number of the flood in year	Qvantity	5	6	5 – 6
Time of the sludge dewatering				
(spring–summer)	day	14	63	39
(autumn–winter)	day	150	193	176
Time of the sludge dewatering to the time in reach water contents of 65 %				
(spring–summer)	day	10	59	37
(winter–season)	day	156	177	170
Dry weight of dewatered sludge	kg/m^3	211	864	388
Sludge water content	%	13,6	78,9	61,2
Dry mass of dewatering sludge	kg/m^3	20	72	42
Organic substances in dewatering sludge	%	53,8	70,9	61,6
Yearly hight of the flood	m	0,75	1,20	1,00
Yearly bed looding	kg/m^2	25,5	53,0	41,7
Complite height of the flood level*	m			9,15
Complite dry mass loading of the sludge*	kg/m^2			375,7

* after nine years operation

Collect height of sludge withered and processed in time of nine – year exploitation of reed bed amount to 0,75 m. Samples collected for research from three levels i.e. from depth 20–35 cm, 40–55 cm and 60–75 cm, have exerted. Afthe first level dry mass of sludge totaled 312 g/kg in which organic substances presented 47,8 % d.m. Water contents amount to 68,8 % at this level. Contents of total nitrogen totaled 2,5 % d.m. and total phosphorus 2,0 % d.m. . Small amounts of potassium – 0,43 % d.m., calcium – 4,0 % d.m. and magnesium – 0,35 % d.m. were detected in the sludge.

At secourid level depth of 40 to 55 cm, the layer of sludge was characterized with water content 69,5 %, which equaled to dry mass of 305 g/kg. Content of organic substance was lower (46 %), however, content of total nitrogen and total phosphorus was higher in comparison to the amount of these substances in sludge from depth of 20 to 35 cm.

At depth of 60 to 75 cm, the layer of sludge was characterized with lowest water content (64,6 %), which equaled to dry mass of 354 g/kg. A considerably smaller content of organic substance, total nitrogen, total phosphorus, potassium, calcium and magnesium was detected in the sludge (table 3).

Table 3. The characteristic of dewatered fermented sludge on the different depth of reed bad after 9 years exploration
Tabela 3. Charakterystyka odwodnionego osadu na różnych głębokościach podczas 9-letniej eksploatacji

Parameters	Units	Depth, cm			
		20–35	40–55	60–75	average
pH		7,1	7,0	7,2	7,1
Dry weight	% d.m.	31,2	30,5	35,4	32,4
Mineral substances	%d.m.	52,2	54,0	61,3	55,8
Organic substances	% d.m.	47,8	46,0	38,7	44,2
Sludge water content	%	68,8	69,5	64,6	67,6
Total nitrogen	(N) % d.m.	2,5	2,7	2,2	2,5
Total fosforus	(P) % d.m.	2,0	2,3	1,7	2,0
Potassium	(K) % d.m.	0,43	0,38	0,34	0,38
Calcium	(Ca) % d.m.	4,0	2,6	2,1	2,9
Magnesium	(Mg) % d.m.	0,35	0,32	0,25	0,31

4. DISCUSION

The application of multilayer floods without necessity of removal of individual layers is the essence of the dewatering process using reed beds. Results obtained through research indicate, that it is possible in climatic conditions of central Poland to apply flood of fermented sludge to reed beds 5 to 6 times per year, which dry mass was averaging 42 g/kg. Applied reed bed loading rates, that were depending on the sludge dry mass poured, were changing from 3,0 for 14,4 kg/m^2 per flood application, which equaled to the yearly bed loading of 25,5 to 53,0 kg/m^2, averaging 41,7 kg/m^2.

Similar fermented sludge dewatering results were obtained Lienard et al. [1990]. Loading of the bed totaled 45,5 kg d.m./m^2 per year, and dry mass of sludge totaled 3,5 %. Nielsen [1990] provides results of research over dewatering of fermented sludge on Regstrup Sewage Treatment Plant in Denmark, where fermented sludge loading totaled 54,6 kg d.m./m^2 per year, but content of dry mass in the sludge applied varied from 3 to 4 %.

Edwards et al [2001] used high loading of 60 kg d.m./m^2 per year on reed beds, during dewatering of sludge from farm of swine flock in Rugeley Staffordshire, Great Britain.

According to Kim and Cardens [1990] in 28 sewage treatment plants in New Jersey, Pennsylvania and Maine, stabilized sludge was dewatered in anaerobic conditions, in which dry mass loading was very high and it totaled 108,5 kg d.m./m^2 per year.

Burgoon et al. [1996] is indicating that in the United States particularly in small Sewage Treatment Plants dewatering of sludge on reed beds is often used. Loading of approximately 40 kg d.m./m^2 per year was used on the Sewage Treatment Plant in Washington State.

Nielsen [2002, 2003, 2005], who lead many research in Denmark on sludge dewatering o reed beds applying different parameters of processes considers that, the reed bed loading for sludge stabilized in anaerobic conditions shall be 60 kg d.m./m^2 per year.

Results of authors research indicate, that applying the parameters of sludge dewatering such as dry mass loading of beds between 25,5 to 53,0 kg d.m./m^2 per year will result in exuberant growth of reeds, which reached a maximum of 3150 g/m^2.

Many researchers confirm the reed grows well on beds achieving even superior values. Hoffman [1990] indicates, the harvest of reed from the reed beds in Ulm, Germany totaled 4 kg d.m./m^2 at the applied relatively low loading of 20 kg d.m./m^2 per year. However, lower production of reed was noted at high loadings, and plant's leaves indicated numerous parasitic forms. According to this author application of non – stabilized or partially stabilized sludge is sometimes a reason of partial dying of these plants. Nielsen [2003, 2005] also reports, that however, reed is susceptible to high rate loadings. Hardey and Ozimek [2001] indicate that harvest of reed on reed beds in Swarzewo totaled 3600g/m^2. So, harvest of reeds on reed beds can be twice reed harvest of those in natural conditions, in Masuria Lakes littoral, as it was indicated by research results of Mochnacka-Ławacz [1974].

Authors have detected in underground parts of reeds, during various years of exploitations of reed beds, average parameters as follows: total nitrogen 3,15 % d.m. and total phosphorus 0,39 % d.m.

Peverly et all. [1995] detected contents of total nitrogen at 2,03 % d.m. and total phosphorus at 0,05 % d.m. in underground parts of reed (roots). Comparing contents of total nitrogen and total phosphorus in underground parts of plants in the hereby elaboration with above mentioned data of authors resulted the total nitrogen content is 1,55 times greater and total phosphorus content is 7,8 times greater.

After nine year exploitation of reed bed, the authors received 0,75 m thick layer of withered and processed sludge. Sludge from the depth of 40 to 55 cm had higher water content, lower content of organic substance, higher content of total nitrogen and total phosphorus in comparison to the amount of those parameters in the sludge layer from depth of 20 to 35 cm.

5. CONCLUSIONS

It is possible to apply reed beds to dewater anaerobically stabilized sludge, particularly in small sewage treatment plants, by applying multilayer floods and without necessity of removal of the already dewatered sludge for a number of years.

- The height of layer was 0,2 m and the amount of discharged sludge layers was 5–6 to per year.
- Average reed bed loading with sludge dry mss was per one flood was 7,6 kg/m^2 and yearly reed bed loading equaled to 53 kg/m^2.
- Fermented sludge after dewatering reduced its volume by approximately 91,8 %.
- Dry mass harvest of reed was in a range of 1978 to 3150 g/m^2.
- Layer of the dewatered and transformed sludge reached 75 cm over a period of nine years.
- Dewatered and processed sludge included biogenic substances (nitrogen, phosphorus and potassium).

REFERENCES

Bittman N., Seidel K., 1969. Entwasserung und Aufbereitung von chemieschlamm mit Hilfe von Ptlanzen. GWF 108, 18: 488–491.

Cytawa S., 1996. Odwadnianie osadów na poletkach trzcinowych . Seminarium Naukowo-Techniczne w ramach programu szkoleniowego „Zlewnia rzeki Rawki”. Warszawa 6–7 listopad, 62–65. (Dewatering of in sludges in reed bed).

Hardej M., Ozimek T., 2002. The effect of sewage sludge flooding on growth and morphometric parameters of *Phragmites australis* (Cav.) Trin. ex Steudel. Ecological Engineering 18: 343–350.

Kalisz L., Sałbut J., 1998. Wykorzystanie trzciny do odwadniania osadów. Badania modelowe. Ochrona Środowiska i Zasobów Naturalnych 15. (Using of reed to dewatering of sludges).

Kalisz L., Sałbut J., 1999. Wykorzystanie trzciny do odwadniania stabilizowanych osadów ściekowych. Monografia. Warszawa, IOŚ. (Using of reed to dewatering of sludges).

Kalisz L., 2001. Informacje uzyskane w czasie zwiedzania oczyszczalni ścieków w zachodniej części powiatu Monmouth (NJ), USA, w skład której wchodzą poletka trzcinowe do odwadniania osadów stabilizowanych w warunkach beztlenowych. Grudzień. (non published).

Kalisz L., Sałbut J., Nechay A., 2002. Odwadnianie osadów ściekowych na poletkach z trzciną. Monografia. Warszawa, IOŚ. (Dewatering of sludges in the reed beds. Monograph).

Kalisz L., Sałbut J., 2003. Stosowanie trzciny pospolitej w odwadnianiu osadów ściekowych stabilizowanych. Polskie Towarzystwo Inżynierii Ekologicznej. Inżynieria Ekologiczna nr 9, Warszawa. (Utilizing of aerobicly stabilized sludge by reed).

Kickuth R., 1969. Hohere wasserpflanzen und Gewasser-einhaltung Schriftenreiche Vereinigung Deutscher Gewasserschutz EV-VDG 19: 3–24.

Kim B.J., Cardenas Jr.R., 1990. Use of reed for dewatering sludge in the USA. W: Use of Constructed Wetlands in Wetlands in Water Pollution Control, Proceedings of the conference. Cambridge: 563–566.

Kim B.J., Smith E.D., 1997. Evaluation of sludge dewatering reed beds: a niche for small systems. Water Science and Technology Vol. 35, No. 6: 21–28.

Lienard A., Esser D., Deguin A., Virloget F., 1990. Sludge dewatering and drying in reed beds: an interesting solution? General investigation and first trials in France. W: Use of Constructed Wetlands in Water Pollution Control, Proceedings of the conference. Cambridge: 257–267.

Lienard A., Payrastre F., 1996. Treatment of sludge from septic tanks in a reed-bed filters pilot plant. 5th International Conference on, Wetland Systems for Water Pollution Control. Vienna.

Maeseneer de J.L., 1996. Sludge dewatering by means of constructed wetlands. 5th International Conference on, Wetland Systems for Water Pollution Control Vienna.

Maeseneer de J.L., 1997. Constructed wetlands for sludge dewatering. Water Science and Technology Vol. 35, No 5: 279–285.

Mochnacka-Ławacz H., 1974. Seasonal changes of *Phragmites communis* Trin. Part I. Growth, morphometrics, density and biomass. Pol. Arch. Hydrobiol. 21, 355–368.

Nielsen S.M., 1990. Sludge dewatering and mineralisation in reed bed systems. W: Use of Constructed Wetlands in Water Pollution Control, Proceedings of conference. Cambridge: 245–256.

Nielsen S.M., 2002. Sludge drying reed beds. In Proceedings of the International Conference on the use of. Constructed Wetlands in Water Pollution Control, held in Arusha, Tanzania, 16–19 September.

Nielsen S.M., 2003. Sludge drying reed beds. Water Science and Technology, 48 (5) 101–109.

Nielsen S.M., 2005. Mineralisation of hazardous organic compaends in a sludge reed bed and sludge storage Water Science and Technology 51 (9) 109–117, JWA Publishing.

Obarska-Pempkowiak H., Zwara W., Cytawa S., 1997. Unieszkodliwianie osadów ściekowych w złożach trzcinowych i na plantacji wikliny. W: Osady ściekowe – odpady czy surowiec. Międzynarodowa Konferencja Naukowo-Techniczna. Częstochowa: 68–75.

Peverly J.H., Surface J.M., Wang T., 1995. Growth and trace metal absorption by *Phragmites australis* in wetlands constructed for landfill leachate treatment. Ecological Engineering 5, 21–35.

Zwara W., Obarska-Pempkowiak H., 2000. Polish experience with sewage sludge utilization in reed beds. Wat. Sci. Technol.; 41, 65–68.

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