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Experiences with Utilisation of Sewage Sludge in Reed Beds

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1. Introduction

Sewage sludge present a serious problem. High-effective methods of sewage treatment caused the significant increase of sewage sludge amount. In 2003 amount of sewage sludge in municipal sewage treatment plants was 446.5 thousands tons of dry matter and it was almost two times higher than amount of sludge in the year 1994.

There are many methods which are used for utilisation of sewage sludge. Unfortunately most of them are very expensive. According to Wielgoński el al. (2003) the costs of agricultural usage were estimated at 70÷200 EUR/t d.m. whereas burning in incinerators is assessed in range: 220÷400 EUR/t d.m.

In the last years there have been made attempts to use new, ecological technologies in the utilisation of sewage sludge. These methods can complement or even replace traditional methods of the utilisation such as: burning, storage or agricultural usage.

New methods are useful especially in the country areas or housing estate where so far sludge was treated only in the traditional sludge drying beds. Relatively new methods are technologies which used hydrophytes i.e. water and water-like plants such as: *Phragmites* (reed), *Scripus* (bulrush), *Typha* (cattails), *Salix* (willow). Hydrophytes grow on the mineral subsoil with delivered layers of sludge. The most common is reed.

Reed bed drying systems can be established in any areas. Reed beds are simple in the build and service. Sludge dewatering in reed beds offers a lot of advantages. First of all this method is low-tech but effective in obtaining a high dry matter content. Due to economical reasons, it is generally cheap compared to traditional technologies. Ecological reasons caused that reed beds may provide an interesting habitat for waterfowl and a green belt in urban areas [10].

Lienard et al. [5] reported that the first experiences with sludge drying reed beds were conducted by Seidel and Kickuth in Karsiruhe (Germany) in the sixties. This method was used in other systems in Germany in the seventies. More interest in sludge drying reed beds appeared only in the eighties. Since the method was introduced it has spread to many country, especially to Denmark ([8, 9]), France ([5]) and east states of USA (Kim i Cardenas, 1990). In Denmark during the period from 1988 to 1996, 27 systems were established, while from 1997 to 2000 next 56 systems were established. Currently approximately 105 systems are expected to be in operation.

In Poland sludge drying reed beds were established in local treatment plants in Darzlubie and Swarzewo near Puck as well as in Zambrow near Suwałki [13].

2. Theoretical aspects

In hydrophyte methods dewatering of sewage sludge is caused by the gravitational flow off of water as well as its evapotranspiration. The fastest draining off occurs directly after loading, next it decreases vehemently and it stops when content of the dry matter approaches to 20% [5, 7]. The movement of rhizomes and roots causes that pores arise which helps in dewatering. In next layers new ways of drainig off water form caused by penetration of rhizomes and roots (Fig.1). Further dewatering (above 20%) takes place by evapotranspiration. Presence of reed increases this proccess in remaining sludge and it causes further dewatering. This process counteracts colmatation of beds [11].

Phragmites australis has the porous tissue called arenechyma which transports water from sludge and then frees it to the atmosphere by evapotranspiration. An air transport by plants from the atmosphere to the soil causes formation of oxygen microzones in the soil. Roots produce substances which cause flocculation and polymerisation of colloidal organic acids. These processes significantly facilitate dewatering of sludge.

In reed beds sludge is also stabilised. The stabilisation is caused by bio-hemical transformations in the vicinity of reed roots. Near the reed roots there re aerobic, anoxic (with NO_3^- and without O_2) anaerobic (without NO_3^- and $)_2$) microzones. Microzones with different degree of oxygenation enable the evelopment of different type of microorganisms (aerobic and anaerobic) which re responsible for decomposition of the organic matter in sludge. In the vicinity f reed roots different conditions are created. For those reasons the organic mat-er and nitrogen compounds are removed (as a result of ammonification, nitrifi-ation and denitrification).

Fig. 1. The sludge drying reed bed
Rys. 1. Złoże trzcinowe odwadniające osady ściekowe

3. The construction of facilities

In the hydrophyte method sludge (content of the dry solid DS is approximately 0.5÷1.0%) is supplied to reed beds. Objects can be ground-based (beds) or underground (basins). These objects are planted first and foremost by reed. Sludge isn't removed during long period: 10 and even 15 years (Fig. 2).

Reed beds are often established as concrete constructions or as tight ground lagoons. There are also trials to adapt existing sludge drying beds [6]. The difference between reed and traditional drying beds consists in the fact that in the first case occurs reject water and aeration system (on the top of bed) and there are high walls which assure long-term operation. Reed drying systems can have walls about 1.0÷1.5 m high or they can form underground lagoon about ight depth [10÷12].

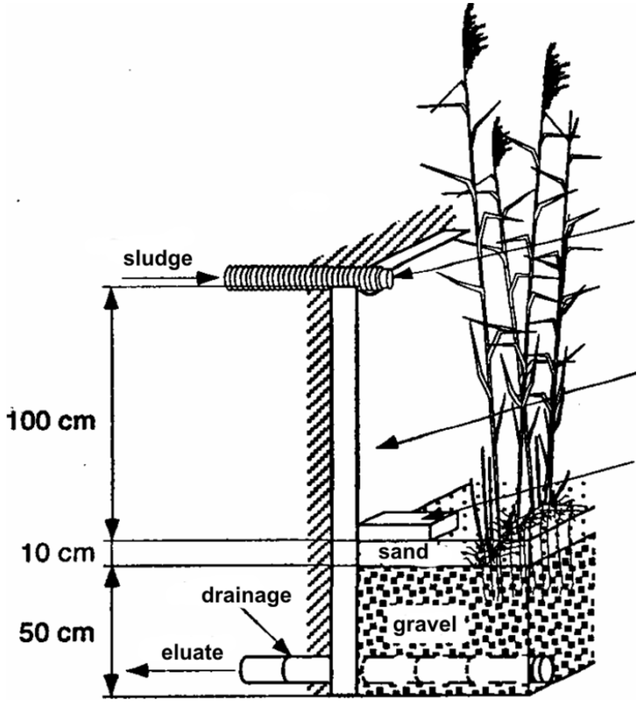


Fig. 2. Scheme of the reed bed for sludge utilisation
Rys. 2. Schemat złoża trzcinowego do utylizacji osadów ściekowych

4. Sludge loading

Proper work of reed beds is determined by correct way of the raw sludge supply. The loading rate, the frequency of sludge supply and the period of rest between next flooding depend on age of plants, type and quality of sludge. The most important is content of the dry matter in sludge [3].

The characteristic of pilot sludge drying reed bed systems in Europe re-orted in papers shows Table 1.

In the first period of the operation low sludge loading is recommended. ı this period roots spread very quickly and it is followed by development of ɛed. Sludge can be supplied to beds when reed is developed. The area loading ıte is determined in relation to the sludge type, climate and in connection with mptying following basins. Doses of sludge as well as frequency of flooding is ɛported in Table 2.

Table 1. The characteristic of pilot sludge drying reed bed systems
Tabela 1. Charakterystyka pilotowych obiektów trzcinowych do utylizacji osadów ściekowych

Municipality	Number of people [PE]	Annual unit sludge loading [m^3/PE year]	Number of basins	Unit area [m^2/PE]	Paper
Regstrup	2 000	0.234	4	0.21	Nielsen, 1993
Allerslev	1 000	0.102	2	0.21	Nielsen, 1993
Nakskov	30 000		10	0.39	Nielsen, 1993
Galten	10 000	0.413	6	0.28	Nielsen, 1993
Rudkobing	15 000	1.400	8	0.27	Nielsen, 2002
Heiligenkreuz	4 000	0.175	2	0.04	Reinhoffer, 1998
Weinitzen	800	0.150	2	0.10	Hoffman, 1992
Grosshart	350	0.200	3	0.31	Hoffman, 1992
Muehien	160	0.200	2	0.27	Hoffman, 1992
Darżlubie	900	0.290	2	0.30	Zwara i Obarska-Pempkowiak, 2000
Swarzewo	35 000	0.200	1	0.71	Cytawa, 1996
Zambrów	25 000	1.400	1	0.22	Alachamowicz i Gałkowski, 2001
Helsinge	40 000		10		Nielsen, 2003
Skive	123 000		18		Nielsen, 2003
Greve	60 000		10		Nielsen, 2003
Kolding	125 000		13		Nielsen, 2003

Table 2. Doses of sludge and frequency of flooding in pilot objects in Europe
Tabela 2. Stosowane dawki osadów oraz częstotliwość zasilania w pilotowych obiektach

City/town (country)	Type of sludge	Dose of sludge m^3/m^2rok	Frequency of flooding	Loading kg d.m./ m^2year
Ulm (Germany)	Sludge after aerobic stabilization and digested sludge	1.6	l x week – actived sludge 1x 2 weeks – aerobic digested sludge 1x2 weeks – digested sludge	20÷30
Bourg-Argental (France)	Unstabilised sludge	1.22	Every 7 days in summer and every l month in winter	15
Heiligenkreuz (Austria)	Sludge after aerobic stabilization	4.0	lx week from May to November	68
Grosshart (Austria)	Sludge after aerobic stabilization	1.4	variously from April to November	23
Rudkobing (Denmark)	Activated sludge and chemical sludge	5.2	l x week	60
Helsinge (Denmark)	Activated sludge	1.67	–	60
Regstrup i Allerslev (Denmark)	Sludge after aerobic stabilization	6.53	variously from May to November	49
	Digested sludge	1.56		55
Darżlubie (Poland)	Digested sludge	1.2	8-times in the year	–
Swarzewo (Poland)	Sludge after aerobic stabilization	3.2	In commissioning period - $10m^3/d$; then variousely from April to November	–
Zambrów (Poland)	Sludge after aerobic stabilization	2.7	variously in vegetative period	34

. Periods of operation.

A sludge reed bed system operation cycle lasts for an average of 10 years. The first part of the cycle includes a commissioning period of two years. After commissioning, the system runs at full capacity for subsequent 10 year cycles of operation, including periods of emptying. Normally, emptying is planned to start in year 8 and is completed in year 12 of each operation cycle (Table 3). Sludge from emptying of basin has form of humus and it can be used in agriculture [8]. In this period content of heavy metals in the sludge should be supervised. In Denmark tests of the sludge are made once a month in every basin. Results are averaged once a year or two years for all basins.

Table 3. A simplified schedule of long term operation for one basin [8]
Tabela 3. Etapy długookresowej eksploatacji złóż hydrofitowych, wg Nielsena [8]

Year	Phase	Operation
1	Commissioning	
2		
3		
4	1st full operation	Basic operation
5		
6		Long term operation
7		
8		
9	Emptying	Rest
10		
11	Re-establishment	1st growing season
12		
13	2nd full operation	Basic operation

After the sludge removal a new cutting of reed are planted. In new beds 4 cuttings of reed on 1 m^2 are planted. Danish Hedelskabet Company recommends that cuttings should be planted in special pots from horticultural plants. Reed grows already in first period after planting. Reed shouldn't be removed. Stems and leaves decay in natural way like in the nature.

An average period of operation is 10 years but there are objects which re operated without emptying longer that 10 years. The period of their operaon can exceed even to 15 years.

. Quality and quantity of dewatering sludge and reject water

The efficiency of dewatering in reed beds are evident in comparison to ıechanical equipment. Table 4 shows the efficiency of dewatering of sludge in eed beds and in mechanical equipment.

Table 4. The efficiency of dewatering in reed beds and mechanical facilities [16]
Tabela 4. Skuteczność odwadniania osadów w złożach trzcinowych i urządzeniach mechanicznych [16]

Dewatering method	Centrifuge	Filter Belt Press	Filter Press	Traditional Sludge Bed	Sludge Reed Bed Systems
DS, %	23 (15÷20*)	24(15÷20*)	32	10**	30÷40

* Average values of operation.
**Variable, depending upon the duration of the treatment period.

Reed beds assure effective dewatering in time. During utilisation of sludge in pilot reed beds the volume of supplied sludge decreased in range 80.3÷98.0% (Table 5).

Table 5. The efficiency of sludge dewatering in pilot objects.
Tabela 5. Skuteczność odwadniania osadów w analizowanych obiektach pilotowych

City/Town (Country)	Sludge loading, m^3/a		Height of supplied sludge, m	Height of sludge after dewatering m	Decrease of vol.*) %	Content of dry solid %
	Supplied	Residual				
Heiligenkreuz (Germany)	812.0	120.0	5.50	0.80	84.9	10.0
Regstrup (Denmark)	1821.0	62.0	4.40	0.15	98.0	–
Allerslev (Denmark)	260.0	21.0	1.20	0.10	91.0	–
Rudkobing (Denmark)	21000.0	4150.0	5.25	0.97	80.3	–
Helsinge (Denmark)	1700.0	210.0	8.20	0.79	91.0	–
Darżlubie (Poland)	3.2	0.1	3.15	0.18	94.3	46.2
Swarzewo (Poland)	11.0	1.0	10.50	1.50	85.7	62.0
Zambrów (Poland)	18.3	0.5	5.90	0.50	91.5	–

Decrease of volume was calculated as the difference between annual loading of supplied and residual sludge divided by annual loading of supplied sludge

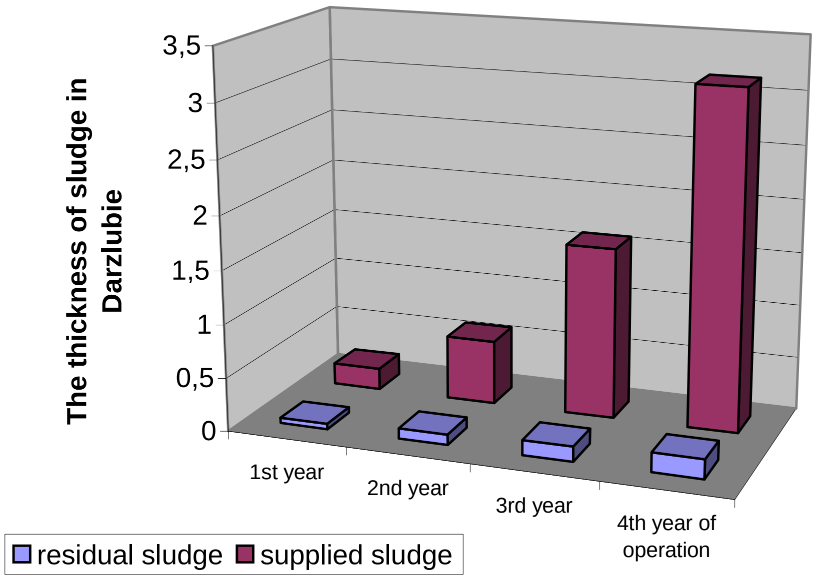
In Poland there are no objects which are in operation for a long time. So thanks to Hedelskabet Company samples collected in Denmark. Investigations concerning changes of content of dry solid was carried out in 4 reed bed systems: Rudkobing, Naskov, Vallo and Helsinge. Period of operation in those objects was 13, 15, 7, 8 years, respectively. The basin in Rudkobing wasn't supplied with raw sludge since 2 years. However the basin in Helsinge was supplied with raw sludge 2 weeks before sample collections. In all objects the samples were collected along the longitudinal profile which was divided on equal 10 cm segments. The content of the dry matter in samples from each object is presented in Table 6.

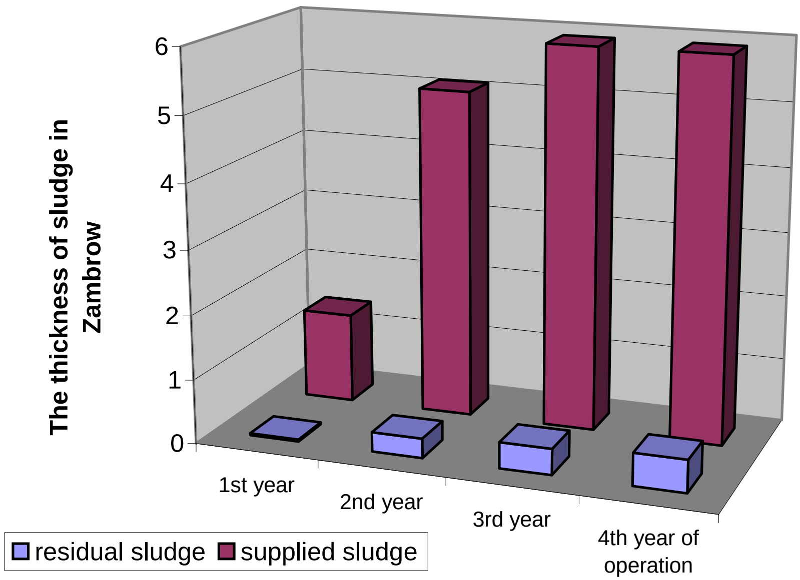
Table 6. Content of DS along the profile from four Danish objects [%].
Tabela 6. Zawartość suchej masy w rdzeniu pionowym z czterech obiektów z Danii [%]

Depth of layer, m	Object			
	Rudkobing	Naskov	Vallo	Helsinge
Superficial layer (0÷10)	26.39±0.36	20.22±0.40	21.58±0.71	14.94±0.37
10÷20	26.54±1.01	21.44±0.57	24.14±0.30	19.59±0.49
20÷30	27.77±1.31	22.50±0.36	25.21±0.48	19.87±0.25
30÷40	28.20±0.36	23.64±0.73	26.86±0.34	19.92±0.25
40÷50	27.69±0.33	23.46±0.43	27.19±0.17	20.54±0.20
50÷60	29.50±0.28	22.72±0.43	29.40±1.64	22.01±0.40
60÷70	31.69±0.89	25.40±0.55	71.52±1.69	21.72±0.36
70÷80	36.95±1.71	29.65±0.53	–	21.57±0.33
80÷90	–	–	–	21.91±0.20
90÷100	–	–	–	25.40±1.87

On the basis of investigations it was indicated that content of the dry solid increase with depth. It means that layers which were deposited earlier have got the lowest moisture content. The moisture content depends on period of dewatering. Sludge from Rudkobing has the lowest moisture content. However sludge from Helsinge (where the basin was supplied 2 weeks before collection of samples) has the highest moisture content. Supply of raw sludge caused derease of content of the dry solid in all layers along the profile.

Figure 3 shows thickness of supplied and residual sludge in time. In Darzlubie thickness of supplied sludge was 3.15 m while residual sludge was only 0.18 m in period of investigation [13]. In Zambrow after 4 years of the operation the thickness of sludge was 5.9 and 0.5 respectively [1].





ig. 3. The thickness of supplied and residual sludge in reed beds
a) in Darzlubie b) in Zambrow

ys. 3. Miąższość osadów doprowadzonych i pozostałych w złożu trzcinowym
a) w Darżlubiu b) w Zambrowie

Fig. 4 shows the relationship between the intensity of gravity outflow of reject water and time of dewatering for tested reed beds in Regstrup and Allerslev [7].

It was found that after 24 hours of dewatering 17.2 m^3 of water flowed out in reed beds in Regstrup. It is 80% of the volume of supplied sludge. In case of reed beds in Allerslev the quantity was 5m^3 and 28%, respectively. After 144 hours 98% for Regstrup and 55% for Allerslev of water flowed out. Nielsen [7] proved that after 6 days sludge contained 15% of dry solids.

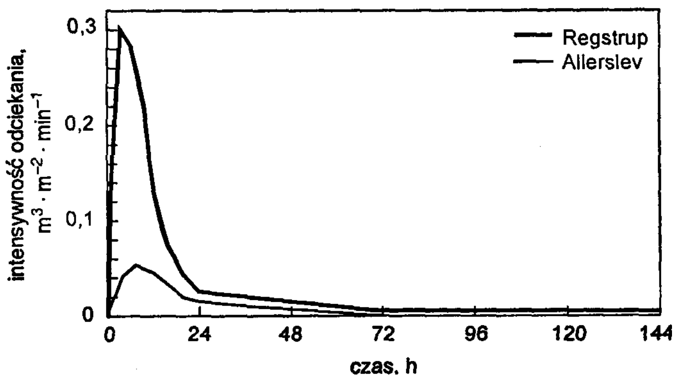


Fig. 4. The intensity of outflow of reject water from reed beds in w Regstrup and Allerslev [7]

Rys. 4. Intensywność odpływu wód ociekowych ze złóż trzcinowych w oczyszczalni w Regstrup i Allerslev, wg Nielsena [7]

Investigations conducted in sludge drying reed beds in Darzlubie show that the greatest intensity of reject water flow out was noticed 1.5 hour after flooding and its quantity was 0.081 l/min·m^2. The volume of reject water was 10% of supplied sludge volume. Average loading of organic substances as COD, N_{tot}, P_{tot} was similar to loadings of contaminants in waste water supplied to sewage treatment plant in Dazrzlubie (Table 7) [16].

Sludge dewatering in reed beds undergo partial stabilisation. Its composition is similar to humus and it can be used in the agriculture. The problem can pose the present of heavy metals.

Average content of heavy metals for three Polish and one Danish object was presented in Table 8. According to Oleszkiewicz [14] decomposition of the organic substances causes increase of heavy metals content. In conducted investigations concerning the utilisation of sludge in reed beds an amount of heavy metals doesn't exceed acceptable values for the agricultural usage.

Table 7. The comparison of the quality of raw sewage from the sewage treatment plant in Darzlubie and the quality of reject water from reed bed
Tabela 7. Porównanie jakości ścieków doprowadzanych do oczyszczalni w Darżlubiu z jakością wód ociekowych odprowadzanych ze złoża osadowego

Parametr	Raw sewage	Reject water from reed bed
Flow	100 m^3/d	4 m^3/d
COD_{Cr}	1000 mg O_2/dm^3	250 mg O_2/dm^3
N_{tot}	100÷150 mg/dm^3	12 mg/dm^3
P_{tot}	10÷20 mg/dm^3	l mg/dm^3

Table 8. Content of heavy metals in sludge dewatered in reed beds
Tabela 8. Zawartości metali ciężkich w osadach odwadnianych w złożach trzcinowych

Object	Heavy metals μg/g						
	Cu	Pb	Ni	Co	Zn	Cr	Cd
Darżlubie	28.20	31.39	16.68	4.08	869.32	22.46	1.69
Swarzewo	21.96	16.44	5.44	1.28	649.32	7.04	0.92
Zambrów	150.00	38.70	11.80	3.10	1258.00	29.70	1.95
Rudkobing	260.00	–	–	–	410.00	39.00	–
Legal limit values for agriculture use in Poland*)							
	800	500	100	–	–	500	10

*)According to the order of Ministry of Environment (Dz. U. 2002/134/1140)

7. Conclusions

Sludge drying reed beds are natural and very effective method of the sludge utilisation. In many cases this method can be used instead of traditional methods of sludge treatment. Reed beds are recommended especially in the country areas. Basing on results of many investigations (in pilot and technical scale) we can formulate following conclusions:

- The important factor of correct work of systems is their proper operation allowed for right frequency of flooding and hydraulic loading.
- An advantage of sludge drying reed bed systems is possibility of their long-term operation without necessity of emptying.
- The volume of sludge in analysed reed beds decreased in average about 89%.
- Sludge drying reed beds assure high degree of dewatering. After end of operation average content of dry solid is even 60% and it is lower than in mechanical equipment or in traditional sludge drying beds.
- In conducted investigations concerning the utilisation of sludge in reed beds an amount of heavy metals doesn't exceed acceptable values for the agricultural usage.

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Doświadczenia z utylizacją osadów ściekowych w złożach trzcinowych

Streszczenie

W ciągu ostatnich kilku lat podejmowane są próby wykorzystywania nowych, ekologicznych technologii unieszkodliwiania osadów ściekowych. Stanowią one uzupełnienie, a niekiedy mogą być stosowane zamiennie w miejsce tradycyjnych metod unieszkodliwiania takich jak: spalanie, składowanie, czy przyrodnicze zagospodarowanie.

Stosunkowo nowym rozwiązaniem są technologie wykorzystujące hydrofity (tzn. rośliny wodne i wodolubne, takie jak np.: trzcina pospolita, pałka wodna, sit, tatarak, czy wiklina) do wzrostu na mineralnym podłożu z naniesionymi warstwami osadów ściekowych. Najczęściej stosowana jest trzcina pospolita.

Hydrofitowa metoda utylizacji osadów polega na stosowaniu wielowarstwowych nawodnień osadami o niskiej zawartości suchej masy 0,5÷1,0% w złożach trzcinowych. Są to obiekty nadziemne (złoża) lub podziemne (baseny) zasiedlone przede wszystkim trzciną pospolitą, w których nie usuwa się doprowadzonych osadów w długim okresie czasu, wynoszącym nawet 10÷15 lat

W metodzie hydrofitowej odwodnienie osadów ściekowych jest spowodowane grawitacyjnym odciekaniem wody oraz ewapotranspiracją. Odwodnione osady w złożach trzcinowych ulegają również stabilizacji. Stabilizacja jest rezultatem przemian biochemicznych osadów zachodzących w sąsiedztwie korzeni trzcin.

Osady ściekowe odwadniane w złożach trzcinowych ulegają częściowej stabilizacji i higienizacji. Otrzymywany materiał charakteryzuje się składem chemicznym zbliżonym do substancji humusowej, a więc nadaje się do rolniczego wykorzystania.

Prawidłowa eksploatacja złóż trzcinowych wymaga określenia optymalnych dawek osadów: ich ilości oraz częstotliwości doprowadzania w celu zapewnienia odpowiedniego okresu spoczynku pomiędzy kolejnymi zalewami. Ilość doprowadzanych osadów w czasie musi być dostosowana do wieku trzciny oraz zależy od rodzaju osadów i zawartości w nich suchej masy. Objętość osadów w analizowanych dotychczas złożach trzcinowych ulegała zmniejszeniu średnio o 89%.

Objętość odprowadzanych wód ociekowych ze złóż trzcinowych malała wraz ze wzrostem miąższości warstwy zgromadzonych osadów i wzrostem ich pojemności retencyjnej.

Obiekty hydrofitowe zapewniają wysoki stopień odwodnienia osadów. Po zakończeniu eksploatacji, średnia wilgotność osadów wynosi nawet około 60% i jest niższa niż w przypadku odwadniania w urządzeniach mechanicznych lub w tradycyjnych poletkach odciekowych.

Na podstawie przeprowadzonych badań wykazano, że wilgotność maleje wraz z głębokością. Oznacza to, że najmniejszą wilgotność mają warstwy najgłębsze, a więc zdeponowane najwcześniej.

Na podstawie badań przeprowadzonych w obiektach polskich i jednym duńskim wykazano, że ilości metali ciężkich w osadach odwadnianych w złożach trzcinowych nie przekraczały wartości dopuszczalnych przy rolniczym wykorzystaniu.