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REMOVAL OF ORGANIC AND BIOGENIC COMPOUNDS FROM REJECT WATER WITH CONSTRUCTED WETLANDS

USUWANIE SUBSTANCJI ORGANICZNEJ ORAZ ZWIĄZKÓW BIOGENNYCH Z ODCIEKÓW METODĄ HYDROFITOWĄ

Abstract: There are 16 dairy processing plants operating in Podlasie region, including 9 that use individual systems for sewage treatment, while others dispose wastewaters to municipal wastewater treatment plants. Personal Equivalent (P.E.) for individual objects ranges from 7000 to almost 240000 at the flow rate from 500 up to 5240 m^3 of sewage daily. Most of objects were built in 70's of the 20th century; they are overloaded due to the increase of production in factories and works observed for over 20 years. The increase of sewage load made also the increase of sewage sludge and reject water amounts. Reject water is in general directed to the beginning of the treatment process, which is a considerable load, namely due to ammonium nitrogen form. Applying the separate reject water treatment using constructed wetland is one of the possibilities to lower the dairy sewage treatment plant loads. The method can be an alternative for advanced and expensive technologies for purifying the reject waters from treatment plants that use anaerobic sludge stabilization. Studies were carried out in August–October 2008 in research installation designed by the author and operating in dairy sewage treatment plant in Bielsk Podlaski.

Reject waters generated in sewage sludge thickening chamber were subject to purification. Mean pollutants concentrations in reject water were: BOD_5 – 118.6 mg $O_2 \cdot dm^{-3}$, COD – 242.1 mg $O_2 \cdot dm^{-3}$, Kjeldahl's nitrogen – 17.2 mg $N_{TKN} \cdot dm^{-3}$, ammonium nitrogen – 10.4 mg $N \cdot dm^{-3}$, and total phosphorus – 7.2 mg $P_T \cdot dm^{-3}$. BOD_5 removal efficiency was 69.4 %, COD 53.7 %, Kjeldahl's nitrogen 55.8 %, ammonium nitrogen 72.1 %, and total phosphorus 19.4 %, on average. Mean effect of organic substance removal measured as BOD_5 was achieved at the level of 20.6 g $BOD_5 \cdot m^{-2} \cdot d^{-1}$, while ammonium nitrogen 1.87 g $N–NH_4 \cdot m^{-2} \cdot d^{-1}$. The study confirmed the usefulness of constructed wetland method application for separate treatment the reject waters from aerobic sewage sludge stabilization. At present, studies on the object designed for reject waters purification for a real scale, were begun. It is the first object of that type, installed in dairy sewage treatment plant in Poland, and it was designed as a result of the research work realized by the author in 2007–2009.

Keywords: reject water, constructed wetlands, biogenic, nutrients and organic substances

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Agro-food industry works, namely dairy plants, dominate in north-eastern Poland. There are nine such plants that are equipped with individual wastewater treatment systems in Podlasie region. In practice, all objects need to be modernized due to increasing sewage load resulting from arising production at these works. Increasing amounts of sewage sludge and reject water generated during their processing is a consequence. Reject water is characterized by significant content of ammonium nitrogen in relation to the raw wastewaters disposed from dairy plants to own wastewater treatment plant or just to a sewage system and municipal wastewater treatment plant. It is returned to the beginning of the purification process, which makes periodical disturbances in stable and efficient sewage treatment.

Separated treatment of reject water can be carried out by means of different methods. There are: precipitation, de-aeration using warm air stream, ammonia evaporation using steam, ionic exchange, as well as biological methods such as conventional and unconventional nitrogen removal: ANAMMOX process, BABE method, shortened nitrification and denitrification process, including SHARON method, combinations of ANAMMOX and shortened nitrification and denitrification process as, for instance, CANON & OLAND method [1, 2]. The SHARON method (*Single Reactor System for High-Rate Ammonia Removal Over Nitrite*) is a full-scale process for reject waters purification. It uses the dependence of the bacterial growth rate on temperature, thus ammonium compounds and nitrites oxidation rate on temperature, as well as differences between growth rates of nitrosobacteria and nitrobacteria [3, 4]. Applying expensive physicochemical method is reasonable in the case of large municipal sewage treatment plants that usually apply the anaerobic sludge stabilization. In the case of smaller objects that stabilize sewage sludge in aerobic way, including dairy plants, applying simpler and much cheaper methods of separate reject water purification, is more suitable.

Studies related to constructed wetlands began in 2006, when the first installation based on a *vertical constructed wetland* (VF-CW) was built within the largest dairy sewage treatment plant in north-eastern Poland (Mlekovita, Wysokie Mazowieckie). In 2007, another installation based on a vertical wetland was launched also within Mlekovita Ltd. (Bielsk Podlaski), while a hybrid system (consisting of vertical plus horizontal flow constructed wetland beds) was initiated in Wysokie Mazowickie can work in cycles, while horizontal ones work continuously. Their application ways are recognized and described in literature [5–7]. The constructed wetland systems are characterized by a simple operation and no chemicals applied. During their work, no wastes characteristic for active sediment method, are generated. However, needs of large area, difficulties in plant adaptation on mineral bed, and oscillations of the purification efficiency within a year, are their main shortcomings. A properly designed and built object can be successfully exploited for many years.

Advantages of the constructed wetland method led to its utilizing for household, municipal, industrial, agricultural, and gas station sewage, rainfall water, reject water from waste dumps, area runoff from cultivated fields and airfield purification. It is also applied to process the sewage sludge. Low energy-consumption, simple construction, and cheap exploitation are the main merits from using constructed wetlands for sewage sludge processing.

Table 1 presents list of general working parameters of two dairy wastewater treatment plants that were analyzed by the author in a view of constructed wetland system incorporation. It contains basic parameters such as amounts of sewage and reject water, equivalent for individual objects referring to raw sewage and reject water quantities. The amounts of ammonium nitrogen load in raw sewage and reject water were also determined.

Table 1

Basic characteristic of chosen dairy wastewater plants belonging to Mlekovita in 2009

Parameter	Unit	Bielsk Podlaski W.W.T.P.	Wysokie Mazowiec-kie W.W.T.P.
Sewage quantity	$[m^3 \cdot d^{-1}]$	570	5240
P.E. of sewage	—	8740	240000
Load of ammonia nitrogen in raw sewage	$[kg\ N\text{-}NH_4 \cdot d^{-1}]$	1.5	9.43
Reject water quantity	$[m^3 \cdot d^{-1}]$	25	530
P.E. of reject water	—	60	1060
Load of ammonia nitrogen in reject water	$[kg\ N\text{-}NH_4 \cdot d^{-1}]$	0.32	5.7

Due to a composition of reject water generated during aerobic sludge stabilization, the research installations were built on a base of vertical flow constructed wetland system that assures the nitrification process. It was observed that the quantity of reject water from aerobic sewage sludge stabilization in dairy wastewater treatment plant is periodically growing. The study was aimed at evaluating the usefulness of high loaded ($0.25\ m \cdot d^{-1}$) vertical flow constructed wetland to remove organic and biogenic compounds from reject water.

Material and methods

The paper present results from studies upon one of the installations designed by the author to perform research within the project *Evaluation of constructed wetland usefulness to purify reject water from aerobic sludge treatment in dairy wastewater treatment plants*. The system works in dairy sewage treatment plant in Bielsk Podlaski and consists of the retention tank, vertical flow bed, and measuring system. Reject water from aerobic sewage sludge processing are subject to purification. The sludge stabilization occurs simultaneously to dairy sewage purification process, which is a typical solution in Promlecz type systems designed for treatment the dairy sewage. Long time when the sewage is retained in an aeration chamber, ensures the sludge stabilization. The excessive sludge is disposed to a thickener, then to dehydration. Separated chambers to active sludge regeneration are used in a sludge course [6]. The vertical flow constructed wetland applied in the research, was designed according to recommendations by Brix [7], Cooper [8], and Obarska-Pempkowiak [9]. It is of 20 m^2 surface area and bed layer thickness of 0.65 m. It is grown by specially prepared seedlings of three-year-old *Phragmities australis.* Figure 1 illustrates the cross-section of the constructed wetland used in the study. It consists of three bed layers (gravel,

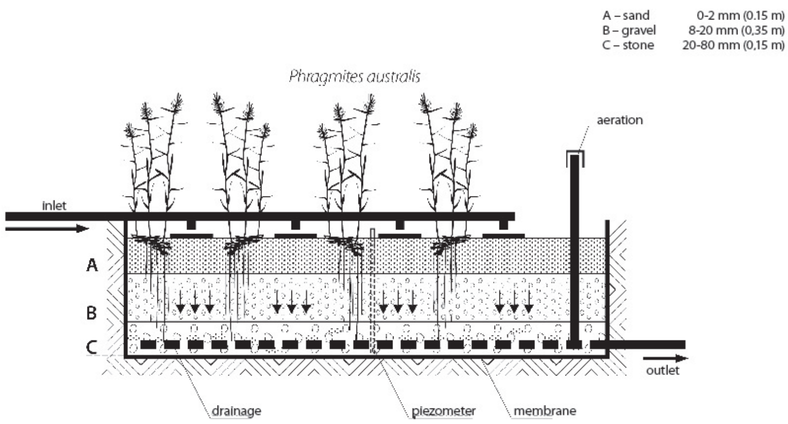

Fig. 1. Cross-section of vertical bed

sand, and stones), reject water is supplied by PVC piping (ID 50 mm), the drainage system is mounted at the bottom, and the ventilation system is also provided. The passive ventilation improves the bed aeration. During the studies made by the author in 2006–2007, the hydraulic load ranged within 0.05–0.15 m · d^{-1} [10, 11]. Due to a prepared project of incorporating the system into the real process, the installation abilities were also verified at higher unit load of bed surface (0.25 m · d^{-1}). Recirculation was not used during this experiment.

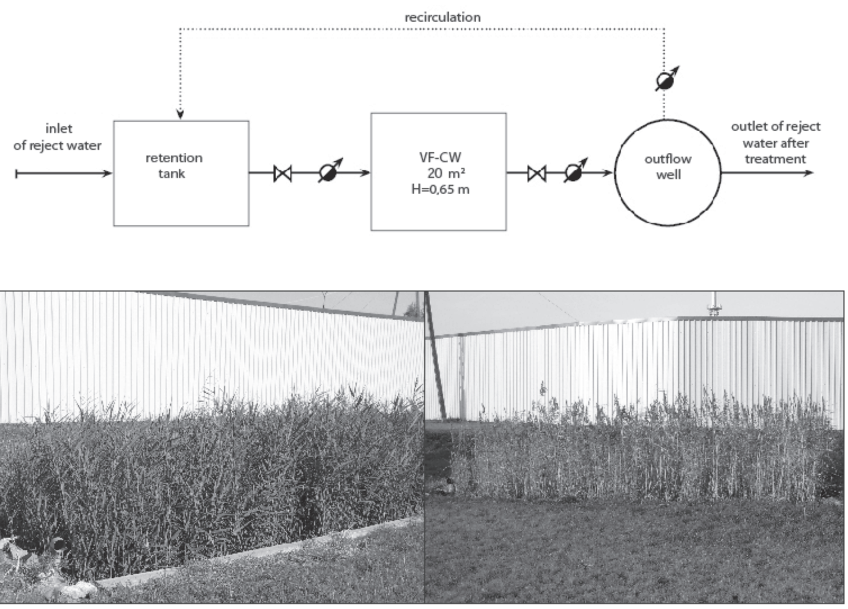

Fig. 2. Flow diagram of the research installation

Figure 2 presents the scheme of the research installation along with the photos taken in spring and autumn 2008. Studies were performed since August till October 2008, samples of reject water supplying the bed, as well as those from the outlet, were collected every 4 days, which made 12 measurement series in total.

The determinations included: BOD_5, COD, TOC, TKN, ammonium nitrogen, nitrates(V), total phosphorus, and suspensions. Table 2 containing study results, also presents permissible values for purified wastewaters disposed from dairy wastewater treatment plant in Bielsk Podlaski to a receiver [12].

Analyses were performed in laboratory of Department of Technology in Engineering and Environment Protection, Technical University in Bialystok. All determinations were performed in accordance to Polish Norms.

Results and discussion

Parameters of dairy sewage, sewage sludge and reject water presented in Tables 1 and 2 confirm that the removal of ammonium nitrogen should be focused on in the case of the separate reject water treatment. Its load in reject water in Bielsk Podlaski treatment plant reached 21.3 % in relation to that in raw dairy sewage. In the other presented object, that value achieved up to 62.4 %. Results from studies upon reject water treatment after statistical processing are presented in Table 2.

The BOD_5 value in reject waters supplied to the vertical flow constructed wetland amounted from 96 to 154 mg $O_2 \cdot dm^{-3}$. The mean value of BOD_5 in reject waters supplied to the purification was at the level of 118.6 mg $O_2 \cdot dm^{-3}$, which at hydraulic load of 0.25 $m \cdot d^{-1}$, resulted in load indicator of 29.6 g $BOD_5 \cdot m^{-2} \cdot d^{-1}$. Average BOD_5 value at the outlet from the installation was 36.2 mg $O_2 \cdot dm^{-3}$, which made the decrease by 69.4 %. Considering COD, mean efficiency of the installation was 53.7 %, while TOC 62.5 %. The Kjeldahl's nitrogen removal efficiency amounted to 55.8 %, whereas ammonium nitrogen 72.1 %, on average. Analysis of the nitrogen forms contents in reject water before and after treatment indicated that the nitrification process occurred. Vertical flow constructed wetland supplied in a cyclic way works under aerobic conditions. The bed aeration is supported by a passive aeration system. The mean bed loading with ammonium nitrogen was 2.6 g $N–NH_4 \cdot m^{-2} \cdot d^{-1}$.

Efficiency of organic substance removal for vertical flow constructed wetland was 20.6 g $BOD_5 \cdot m^{-2} \cdot d^{-1}$, while for ammonium nitrogen 1.87 g $N–NH_4 \cdot m^{-2} \cdot d^{-1}$, on average. According to author's earlier studies (carried out in 2007) involving the same installation, the efficiency of BOD_5 was 11.5 g $BOD_5 \cdot m^{-2} \cdot d^{-1}$. The increase of purification efficiency can be elucidated with the fact that here presented results were achieved in two years of the installation operating and studies were performed during the most intensive plant vegetation.

The average ammonium nitrogen removal efficiency for the other installation, where studies upon reject waters purification were also conducted, amounted from about 1.77 to 1.79 g $N–NH_4 \cdot m^{-2} \cdot d^{-1}$ in 2007, depending on the bed layer thickness [10, 13]. Phosphorus removal efficiency was poor amounting to 19.4 %, while average phosphorus content at the outlet from the experimental installation was 5.8 mg $P \cdot dm^{-3}$

Table 2

Effectiveness of constructed wetland in Mlekovita Bielsk Podlaski for reject water treatment

Parameter	BOD_5	COD	TOC	N-TKN	$N\text{-}NH_4$	$N\text{-}NO_3$	Total P
	$[mg\ O_2 \cdot dm^{-3}]$		$[mg\ C \cdot dm^{-3}]$	$[mg\ N \cdot dm^{-3}]$	$[mg\ N\text{-}NH_4 \cdot dm^{-3}]$	$[mg\ N\text{-}NO_3 \cdot dm^{-3}]$	$[mg\ P \cdot dm^{-3}]$
Inlet to VF-CW							
Minimum	96.0	196.0	32.0	15.3	8.2	0.4	8.1
Maximum	154.0	255.0	48.0	24.2	14.7	1.7	4.1
Mean	118.6	242.1	38.4	17.2	10.4	1.9	7.2
Standard deviation	11.2	16.3	4.2	2.1	1.1	0.2	0.5
Outlet from VF-CW							
Minimum	24.0	92.0	10.0	7.0	1.4	8.2	5.2
Maximum	39.0	119.0	16.0	9.1	3.6	10.1	6.1
Mean	36.2	112.0	14.4	7.6	2.9	9.7	5.8
Standard deviation	5.1	8.7	1.6	1.1	0.3	1.2	0.5
Limits for dairy wastewater after treatment in Mlekovita Bielsk Podlaski	50	125	30	30	10	—	1.5
Mean effectiveness of reject water treatment	69.4 %	53.7 %	62.5 %	55.8 %	72.1 %	—	19.4 %

at permissible value for dairy sewage treatment plant in Bielsk Podlaski of 1.5 mg $P \cdot dm^{-3}$. The constructed wetlands are not adapted to intensive phosphorus removal. In order to improve the removal efficiency, special filling in a form of lime gravel or separate filters for its removing should be applied [14]. Nitrate nitrogen content was 9.7 mg $N–NO_3 \cdot dm^{-3}$ after purification complete while 1.9 mg $N–NO_3 \cdot dm^{-3}$ before . In the case of Bielsk Podlaski dairy wastewater treatment plant, reject water after purification may be returned to the beginning of purification process or directly to the active sludge chamber that works under aerobic conditions. If a dairy sewage treatment plant operates using the chambers for intensive phosphorus removal by biological means, reject water, after separate pre-purifying, should be directed to the denitrification chamber in such a way not to disturb the process of phosphorus removal from the sewage.

Conclusions

1. The vertical flow constructed wetland may be used to decrease the reciprocal load due to reject waters from aerobic sewage sludge processing in a dairy wastewater treatment plant. Necessary surface area of the constructed wetland should be calculated on a base of the bed surface load both due to BOD_5 and ammonium nitrogen.

2. Vertical flow bed ensures a high effect of organic substance removal measured with such indicators as BOD, COD, or TOC. The effective nitrification is possible at a hydraulic load reaching to $0.25\ m \cdot d^{-1}$.

3. In dairy sewage treatment plants that do not use intensive removal of phosphorus by biological means, reject water – after purification – should be directed to the beginning of the sewage purification process. Due to a low efficiency of phosphorus removal in VF-CW system and requirements on purified sewage quality, it is necessary to apply additional elements for its removal or use special filling making possible to phosphorus removal.

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USUWANIE SUBSTANCJI ORGANICZNEJ ORAZ ZWIĄZKÓW BIOGENNYCH Z ODCIEKÓW METODĄ HYDROFITOWĄ

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Abstrakt: W województwie podlaskim działa 16 zakładów przetwórstwa mleczarskiego, z których 9 korzysta z indywidualnych systemów oczyszczania ścieków, pozostałe zaś odprowadzają ścieki do oczyszczalni komunalnych. Równoważna Liczba Mieszkańców (RLM) dla obiektów indywidualnych waha się od 7000 do niemal 240000, przy przepływie od 500 do 5500 m^3 ścieków na dobę. Większość obiektów pochodzi z lat 70. ubiegłego wieku. Są one przeciążone ładunkiem zanieczyszczeń ze względu na wzrost produkcji w zakładach obserwowany od ponad 20 lat. Wzrost ładunku ścieków spowodował zwiększenie ilości osadów ściekowych oraz odcieków z ich przeróbki. Odcieki są z reguły kierowane na początek procesu oczyszczania, stanowiąc znaczne obciążenie, szczególnie w odniesieniu do azotu amonowego. Jedną z możliwości zmniejszenia obciążenia oczyszczalni mleczarskiej jest zastosowanie wydzielonego oczyszczania odcieków z wykorzystaniem metody hydrofitowej. Metoda ta może stanowić alternatywę dla zaawansowanych i kosztownych technologii przeznaczonych do oczyszczania odcieków z oczyszczalni stosujących beztlenowa stabilizację osadów. Wykonane w okresie sierpień–październik 2008 r. badania przeprowadzono dla instalacji badawczej zaprojektowaną przez autora i działającą na terenie oczyszczalni ścieków mleczarskich w Bielsku Podlaskim. Oczyszczaniu poddano odcieki powstające w komorze zagęszczania osadu.

Wartości średnie wskaźników zanieczyszczeń w odciekach poddanych oczyszczaniu wynosiły: BZT_5 – 118,6 mg $O_2 \cdot dm^{-3}$, ChZT – 242,1 mg $O_2 \cdot dm^{-3}$, azot Kjeldahla – 17,2 mg $N_{TKN} \cdot dm^{-3}$, azot amonowy – 10,4 mg $N \cdot dm^{-3}$ oraz fosfor całkowity – 7,2 mg $P_T \cdot dm^{-3}$. Średnia efektywność usuwania wynosiła 69,4% BZT_5, 53,7% ChZT, 55,8% azotu Kjeldahla, 72,1% azotu amonowego i 19,4% fosforu całkowitego. Osiągnięto średni efekt usuwania substancji organicznej mierzonej przez BZT_5 na poziomie 20,6 $BZT_5 \cdot m^{-2} \cdot d^{-1}$, natomiast azotu amonowego 1,87 g $N–NH_4 \cdot m^{-2} \cdot d^{-1}$. Na podstawie uzyskanych wyników stwierdzono możliwość zastosowania metody hydrofitowej do wydzielonego oczyszczania odcieków z tlenowej przeróbki osadów ściekowych. Obecnie rozpoczęto badania na obiekcie zaprojektowanym do oczyszczania odcieków w skali rzeczywistej. Jest to pierwszy tego typu obiekt w oczyszczalni mleczarskiej na terenie Polski, który powstał jako wdrożenie wyniku pracy badawczej zrealizowanej przez autora w latach 2007–2009.

Słowa kluczowe: odcieki, złoża hydrofitowe, biogeny, związki organiczne