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THE EFFECTIVENESS OF ORGANIC POLLUTANTS REMOVAL IN CONSTRUCTED WETLAND WITH HORIZONTAL SUB-SURFACE FLOW

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Abstract

This paper presents the results of the research work related to the removal efficiency from wastewater organic pollutants and suspended solids at HSSF (horizontal subsurface flow) construcred wetland. The average effectiveness defined as loss of value COD in wastewater has reached 77%, for BOD_5 - 80% and TOC - 82%. The effect of seasonal temperature changes and the period of plant vegetation and rest on the effectiveness of wastewater treatment were also analyzed. The results of the presented research showed a decrease in the efficiency of removing organic pollutants from wastewater and suspended solids in the autumn and winter. During the vegetation the object in Małyszyn has been characterized by the effectiveness of wastewater treatment at the level of 78% for COD, 82% for BOD_5, and in the non-vegetation period the effectiveness has decreased up to 75% for COD and 74% for BOD_5. During the plants growth the total suspension was removed in 88%, whereas during the plants rest efficiency of removing lowered to 69%.

Keywords: wastewater treatment, constructed wetlands

1. INTRODUCTION

The hydrophyte method of wastewater treatment is a biological process occurring in a ground-water environment with participation of heterotrophic microorganisms and water plants, or the so called hydrophytes. Wastewater treatment in these systems is a result of intensification of mechanical, chemical

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and biological processes that occur in a natural soil-vegetable and water environment.

The process of biological wastewater treatment with hygrophytes depends on the plants used, their root range, type of subsoil, its porosity and the depth of the sector on which the process is run as well as on technical parameters such as hydraulic load, wastewater holding time, composition and concentration of organic substances in wastewater. Removal of wastes is made by sorption, biochemical oxidation-reduction reactions as well as as a result of biological activity of soil microorganisms and hydrophyte plants. The speed with which organic wastes decompose depends on environmental factors, such as: temperature, reaction and oxygen contents [17].

In the wetlands ecosystem organic substances gather as a result of a continuous wastewater inflow, plant mass increase, occurrence of dead organisms and the undergoing biomechanical transformations.

According to Mausbach and Richardson [15] an important condition of an organic substance transformation is water arrangement in a macrophyte bed. If the soil is flooded or water saturated, then the decay line is located close to the ground surface. Organic substance that is formed from dead parts of plants accumulate in the surface layer. If the wastewater level is at least 30 cm below the surface, then accumulation of organic substances is similar to the one that occurs in dry soils and organic compounds undergo aerobic decomposition.

So far it has been proved that reed beds with horizontal sub-surface flow HF-CW provide good conditions for organic substance decay as well as for denitrification process [8].

According to Cooper et al. very good results have been obtained for removing organic substance expressed in BOD_5 and suspended solids from such beds. Frequently, however, nitrification process does no occur due to a limited amount of oxygen [5]. Effectiveness of removing suspension and organic substance from wastes expressed in BOD_5 and COD in HF-CW facilities have been well evidenced as shown in book references by Vymazal [23, 24, 25, 26, 27], Brix [2, 3], Obarska-Pempkowiak [9, 16, 17] among others [10,19]. The hydrophyte facilities under analysis were noted for their high, over 90% of effectiveness in removing total suspension. Similarly, the effectiveness of removing organic substance was high and for BOD_5 it varied from 71.5% to 94.1% and for COD the value was from 59.7% to 89.0%.

According to the research made by Bucksteeg [4], who analyzed operation of 80 reed bed wastewater tretament plants, the effectiveness of watsewater treatment expressed by a decrease in the BOD_5 and COD value was high and reached 95% and 50% of total nitrogen was removed from wastewater.

Schierup *et al.* [20] when evaluating operation of several Danish hydrophyte wastewater treatment plants noted a high, from 60% to 80%, decrease of the BOD_5 value whereas the amount of total nitrogen removed from wastes varied from 6% to 57% and the total phosphorus removed was only in 9-10%.

The information collected by Brix [2] for 104 macrophyte bed with horizontal sub-surface flow shows the possibility of lowering the value of BOD_5 in wastewater by 85%, removal of suspensions by 83%, total nitrogen by 42% and the total phosphorus by 34%.

According to Fidrysiak [7] the effectiveness of watsewater treatment reached: for BOD_5-97%, COD-93%, suspended solids 82-99%, total nitrogen 56-83%, ammonium nitrogen 62-88% and the total phosphorus 56-82%.

Soroko [21] also indicates a very high efficiency of wastewater treatment in the model reed beds. The effectiveness of watsewater treatment expressed by a decrease in the BOD_5 value reached 94-96%, removal of suspended solids by 60%, total nitrogen 50-62% and the total phosphorus was in 95-98%.

Studies also carry constructed wetlands Dune and Reddy [6], Kadlec and Wallace [11], Reddy and DeLaune [18], Bergier [1].

The objective of the paper is assess to the removal efficiency from wastewater organic pollutants expressed in COD, BOD_5, TOC and suspended solids in constructed wetland in Małyszyn. Also analyzed the effect of seasonal temperature changes and the period of plant vegetation and rest on the effectiveness of wastewater treatment.

2. MATERIAL AND METHODS

The tests were carried out in a constructed wetland with horizontal sub-surface flow located in the Lubuski region in the town of Małaszyn. The facility was designed for 1300 PE and commissioned in April 1993. The surface of the HSSF is 3800 m^2 and it is planted with reeds *(Phragmites australis)*. The hydraulic load surface of the deposit is 0,06 $m^3/m^2 \cdot d$. In accordance with design assumptions the root pond’s bottom and its slopes are to be sealed using clay. The arrangement of sealing layers is the following:

- clay layer of thickness of 40 cm,
- gravel and boulders layer of thickness of 40 cm,
- soil and sand layer of thickness of 40 cm.

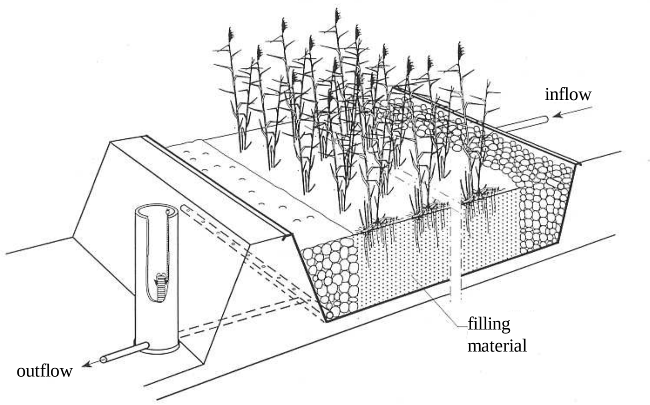

Fig. 1.The profile of the reed bed

After mechanical treatment in a 3-chamber septic tank wastewater is directed to a distribution well located just before the deposit. Then, in a filter layer, the wastewater is distributed by means of perforated hole pipelines evenly across the whole width of the deposit. The root pond has a rectangular shape with the width of 40m and the length of 95m. After the wastewater leaves the hydrophyte bed it goes through a collecting pipeline to a collecting well and then through a drainage ditch it reaches stabilization the ponds and finally the collector.

For testing the wastewater samples was collected every 6 weeks from June, 2005 until July 2006. For testing the wastewater samples was collected every six weeks from June to July of the following year. Wastewater samples were taken from a drain located at the place where wastewater flows into the hydrophyte bed and from the collecting well located at the place where water flows out of the treatment plant. The research covered summer period (from 1 April to 30 September) that corresponded to the vegetation period and winter period from 1 October to 30 March (post-vegetation period).

The wastewater samples were taken in accordance with PN-ISO 5667-10:1997. The contents of pollutans was determined in the averaged wastewater samples was analyzed in time-proportional samples taken each two hours for one day.

The scope of physical-chemical analyses of sewage samples included the characterisation of:

- pH - potentiometrically by means of an ion-selective electrode in accordance with PN-90-C-04540.01:1990,
- Temperature - potentiometrically (when sampling),
- Chemical oxygen demand, COD - with the potassium dichromate method, as per PN-74/C-04578.03, PN-ISO 6060:2006,

- Biochemical oxygen demand, BOD5 - with the manometric method, using the OxiTop Control OC110 measurement system made by WTW,
- Total organic carbon, TOC - using the Analyzer total organic carbon TOC-V CSN device by Shimadzu,
- Total suspended solids - gravimetric method using membrane filters, in accordance with PN-EN 872:2005.

3. RESULTS

The pollutants concentration ranges in the influent wastewater as well as in the treated wastewater were illustrated by the box plot graphs made for BOD_5, COD, total organic carbon and total suspended solids (Fig. 2). A narrow area between the upper and lower quartile in the organic pollutants graphs means a big homogeneity of pollutants concentration in the treated wastewater having rejected 25% of the lowest and 25% of the highest values. As far as the untreated wastes are concerned, there were observations deviating from the rest of the data. It was found that they occurred in June and could have been caused by influent distillery wastewater from the Research Centre in Małyszyn.

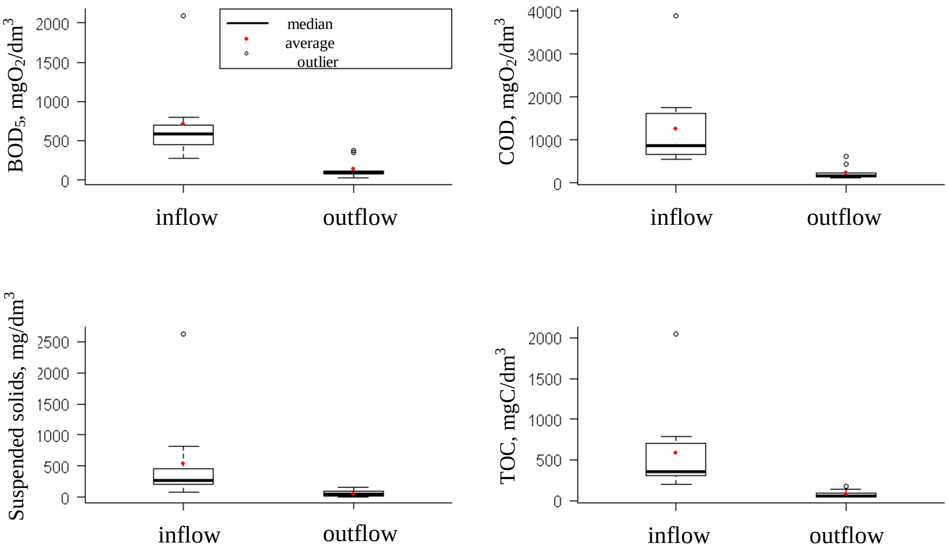

Fig. 2. The concentrations of pollutants in wastewater

The average values of organic pollutants expressed in COD, BOD_5, TOC and total suspended solids are shown in Tab. 1.
COD in the wastewater reaching the hydrophyte bed oscillated from 544 to 3906 mgO_2/dm^3 (the average of 1259.8±1015.8 mgO_2/dm^3), whereas the COD for the treated wastes was from 122 to 624 mgO_2/dm^3 (the average of 244.6±161.4 mgO_2/dm^3).

Table 1. Physico-chemical composition of mechanically treated wastewater and treated wastewater

	COD mgO_2/dm^3	BOD_5 mgO_2/dm^3	TOC mgC/dm^3	TSS mg/dm^3
mechanically treated wastewater	1259.8±1015.8 872*	705.8±515.2 583.0*	589.4±546.0 350.7*	543.4±759.7 276*
treated wastewater	244.6±161.4 180*	134.5±120.8 90.9*	79.3±42.9 59.8*	58.2±49.7 47*

*median

Fig. 3 illustrates COD values of the mechanically treated and treated wastewater including the efficiency of removing COD from wastewater during the successive months. In the period under analysis the efficiency of lowering this value was from 72 to 91% (the average of 77%). The test results for January and April showed a decrease in the wastewater treatment efficiency to 61%, which proves the effect of temperature on operation of hydrophyte facilities.

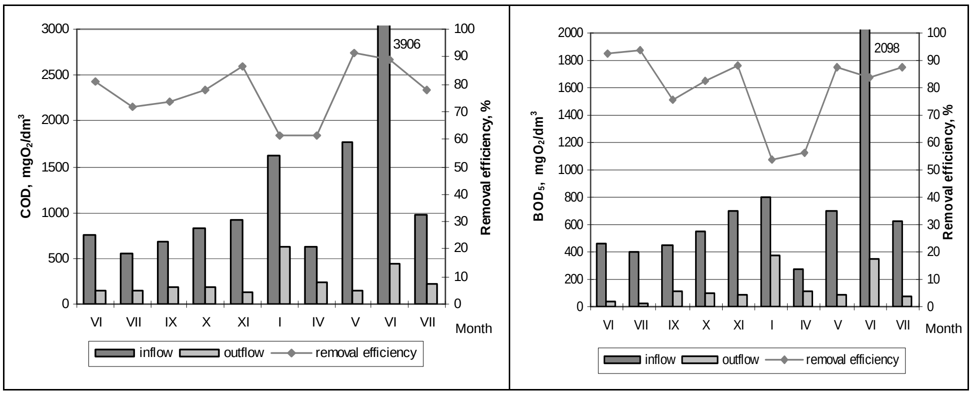

Fig. 3.The concentrations of COD and BOD_5 in wastewater inflow and outflow of HF - CW

The tests showed that BOD_5 in wastes reaching the constructed wetand was from 270 to 2098 mgO_2/dm^3. The average values of BOD_5 was reached 705.8±515.2 mgO_2/dm^3 (Tab. 1). A very high value of BOD_5 in the untreated wastewater was noted in June and was 2098 mgO_2/dm^3. As far as the value of BOD_5 in treated wastewater is concerned, it was from 25 to 369 mgO_2/dm^3 (the average of: 134.5±120.8 mgO_2/dm^3). During the period under analysis BOD_5 in wastewater was removed from watsewater in 80% on average. The greatest efficiency in lowering BOD_5 in watsewater was obtained in the period from May to July (83-93%). In the period from January to April the efficiency dropped to the level of 54÷56%.

The total organic carbon concentrations in wastewater flows into the hydrophyte bed were from 203 to 790 mgC/dm^3 (Fig. 4). The exception was a wastewater sample collected in June in which the TOC value was 2048 mgC/dm^3. The average concentration of total organic carbon in the influent wastewater was 589.4÷546.0 mgC/dm^3 (Tab.1).

The value of TOC in treated wastewater was from 48 to 170 mgC/dm^3 (the average of: 79.3±42.9 mgC/dm^3). In the period under analysis the average efficiency of lowering TOC from sewage was 82%. The greatest efficiency in lowering total organic carbon in watsewater was obtained in May and June (92% and 93%). The lowest efficiency was obtained in April (64%) and July (72%).

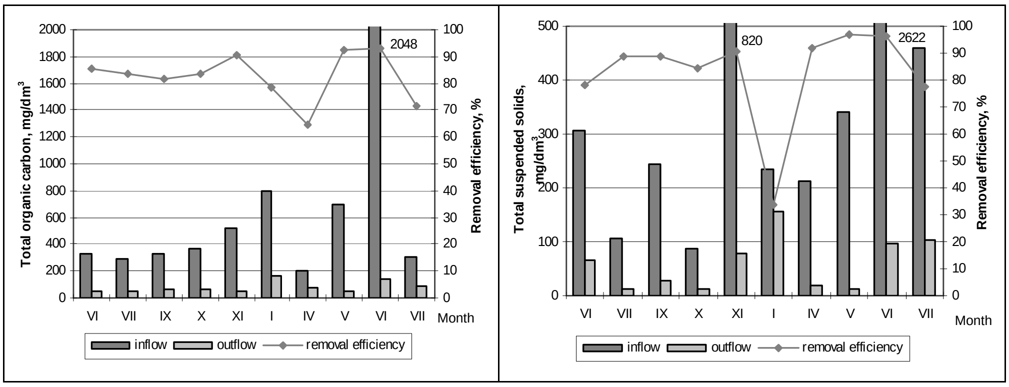

Fig. 4. The concentrations of TOC and total suspended solids in wastewater inflow and outflow of HSSF

The concentrations of the total suspension were varied and ranged from 88 to 2622 mg/dm^3 (Fig. 4). On average, the total suspension content in the mechanically treated wastewater was 543.4±759.7 mg/dm^3. In the treated wastewater the suspension content oscillated between 11 and 155 mg/dm^3, whereas the average value was 58.2±49.7 mg/dm^3. During the period under analysis suspended solids in wastewater was removed from watsewater in 83% on average.

The tests showed, that the values of contamination concentration in the wastewater samples collected in June were several times higher than in the samples collected in the other months. High values of contamination concentration in the wastewater reaching the HSSF bed could have been caused by the inflow of the distillery wastewater or by an incorrect operation of the primary settling tank.

4. DISCUSSION

The effectiveness of removing organic substance in Małyszyn was high and for BOD_5 it was 80% and for COD was 77%. In 1994-2000 years the efficiency of organic pollutants expressed in COD was lower - 52%, and for BOD_5 58% [10,19].

Wastewater biodegradability can be assessed on the grounds of the COD/BOD_5 quotient. According to Kułakowski wastewater is found to be biodegradable if COD/BOD_5 quotient were from 1.5 to 2.5 [14]. The values of this quotient in the wastewater flowing into the reed bed in Małyszyn were from 1.3 to 2.5 which means that the wastewater is biodegradable.

In the treated wastewater the content of easily biodegradable compounds is decreasing, whereas the amount of compounds which decompose with difficulty remains almost constant. This causes that the value of the COD/BOD_5 quotient increases to approximately 4÷6, and even above 10÷12 [13,14].

The COD/BOD_5 quotient determined for the treated wastewater in the constructed wetand in Małyszyn accepted the values from 1.3 to 6.0. In June and July the COD/BOD_5 quotient varied from 3 to 6, which speaks for a good biodegradability of wastewater. In the other months the values of the COD/BOD_5 quotient in the treated wastewater were below 3, which speaks for a poor effectiveness of biological wastewater treatment. The reason for this may be overloading of the hydrophyte bed with wastewater or its clogging.

Since the beginning of the plant operation several seasonal drops in treatment efficiency have been spotted. The test results showed that wastewater treatment efficiency lowers in winter, thus it depends on temperature.

When analyzing the efficiency in removing organic substances from wasterwater in HSSF in Małyszyn the research found out that it decreases 12% lower pollutant removal efficiency when temperature gets lower. Changes in the efficiency of removing organic substances expressed in COD, BOD_5 and TOC from wastewater depending on temperature are shown in Figure 5.

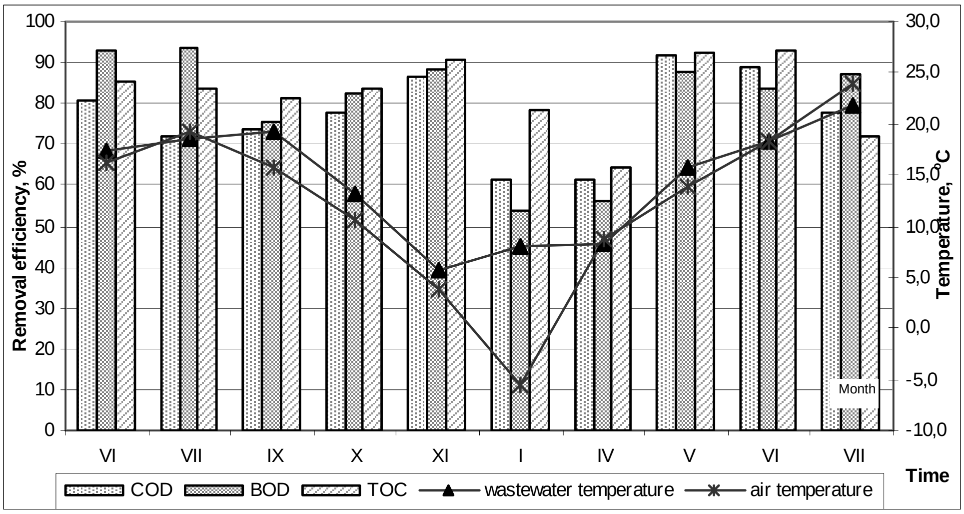

Fig. 5. Removal efficiency of organic pollutants in HSSF depending on temperature

The lowest efficiency of organic substance removal was noted from January to April, that is in the period with lowest temperature. In October, despite the low average monthly temperature, although the efficiency of wastewater treatment was high.

The seasonal temperature changes are strongly connected with changes in the periods of the hydrophyte reed bed vegetation and post-vegetation. During the vegetation period (from April to September) the air temperature in the area of the constructed wetand in Małyszyn was from 8.8 to 23.9°C. The wastewater temperature was close to the air temperature and varied from 8.3 to 21.9°C.

During the post-vegetation season from October until the end of March the air temperature varied from -5.6°C to 10.6°C, whereas the temperature of wastewater oscillated from 5.8 to 13.1°C. The average air temperature determined for this period was 1.5°C, the average wastewater temperature was 8.9°C.

The efficiency of removing contamination from wastewater expressed in COD and BOD_5 in hydrophyte facilities during both the vegetation as well as post-vegetation periods obtained as a result of the tests performed and referred to in the bibliography are shown in Table 2.

Table 2. Physico-chemical composition of mechanically treated wastewater and treated wastewater

	The effectiveness of pollutants removal, %			
	Vegetation period		Non-vegetation period	
	COD	BOD_5	COD	BOD_5
Małyszyn (own research)	62÷92	56÷94	62÷87	54÷88
Kalisz i Sałbut, 1996	70÷91	78÷94	46÷85	44÷83
Tuszyńska i Obarska Pempkowiak, 2006	63.5	71.9	61.4	70.3

During the reed growth period removal of organic contamination stayed at 78% for COD and 82% for BOD_5. During the post-growth period the efficiency of wastewater treatment lowered to 75% for COD and 74% for BOD_5.

The efficiency of wastewater treatment noted in Małyszyn were comparable to the data provided by Kalisz and Sałbut [12]. The authors investigated the three objects on a technical scale constructed wetland with horizontal subsurface flow of sewage (Tab. 2). During the vegetation period the wastewater treatment efficiency was from 70÷91% for COD and 78÷94% for BOD_5. While in the post-vegetation season then lowered to 46÷85% for COD and 44÷83% for BOD_5.

The test results are also confirmed by the observations referred to by Tuszyńska and Obarska-Pempkowiak [22]. The authors indicated that in the HF-CW bed in Wieszyno, being the first step of treatment, the efficiency of removing contamination from wastes varied depending on the season. During the vegetation period the average efficiency was 63.5% for COD and 71.9% for BOD_5, whereas in the post-growth period it decreased to 61.4% and 70.3% respectively.

The tests performed in constructed wetand in Małyszyn showed that the biggest difference between the vegetation and post-vegetation period were noted for the total suspension. During the plants growth the total suspension was removed in 88%, whereas during the plants rest efficiency of removing lowered to 69%.

The test results showed a lower efficiency in removing total organic carbon during the vegetation (82%) period than during post-vegetation period (84%). The percentage efficiency of waste water treatment was lowered by the samples collected in April, the results that were classified as the results of the vegetation period, however, low temperatures at the time lead to a very low efficiency in removing TOC from wastewater.

5. CONCLUSIONS

The presented test results are a basis for the formulation of final conclusions:

- Research has documented a high removal efficiency of organic pollutants and total suspended solids in subsurface flow constructed wetland during the research period.
- The average effectiveness of removing organic pollutants from wastewaters expressed in COD was 77%, BOD_5 - 82%, TOC - 82%, and total suspension - 83%.
- The test results confirm observations made by the other authors, that seasonal temperature changes affect the efficiency of removing contamination and total suspension from wastewater.
- The efficiency of removing organic substances from wastewater also depends on the vegetation and post-vegetation period and decreases in the plant post-grow period.
- During the vegetation period the efficiency of treating wastewater expressed in COD and BOD_5 was: 78 and 82% respectively and during the post-vegetation period the efficiency was slightly lower: 75% for COD and 74% for BOD_5.
- The biggest difference between the vegetation and post-vegetation period were noted for the total suspension. During the plants growth the total suspension was removed in 88%, whereas during the plants rest efficiency of removing lowered to 69%.

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ADDITIONAL INFORMATION

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EFEKTYWNOŚĆ USUWANIA ZANIECZYSZCZEŃ ORGANICZNYCH W OCZYSZCZALNI HYDROFITOWEJ

S t r e s z c z e n i e

W pracy przedstawiono wyniki badań dotyczące efektywności usuwania ze ścieków zanieczyszczeń organicznych w oczyszczalni hydrofitowej. Średnia skuteczność oczyszczania wyrażona jako obniżenie wartości ChZT w ściekach była na poziomie 77%, dla BZT_5 80%, a dla OWO 82%. Analizowano również wpływ sezonowych zmian temperatury oraz okresu wegetacji i spoczynku roślin na skuteczność oczyszczania ścieków. Wyniki badań wykazały obniżenie efektywności usuwania zanieczyszczeń organicznych ze ścieków wyrażonych przez ChZT i BZT_5 oraz zawiesiny ogólnej w okresie jesienno-zimowym. W okresie wegetacyjnym obiekt w Małyszynie charakteryzował się efektywnością oczyszczania ścieków na poziomie: 78% dla ChZT, 82% dla BZT_5, a w sezonie pozawegetacyjnym skuteczność uległa obniżeniu do 75% w przypadku ChZT oraz 74% dla BZT_5. Zawiesina ogólna w okresie wegetacji trzciny usuwana była w 88%, a w okresie powegetacyjnym w 69%.

Słowa kluczowe: oczyszczanie ścieków, oczyszczalnie hydrofitowe

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