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Efficiency of organic substance removal in a hybrid sand filter with horizontal flow

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Abstract

The paper presents the results of the research about the efficiency of organic substance removal in a hybrid sand filter. The investigations were carried out on a model wastewater treatment plant consisting of a preliminary sedimentation tank and two sand filter with a horizontal flow of wastewater (aerobic and anaerobic beds). The efficiency of BOD_5 and COD removal was analysed for different wastewater hydraulic load levels: 0.72; 1.08; 1.44 $dm^3 \cdot d^{-1}$. The best efficiency of BOD_5 and COD removal was obtained when the hydraulic load level was 1.08 $dm^3 \cdot d^{-1}$, respectively 83.8 and 72.3%. The average values of BOD_5 and COD in the treated wastewater were significantly higher than the values deemed acceptable by relevant regulations in Poland. Based on the studies in the analyzed case, it was found that, sand filters with horizontal flow, do not guarantee high effluent treatment effect of typical household wastewater. In order to obtain a better efficiency of organic substance removal in a hybrid sand filter wastewater need to be oxygenate before being carried to these systems.

Key words: *BOD_5, COD, efficiency, horizontal flow, sand filter, wastewater treatment*

INTRODUCTION

In recent years in rural areas in Poland, there can be seen an intensive development of water and waste water management [BUGAJSKI *et al.* 2017; JÓŹWIAKOWSKI 2016; JÓŹWIAKOWSKI, PYTKA 2010; JÓŹWIAKOWSKI *et al.* 2012; PAWEŁEK 2016], which is connected with the implementation of the requirements from Council Directive 91/271/EC signed on 21st May 1991 concerning the issue of urban wastewater treatment. The realization of these requirements includes investment activities concerning building, expansion and modernisation of sewerage systems as well as collective and domestic wastewater treatment plants.

According to the Central Statistical Office of Poland (Pol. Główny Urząd Statystyczny – GUS) data [GUS 2016] in 2015 94.6% of cities inhabitants used collective wastewater treatment plants, whereas in the country there was the amount of only 39.6%. Such a disproportion is connected with a huge dispersion of houses on the rural areas, which is why it would be economically ungrounded to build collective wastewater sewerage systems and sewage treatment plants. In such areas wastewater is generally hold in septic tanks known as cesspits and in 2015 there were over 2 million of them [GUS 2016]. For over 20 years there has been observed a systematic fall in the amount of septic tanks for the benefit of the number of domestic wastewater treatment plants. In 2015 in Poland there were 202 783 such objects registered and every year this quantity increases by about 22 000 pieces. So far, the biggest number of domestic wastewater treatment plants has been constructed in such voivodeships: Masovian – 27 056, Kuyavian-Pomeranian – 24 162 and Lublin – 22 329. Nonetheless, the least of such objects have been built in these voivodeships: Opole – 4131 and Podkarpackie – 2460 [GUS 2016; SIWIEC 2017]. Among the technological solutions used in domestic sewage treatment plants are: 1 – systems with spreading drainage, 2 – sand filters, 3 – treatment plants with active sediment, 4 – treatment plants with biological bed, 5 – hybrid systems

(active sludge + biological bed), 6 – constructed wetland systems (one-stage and hybrid) [JAWECKI *et al.* 2017; JÓŹWIAKOWSKI *et al*. 2015]. The technological solution chosen to be used in domestic sewage treatment plants, which are planned to be built in the area of the community, must be in accordance with sustainable development [JÓŹWIAKOWSKI *et al*. 2015; MUCHA, MIKOSZ 2009]. However, the fact that in Poland for many years so far the most commonly (71%) used ones are systems with the spreading drainage [JÓŹWIAKOWSKI *et al.* 2012]. According to many authors these systems should not be installed as they enable only mechanical sewage treatment and they contribute to the degradation of the surface water and groundwater quality [JUCHERSKI, WALCZOWSKI 2001; OBARSKA-PEMPKOWIAK 2005; ORLIK, JÓŹWIAKOWSKI 2003; PALUCH, PULIKOWSKI 2004]. An increase in the amount of domestic wastewater treatment plants used in Poland indicates that there is a strong need to control them in the field of the efficiency and their functional reliability [JÓŹWIAKOWSKI *et al.* 2017a]. Special attention must be given to the research connected with the exploitation of spreading drainage systems and sand filters, which are the most often used in rural areas in Poland [CHMIELOWSKI, ŚLIZOWSKI 2008; JÓŹWIAKOWSKI *et al.* 2012].

The aim of the work is to determinant of the removal effectiveness of an organic substance describe by the two indicators: BOD_5 and COD in the hybrid systems. This system is consist of: settling tank and two sand filters with horizontal sewage flow. Moreover the idea of research was to show, if this type of systems can be uses in the field conditions to protect quality of surface and underground water.

CHARACTERISTICS OF THE EXPERIMENTAL OBJECT

The research was carried out on the experimental object constructed in the laboratory conditions. The research installation consisted of two main pieces:
1) controlling, measuring and checking apparatus;
2) model wastewater treatment plant (Fig. 1).

The controlling, measuring and checking apparatus consisted of: a special driver of the chemical process SPC 10, 4 peristaltic pumps from an American company Gorman-Rupp Industries, a temporal flow regulator, oxygen probe Oxyferm 120 and pH electrode Easyferm 120 from an American company Hamilton, temperature detector PT-100 from a Polish company Elmetron and a computer.

The model wastewater treatment plant consisted of three parallel wastewater treatment systems containing a dual-chamber preliminary sedimentation tank and two further sand beds with a horizontal sewage flow: aerobic and anaerobic ones (Fig. 1). The area of the sand beds (aerobic and anaerobic) was 0.0916 m^2 and their depth was 0.07 m. The canal's

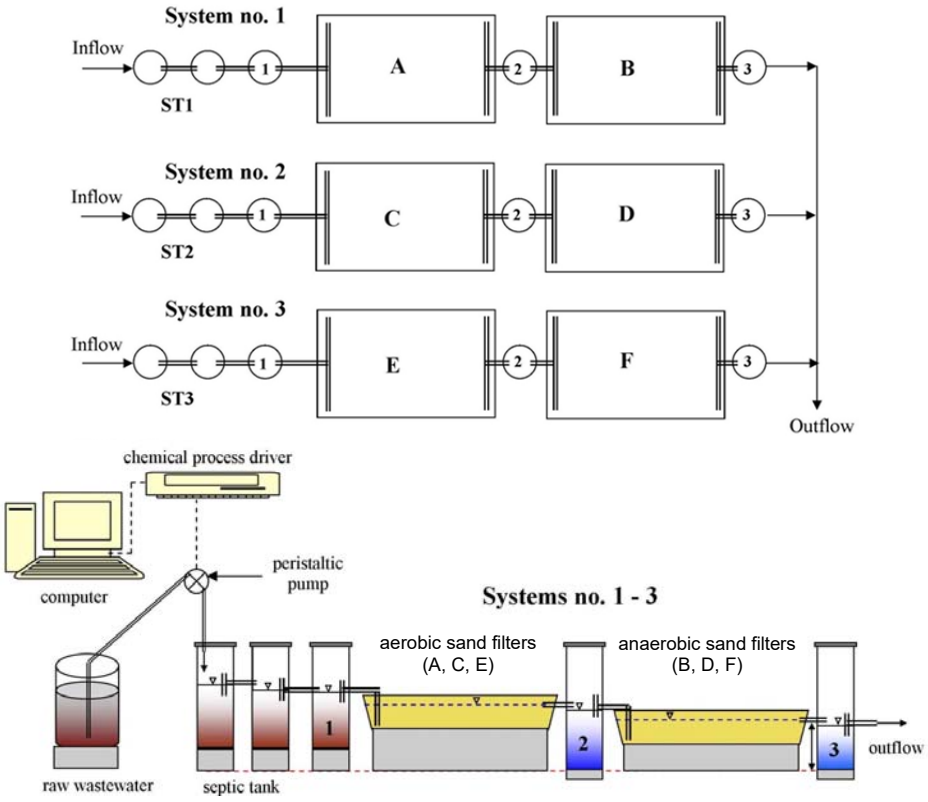

Fig. 1. A schematic diagram of the wastewater treatment plant model (WWTP); ST1, ST2, ST3 = two-chamber septic tanks; 1, 2, 3 = sampling points; A, C, E = sand filters with horizontal flow (with oxygen); B, D, F = sand filters with horizontal flow (without oxygen); source: own elaboration

gradient in the beds was 1% towards the sewage outflow. The spreading drainage – inflow and the collecting one – outflow were constructed from pipes with a diameter of $\phi = 0.01$ m with special cuts. In order to fill the beds with a horizontal flow (A, B, C, D, E, F) mean sand was used ($\phi = 1$–2 mm). The main parameters of the model wastewater treatment plant have been shown in the Table 1.

Table 1. Basic technological parameters of the model wastewater treatment plant

Parameter	Measurement unit	Primary sedimentation tank chambers I and II	Aerobic and anaerobic sand filters
Lenght L	m	–	0.390
Width W	m	–	0.235
Diameter D	m	0.075	–
Total depth H	m	0.240	0.060
Height of wastewater level h	m	0.160	0.050
Area A	m^2	–	0.092
Total volume V	dm^3	1.059	5.499
Acive volume V_{cz}	dm^3	0.707	4.582

Source: own elaboration.

METHODS OF RESEARCH

The research concerning the efficiency of organic substance removal, shown with such indicators as BOD_5 and COD, was being carried out in the model wastewater treatment plant for 8 weeks. Domestic waste water used in the research was brought once a week from the preliminary sedimentation tank of the domestic wastewater treatment plant functioning in real conditions. The tests were conducted with such sewage flow levels: 0.72; 1.08 and 1.44 $dm^3 \cdot d^{-1}$, which suited to the sewage inflow to three analysed systems in a quantity of: 0.5; 0.75 and 1 $ml \cdot min^{-1}$. The hydraulic sewage load of the beds'(aerobic and anaerobic) area ranged from 0.008 to 0.016 $m^3 \cdot m^{-2} \cdot d^{-1}$, while the waste water retention time ranged from 11 h 47 min to 23 h 32 min – in the preliminary sedimentation tanks and from 30 h 33 min to 61 h 06 min – in the aerobic and anaerobic beds.

In order to show the effects of organic substance removal in various levels of hydraulic load of BOD_5 and COD were measured: 1 – in the wastewater after it's mechanical purification, 2 – in the sewage outflowing from the aerobic bed and 3 – in the sewage outflowing from the anaerobic bed. During the research there were taken altogether 6 series of the analysis – 2 series for each hydraulic load level. The analysis of the size of the measured indicators in the sewage were made in accordance with the commonly used methods [APHA 2002; 2005]. The calculation of the effects of the decrease of BOD_5 and COD at each treatment stage were based on the change in the amount of analysed indicators in the inflow and outflow waste water in the particular element of the treatment plant and this formula was used:

$$\eta = \left(-\frac{C_d - C_o}{C_d}\right)100\% \quad (1)$$

where: C_o = the concentration of the pollutants in the sewage outflowing from the treatment plant; C_d = the concentration of the pollutants in the sewage inflowing to the treatment plant.

RESULTS OF THE RESEARCH AND THE DISCUSSION

In the Table 2 there has been shown the composition of the sewage treated in the model wastewater treatment plant with different levels of hydraulic load.

During the research the temperature of wastewater inflowing to the model treatment plant ranged from 14.9 to 18.8°C. However, the pH value was about 7.01–7.46, which shows it's soft alkaline character. The tests have revealed a small amount of oxygen dissolved in the waste water after mechanical treatment: 0.19–0.56 mg $O_2 \cdot dm^{-3}$. From the literature we know that the concentration of oxygen dissolved at this level can restrict the effective waste water treatment. The minimal concentration of oxygen should range from 1 to 2 mg $O_2 \cdot dm^{-3}$ in order to enable an effective process of pollutants oxidation [BERNACKA *et al*. 1995].

Sewage delivered to the tested purification systems were characterised by different amounts of BOD_5 and COD. The value of BOD_5 ranged from 213 to 255 mg $O_2 \cdot dm^{-3}$ and the value of COD: from 340 to 530 mg $O_2 \cdot dm^{-3}$. The composition of the sewage delivered to the tested object was similar to this which is common in the typical domestic wastewater discharged from the households [BERGIER, WŁODYKA-

Table 2. The parameters of sewage treated in the model sewage treatment plant with different hydraulic load levels

Parameter	Measurement unit	Hydraulic load Q_d								
		$Q_1 = 1.44\ dm^3 \cdot d^{-1}$			$Q_2 = 1.08\ dm^3 \cdot d^{-1}$			$Q_3 = 0.72\ dm^3 \cdot d^{-1}$		
		1	2	3	1	2	3	1	2	3
Temperature of wastewater	°C	16.90	16.50	17.00	14.90	14.60	14.50	18.80	18.60	18.60
pH	–	7.46	7.84	8.21	7.38	7.94	8.06	7.01	7.94	8.17
O_2	mg $O_2 \cdot dm^{-3}$	0.42	0.98	1.39	0.56	1.15	2.00	0.19	0.57	3.12
BOD_5	mg $O_2 \cdot dm^{-3}$	255	173	145	253	54	41	213	117	83
COD	mg $O_2 \cdot dm^{-3}$	530	230	210	470	140	130	340	230	100

Explanations: 1 = sewage after mechanical treatment, 2 = sewage outflowing from the aerobic beds, 3 = sewage outflowing from the anaerobic beds; BOD_5 = 5 day biochemical oxygen demand, COD = chemical oxygen demand.
Source: own study.

-BERGIER 2012; BUGAJSKI, BERGEL 2008; CHMIELOWSKI *et al.* 2016; HEIDRICH, KOZAK 2009; KACZOR 2009].

On the ground of the level of an average daily sewage inflow to the model treatment plant and the values of BOD_5 and COD in the waste water there had been calculated the pollutant load in the tested system (Fig. 2).

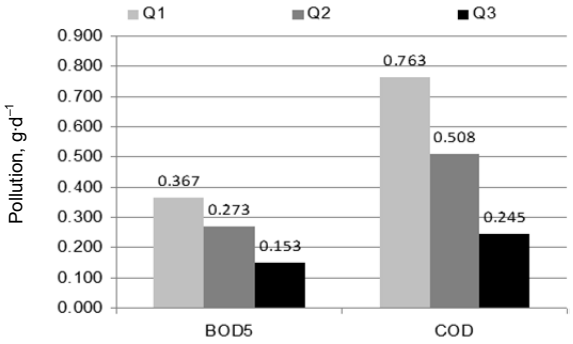

Fig. 2. The pollutant load in the sewage inflowing to the model treatment plant; Q_1 = 1.44 $dm^3 \cdot d^{-1}$, Q_2 = 1.08 $dm^3 \cdot d^{-1}$, Q_3 = 0.72 $dm^3 \cdot d^{-1}$; source: own study

According to the data shown at the Figure 2 it can be seen that the organic pollutant load inflowing to the tested object depended especially on the amount of the inflowing waste water. It has been observed that the biggest pollutant loads were brought to the model treatment plant by the highest hydraulic load (Q_1 = 1.44 $dm^3 \cdot d^{-1}$) and alongside with its decrease (to Q_3 = 0.72 $dm^3 \cdot d^{-1}$), they were significantly diminishing – even by over 50% (Fig. 2). It has been stated that the organic pollutant load level of 1 dm^3 of the sewage inflowing to the analysed object decreased from 0.367 $g \cdot d^{-1}$ (by Q_1) to 0.153 $g \cdot d^{-1}$ (by Q_3) – for BOD_5 and from 0.763 $g \cdot d^{-1}$ (by Q_1) to 0.245 $g \cdot d^{-1}$ (by Q_3) – for COD.

The values of the indicators tested in the sewage out flowing in the particular stages of the purification were much smaller than in the inflow wastewater. The effects of the organic pollutants (BOD_5 and COD) removal in the analysed treatment plant were various at different hydraulic and pollutant loads which has been indicated in the research results shown in the Figure 3.

The research has shown that the best effects of the organic substance removal, expressed by such indicators as BOD_5 (83.8%) and COD (72.3%), were in the whole wastewater treatment plant achieved by the Q_2 = 1.08 $dm^3 \cdot d^{-1}$ hydraulic load. On the other hand, the least effects of BOD_5 and COD decrease were obtained by the biggest hydraulic load Q_1 (Fig. 3). To compare, according to the research carried by CHMIELOWSKI *et al.* [2011] the effects of BOD_5 and COD elimination in the sand filter with a horizontal flow are respectively: 83–90%. It has been observed that the best effects of BOD_5 and COD removal in the tested system were achieved the most often in the I aerobic bed – respectively: 32.0–78.9% and 32.4–

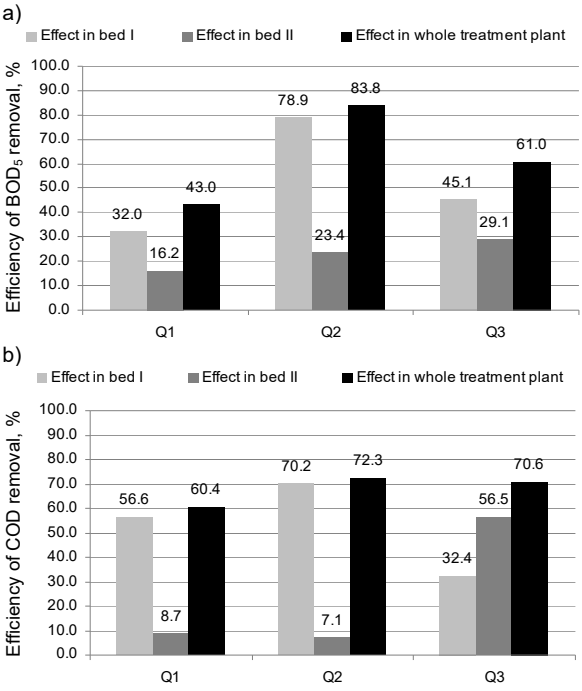

Fig. 3. The effects of the organic pollutants removal at particular stages of wastewater treatment by different levels of hydraulic load; Q_1, Q_2, Q_3 as in Fig. 2; source: own study

70.7% but much worse in the II anaerobic bed – respectively: 16.2–29.1% and 7.1–32.4% (Fig. 3).

The results of the research shown in the Table 2 indicate that the COD values in the outflow, by the hydraulic load Q_2 and Q_3, did not exceed permitted levels (150 mg $O_2 \cdot dm^{-3}$) determined in the Regulation of The Minister of The Environment [Rozporządzenie MŚ… 2014]. However, by the hydraulic load Q_1 the permitted value of COD was exceeded. For BOD_5 the permitted level (40 mg $O_2 \cdot dm^{-3}$) determined in the regulation [Rozporządzenie MŚ… 2014] in the sewage out flowing from the tested sand filters was exceeded by all three levels of the hydraulic load (Tab. 2).

The research revealed that the sand filters working in laboratory conditions with specific hydraulic and pollutant load do not provide suitable efficiency of the elimination of organic substance expressed by such indicators as BOD_5 and COD. According to the research of ORLIK and JÓŹWIAKOWSKI [2003] the efficiency of organic substance removal in the systems with spreading drainage (with a vertical flow) used in real conditions is also small. These authors proved that the effects of BOD_5 and COD decrease in such objects were respectively: 29.4–38.2% and 21.2–30.4%, so they were much lower than these ones obtained in the model installation.

The received results show that sand filters with a horizontal flow should not be used to treat domestic wastewater, as well as domestic wastewater treatment plants using only systems with spreading drainage, which are not able to purify sewage [ORLIK, JÓŹWIAKOWSKI 2003]. The main reason of a small efficiency of organic substance removal in such systems is the

lack of oxygen in the treated sewage and that is why the processes of biological removal of organic substances and nitrogen compounds do not proceed appropriately. The effects of the decrease of BOD_5 and nitrogen compounds in such objects can be improved for instance by using hydrogen peroxide (H_2O_2). The research done by JÓŹWIAKOWSKI *et al.* [2017b] has shown that by using this unconventional method of sewage oxygenation the effects of BOD_5 decrease in a one-stage sand filter with a horizontal flow were maximally 94.3%, whereas the average value of BOD_5 in the purified wastewater was 4.4 mg $O_2 \cdot dm^{-3}$.

CONCLUSIONS

1. There has been proved that the tested hybrid sand filters are not able to prove an efficient elimination of organic substance expressed by such indicators as: BOD_5 and COD. The best effects of the reduction of these parameters in analysed systems obtained by the hydraulic load at the level of Q_2 = 1.08 $dm^3 \cdot d^{-1}$ were respectively: 83.8 and 72.3%. The BOD_5 and COD removal by the Q_1 hydraulic load were respectively 40.3% and 60.4% and by Q_3 these values were respectively 61.0% and 70.6%.

2. The biggest effects of BOD_5 and COD reduction were obtained mainly in the I aerobic bed and much smaller ones in the II anaerobic bed.

3. The average values of BOD_5 and COD in the treated wastewater usually were significantly higher than the values deemed acceptable by relevant regulations in Poland.

4. The results achieved in this research show that the sand filters with the horizontal flow should not be used to treat domestic wastewater. In order to obtain better effects of organic substance removal in sand filters there is a strong need to oxygenate the sewage before delivering them to these systems.

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Krzysztof JÓŹWIAKOWSKI

Efekty usuwania substancji organicznej w hybrydowych filtrach piaskowych z przepływem poziomym

STRESZCZENIE

W pracy zaprezentowano wyniki dotyczące efektywności usuwania substancji organicznej w hybrydowych filtrach piaskowych. Badania prowadzono w modelowej oczyszczalni ścieków składającej się z osadnika wstępnego i dwóch filtrów piaskowych z poziomym przepływem. Efektywność zmniejszania BZT_5 i ChZT była analizowana w warunkach różnego obciążenia hydraulicznego ściekami: 0,72; 1,08; 1,44 $dm^3 \cdot d^{-1}$. Najlepsze efekty obniżania BZT_5 i ChZT uzyskano w warunkach obciążenia hydraulicznego na poziomie 1,08 $dm^3 \cdot d^{-1}$, odpowiednio 83,8 i 72,3%. Średnie wartości BZT_5 i ChZT w oczyszczonych ściekach były zazwyczaj większe niż dopuszczalne w odpowiednich przepisach w Polsce. Na podstawie badań w analizowanym przypadku stwierdzono, że filtry piaskowe o przepływie poziomym nie dają gwarancji wysokiej sprawności oczyszczania ścieków bytowych. W celu uzyskania lepszych efektów eliminacji substancji organicznej w filtrach piaskowych konieczne jest napowietrzanie ścieków przed doprowadzeniem ich do tych systemów.

Słowa kluczowe: *BZT_5, ChZT, efektywność oczyszczania ścieków, filtr piaskowy, przepływ poziomy*