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Treatment of high strength domestic sewage on filters filled with polyurethane foam with addition of effective microorganisms

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Abstract: The study discusses an experimental method for treatment of high strength domestic sewage on biofilters filled with polyurethane (PUR) waste in the form of trims of upholstery foam. We determined effectiveness of two biological preparations containing effective microorganisms in elimination of organic and biogenic compounds, indicator bacteria and total suspended solids from the sewage pretreated in a septic tank. After four months of work under a hydraulic loading of 76.4 mm·d^{-1} we found the filter with 60 cm foam layer to be the most efficient in the elimination of BOD_5, COD_{Cr}, NH_4^+-N and coliform bacteria. An average reduction in these pollutants reached 79.4%, 67.8%, 58.0% and 88.0%, respectively. Vertical filters filled with trims of upholstery foam and supplied with effective microorganisms ensured favorable conditions for development of heterotrophic and nitrifying bacteria without any need for additional aeration.

Introduction

A septic tank combined with a sand filter or drainage system is one of the most common on-site sewage treatment solutions (Pawełek and Bugajski 2017). It yields good results at low costs but its main disadvantages include possible clogging of the filter bed. Moreover, relatively low porosity of the sand filters results in their poor aeration.

To increase the removal rate of organic and biogenic compounds and to prevent filter silting up, the sand filling may be replaced with natural and plastic porous materials. Thanks to internal pores of variable size, they provide huge specific surface and absorbing capacity. Artificial porous materials are less prone to clogging and provide good aeration and transfer of oxygen and other resulting gases. Commercial artificial fillings of biological filters are produced as packaged or bulk fillings. Research conducted by Marzec and Jóźwiakowski (2011) regarding the hybrid method (activated sludge and biological submerged bed with filling in the form of plastic beads), used in the aeration chamber, showed the possibility of obtaining a 92–97% degree of removing organic pollutants and total suspended solids. A wastewater treatment plant consisting of a hybrid reactor and two settling tanks – primary and secondary – also proved to be effective in treating wastewater with an ammonium nitrogen content of 37 mg N-NH_4·dm^{-3}. Although non-woven materials are increasingly popular, they dry up in periodically supplied filters, which negatively affects biofilm and thus wastewater treatment effectiveness (Mazur et al. 2016). Polyurethane or polyethylene foams are promising materials capable of holding up moisture. Developing countries use them in UASB-DHS (Upflow Anaerobic Sludge Blanket – Downflow Hanging Sponge Reactor) reactor systems to treat moderately polluted municipal wastewater (Machdar et al. 2000, Uemura et al. 2002, Tandukar et al. 2007, Tawfik et al. 2010, Tawfik and Klapwijk 2010, Onodera et al. 2014b,). So far, six generations of DHS sewage pretreatment reactors have been tested. A DHS reactor has many advantages but it cannot be used for treatment of raw sewage containing high concentrations of suspended solids (SS). Their presence in the media flowing through the foams prevents oxygen and substrates supply to a biofilm. It is therefore recommended to remove larger suspended matter and solids before the sewage enters the DHS reactor.

Tawfik et al. (2011) investigated direct treatment of pretreated sewage using an independent DHS system with randomly packed foams to treat gray sewage. This allowed for elimination of 90–96% ± 2% COD, 26.7–86% ± 13% NH_4^+-N and 93.5–98.2% ± 1% total suspended solids. Ehsas (2013) employed a laboratory-scale independent DHS system to treat synthetic sewage (tap water with dog feed added). With cylindrical polyurethane foams randomly packed into the reactor modules, the pollutants reduction reached 56–76% for COD, 58–91% for BOD_5, 83–100% for ammonium nitrogen, and 58–97% for total suspended solids.

Supporting the technology with biological preparations containing so called Effective Microorganisms (EM) seems an attractive approach. EMs comprise multiple strains of co-existing, effective, favorable and non-pathogenic microorganisms. Basically, these preparations include aerobic and anaerobic microorganisms commonly present in most of all ecosystems. According to Higa (1998), EMs comprise about 80 species of microorganisms such as photosynthetic bacteria, lactic acid bacteria, yeasts, *Actinobacteria* and fermenting fungi capable of purifying and reinstating the environment. Biopreparations are specially prepared and selected populations of live bacteria and sometimes also of enzymes and fungi. Their job in on-site sewage treatment systems is to decompose organic matter. They accelerate decomposition of organic substances and facilitate transformation of nitrogen and phosphorus compounds, thus neutralizing unpleasant odors (BioTrakt, http://www.emgreen.pl). Some authors (Jin et al. 2005, Maalim et al. (2013) showed that the addition of EM might improve reactor performance by providing conditions that may positively affect the growth of other essential beneficial microorganisms.

An important group of EMs are lactic acid bacteria. Their influence lies primarily in the production of various types of metabolites, mainly in the form of bacteriocins, which can effectively inhibit the growth of microorganisms, such as *Salmonella* spp. or *Escherichia coli*. The antimicrobial laboratory tests conducted by Wroński et al. (2010) and Safwat and Rozaik (2018) showed that EM can inhibit the growth of pathogenic bacteria such as *Escherichia* coli, *Pseudomonas aeruginosa*, and *Streptococcus faecalis*.

According to the circular economy concept, the waste should be treated as materials which can be recycled, processed and reused. The waste may be recycled using mechanical, chemical, biological or thermal methods of waste treatment. These two last processes are determined as basic action directions in Polish waste management (Rosik-Dulewska 2015).

The aim of the research

This article evaluates a possibility of using plastic waste in the form of polyurethane foam for sewage treatment after pre-treatment in a primary sedimentation tank. The effects of treatment of wastewater with elevated ammonium nitrogen content for foam-filled filters with the addition of effective microorganisms were presented. The study shows wastewater treatment effectiveness (removal of organic compounds, biogenic compounds, total suspended solids and indicator bacteria) during three stages of filter operation under hydraulic load of 76.4 $mm \cdot d^{-1}$.

Analysis of the composition of wastewater treated in household wastewater treatment plants indicates significantly increased loads of biogenic compounds, in particular ammonium nitrogen to near 100 mg $N\text{-}NH_4 \cdot dm^{-3}$ (Jóźwiakowski 2012, Jucherski and Nastawny 2012, Jóźwiakowski 2017). For this reason, the name was changed from "high strength wastewater" to "wastewater with elevated ammonium nitrogen content".

The authors treated the sewage, where the concentration of ammonium nitrogen was about five times higher than reported in the literature. Secondly, the analyzed wastewater was treated directly after the septic tank. In contrast, the literature describes tests where waste water is pre-treated in a UASB reactor prior to being directed to the DHS reactor (with the filling in the form of brand new sponges).

Experimental part

Materials

The biofilters were filled with trims of polyurethane foam of random shapes used commercially as upholstery foam. The foam is manufactured by Eurofoam Polska Sp. z o.o. In Table 1 the types and physical properties of new foams are presented. In this research we used a mixture of waste foams which featured high porosity of 94.5% (unpublished materials). Nominal diameters d_{10} and d_{60} of PUR foam waste were 4 mm and 10 mm respectively. The coefficient of graining non-uniformity d_{60}/d_{10} had the value of 2.5.

The experimental filters were sectional models of a vertical flow filter, studied on a semi-technical scale. The experimental model consisted of three identical PVC columns, of 10 cm in diameter and 100 cm high. The foam layer in the filters was 60 cm thick. A grate supporting the bed was installed at the bottom of each filter layer. Figure 1 shows a diagram of the column model.

Table 1. Types and physical properties of new foams specified Eurofoam Polska Sp. z o.o.

Type	Bulk density [$kg \cdot m^{-3}$]	Rigidity [kPa]	Basic color	Content [%]
N 1418	13.5–15.5	1.6–2.3	white	21.1
N 1819	16.0–19.0	1.2–2.0	white	
N 2030	17.0–21.0	2.7–3.6	white	
N 2121	19.5–22.5	1.8–2.6	yellow	21.4
N 2434	21.0–25.0	2.7–4.1	pink	3.8
N 2538	22.0–26.0	3.3–4.6	lilac	0.8
N 2544	22.0–26.0	3.6–5.0	grey	1.9
N 2838	24.0–28.0	3.5–4.5	orange	6.7
N 3030	27.5–31.0	2.7–3.7	green	6.5
N 3050	27.0–31.0	4.4–5.8	blue	10.6
N 3543	32.0–36.0	3.8–5.0	green	26.3
N 3843	34.0–38.0	4.0–5.3	blue	0.9

The amount of adsorbed pollutants was determined as a difference between the dry weight of 1 liter of foams after testing and 1 liter of foams before testing. The amount of biomass was determined as content of organic pollutants rinsed from 1 liter of foams after testing. In addition, a visual assessment of the present biofilms in the filtrate from the columns was made.

Test methods

The tests involved sewage pretreated in a septic tank and then collected in an intermediate tank. The sewage was dosed onto the model columns with peristaltic pumps started cyclically on hourly basis. All three columns were exposed to the same hydraulic load of 76.4 $mm \cdot d^{-1}$. G1 column was a reference one, without the addition of effective microorganisms during the tests. Every 2–3 weeks the same doses of commercial preparations EM1 and EM2, containing two different populations of effective microorganisms were added to the other two columns.

The EM1 and EM2 preparations contained yeast and lactic acid bacteria. EM2 additionally contained molasses from sugar cane. The total number of lactobacilli (*Lactobacillus casei*, *Lactobacillus plantarum*) was $5.0 \cdot 10^6$ CFU/ml, while the total number of yeast *Saccharomyces cerevisiae* was $5.0 \cdot 10^3$ CFU/ml.

The pretreated sewage was collected from a separating chamber downstream of the septic tank, and the treated sewage was collected as filtrates from individual columns. Sewage samples underwent physical and chemical analyses for the following indicators of pollutants: pH, dissolved oxygen, BOD_5, COD_{Cr}, total suspended solids, content of organic suspension, ammonium nitrogen, and orthophosphates. Physiochemical and microbiological analyses were carried out on average for 10 measurement series performed at an initial period of the filter operation (start-up stage, stage I) and for 10 measurement series performed for four months of continuous filtration (stage II). Sampling of sewage was carried out in accordance with the standards PN-74/C-04620-11:1974 and PN-EN ISO 5667-1:2007.

Under normal conditions, the start-up of the reactor takes some time depending on available anaerobes and how they interact with changes in organic loading, temperature and other environmental conditions which directly interfere with their metabolic process and growth.

Start-up stage for the organic compounds and suspended solids was determined for a 6 week period. Start-up stage for the biogenic compounds was 2 weeks shorter.

Analytical methods

The concentration of dissolved oxygen and pH were determined with a multiparameter CPO-401 meter manufactured by ELMETRON (PN-EN 5814:2013-04 standard). BOD_5 was determined with a manometric method using OXITOP® bottle set (PN-EN 1899-1:2002 standard). COD_{Cr} was established with dichromate method and Aquanal Spectro 3 photometer

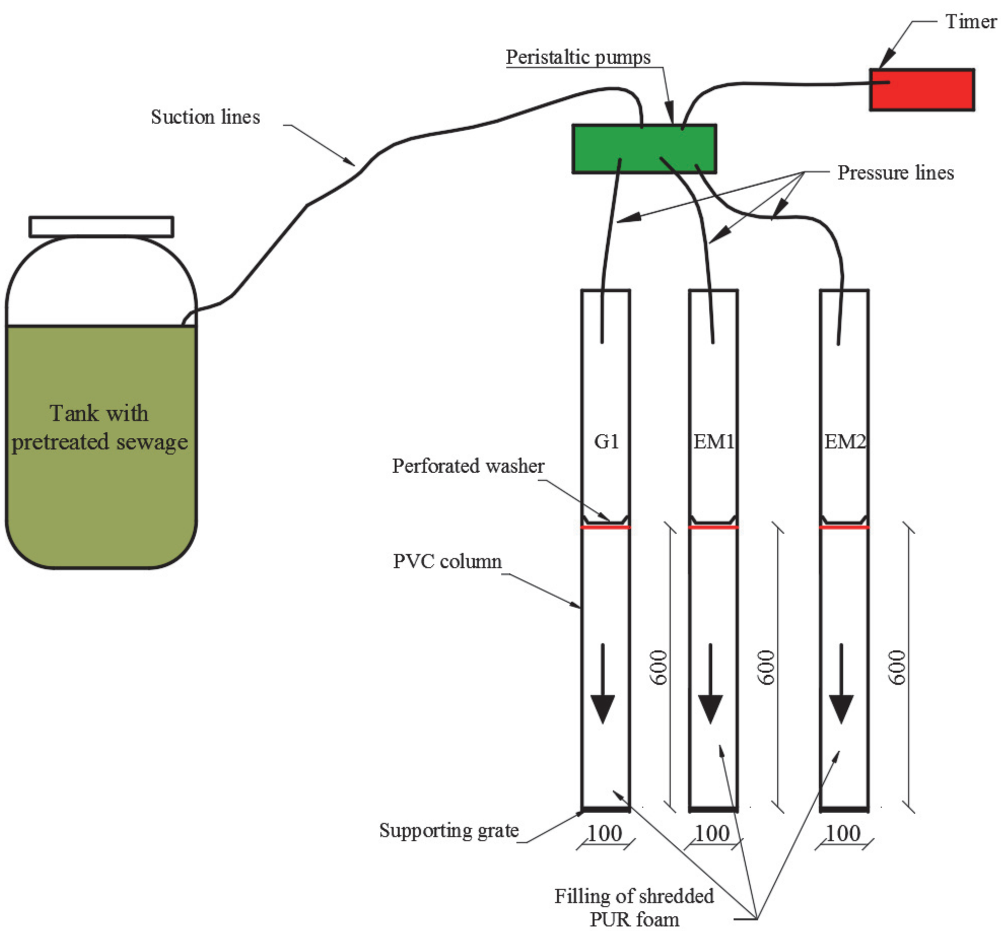


Fig. 1. Diagram of the column model

(PN-ISO 6060:2006 standard). The concentration of suspended solids was figured out by filtering on glass fiber filters (PN-EN 872:2007 standard), and that of ammonium nitrogen by direct nessleration (PN-C-04576-4:1994 standard). Coliform bacteria (*Klebsiella, Enterobacter, Citrobacter, Proteus, Escherichia coli)* were counted by dilution and surface plating on ENDO medium.

Statistical analysis was performed using Statistica 13 software. The study outcomes were subjected to ANOVA. A dependent variable was assumed as the values of individual pollutants parameters, i.e. concentration of dissolved oxygen, BOD_5, COD_{Cr}, suspended solids, ammonium nitrogen, orthophosphates, *Escherichia coli* and coliform bacteria. First, we assessed the normality of the distribution with Shapiro-Wilk test (α=0.05). Then, the Levene test was used for equality of variances to analyze the significance of differences between variances.

Finally, we employed Kruskal-Wallis test, a nonparametric counterpart of ANOVA, to analyze the source data and to compare the differences between individual pollutants indicators at both investigated stages. Contrary to ANOVA, which is based on mean values, Kruskal-Wallis test analyzed the data by ranks. A difference in means for a given pair of rank groups was considered significant when the probability value (p-value) was below 0.05.

Discussion

The sewage entered the columns from the intermediate tank in which the organic sediments deposited after leaving the septic tank. Table 2 presents basic descriptive statistics of pretreated sewage entering the experimental model.

Variability of COD_{Cr} concentration in the sewage entering the columns from the intermediate tank was 0.21, and its values varied from 144.0 $mgO_2 \cdot dm^{-3}$ to 306.0 $mgO_2 \cdot dm^{-3}$. Mean COD_{Cr} was 235.4 $mgO_2 \cdot dm^{-3}$, with standard deviation of 48.4 $mgO_2 \cdot dm^{-3}$. Mean BOD_5 for pretreated sewage reached 120.5 $mgO_2 \cdot dm^{-3}$. This indicator was more variable than COD_{Cr} (WN=0.62) and ranged from 25.0 $mgO_2 \cdot dm^{-3}$ to 250.0 $mgO_2 \cdot dm^{-3}$. These values demonstrate a significant variation in the quality of supplied sewage, with the spread of 225.0 $mgO_2 \cdot dm^{-3}$. The mean value of COD_{Cr}/BOD_5 ratio in the sewage fed onto individual columns was 1.95, and this implies the presence of easily and hardly degradable organic pollutants (Bever et al. 1997). Other authors (Wąsik and Chmielowski 2017, Dacewicz and Chmielowski 2019) obtained similar results for organic compounds in domestic sewage pretreated in a septic tank. Spread of the values of suspended solids entering the experimental model reached 119.3 $mg \cdot dm^{-3}$ and standard deviation was 37.5 $mg \cdot dm^{-3}$. Its mean concentration was 84.1 $mg \cdot dm^{-3}$ for the coefficient of variation as low as 0.45. The content of organic suspended solids ranged from 6.1 to 74.9%, with a mean of 55.0%. Other authors (Chmielowski and Ślizowski 2008, Wąsik and Chmielowski 2014) reported higher concentrations of organic compounds and total suspended solids in the sewage leaving the septic tank. The sewage discharged from the intermediate tank showed small variability of ammonium nitrogen and orthophosphate concentrations (WN=0.18 and WN=0.24, respectively), which ranged from 116.4 to 238.2 $mgNH_4^+\text{-}N \cdot dm^{-3}$ and from 15.5 to 60.0 $mgPO_4^{3-} \cdot dm^{-3}$. Mean concentrations reached 163.6 $mgNH_4^+\text{-}N \cdot dm^{-3}$ and 37.8 $mgPO_4^{3-} \cdot dm^{-3}$ and were similar to those reported in other studies (Wąsik and Chmielowski 2014). The high value of ammonium nitrogen allows to determine domestic sewage strength as high.

Parameters of G1, EM1 and EM2 column operation (pH, oxygen concentration, content of organic suspension in the filtrate) for all investigated stages are presented in Figures 2 and 5.

The sewage discharged from the model columns was slightly basic (pH about 8) (Fig. 2). Despite a very low concentration of oxygen in the sewage entering the columns (Table 2) and its decreasing values in effluents, in stage II the filtrates featured high mean concentration of dissolved oxygen: 3.16 $mgO_2 \cdot dm^{-3}$ (G1). This indicates highly efficient oxygen saturation of the filter beds filled with the trims of upholstery foam waste during four months of the study. Similar results were reported by (Onodera et al. 2014a), who determined the content of dissolved oxygen in a filtrate discharged from UASB/DHS reactor to be 3 $mgO_2 \cdot dm^{-3}$. In their work on gray wastewater, Tawfik et al. (2011) achieved DO values of 3.1 $mgO_2 \cdot dm^{-3}$. The sewage treated on the columns filled with foams with the addition of effective microorganisms contained slightly lower mean concentrations of dissolved oxygen than

Table 2. Quality characteristics of pretreated sewage entering the model columns

Indicator	Unit	Basic descriptive statistics					
		Mean value	Median	Maximum value	Minimum value	Standard deviation	Coefficient of variation
pH	–	8.32	8.12	9.38	7.85	0.49	0.06
Dissolved oxygen	$mgO_2 \cdot dm^{-3}$	0.39	0.12	2.40	0.03	0.57	1.47
COD_{Cr}	$mgO_2 \cdot dm^{-3}$	235.4	244.5	306.0	144.0	48.4	0.21
BOD_5	$mgO_2 \cdot dm^{-3}$	120.5	100.0	250	25.0	74.6	0.62
Suspended solids	$mg \cdot dm^{-3}$	84.1	84.4	158.0	38.7	37.5	0.45
Organic suspended solids	%	55.0	58.5	74.9	6.1	17.3	0.18
NH_4^+-N	$mg \cdot dm^{-3}$	163.6	160.0	238.2	116.4	30.1	0.18
Orthophosphates	$mg \cdot dm^{-3}$	37.8	41.2	60.0	15.5	12.8	0.24

those discharged from the control column (2.80 $mgO_2 \cdot dm^{-3}$ for EM1 column and 2.57 $mgO_2 \cdot dm^{-3}$ for EM2 column).

The results of non-parametric Kruskal-Wallis test for dissolved oxygen levels in the treated sewage at individual stages of the experiment are presented in Table 3. At all stages the p-value was above 0.05, and this means that differences in DO values for G1, EM1 and EM2 columns were not significant.

Figures 3–6 present the effectiveness of pollutants removal on individual filters for the analyzed study period.

At the start-up stage, the EM1 column was characterized by the highest removal of organic substances, whereas the EM2 column – the lowest removal (Fig. 3).

At stage I, the limitation of organic substances increased in all three columns. In the columns G1 and EM1 the elimination

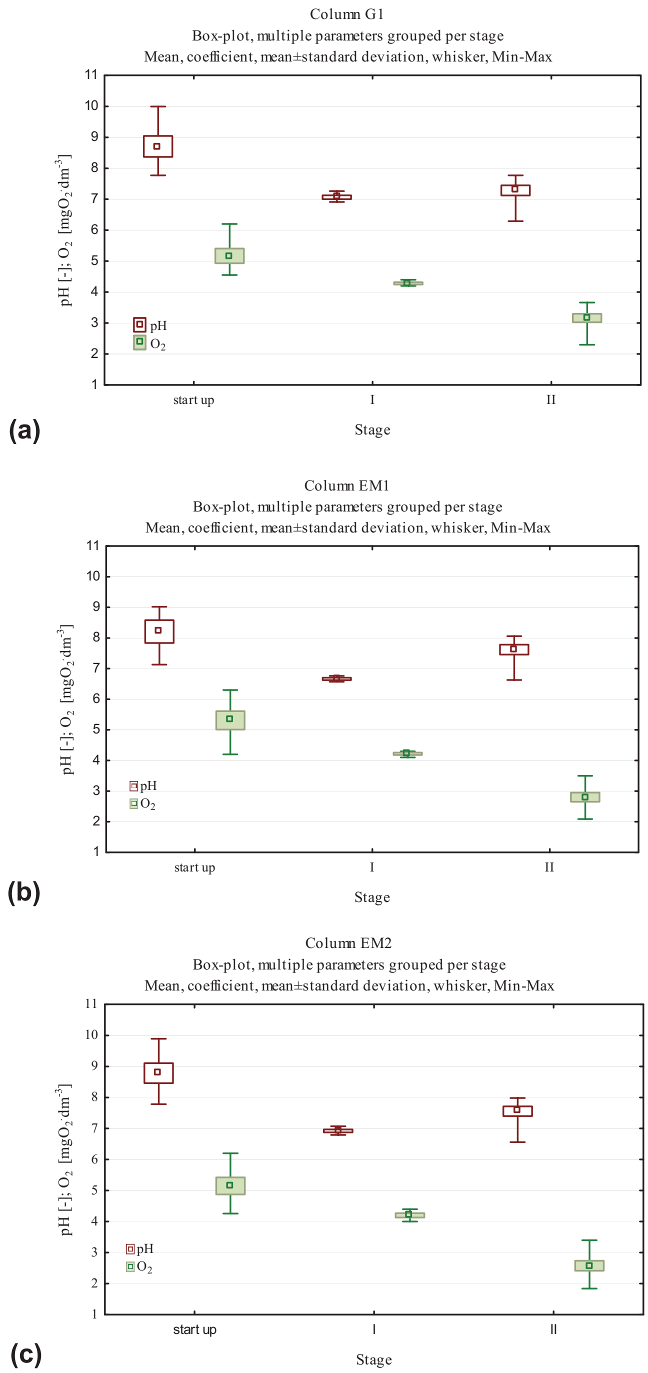


Fig. 3. Laccase (a), MnP (b), LiP (c) activities in eluted samples of gel chromatography

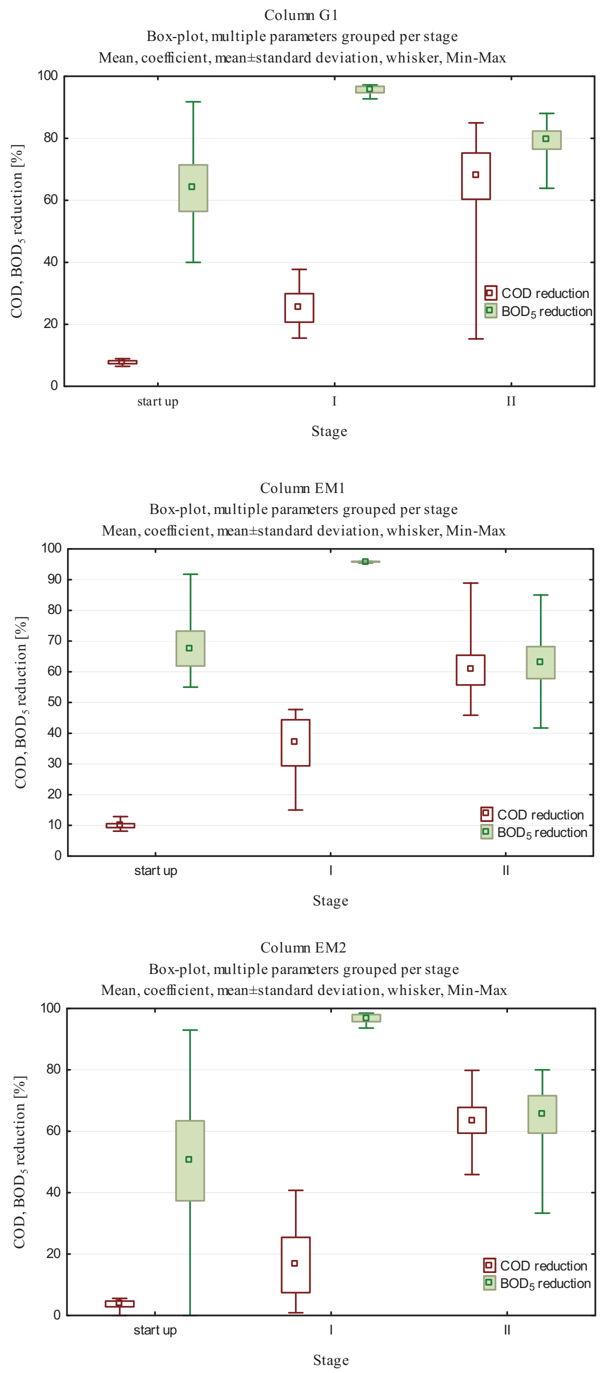
Table 2. Kruskal-Wallis test results for dissolved oxygen levels in treated sewage during four months of the experiment

Start-up stage	Stage I	Stage II
0.1849741 p = 0.9470	1.183784 p = 0.5533	5.918957 p = 0.0518

of easily biodegradable substances (BOD_5 index) increased by approx. 30%, while in the case of EM2 column – by 46.5%. The largest increase of 27% in the elimination of hardly biodegradable substances occurred in the EM1 column.

At stage II the control column G1 was the most effective in eliminating COD_{Cr}, and ensured an average reduction rate of 67.8% (Fig. 3a). It was also the best suited for the limitation of easily degradable organic compounds, average elimination of which reached 79.4%. EM1 and EM2 columns (Fig. 3b–c) were also effective in organic compounds limitation. At stage II, COD_{Cr} maximum reduction reached the level of 90% for EM1 column. Similar high values for new fillings were reported by Tawfik et al. (2011) in gray water, and Bundy et al. (2017) during filtration of household sewage on foam beds of different thickness. At stage II for columns with effective microorganisms the average COD elimination was over 60%. Both EM1 and EM2 columns reduced BOD_5 by ca. 63% (Fig. 3b–c) but it was about 15% lower than the reduction of easily biodegradable organic compounds on column G1 (Fig. 3a). During the last stage the reduction of hardly biodegradable organic compounds on column G1 ranged from 15% to 85% (Fig. 3a).

Low efficiency of COD_{Cr} elimination could result from a presence of hardly degradable organic compounds, as mean COD/BOD ratio in raw sewage was 1.95. On the other hand, high reduction rate of easily biodegradable organic compounds



(a)

(b)

(c)

Fig. 3. Box-plot for BOD_5 and COD_{Cr} in the treated sewage at individual experimental stages for columns a) G1, b) EM1, and c) EM2

indicated an increase in biomass of heterotrophic bacteria. This could result in blocking of foam pores, leading to reduced ability for transport of substrates and to a drop in dissolved oxygen levels (Fig. 2) (Tawfik et al. 2011).

The COD_{Cr} to BOD_5 ratio in the treated sewage, spanning from 4.0 to 11.1, indicated only a presence of chemical compounds that could not be degraded with biological methods during four months of the experiment (Miksch end Sikora 2010). The addition of effective microorganisms in the form of EM1 preparation improved the reduction of hardly biodegradable substances by 2% (start-up stage) and 12% (stage I). In the stage II the EM1 and EM2 columns were characterized by a smaller spread and were more stable than the G1 column for the reduction of COD_{Cr}. However, the research after four-month columns operation does not confirm the positive impact of EM on the increase in COD elimination. Maalim et al. (2013) showed similar observations. They noted no significance difference in COD elimination between the reactors inoculated with EM consortium. The conventional UASB reactor without EM showed better performance in limitation of COD.

At the start-up stage, the G1 column was characterized by the highest removal of suspended solids, whereas the EM1 I EM2 column – the lowest removal (Fig. 4).

At stage I, the removal of suspended solids increased in all three columns. All of the columns achieved a similar 84%

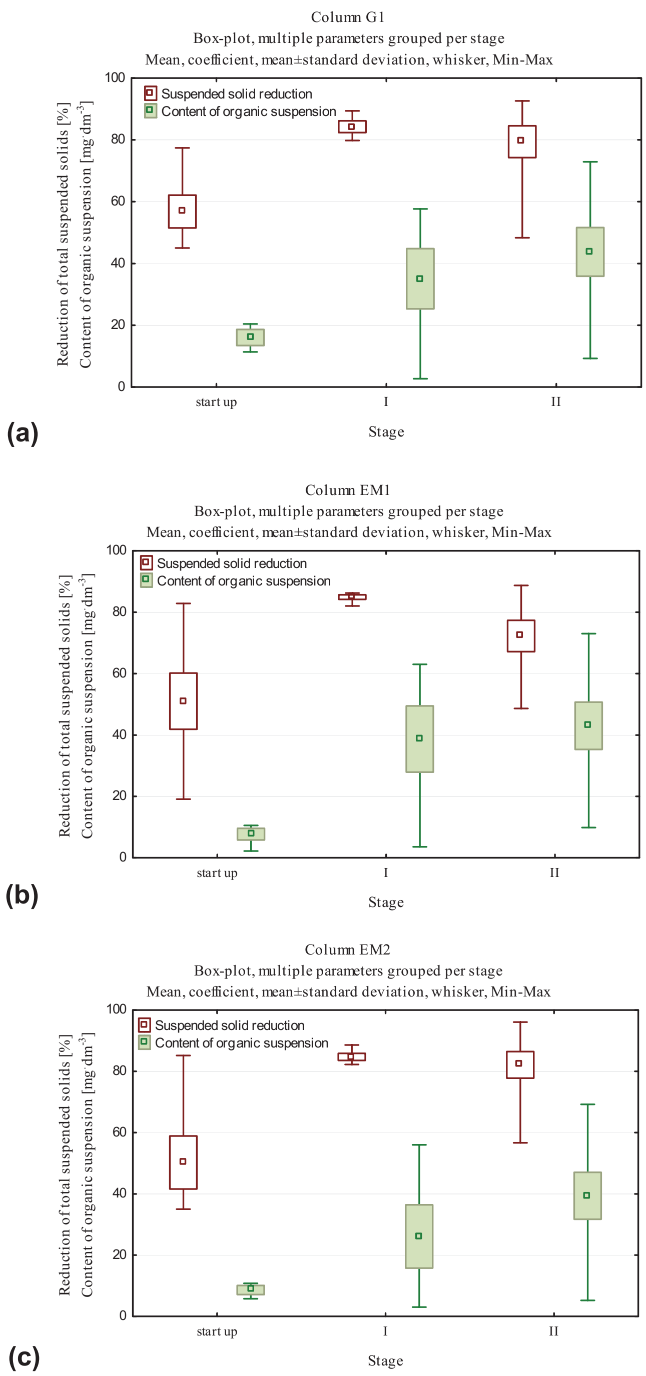


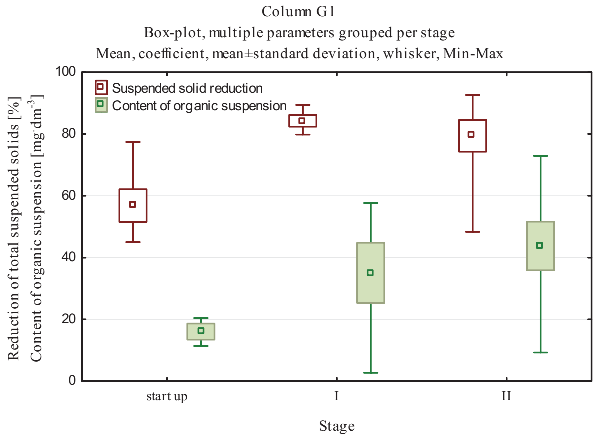
Fig. 4. Box-plot for elimination of total suspended solids and content of organic suspension in the treated sewage at individual experimental stages for columns a) G1, b) EM1, and c) EM2

removal of suspended solids. At the step II for G1 and EM2 columns, the highest elimination of suspended solids (ca. 80%) and high content of organic suspension were observed (ca. 40%). Biomass present in the filtrate consisted in dead bacteria was washed out from the column. Their amount was determined as a content of organic suspension. The lowest content of organic suspension in the filtrate from the column meant the highest removal of suspended solids. The removal of the total suspended solids on foam in column EM2 ranged over the entire study from 19.9% (start-up stage) to 96.1% (Stage II).

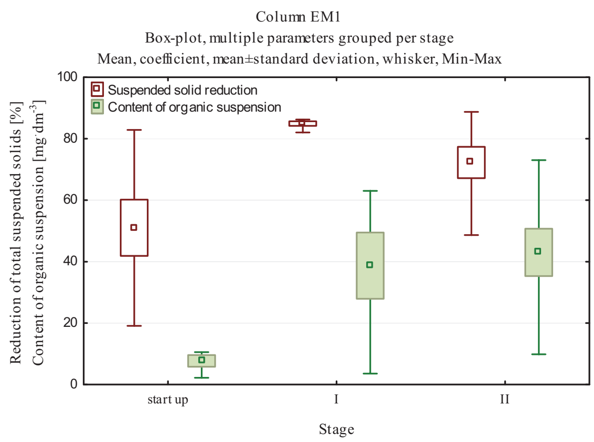
At the start-up stage, the G1 column was characterized by the highest reduction of NH_4^+-N (an average 44.0%) and the lowest reduction of PO_4^{3-} (an average 11.1%) (Fig. 5).

At stage I, the reduction of ammonium nitrogen increased in all three columns. In the columns EM1 and EM2 the elimination of NH_4^+-N increased by approx. 40%, while in the case of G1 column – by 28%. After four months of the filter operation, ammonium nitrogen reduction at stage II was lower than (comparing to) that at stage I.

At stage II average reduction rate of NH_4^+-N was similar in EM1 and EM2 column and reached 50% (Fig. 5b–c). The control column G1 allowed for elimination of 58.0% of ammonium nitrogen (Fig. 5a). High porosity of the polyurethane material provided comparable oxygen conditions in both biofilters, conducive to nitrifying bacteria development, as well as favorable environment for mass transfer of the substrate and nutrients.



(a)



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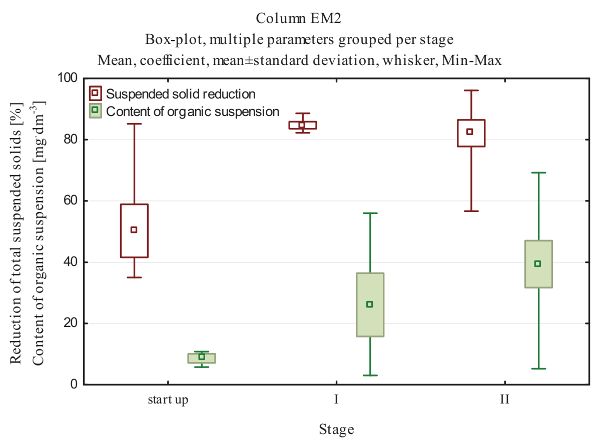

(c)

Fig. 5. Box-plot for the reduction of ammonium nitrogen and orthophosphates in the treated sewage at individual experimental stages for columns a) G1, b) EM1, and c) EM2

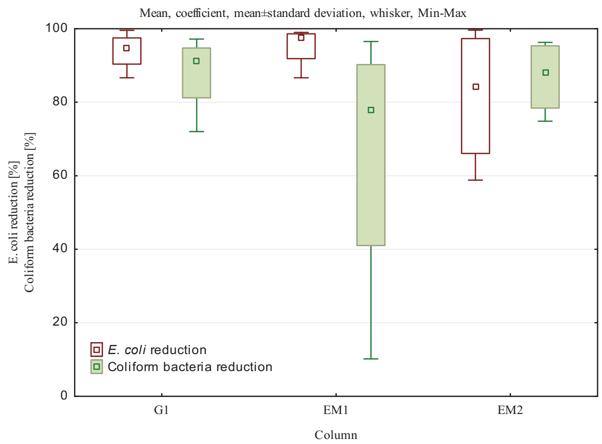

Fig. 6. Box-plot depicting reduction in the count of *Escherichia coli* and coliform bacteria in the sewage treated on columns G1, EM1 and EM2

Table 4. The amount of pollutants and biomass (dry weight) adsorbed by 1 dm^3 foam

Column G1	Column EM1	Column EM2
The amount of adsorbed pollutants		
1.87 $g \cdot dm^{-3}$	1.36 $g \cdot dm^{-3}$	0.79 $g \cdot dm^{-3}$
The amount of biomass		
0.1674 $g \cdot dm^{-3}$	0.1223 $g \cdot dm^{-3}$	0.1054 $g \cdot dm^{-3}$

Waste polyurethane foam was similarly effective in the treatment of household sewage downstream of the primary sedimentation tank during four months of the experiment, as the DHS technology coupled with the anaerobic UASB reactor (Onodera et al. 2014b). The rate of pollutant elimination in a system of new sponges, a so-called "curtain" (DHS of second generation), was 95%, 84% and 61% for BOD_5, COD and ammonium nitrogen, respectively (Tandukar et al., 2005, Miyaoka et al., 2017). While investigating the third and fourth generation of DHS, Tawfik et al. (2006) and Tandukar et al. (2006) achieved COD, BOD_5 and ammonium nitrogen reduction at the level of 95%, 98% and 86%, respectively. In their studies, NH_4^+-N level in the sewage treated in the above system was about five times lower than in our experiments with PUR waste.

The efficiency of orthophosphates reduction (Fig. 5) ranged from 0% (stage II, column G1) to 45.3% (stage II, column EM2). The most effective column was EM2 (contained EM with molasses), where an average elimination of PO_4^{3-} reached 17.0% (start-up stage) and 19.4% (stage II). The average elimination rate for the column without effective microorganism was the lowest and amounted to only 3.6% (Fig. 5a). Other authors also noted a higher reduction of phosphates with the addition of EMs. Rashed, E.M., & Massoud, M. (2015) showed that using effective microorganisms activated with molasses in activated sludge technology proved to be successful as an enhanced biological phosphorus removal. However, the use of biopreparation in the hydrophyte bioreactor contributed to the increase in phosphorus elimination by 11% (Warężak et al. 2014).

A very large spread of the obtained results of BOD_5 and NH_4^+-N at start-up stage can be a result of not yet finished biofilm formation (changes in dominating microorganisms).

The highest, 95% reduction rate of *Escherichia coli* from the foams with added microorganisms EM1 (Fig. 6) may be explained by unfavorable conditions for the growth of these bacteria. Indicator coliform bacteria were the most effectively eliminated in the control column G1 (Fig. 6). Similar relationships were reported by Tawfik et al. (2011). Yoochatwchaval et al. (2014) observed that during the 300-day operating cycle, the DHS reactor had a high efficiency in removing pathogens. *Escherichia coli* and other bacterial colonies were removed to a high degree of 99.4 and 98.1%, respectively.

As the last step of the study we verified whether the addition of effective microorganisms significantly affected the values of BOD_5, COD_{Cr}, total suspended solids, content of organic suspension, ammonium nitrogen and orthophosphates in the treated sewage leaving individual columns of the experimental model. Table 5 presents the results of non-parametric Kruskal-Wallis test for variables that lack normal distribution and show non-homogeneous variance.

Variance of the elimination of BOD_5 indicator, total suspended solids and content of organic suspension had no significant differences throughout the experiment. However, significant discrepancies appeared for COD_{Cr} and biogenic substances (ammonium nitrogen and orthophosphates). Test probability p did not exceed 0.05 for the limitation of these compounds, which signified negligible differences in their reduction for the compared stages.

Jin et a. (2005) noted that EM played an important role in speeding up start-up processes by facilitating the growth of diverse microbes in the MBR reactor. Our data showed that the columns with foam filling containing EM consortium were not able to stabilize faster than the control column. The difference

Table 5. Kruskal-Wallis test results for the four month study period based on pollutant elimination rate

Pollutants indicator elimination	Start-up stage	Stage I	Stage II
COD	8.76931 p = 0.0125 {EM1, EM2}	2.807692 p =0.2457	2.608294 p = 0.2714
BOD_5	0.1571429 p = 0.9244	1.578345 p = 0.4542	5.467306 p = 0.0650
Total suspended solids	0.9048000 p = 0.2000	0.0050089 p = 0.9975	2.195000 p = 0.3337
Content of organic suspension	5.790909 p = 0.0553	0.9967800 p = 0.6075	2.195000 p = 0.3337
NH_4^+-N	0.4615385 p = 0.7939	0.5862709 p = 0.7459	6.952381 p = 0.0309 {G1, EM1}
Orthophosphates	1.341228 p = 0.5114	1.353188 p = 0.5083	9.711890 p = 0.0078 {G1, EM2}

Statistically significant differences are marked in red

in the pollutants reduction between columns with different EMs was visible only for COD_{Cr}.

As results of Kruskal-Wallis test demonstrated, the foam filling with and without effective microorganism turned out to be the factor determining mainly the concentration of orthophosphates in the treated sewage. This may indicate that all three columns provided good conditions for the development of bacteria reducing easily biodegradable organic compounds and ammonium nitrogen. According to Higa (1996) the EM mixture is enhanced by antioxidation, which inactivates oxygen (through biochemical reaction and binding of oxidizing compounds), and thus may maintain an anaerobic environment. In EM2 column (Fig. 3c) there were created proper, close to anoxic, conditions for the bacteria which removed the orthophosphates.

Conclusions

1. Column G1 filled with foam without effective microorganism was the most effective in the reduction of BOD_5, COD_{Cr}, NH_4^+-N and coliform bacteria. After four months of work under the hydraulic loading of 76.4 mm·d^{-1} an average reduction in these pollutants was 79.4%, 67.8%, 58.0% and 88.0%, respectively. EM2 column with effective microorganisms was equally effective in COD_{Cr} reduction.
2. It can be concluded that EM2 consortium enhanced the performance of filter in terms of reduction of PO_4^{3-}.
3. Filling the biofilters with foam trims of porosity 94.5% allowed for the growth and development of microorganisms that caused the elimination of organic and ammonium nitrogen at the level of 80%.
4. The use of PUR waste in the form of trims of upholstery foams as elements of a system consisting of a septic tank/intermediate tank and a vertical flow filter, proved to be an efficient way for direct treatment of domestic sewage. Filter beds with such a filling can be an alternative to costly, based on aeration, solutions based on biological reactors such as SBR. Aeration of aerobic chambers generates more than 50% of the total energy consumption in sewage treatment plants. In turn, the proposed technology is uncomplicated, easy to control, and cost effective, because it does not require additional aeration and secondary settling tank.
5. The introduction of effective microorganisms by addition preparations on the filters filling used in on-site sewage treatment facilities may improve the filter stability and reduce the amount of *Escherichia coli* in treated sewage.
6. Further research should be performed to indicate the feasibility of using EM in a disinfection step in wastewater treatment.

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Oczyszczanie stężonych ścieków bytowych na filtrach wypełnionych pianką poliuretanową z dodatkiem efektywnych mikroorganizmów

Streszczenie: W artykule poddano analizie możliwość zastosowania odpadów z tworzyw sztucznych w postaci gąbek poliuretanowych do bezpośredniego oczyszczania ścieków bytowych po osadniku wstępnym. Przedstawiono wyniki badań nad oczyszczaniem ścieków bytowych z użyciem efektywnych mikroorganizmów immobilizowanych na gąbkach poliuretanowych. Oceniono sprawność usuwania ze ścieków wstępnie oczyszczonych związków organicznych, związków biogennych, zawiesiny ogólnej oraz bakterii wskaźnikowych przy obciążeniu hydraulicznym 76,4 $mm \cdot d^{-1}$ porównując dwa etapy pracy biofiltrów.

Jako filtry eksperymentalne badano w skali półtechnicznej modele wycinkowe filtra o przepływie pionowym. Model badawczy składał się z trzech jednakowych kolumn wykonanych z PVC o średnicy 10 cm i wysokości 100 cm. Wypełnienie kolumn stanowiły ścinki gąbek o miąższości 60 cm. Na dnie każdej warstwy filtracyjnej znajdował się ruszt podtrzymujący złoże.

Kolumna G1 z wypełnieniem z gąbek bez dodatkowej immobilizacji efektywnych mikroorganizmów okazała się najbardziej efektywna w procesie redukcji BZT_5, $ChZT_{Cr}$, $N\text{-}NH_4^+$ oraz bakterii coli. Średnie zmniejszenie tych zanieczyszczeń w czasie trzymiesięcznego cyklu badań przy obciążeniu hydraulicznym 76,4 $mm \cdot d^{-1}$ wyniosło odpowiednio 80,6%, 43,7%, 60,0% oraz 88,0%. Równie efektywna pod względem usuwania $ChZT_{Cr}$ okazała się kolumna z wypełnieniem, na którym zaimmobilizowano mikroorganizmy wchodzące w skład biopreparatu EM2.

Użycie odpadów z pianki poliuretanowej w postaci ścinków gąbek tapicerskich, polegające na ich wykorzystaniu w układzie osadnik gnilny/pośredni – biofiltr o przepływie pionowym, okazało się skutecznym sposobem bezpośredniego oczyszczania ścieków. Ta nieskomplikowana, łatwa do sterowania oraz ekonomiczna ze względu na brak potrzeby dodatkowego napowietrzania technologia w porównaniu do większości istniejących systemów tlenowych wydaje się być interesującym rozwiązaniem biologicznego oczyszczania ścieków bytowych.