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APPLICATION OF THE FILTRATION BED WITH A FOAM-SAND FILLING FOR TREATMENT OF SEWAGE WITH AN ELEVATED CONCENTRATION OF AMMONIA NITROGEN

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Abstract

The two-stage technological system for the treatment of domestic sewage, characterized by an elevated concentration of ammonium nitrogen, consisted of a settling tank and a vertical flow multi-layer filter bed with a sponge-sand filling was analyzed. In the upper part of the filling in the form of spongy polyurethane foams there was the removal of hardly decomposable organic compounds and ammonium nitrogen without the need for additional aeration. In the lower layer of quartz sand, the removal of orthophosphates and pathogenic bacteria took place. After 400 days of operation, multi-layered filter beds achieved high average removal efficiency under variable hydraulic load conditions. The upper 30 cm layer of waste foams used, combined with the 60-cm bottom layer of sand, proved to be very effective in the removal of ammonium nitrogen and organic compounds. The degree of $N\text{-}NH_4^+$, COD_{Cr} and BOD_5 elimination was at 91.6, 77.4 and 91.7% respectively. The 30-cm upper layer of waste foams used combined with the 60-cm lower layer of sand allowed for removal of *Escherichia coli* in 98.9% on average, whereas coliform bacteria – in 95.0%.

Keywords: filtration bed, polyurethane foams, sewage, treatment

INTRODUCTION

In the case of household treatment plants serving up to 2000 PE, the Regulation (2014) does not specify the required level of biogenic pollution reduction in treated sewage discharged into flowing waters. Consequently increased loads of nitrogen and phosphorus, flowing into watercourses from small sewage treatment plants can be observed. Numerous authors point out that in household wastewater treatment plants based on the activated sludge method, biogenic compounds are only removed in the range from 40 to 60% (Kaczor and Bugajski 2006a and 2006b, Bugajski *et al*. 2013, Bugajski *et al*. 2015, Pawełek and Bugajski 2017).

For some time, both in Poland and in countries with a high population density, there is a tendency for a decrease in water consumption. On the one hand, the results in a reduction in the volume of wastewater produced, and on the other hand, causes pollution in domestic wastewater to be more concentrated (Henze and Comeau 2008, Awuah *et al*. 2014, Anda *et al*. 2018). The biggest problem is the increased concentrations of ammonium nitrogen, reaching 100 $mg \cdot dm^{-3}$ (Jucherski and Nastawny 2012, Chmielowski 2013, Jóźwiakowski 2017). Treatment of such wastewater in activated sludge technology is highly costly, especially due to the operating costs associated with the aeration process. Removal of ammonium nitrogen from domestic wastewater is achieved during nitrification, and this process requires about 4.5g O_2 per 1g of $N\text{-}NH_4^+$ removed (Miksch 2010). Only 1g of O_2 per 1g of BOD removed is sufficient to remove organic compounds; however, it should be remembered that with increasing organic pollutants in concentrated sewage, the costs associated with the required degree of oxygenation of sewage increase (Khan *et al*. 2013).

It should also be noted that treated sewage, which is not subjected to disinfection processes, can become a source of microbial contamination, including pathogenic bacteria, which discharged into the environment cause deterioration of its sanitary condition. This problem concerns both wastewater discharged from municipal collective wastewater treatment plants and from household wastewater treatment plants (Michałkiewicz *et al*. 2011, Olańczuk-Neyman and Quant 2015). According to literature reports, the effectiveness of elimination of pathogenic bacteria in household wastewater treatment plants is insufficient (Budzińska *et al*. 2007, Dębska *et al*. 2015). One of the examples of household treatment plants meeting these requirements is a solution with a technological system based on a septic tank, cooperating with a vertical flow sand filter. As a result of the use of sand, it is possible to obtain treated sewage containing $1 \cdot 10^2 – 2 \cdot 10^4$ CFU (colony forming units)/100 ml of *Escherichia coli* and $1 \cdot 10^3 – 3 \cdot 10^5$ CFU/100 ml of coliforms (Chmielowski 2013, Wąsik and Chmielowski 2019, Nancy *et al*. 2014, Seeger *et al*. 2016). The basic disadvantage of using quartz sand in biofilters is the possibility of its colmatation. According to Spychała and Nieć (2013), the clogging of sand filters is often caused by the remains of toilet paper, which was not biodegraded in the septic tank and was rinsed out of it. The use of a filling in the form of porous materials prevents the colmatation of the filter bed and increases the efficiency of removing organic and biogenic compounds. The polyurethane sponge is an interesting synthetic porous filling material that maintains moisture. For twenty years, it has been used to treat slightly concentrated urban wastewater in the *Upflow Anaerobic Sludge Blanket Reactor* (UASB) and *Down-flow Hanging Sponge Reactor* (DHS) system (Bressani-Ribeiro *et al*. 2018, Nurmiyanto and Ohashi 2019).

The aim of the study was to analyze the operation of filter bed with a filling made of polyurethane foams with a sponge structure and quartz sand, and to assess the possibility of their use for the treatment of domestic sewage with an elevated concentation of ammonium nitrogen.

RESEARCH MATERIALS AND METHODS

The assessment of the filtration bed influence, including the type and thickness of the fill, on the process of biological degradation of pollutants in domestic sewage, was carried out using two models of a household treatment plant on a semi-technical scale. The research models constructed in the model room of the Department of Sanitary Engineering and Water Management at the University of Agriculture in Kraków consisted of a two-chamber septic tank and vertical flow filtration tanks, where two plastic tanks in series with a capacity of 1000 dm^3 each were used as the septic tank. In the septic tank, preliminary removal of organic compounds, total suspended solids, oils and permanent and floating contaminants took place. The filtration beds were made in the form of columnar models, reflecting the operation of such a bed and were in the form of identical PVC columns with a height of 1000 mm and a diameter of 100 mm pipes.

Domestic sewage pre-treated in the septic tank was periodically (every hour) dispensed into individual filter beds using peristaltic pumps. The hydraulic load in the research models operated for over a year ranged from 76.4 to 229.2 $mm^3 \cdot mm^{-2} \cdot d^{-1}$. The sewage brought from the top to individual column models in each dose was similar in physicochemical as well as bacteriological terms (Table 1).

In the analyzed models of beds, new cylindrical polyurethane sponges(PN) and waste spongy polyurethane foams with a spongy structure (PO) were utilized as the filling of the upper layer. The mechanically disintegrated waste used in the research was a mixture of elastic polyurethane material of random shapes (Figure1). Their detailed description is presented in the author’s previous studies (Dacewicz and Chmielowski 2019, Dacewicz and Jurik 2019). Quartz washed sand constituted the bottom layer (PS), which had an effective diameter d_{10} = 0.32 mm.

a) b)

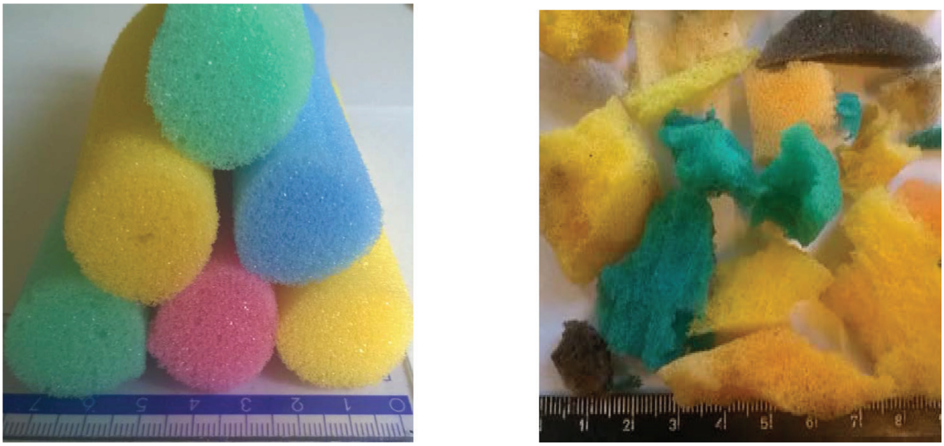

Figure 1. Polyurethane foams in the form of a) new cylindrical sponges, b) spongy waste

In the PN30/PS60 and PO30/PS60 columns, the 30-cm upper layer was filled with PN foams (PN30) and PO foams (PO30), while quartz sand constituted the 60-cm bottom layer (PS60). In the PN60/PS30 and PO60/PS30 columns, the upper two layers formed foams – PN and PO, respectively – with a total thickness of spongy filling of 60 cm (PN60 or PO60). In the 30-cm bottom layers sand was applied (PS30). PS60 and PS30 columns, which constituted comparative filtration beds, were filled with sand of a thickness of 60 cm and 30 cm, respectively.

Samples of pre-treated sewage were collected from the distribution chamber located after the septic tank, and treated sewage from tanks to which the filtrates from individual columns were discharged. The raw and treated sewage pH value was determined using the electrometric method in compliance with PN-EN ISO 10523:2012 standard. The determination of ammonium nitrogen was performed in compliance with PN-C-04576-4: 1994, and orthophosphates in compliance with PN-EN ISO 6878:2006 standard. In pre-treated and treated sewage, the indicators of organic pollutants were determined: BOD_5 in accordance with PN-EN 1899-1:2002 and PN-EN 1899-2:2002, COD_{Cr} in accordance with PN-ISO 6060:2006. Total suspended solids content was determined in compliance with the PN-EN 872:2007 standard. During the tests for bacteriological analysis, sterile samples of sewage were collected. Two types of pathogenic indicator bacteria, i.e. *Escherichia coli spp*. and coliforms, i.e. *Citrobacter spp., Enterobacter spp., Klebsiella spp., Proteus sp.* were marked. The CFU number in the wastewater flowing into the bed was determined employing surface seeding method, beforehand though making appropriate dilutions of sewage. For the analysis of the amount of bacteria in treated sewage, a membrane filtration method was additionally applied (PN-EN ISO 9308-1: 2009).

The research results were subjected to statistical analysis by calculating the basic descriptive statistics of the sewage pollution indicators tested i.e. pH, dissolved oxygen concentration, ammonium nitrogen, orthophosphates, BOD_5, COD_{Cr}, total suspended solids, *Escherichia coli* and coliform bacteria.

In order to compare the differences between individual pollutant reduction rates in the analyzed research period, an analysis of the variance of source data using the non-parametric Kruskal-Wallis test was carried out. The difference in means for a given pair of rank groups was considered significant if the test probability p was> 0.05. Statistical analysis was conducted applying the Statistica 12 program.

DISCUSSION OF RESULTS

Quality of wastewater used in the experiment

Table 1 presents the qualitative composition of sewage pretreated in the septic tank, i.e. after preliminary removal of organic compounds, total suspended solids, oils as well as floating and dragged solid contaminants from household wastewater.

Table 1. Quality composition of pretreated domestic sewage

Parameter / indicator	Unit	Mean value	Minimum value	Maximum value	Standard deviation	Coefficient of variation
pH	-	7.86	7.12	8.51	0.34	0.04
Dissolved oxygen	$mgO_2 \cdot dm^{-3}$	0.40	0.00	4.34	1.07	2.65
COD_{Cr}	$mgO_2 \cdot dm^{-3}$	224.2	50.0	696.0	142.9	0.64
BOD_5	$mgO_2 \cdot dm^{-3}$	140.4	25.0	400.0	86.3	0.61
Total suspended solids	$mg \cdot dm^{-3}$	83.9	25.0	248.0	55.0	0.66
Ammonium nitrogen	$mg \cdot dm^{-3}$	154.0	119.7	186.9	18.5	0.12
Orthophosphate	$mg \cdot dm^{-3}$	42.2	23.0	59.0	7.4	0.18
Escherichia coli	CFU/100ml	$1.16 \cdot 10^6$	$1.60 \cdot 10^4$	$6.0 \cdot 10^6$	$1.6 \cdot 10^6$	1.36
Coliform bacteria	CFU/100ml	$3.87 \cdot 10^6$	$3.52 \cdot 10^5$	$8.0 \cdot 10^6$	$2.6 \cdot 10^6$	0.67

The pre-treated sewage was characterized by average pH value and concentration of dissolved oxygen 8.86 and 0.4 $mgO_2 \cdot dm^{-3}$, respectively. Taking into account the concentrations of ammonium nitrogen and orthophosphates, it was proved that the sewage after the transitional septic tank was characterized by their low variability (RC at the level of 0.12 and 0.16 respectively). The values of these biogenic compounds oscillated from 119.7 to 186.9 $mgN\text{-}NH_4^+ \cdot dm^{-3}$ and from 43.0 to 59.0 $mgPO_4^{3-} \cdot dm^{-3}$. Their mean value was 154.0 $mgN\text{-}NH_4^+ \cdot dm^{-3}$ and 42.2 $mgPO_4^{3-} \cdot dm^{-3}$ respectively. Concentrations of ammonium nitrogen in the sewage after the septic tank showed that these values were much higher than those reported by literature (Henze 1997, Henze and Comeau 2008), and wastewater can be described as sewage with an increased content of nitrate nitrogen.

The COD_{Cr} index values ranged from 50.0 $mgO_2 \cdot dm^{-3}$ to 696.0 $mgO_2 \cdot dm^{-3}$ and were on average 224.2 $mgO_2 \cdot dm^{-3}$. In the case of BOD_5, its values ranged from 25.0 $mgO_2 \cdot dm^{-3}$ to 400.0 mgO_2/L, and the average value of this indicator was at the level of 140.4 $mgO_2 \cdot dm^{-3}$. The coefficients of variation of organic compounds in pre-treated sewage showed that the BOD_5 index changed at a level lower by 0.03 than COD_{Cr} (RC = 0.61). Analyzing the values of total suspended solids in the sewage entering the model, their mean concentration was estimated at the level of 83.9 $mg \cdot dm^{-3}$. The coefficient of variation of this impurity was 0.66. Wąsik and Chmielowski (2017), Chmielowski *et al*. (2018) as well as Dacewicz and Chmielowski (2019) obtained mean indicators of discussed pollutants at a similar level.

In the case of bacteriological contamination, sewage flowing into individual columns of the system contained *Escherichia coli* at the level of $1.16 \cdot 10^6$ CFU/100ml and coliform bacteria at the level of $3.87.10^6$ CFU/100ml and these are values similar to those given by other authors (Kauppinen *et al*. 2014, Yaya Beas *et al*. 2015, Wąsik and Chmielowski 2019).

Quality of effluent – different parameters

The efficiency of removal of ammonium nitrogen and orthophosphate in individual columns for the analyzed period is shown in Figure 2.

The PO30/PS60 column filled with foam waste was characterized by the highest efficiency of $N\text{-}NH_4^+$ removal. This column, on average, eliminated ammonium nitrogen at a high level that is 91.6%. In the filtrate discharged from the PN30/PS60 column, the average ammonium nitrate removal at the level of 70.7% was noted. Tawfik *et al*. (2010) found the efficiency of ammonium nitrogen removal in the UASB-DHS system with filling in the form of third and fourth generation sponges at the level of 86%. In these studies, the high porosity of both new and waste polyurethane material ensured similar oxygen conditions in these filters, beneficial for the growth of both heterotrophic and nitrifying bacteria. Comparison columns filled only with sand proved to be the least effective in removing $N\text{-}NH_4^+$. After seven months of operation of the PN60/PS30 column, the formation of a colmatation layer on the surface of the sand was noted and immediately removed. At the end of the research, colmatation of other three beds was revealed, which affected the large range in the $N\text{-}NH_4^+$ removal (Figure 2). The PN30/PS60 column and comparison columns PS60 and PS30 were clogged after 390, 394 and 400 days respectively under varying hydraulic conditions. Maharjan *et al.* (2016) found clogging of the sand filter with the upper layer of sponges, representing 21% of its volume, and the comparison sand filter on days 102 and 84, respectively.

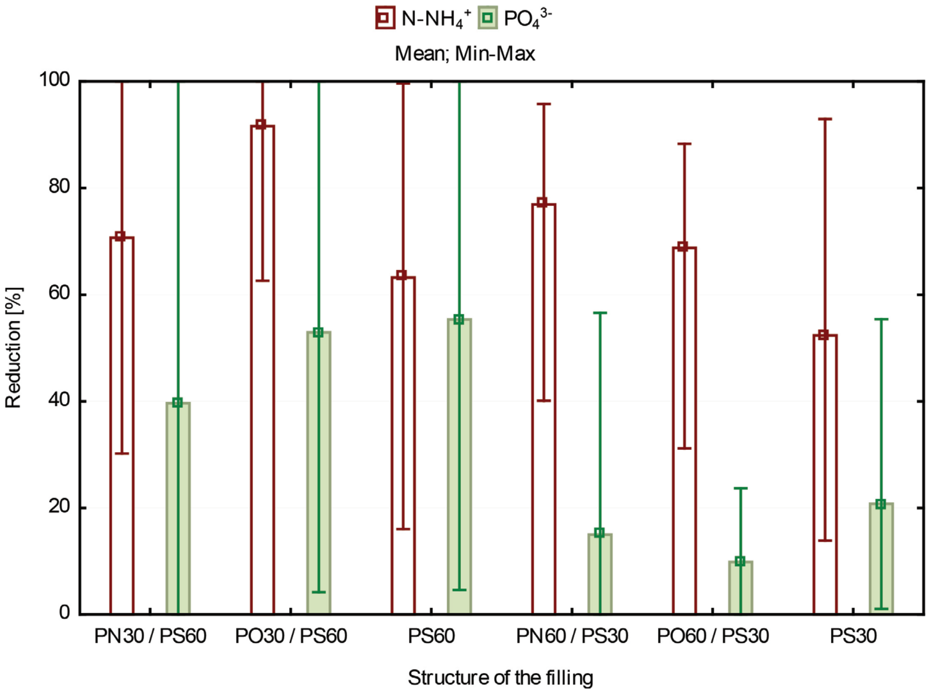

Figure 2. Box-plot chart for the reduction of ammonium nitrogen and orthophosphates in treated wastewater in filtration beds of the various structure of the filling

During more than 400 days of research in changing hydraulic conditions, the filtration beds with a 60-cm lower layer of sand were characterized by the highest sorption complex of phosphorus, and thus a high mean rate of orthophosphate removal of 40-55%. The comparison column with a 60-cm thick sand fill was characterized by the highest PO_4^{3}– removal, which amounted on average to 55.4% in the entire study period. In the sand column with a 30-cm thicknes, the mean reduction of orthophosphate at a level more than a half lower, i.e. 21% was calculated. The depletion of the sorption complex was observed, which resulted in a gradual decrease of the elimination of PO_4^{3}– (a large range in the reduction shown in Figure 2).

Figure 3 illustrates the effectiveness of reduction of organic pollutants in individual filter beds for more than one-year research period. In the case of factory filled columns with brand new sponges making the filling of the columns

PN30/PS60 and PN60/PS30, a high mean COD_{Cr} removal rate for this filling (about 68%) was observed. Similarly, high values with new sponges in the form of rolls were obtained by Tawfik et al. (2011) during the direct treatment of gray sewage, as well as by Yaya Beas *et al*. (2015) during half a year sewage filtration in the UASB reactor system – DHS with cuboidal filling. For a comparison column with a 60-cm layer of sand, a higher removal rate of readily decomposable organic substances, which amounted to an average of 71.4% was observed.

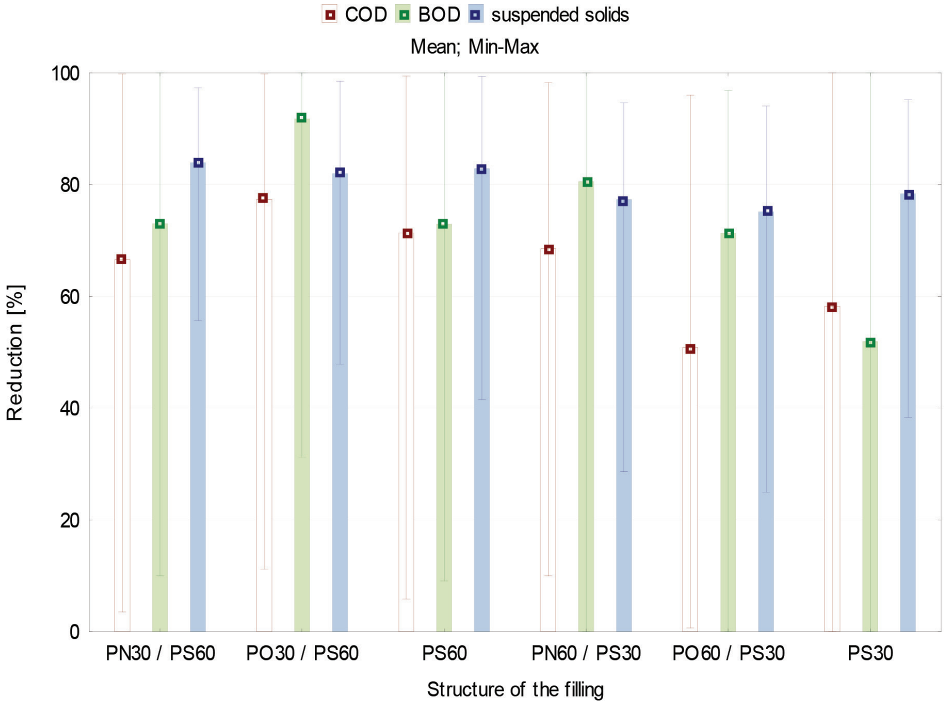

Figure 3. Box-plot chart for the reduction of COD_{Cr} and BOD_5 indicators as well as total suspended solids in treated wastewater in filtration beds of the various structure of the filling

During the filtration of wastewater pre-treated by filling in the form of foam waste, there was a difference in the removal of organic compounds in favour of the bed with a greater thickness of sand in the lower layer. The PO30/PS60 column proved to be the most effective in terms of reducing both COD_{Cr} (77.4%on average) and BOD_5 (91.7%on average). Yaya Beas *et al*. (2015) observed similar effectiveness in the removal of organic compounds during half a year period of sewage filtration in the UASB-DHS system by new sponges in the form of cuboids. Maharjan *et al*. (2016), examining in laboratory conditions a sand filter with an upper layer of sponges as the third stage of urban wastewater treatment after the UASB-DHS process found 99% removal of BOD_5.

For the comparison bed with a sand filling and of 30-cm thickness, the mean reduction of COD_{Cr} and BOD_5 was low and amounted to 58.3% and 51.9%, respectively.

During 400-day studies, all of the filter beds in question with a 60-cm sand layer were characterized by a high mean removal rate of total suspended solids of 83% (Figure 2).

Figure 4 presents the elimination degree of pathogenic bacteria for six columns in the analyzed period of research.

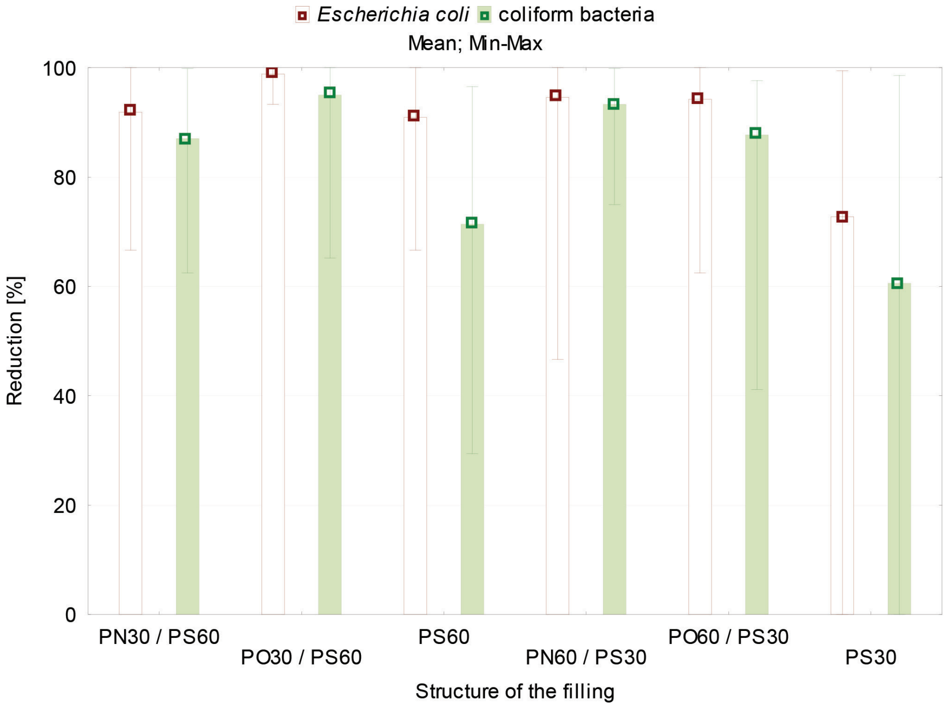

Figure 4. Box-plot chart for the reduction of *Escherichia coli* and coliforms in treated wastewater in filtration beds of the various structure of the filling

In the PN30/PS60 column, filled with new stiffened foams, the removal of *Escherichia coli* and coliforms at the level of 91.9 and 87.1% respectively was observed. An additional 30-cm layer of foams (PN60/PS30 column) increased the removal of pathogenic bacteria by 2.7% and 6.2%, respectively. Tawfik (2006) as well as Tawfik and Klapwijk (2010) reported that the factors that influence the removal of bacteria from the coli group in the DHS system include adsorption on the surface of the biofilm and predation by higher organisms. These authors stated that the increase in the number of protozoa in the spongy filling contributed to a greater extent of removal of the total number of coliforms. In the present studies, the conditions prevailing in two 30-cm layers of spongy material in the PN60/PS30 column resulted in the adsorption of pathogenic bacteria on the surface of the biofilm produced in the pores of the filling. On the other hand, the development of appropriate higher organisms, i.e. rotifers and free-floating ciliates took place. They, due to their predation, increased the removal of pathogenic bacteria. In the column filled in the upper layer with foam wastes of 30-cm thickness combined with the 60-cm bottom sand layer, the greatest effectiveness of elimination of pathogenic bacteria was noticed. The PO30/PS60 column removed *Escherichia coli* and coliforms at the level of 98.9 and 95.0%, respectively. Similar relations were described by Tawfik *et al*. (2011). Yoochatwchaval *et al*. (2014) observed that during the 300-day operating cycle, the DHS reactor had high efficiency in removing pathogens and claimed that *Escherichia coli* and other bacterial colonies were removed to a high degree of 99.4 and 98.1%, respectively. Maharjan *et al*. (2016), examining in laboratory conditions a sand filter with an upper layer of sponges, treating urban sewage after the UASB-DHS process, detected *Escherichia coli* and coliform bacteria at the level of 10^3 CFU/100ml.

The PO60/PS30 column, where the filling proportions were reversed, was characterized by a lower elimination level of *Escherichia coli* (94.3% on average) and coliform bacteria (87.7% on average). Tawfik (2006) observed that the elimination of coliforms from grey sewage treated in the DHS system depended on the pore diameter of the sponges applied. With the increase in diameter from 0.56 mm to 1.92 mm, there was an increase in the number of pathogenic bacteria in treated wastewater from $9.3 \cdot 10^3$ CFU/100ml to $1.8 \cdot 10^5$ CFU/100ml. The comparison columns with sand were characterized by low removal of *Escherichia coli* and coliforms. A 60-cm sand layer allowed the average removal of these contaminants that is 90.9 and 71.4% respectively. Application of half the thickness of the sand allowed to stop *Escherichia coli* at the level of 72.8% on average, while coliforms were retained only at the level of 60.6%. The average amount of *Escherichia coli* and coliforms for the PS60 and PS30 columns was in the range from 10^5 CFU/100ml and 10^6 CFU/100ml, respectively. Kauppinen *et al*. (2014) observed an amount of *Escherichia coli* at the level of 10^2-10^5 CFU/100ml after a sand filter which had been exploited for a year in a cool climate.

It was noted that in the sewage discharged from the PO30/PS60 column the amount of *Escherichia coli* and coliforms on the average level amounted to $6.43 \cdot 10^3$ CFU/100ml and $1.34 \cdot 10^5$ CFU/100ml, respectively. In the remaining columns with the upper layer in the form of foams, the average amount of *Escherichia coli* and coliform bacteria was 4.23-$16.4 \cdot 10^4$ CFU/100ml and 3.21-$4.19 \cdot 10^5$ CFU/100ml, respectively. Khan *et al*. (2012) found the amount of coliforms at a lower level of $2.3 \cdot 10^3$ CFU/100ml in the sewage flowing out of the Karnal sewage treatment plant, working in the UASB-DHS system.

The next stage of the analysis of the results was to determine whether the filtration bed filling is the factor significantly differentiating the reduction of ammonium nitrogen, orthophosphates, BOD_5, COD_{Cr}, total suspended solids and pathogenic bacteria in treated wastewater discharged from individual columns of the research model. The results of the nonparametric Kruskal-Wallis test, made for variables characterized by the lack of normal distribution and the heterogeneity of variance are presented in Table 2. The removal of the total suspended solids due to the use of sand proved to be stable during more than 400 days of testing under varying hydraulic conditions. On the other hand, statistically significant differences at the assumed significance level of 0.05 in the elimination of other pollutants, i.e. biogenic compounds and organic substances, with the PO30/PS60 filter bed clearly differing from other fillings were noted. In the case of orthophosphate removal, the comparison column PS60 clearly differed from the other beds.

Table 2. Kruskal-Wallis test results – physicochemical parameters

Reduction of physicochemical parameter [%]				
$N\text{-}NH_4^+$	PO_4^{3-}	COD_{Cr}	BOD_5	Suspended solids
p =0,0000 {PO30/PS60} and {other}; {PS30} and {PN60/PS30}	p =0,0000 {PO30/ PS60;PS60} and {PO60/PS30; PN60/PS30; PS30}; {PN30/PS60} and {PO60/PS30}	p = 0,006 {PO30/ PS60; PS60} and {PO60/ PS30}	p =0,0000 {PO30/PS60} and {PN30/PS60; PO60/ PS30; PS30}	p = 0,2731

statistically, significant differences are marked in red

The final stage of the analysis of the results was to determine whether the filtration bed filling is the factor significantly differentiating the value of pathogenic bacteria in treated sewage flowing away from individual columns of the research model. The results of the non-parametric Kruskal-Wallis test, performed for variables characterized by the lack of normal distribution and heterogeneity of variances, are presented in Table 3. Throughout the entire research period, statistically significant differences at the assumed significance level of 0.05 in removing *Escherichia coli* and coliforms in individual columns operating in variable hydraulic conditions were noted. The results of the Kruskal-Wallis test confirmed the fact that the degree of removal of pathogenic bacteria in the comparison columns with sand (PS60 and PS30) clearly differed from the columns with additional upper foam filling.

Table 3. Kruskal-Wallis test results – bacteriological parameters

Hydraulic loading [$mm^3 \cdot mm^{-2} \cdot d^{-1}$]	Reduction of bacteriological parameter [%]	
	Escherichia coli	Coliform bacteria
76,4 – 229,2 (all stages)	p = 0,0003 {PS30} and { PO30/ PS60; PN60/PS30; PO60 /PS30}	p =,0001 {PS60; PS30} and {PO30/PS60; PN60/ PS30}

statistically, significant differences are marked in red

SUMMARY AND CONCLUSIONS

Currently used systems in household sewage treatment plants should meet stricter requirements as to the quality of sewage discharged to the receiver. Increasing the effectiveness of removing nitrogen and phosphorus compounds as well as pathogenic bacteria is particularly vital. The results obtained during the 400-day research cycle on the application of a layer filter (in the form of polyurethane foams and sand) for the treatment of household wastewater after the preliminary settling tank indicate the proper conditions for the development of nitrifying bacteria created in the spange filling,. Filling the upper layer of the filter in the form of polyurethane foams with the lower sand layer proved to be very effective in removal of ammonium nitrogen from domestic sewage with its elevated concentration. The over 80% efficiency of elimination of $N\text{-}NH_4^+$ is comparable to that obtained for the UASB-DHS reactor system. However, it should be emphasized that the concentration of ammonium nitrogen in municipal sewage treated in the aforementioned system was about five times lower than in the current research using polyurethane waste.

Throughout the entire research period in the easily biodegradable organic compounds (BOD_5 indicator) removal process, the column filled with 30 cm of waste of random shaped foam and with 60 cm of sand proved to be the most effective.

In the case of indicator bacteria removal, the presence of material in the form of foams resulted in their additional elimination. The proposed technological system of the household treatment plant in addition to the high efficiency of organic compounds removal, defined in the Regulation (2014), also provided effective removal of eutrophic pollutants from sewage and partial protection of the receiver against pathogenic microorganisms.

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