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Purpose of the housing double stage polypropylene-carbon cartridges filters usage in bath gray water treatment

Key words: gray water, filtration, cartridge filter, water and wastewater quality, gray water turbidity

Introduction

In Poland, water resources are limited. Considering water consumption for industry and agriculture, the amount of water that can be used for communal purposes is only approx. 365 $m^3 \cdot M^{-1} \cdot year^{-1}$ (Kundzewicz, Zalewski, Kędziora & Pierzgalski, 2010). Such a quantity of water should theoretically be enough to meet the needs of human consumption. Water consumption in households is around 36.5–54.75 $m^3 \cdot M^{-1} \cdot year^{-1}$ (Chudzicki & Sosnowski, 2011b). However, it is necessary to consider the periods of drought occurring in Poland that contribute to lowering the level of groundwater and drinking water shortages.

Water quality in recent years in Poland is improving, but the amount of drinking water in the rivers is still unsatisfactory. Kundzewicz et al. (2010) determined the good condition of waters only for 7% of the Vistula and Odra river basins. Additionally, it should be remembered that the occurring floods also do not improve the situation (Kundzewicz et al., 2010). They cause pollution of surface waters. This, in turn, adversely affects the drinking water resources.

Analyzing the water usage in a typical household (Chudzicki, 2010; Chudzicki & Sosnowski, 2011b), it turns out that nearly 30% is used to flush toilet bowls. Usually tap water is used here. The question arises whether water needs to be used for this purpose with the parameters of drinking water quality that meets the 2017 Regulation of the Minister of Health on water quality for human consumption. It is believed that gray water may be used to the toilet after pre-treatment (Abdel-Shafy & Al-Sulaiman, 2014; Gross, Maimon, Alfiya & Friedler, 2015; Vuppaladadiyam et al., 2019). Considering the amount of gray sewage generated in homes (about 51% of the total amount of sewage), one can notice enough of them to rinse the toilet bowls. Currently in Poland, sewage in households is entirely discharged into collective sewage systems (Kalenik, 2015; Bugajski, Chmielowski & Kaczor, 2016) or are cleaned in household wastewater treatment plants (Kalenik, 2014; Spychała, 2016).

Gray water reuse gives the possibility of economic management of drinking water. It is estimated that re-use of gray water can bring savings of 30–50% (Mucha & Jodłowski, 2010). The problem, however, is their quality. Gray water (sewage from the bath – approx. 26% of sewage, body wash – approx. 10%, laundry – approx. 15%) are considered as contaminated water without faeces. However, these wastewater often contain various types of soaps, washing powders and liquids, fats of human origin, solid impurities (Christowa-Boal, Eden & McFarlane, 1996; Mucha & Jodłowski, 2010; Boyjoo, Pareek & Ang, 2013). This is the reason for the reluctance of potential users to use them even in toilets. Gray water frequently contributes to excessive deposition of contaminants on the surfaces of ceramic sanitary facilities (Chudzicki & Sosnowski, 2011b). They can also cause the production of dangerous aerosols when flushing the toilet bowls (Mucha & Jodłowski, 2010; Chudzicki & Sosnowski, 2011a).

In Poland, there are currently no legal regulations regarding the quality of water used in households for other purposes than consumption or bathing. The literature specifies that this water should be safe for life and health, it should not be a habitat for flies, it cannot pose a threat to the environment, it should look aesthetically. These guidelines, presented in the work of Mucha and Jodłowski (2010), are the basic parameters of the quality of liquid used for economic purposes. The authors also present gray water to be used for this purpose, citing various solutions using gray water in toilets without prior pre-treatment. However, such installations may be used only in the case of direct use of gray water to rinse the toilet bowls without holding them longer time and when the appearance and smell are acceptable.

The gray water system should be easy and friendly to use. If it is necessary to keep gray water before their secondary use, it is advisable to clean them up to a level that does not endanger human health and life. In addition, this installation should minimize the possibility of deposition of contaminants on sanitary ceramics (Malarski, 2013).

The pre-treatment of gray water can be carried out in many ways. Christowa-Boal, Eden and McFarlane (1996), March, Gual and Orozco (2004), Gual, Moia and March (2008), Abudi (2011), Khalaphallah (2012), Abdel-Shafy, El-Khateeb and Shehata (2013), Ushijima, Ito, Ito and Funamizu (2013), Charchalac Ochoa, Ushijima, Hijikata and Funamizu (2015) propose the use of a system based on filtration of gray water through polypropylene mesh filters, sand filters and chlorine disinfection. The literature also refers to systems based on biofiltration system with swamp plants (Masi et al., 2010; Abdel-Shafy & Dewedar, 2012; Abdel-Shafy & El-Khateeb, 2013), and RBC type devices (rotating biological contactor), UASB (upflow anaerobic sludge blanket) or membrane reactors (Hourlier et al., 2010; James, Surendran, Ifelebuegu, Ganjian & Kinuthia, 2016; Huelgas-Orbecido & Funamizu, 2019; Wu, 2019). These devices are proposed for installation in collective use buildings, multi-family residential buildings, housing estates or their surroundings. They are often large devices used to treat wastewater from the entire household. Unfortunately, this often results in a high price and a significant reduction in applicability in a single sanitary point in the household.

The aim of the research was to determine the suitability of using double stage cartridge filters for pre-treatment of bathing gray water for possible secondary use of it. The possibilities of using double stage polypropylene-carbon cartridge filter FCCA-STO, as well as polypropylene FCPS10 and carbon FCCA cartridges filter, constituting single stages of a double stage cartridge were determined.

Material and research methodology

Analyzed gray water contained pollution coming from washing and bathing sources of a typical two-family building used by seven people. The effluent for tests was collected at the outflow from sanitary facilities. The effluent were collected in a septic tank and then passed through cartridge filter with a fixed initial capacity of 0.1 $dm^3 \cdot s^{-1}$. This value corresponds to the normative outflow of water into the toilet bowl from the water supply system (PN-92/B-01706, PN-EN 806-3:2006). Performing filtration on the cartridge filter, it was attempted to determine the possibility of using a selected cartridge filter for pre-treatment of bath gray water. The characteristics of gray water are shown in Table 1.

Housing cartridge filters are small devices (Aquafilter 2016, BWT 2016), with a standard height of approx. 30 cm and a diameter of approx. 12 cm. Filter element with a height of 10” and a diameter of 2.5” can be replaced alone without the participation of specialized service. In the case of drinking water purification, the filter cartridge should be replaced every 6 months (Aquafilter 2016, BWT 2016). However, for the pre-treatment of gray water, the “lifetime” of cartridges is not estimated.

The research was divided into three experiments that differ in the type of filter cartridge used. In the first experiment, a double stage polypropylene-carbon cartridge filter FCCA-STO was used. However, the other two experiments that examined individual filtration stages were made on a single polypropylene cartridge FCPS10 with a filtration accuracy of 10 μm (the second experiment) and on a single carbon cartridge filter FCCA (third experiment).

During the tests, samples of raw gray water and filtrate were collected for analytical tests of their quality. The samples were tested for the following parameters:

- pH – electrometric measurement (PN-EN ISO 10523:2012) using the Hach Lange Sension 4 pH meter and Elmetron EPP-3 electrode,
- suspended and dissolved solids – measurement by weight in relation to the procedure included in the PN--78/C-04541 standard,

– turbidity – measurement by nephelometric method (PN-EN ISO 7027:2003. Chapter 6) with the use of turbidimeter 2100N IS Turbidimeter,
– conductivity – conductometric measurement (PN-EN 27888:1999),
– biochemical oxygen demand (BOD_5) – measurement using the WTW bottle method, in accordance with the PN-EN 1899-1:2002, 2:2002 standard,
– decay – measurement by visual method (PN-C-04626:1976),
– chemical oxygen demand (COD) – measurement by means of a titration method (PN-ISO 15705:2005).

The research focused mainly on the results of turbidity and decay of the investigated gray water. These parameters show the time of possible liquid retention before its secondary use, e.g. for flushing the toilet bowls and organoleptic acceptance by the potential user. The results of the tests were compared for each measurement series separately.

Results and discussion

Bathing gray water is characterized by high variability of quality parameters. Their composition depends mainly on the contamination of the person taking a bath, as well as on the amount and type of detergent (Malarski, 2013, 2016; Malarski, Matusiak & Cybula, 2016). Table 1 presents the results of testing the quality of gray water from the bath. Samples of gray water from baths of a two-family building inhabited by seven people were tested. Limit values of obtained results as well as average values, standard deviation and median of individual quality parameters are presented.

According to Dixon et al. (1999) and Boyjoo et al. (2013) gray water should not last longer than 48 h without treatment. It results from biodegradability of gray water. In the Malarski study (2013) carried out on gray water from the bathtub, the results of decay were obtained at the level of 170 h. In the own research, however, a different time of gray water is noticeable, average 74 h. This proves a significant diversity of gray water depending on their origin. At the same time, it shows the need for an individual approach to the possible use or treatment of gray water. Often forcing them to purify almost immediately, which is consistent with the guidelines for using gray water in many countries (Yu, Rahardianto, De Shazo, Stenstrom & Cohen, 2013; Oron et al., 2014; James et al., 2016).

Tested gray water was characterized by a similar turbidity value (average 74.9 NTU) to the Jabornig and Favero (2013) tests results about 133 NTU, Oron et al. (2014) tests results about 50–250 NTU, Šostar-Turk, Petrinić and Simonič (2005) tests results about 35 NTU, Gual et al. (2008) tests results about 38.8 NTU, Jamrah, Al-Futaisi, Prathapar and Harrasi (2008) tests results about 279 NTU, March et al. (2004) tests results about 20 NTU. In the author's own research, studies were carried out on gray water from bath, as in the presented literature. The turbidity of gray water after bathing can be set at different levels depending on the "soiling" of the person taking a bath and the consumption of washing agent.

Analyzing the obtained results of the gray water quality tests an increased concentration of COD and BOD values

TABLE 1. Ranges of values of selected indicator of pollutants in bath gray water testing (own studies)

Indicator	Unit	Values	*AVG*	*M*	*SD*
Turbidity	NTU	28–156	74.9	71.9	29
pH	–	7.12–9.39	8.21	8.33	0.60
Conductivity	$\mu s \cdot cm^{-1}$	1 234–2 900	1 752	1 687	483
Decay	h	64–90	74	75	8
COD	mg $O_2 \cdot dm^{-3}$	182–273	224	224	25
BOD_5	mg $O_2 \cdot dm^{-3}$	71–180	118	115	25
Total suspended solids (TSS)	$mg \cdot dm^{-3}$	74–892	482	476	233
Fixed suspended solids (FSS)	$mg \cdot dm^{-3}$	48–445	227	202	100
Volatile suspended solids (VSS)	$mg \cdot dm^{-3}$	26–640	255	280	162
Total dissolved solids (TDS)	$mg \cdot dm^{-3}$	854–3 715	2 452	2 281	829
Total fixed solids (TFS)	$mg \cdot dm^{-3}$	315–2 285	1 325	1 327	496
Total volatile solids (TVS)	$mg \cdot dm^{-3}$	539–1 768	1 127	1 054	404

is noticeable. Values exceed the limit set out in the 2014 Regulation of the Minister of Environment on conditions of sewage and substances particularly harmful to water environment for wastewater that may be introduced into waters or into the ground.

High turbidity, variable value of decay, and often also the color of gray water may cause reluctance to their possible re-use. Therefore, in determining the efficiency of operation of selected filter cartridges in each research series, the quality of raw gray water was tested.

Experiment 1. Filtration on a filter with a double stage polypropylene--carbon FCCA-STO cartridge

In series 1 of tests, the filtration of bath gray water was carried out using a double stage polypropylene carbon filter cartridge FCCA-STO. For this purpose, baths gray water from the two-family building was stored in the tank – about 300 dm^3. Then, 80 dm^3 of averaged gray water was filtered on the prepared test stand, without getting a full colmatation of the filter cartridge. Five filtrate samples and one raw gray water sample were collected. The remaining gray water was used to carry out experiments 2 and 3. The experiments were carried out twice at an interval of two weeks.

As a result of the tests, parameters of the filter cartridge were determined in terms of selected quality parameters. Table 2 presents the average values of the parameters from two conducted experiments.

As a result of filtration, the quality indicators of gray water underwent slight changes. The best effect was obtained for suspensions. After filtering 40 dm^3 of gray water, a reduction of 80% was obtained. The remaining tested quality indicators showed a smaller reduction. The turbidity reduction was 44% in the samples taken after filtration of 20 dm^3 gray water, for COD reduction by 13%, BOD_5 by 30%, TDS by 14% in samples of 10 dm^3. The remaining analyzed indicators of the quality of the liquid practi-

TABLE 2. Characteristics of bath gray water raw and treated on the housing double-stage polypropylene-carbon cartridge filter FCCA-STO (own studies)

Indicator	Unit	Raw gray water	Volume of filtrate [dm^3]				
			10	20	40	60	80
Turbidity	NTU	45.6	26.1	25.4	27.1	28.2	27.5
pH	–	7.58	7.80	7.81	7.79	7.75	7.82
Conductivity	$\mu s \cdot cm^{-1}$	1 386	1 296	1 310	1 356	1 341	1 330
Decay	h	70	70	70	70	70	70
COD	mg $O_2 \cdot dm^{-3}$	224	195	214	205	205	200
BOD_5	mg $O_2 \cdot dm^{-3}$	103	72	80	92	85	95
Total suspended solids (TSS)	$mg \cdot dm^{-3}$	706	185	162	141	165	148
Fixed suspended solids (FSS)	$mg \cdot dm^{-3}$	75	65	60	52	63	58
Volatile suspended solids (VSS)	$mg \cdot dm^{-3}$	631	120	102	89	102	90
Total dissolved solids (TDS)	$mg \cdot dm^{-3}$	1 078	932	968	970	954	972
Total fixed solids (TFS)	$mg \cdot dm^{-3}$	754	654	676	679	666	678
Total volatile solids (TVS)	$mg \cdot dm^{-3}$	324	278	290	291	288	294

cally showed no major changes. The test results are presented in Table 2.

In the research, a double stage filter cartridge was used, obtaining the results of reduction of pollutants at a level similar to the reduction values of the investigated pollutants obtained by March et al. (2004) and Gual et al. (2008) in studies based on filtration of gray water from hotel rooms through a nylon filter. Similarly to own research, the researchers conducted studies on bath gray water coming from bathrooms, for which the initial concentrations and as well as values obtained after the filtration process on the used cartridge are still high, significantly exceeding the permissible values for waste water introduced into water or soil in accordance with the 2014 Regulation of the Minister of Environment.

On the basis of the obtained results, it can be only assume the legitimacy of the use of housing cartridge filters in the tests of treating gray water from the bath at least in the first stage of treating. The use of a carbon element in the filter for the purification of this type of gray water is not a good solution at this stage of treating. The carbon filter should provide sorption processes. In the case analyzed in the experiment, most likely the pores in the carbon element of the filter cartridge were quickly blocked by impurities contained in the gray water and the filter acted as a normal filter with mechanical removal of impurities. Therefore, it seems necessary to determine the effectiveness of the individual fractions of the filter cartridge used.

A double stage polypropylene-carbon filter was used for testing without the possibility of sampling between individual stages. Hence, to determine the effect of individual filter stages on wastewater treatment, tests were carried out on single polypropylene filter cartridges FCPS10 (experiment 2) and carbon FCCA (experiment 3). These cartridges are made of filter material used to build the FCCA-STO cartridge used in experiment 1.

Experiment 2. Filtration on a filter with a polypropylene cartridge with a filtration accuracy of 10 µm – FCPS10

In the second experiment, filtration of bath gray water through a filter with a polypropylene cartridge with a filtration accuracy of 10 µm FCPS10. The research was carried out in the same way as in experiment 1, using gray water remaining in the tank. Amount of 80 dm^3 of gray water were filtered. During the tests samples of the filtered liquid were collected. Five samples of filtrate were taken during the experiment. Analogously to the experiment 1, tests were carried out twice at an interval of two weeks. The results of laboratory tests on the concentrations of selected quality parameters of collected samples are presented in Table 3, as mean values from tests. During the filtration, no full colmatation of the deposit was obtained.

The filtration of bath gray water through the analyzed filter cartridge did not significantly change the parameters of their quality. Individual quality indicators did not change much. Maximum recorded average reductions of ratios from duplicate tests were obtained for samples collected after filtration of 20 dm^3 of sewage: for turbidity – reduction by 65%; TSS – by 81%; TDS – by 22%; COD – by 13%; BOD_5 – by 41%.

There is a noticeable fluctuation in the concentration of COD in individual

TABLE 3. Characteristics of bath gray water raw and treated on the housing polypropylene cartridge filter FCPS10 (own studies)

Indicator	Unit	Raw gray water	Volume of filtrate [dm^3]				
			10	20	40	60	80
Turbidity	NTU	45.6	16.0	15.8	16.1	16.3	16.5
pH	–	7.58	7.63	7.67	7.59	7.55	7.69
Conductivity	$\mu s \cdot cm^{-1}$	1 386	1 389	1 366	1 376	1 381	1 379
Decay	h	70	77	77	77	77	77
COD	$mg\ O_2 \cdot dm^{-3}$	224	214	195	200	205	200
BOD_5	$mg\ O_2 \cdot dm^{-3}$	103	70	61	65	69	65
Total suspended solids (TSS)	$mg \cdot dm^{-3}$	706	140	131	155	163	147
Fixed suspended solids (FSS)	$mg \cdot dm^{-3}$	75	15	17	19	18	18
Volatile suspended solids (VSS)	$mg \cdot dm^{-3}$	631	125	114	136	145	129
Total dissolved solids (TDS)	$mg \cdot dm^{-3}$	1 078	831	843	862	851	854
Total fixed solids (TFS)	$mg \cdot dm^{-3}$	754	582	592	601	602	595
Total volatile solids (TVS)	$mg \cdot dm^{-3}$	324	249	251	261	249	259

samples of filtered liquid. However, considering their small reduction relative to the raw gray water, at the same time relatively low value compared to industrial wastes (Malarski, Czajkowska & Nowak, 2018), these changes should be considered as the result of measurement error.

Compared to the obtained values of squashing with the Dixon et al. study (1999), a longer time was obtained. However, as in Malarski's research (2013), this index has not improved significantly during filtration.

For the potential user of gray water an important parameter of their quality is decay. This indicator for raw gray water was 70 h. During filtration the value of this parameter slightly improved to 77 h. Some of indicators, which case decay decrease during filtration, that is confirm by other parameters tested.

Experiment 3. Filtration on a filter with a carbon cartridge – FCCA

In the third experiment, filtration of bath gray water through a carbon cartridge filter FCCA was carried out. The aim of the conducted research in the experiment was to determine the impact of the second stage of the FCCA-STO filter on the filtration of bath gray water. The research was carried out in the same way as in experiments 1 and 2, using the remaining gray water from the bath accumulated in the tank. The experiment was completed after filtering 80 dm^3 of gray water. The filter cartridge has not been fully colmatated. During the tests, five samples of filtered gray water were collected. The tests were carried out twice at an interval of two weeks. The tests results of the analyzed quality parameters at taken samples were presented as mean values from the tests in Table 4.

TABLE 4. Characteristics of bath gray water raw and treated on the housing carbon cartridge filter FCCA (own studies)

Indicator	Unit	Raw gray water	Volume of filtrate [dm^3]				
			10	20	40	60	80
Turbidity	NTU	45.6	33.2	35.1	35.9	35.9	36.0
pH	–	7.58	7.66	7.71	7.65	7.68	7.71
Conductivity	$\mu s \cdot cm^{-1}$	1 386	1 355	1 368	1 380	1 369	1 372
Decay	h	70	72	72	72	72	72
COD	$mg\ O_2 \cdot dm^{-3}$	224	200	200	205	214	205
BOD_5	$mg\ O_2 \cdot dm^{-3}$	103	85	81	88	91	88
Total suspended solids (TSS)	$mg \cdot dm^{-3}$	706	146	141	133	150	148
Fixed suspended solids (FSS)	$mg \cdot dm^{-3}$	75	37	36	35	39	38
Volatile suspended solids (VSS)	$mg \cdot dm^{-3}$	631	109	105	98	111	110
Total dissolved solids (TDS)	$mg \cdot dm^{-3}$	1 078	916	905	925	909	891
Total fixed solids (TFS)	$mg \cdot dm^{-3}$	754	641	633	648	630	625
Total volatile solids (TVS)	$mg \cdot dm^{-3}$	324	375	372	277	279	266

The filtration of bath gray water through the analyzed filter cartridge did not significantly affect the quality parameters of liquid. They have improved to a small extent, but the analyzed liquid quality indicators have not changed significantly.

The obtained results showed lower efficiency of the carbon cartridge in the gray water pretreatment process as compared to experiments 1 and 2. Considering that the analyzed filter cartridge is a carbon cartridge used mainly as a sorption cartridge for removing dissolved pollutants, its lower efficiency in treating gray water containing a series of impurities in a suspended form is justified.

Based on the results of the research, it can be assumed that the used filter cartridge in the case of gray water filtration on it acted like an ordinary mechanical filter with low filtration efficiency.

Because of filtration, the following quality parameters have slightly changed: turbidity (up to approx. 27% in the first sample), COD (up to approx. 11% in samples 1 and 2), TDS (up to 17% in sample 5), BOD_5 (up to about 21% in sample 2). Higher reduction was obtained for the TSS (up to about 81% in sample 3).

Based on the test results, it can be assumed that the sorption capacity of the filter cartridge was quickly exhausted with the first portion of gray water as a result of clogging of the pores of the filter bed. After that the cartridge still worked only as a bed of mechanical filtration. This is confirmed by a greater reduction of turbidity and TSS in the analyzed filtrate samples.

The tests on single FCPS10 and FCCA filtration cartridges confirm the assumption that follows the first series of tests (experiment 1) with a double stage polypropylene-carbon filter. The amount of pollution reduction on the FCPS10 filter is at the same level as on the filter with the FCCA-STO cartridge, while the use of the FCCA cartridge (carbon cartridge) showed worse results. Hence it can be concluded that the carbon filter, which is a sorption filter, under these conditions in the experiment does not work properly. Using it for the treatment of bath gray water acts as an ordinary mechanical filter with low efficiency of removing impurities. For comparison, in studies conducted by Šostar-Turk et al. (2005) on bath gray water, the obtained pollution reduction was at the level of 85–95% using a coagulation process in combination with filtration on a 1 m filter column filled with sand and filtration through a 1m column with granular activated carbon.

For the potential user of recycled gray water, an important parameter of wastewater quality is their appearance. This parameter can be determined by wastewater turbidity. In order to determine the effectiveness of individual tested filter cartridges, their effectiveness in terms of turbidity reduction was analyzed.

The analysis of gray water treatment efficiency in terms of turbidity was conducted for all experiments performed using the values of the turbidity parameter presented in Tables 2–4. To minimize the impact of analytical errors, an attempt was made to approximate the measurement points with different functions. The best reflection of the points was obtained using the hyperbolic function. For this reason, the diagrams shown in Figure 1 were constructed, where the vertical axis is turbidity (S) and the horizontal filtered volume of sewage. The determination coefficients (R^2) have been determined for the presented functions. It was assumed that the function with the highest value of the R^2 coefficient would be a good fit of the function. Linear functions and their R^2 determination coefficients are shown in Figure 1.

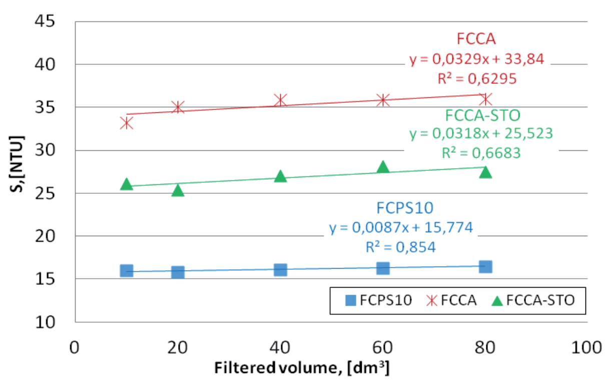

FIGURE 1. Hyperbolic dependence of turbidity as a function of gray water flow (own studies)

The functions presented in Figure 1 were used to calculate the effectiveness of gray water treatment using the following formula

$$\eta = \frac{S_p - S_i}{S_p}$$

where:
η – efficiency of decreasing wastewater turbidity,
S_p – initial turbidity of gray water,
S_i – turbidity after filtering a given volume.

Effectiveness of gray water treatment on individual filter cartridges is shown in Figure 2. As can be seen there, the functions of the turbidity reduction efficiency are decreasing. This means that the analyzed cartridges, together with the amount of filtered gray water, have less ability to remove turbidity. At the same time, a faster decrease in the turbidity reduction efficiency in the filtrate is noticeable by using a contribution with activated carbon content relative to the polypropylene cartridge. Comparing the method of pollution reduction applied in the own research with a double stage filter cartridge, for example with the Vakil, Sharma, Bhatia, Kazmi and Sarkar (2014), using the electrocoagulation processes, the obtained effect is minimal. The researchers obtained the turbidity reduction effect at the level of 85%, where in the authors' own research the effect was obtained at only 40% for a double stage cartridge.

Used FCCA carbon cartridges, FCPS10 polypropylene cartridges and FCCA-STO polypropylene carbon cartridges were not blocked during the tests. Only 80 dm^3 of gray water were filtered each time, and then the experiments were stopped. Based on the assumption of FCCA-STO and FCCA filters operation

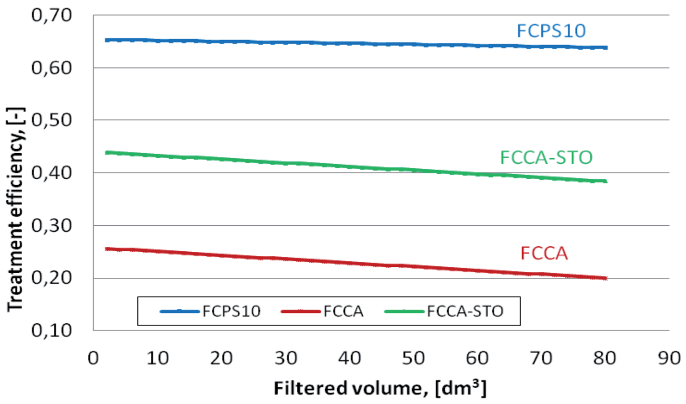

FIGURE 2. Effectiveness of turbidity decomposition according to gray water flow filtration (own studies)

as ordinary mechanical cartridge filters instead of sorption filters and a straight decrease in their efficiency, their turbidity removal capacity will run out after filtering about 630 dm^3 of gray water with an FCCA-STO cartridge, 360 dm^3 with an FCCA cartridge and 3,400 dm^3 with a FCPS cartridge.

It may seem to be problematic why filtration using the double stage polypropylene carbon cartridge FCCA-STO showed lower efficiency of turbidity reduction from gray water relative to the single stage filtration system on the FCPS10 polypropylene cartridge and at the same time higher relative to the system using the single stage FCCA carbon cartridge. The carbon cartridge, which is a sorption filter, under the given conditions works most likely like an ordinary mechanical filter after the rapid exhaustion of its sorption capacity. It should be noted that for the FCCA-STO and FCPS10 cartridge, the contact time of gray water with a polypropylene bed at the same flow will be different due to the twice the bed layer for the FCPS10 cartridge.

Conclusions

The filtration of natural bath gray water through the cartridge filters did not show significant improvement in the quality of the liquid. The filter cartridges used only contribute to the reduction of turbidity in the treated gray water. The remaining quality parameters after gray water filtration remained at a similar level to the initial values.

The carbon cartridge, which is a sorption filter, in the case of filtration of gray water, most likely acts as a filter for mechanical removal of pollutants. Its sorption capacity is exhausted very quickly. And the quality parameters of gray water are practically not improved.

The used filter cartridges for gray water treatment can be used as preliminary stages of purification. However, the use of a carbon refill at this stage of purification is not recommended due to the minimal efficiency and, at the same time, unnecessary increase in the costs of potential gray water treatment.

Decay and turbidity can be important parameters for a potential user of a gray water recycling plant. The values of these parameters obtained in the tests can be accepted by the user. Relatively low turbidity (FCPS10 – 16 NTU, FCCA-STO – 27 NTU, FCCA – 35 NTU) and long time of decay (three days) give the possibility of their reuse in the household. However, it should be remembered that gray water from the bath is characterized by high variability. The obtained parameters from gray water filtration may be significantly worse in bath gray water with a higher degree of biodegradability (higher BOD_5, lower decay, higher turbidity, etc.). Therefore, the filtration of gray water from the bath, even through a double stage filter cartridge, is not recommended as the only way to prepare them.

References

Abdel-Shafy, H.I. & Al-Sulaiman, A.M. (2014). Assessment of physic-chemical processes for treatment and reuse of greywater. *Egyptian Journal of Chemistry*, *57*(3), 215-231.

Abdel-Shafy, H.I. & Dewedar, A. (2012). Constructed wetlands for urban wastewater treatment in Egypt. *Journal Sustainable Sanitation Practice*, *12*, 27-32.

Abdel-Shafy, H.I. & El-Khateeb, M.A. (2013). Integration of septic tank and constructed wetland for the treatment of wastewater in Egypt. *Desalination and Water Treatment*, *51*(16-18), 3539-3546.

Abdel-Shafy, H.I., El-Khateeb, M.A. & Shehata, M. (2013). Grey water treatment using different designs of sand filters. *Desalination and Water Treatment*, *52*(28-30), 5237-5242.

Abudi, Z.N. (2011). The effect of sand filter characteristics on removal efficiency of organic matter from grey water. *Al-Qadisiya Journal for Engineering Sciences*, *4*(2), 143-155.

Aquafilter (2016-04-10). *Materiały techniczne Aquafilter INC* [*Technical materials – Aquafilter INC*]. Retrieved from: https://www.aquafilter.com [access 10.04.2016].

BWT Polska (2015-06-15). *Materiały techniczne Best Water Technology* [*Technical materials – Best Water Technology*]. Retrieved from: https://www.bwt.pl [access 15.06.2015].

Boyjoo, Y., Pareek, V.K. & Ang, M. (2013). A review of grey water characteristics and treatment processes. *Water Science and Technology*, *67*(7), 1403-1424.

Bugajski, P., Chmielowski, K. & Kaczor, G. (2016). Wpływ wielkości dopływu wód opadowych na skład ścieków surowych w małym systemie kanalizacyjnym. *Acta Scientiarum Polonorum – Formatio Circumiectus*, *15*(2), 3-11.

Charchalac Ochoa, S.I., Ushijima, K., Hijikata, N. & Funamizu, N. (2015). Treatment of domestic greywater by geotextile filter and intermittent sand filtration bioreactor. *Journal of Water Reuse and Desalination*, *5*(1), 39-49.

Christowa-Boal, D., Eden, R.E. & McFarlane, S. (1996). An investigation into grey water reuse for urban residential properties. *Desalination*, *106*(1-3), 391-197.

Chudzicki, J. (2010). *Oszczędzanie wody bez rezygnacji z komfortu* [*Saving water without sacrificing comfort*]. Ładny Dom. Retrieved from: http://ladnydom.pl/budowa/1,106590,6719177,Oszczedzanie_wody_bez_rezygnacji_z_komfortu___Druga.html [access 10.12.2019].

Chudzicki, J. & Sosnowski, S. (2011a). *Instalacje kanalizacyjne. Projektowanie, wykonawstwo, eksploatacja* [*Sewage installation. Design, execution, operation*]. Józefosław: Wydawnictwo Seidel-Przywecki.

Chudzicki, J. & Sosnowski, S. (2011b). *Instalacje wodociągowe. Projektowanie, wykonawstwo, eksploatacja* [*Water installation. Design, execution, operation*]. Józefosław: Wydawnictwo Seidel-Przywecki.

Dixon, A.M., Butler, D., Fewkes, A. (1999). Guidelines for Greywater Re-Use: Health Issues. *Water and Environment Journal*, *13*(5), 322-326.

Gross, A., Maimon, A., Alfiya, Y. & Friedler, E. (2015). *Grey water reuse*. Boca Raton: CRC Press, Taylor & Francis Group.

Gual, M., Moia, A. & March, J.G. (2008). Monitoring of an indoor pilot plant for osmosis rejection and greywater reuse to flush toilets in a hotel. *Desalination*, *219*(1-3), 81-88.

Hourlier, F., Massé, A., Jaouen, P., Lakel, A., Gerente, C., Faur, C. & Le Cloirec, P. (2010). Membrane process treatment for greywater recycling: Investigations on direct tubular nanofiltration. *Water Science & Technology*, *62*(7), 1544-1550.

Huelgas-Orbecido A. & Funamizu N. (2019). Membrane system for gray water. In: N. Funamizu (ed.), *Resource-oriented agro-sanitation systems* (pp. 185-193). Tokyo: Springer.

Jabornig, S. & Favero, E. (2013). Single household grey water treatment with a moving bed biofilm membrane reactor (MBBMR). *Journal of Membrane Science*, *446*, 277-285.

James, D.T.K., Surendran, S., Ifelebuegu, A.O., Ganjian, E. & Kinuthia, J. (2016). *Grey water reclamation for urban non-potable reuse challenges and solutions: A review.* The 7th International Conference on Sustainable Built Environment. Kandy, Sri Lanka, 16-18.12.2016.

Jamrah, A., Al-Futaisi, A., Prathapar, S. & Al Harrasi, A. (2008). Evaluating grey water reuse potential for sustainable water resources management in Oman. *Environmental Monitoring and Assessment*, *137*, 315-327. DOI 10.1007/s10661-007-9767-2

Kalenik, M. (2014). Skuteczność oczyszczania ścieków w gruncie piaszczystym z warstwą naturalnego klinoptylolitu [Sewage treatment efficacy of sandy soil bed with natural clinoptiolite assist layer]. *Ochrona Środowiska*, *36*(3), 43-48.

Kalenik, M. (2015). Empirical formulas for calculation of negative pressure difference in vacuum pipelines. *Water*, 7(10), 5284-5304.

Khalaphallah, R. (2012). *Greywater treatment or reuse by slow sand filtration: study of pathogenicmicroorganisms and phage survival* (doctoral thesis, Ecole des Mines de Nantes, Nantes).

Kundzewicz, Z.W., Zalewski, M., Kędziora, A. & Pierzgalski, E. (2010). Zagrożenia związane z wodą [Water-related hazards]. *Nauka*, *4*, 87-96.

Malarski, M. (2013). Treatment of bath grey water using cartridge filters as a way to reduce water consumption in households. *Annals of Warsaw University of Life Sciences – SGGW. Land Reclamation*, *45*(1), 49-59.

Malarski M. (2016). Jakość ścieków szarych zawierających płynne środki chemii gospodarczej [The quality of grey waters containing liquid household chemicals]. *Scientific Review – Engineering and Environmental*, *25*(4), 433-443.

Malarski, M., Czajkowska, J. & Nowak, P. (2018). Preliminary studies on the use of Fenton reagent to reduce pollution from wastewater from the production of household chemicals. *Annals of Warsaw University of Life Sciences – SGGW. Land Reclamation*, *50*(4), 301-312.

Malarski, M., Matusiak, K. & Cybula, J. (2016). Wpływ wybranych produktów chemii gospodarczej na jakość ścieków szarych [The influence of selected household chemical products on the quality of greywater]. *Scientific Review – Engineering and Environmental*, *25*(1), 61-71.

March, J.G., Gual, M. & Orozco, F. (2004). Experiences on grey water re-use for toilet flushing in a hotel (Mallorca Island, Spain). *Desalination*, *164*(3), 241-247.

Masi, F., El Hamouri, B., Abdel, Shafi, H., Baban, A., Ghrabi, A. & Regelsberger, M. (2010). Treatment of segregated black/grey domestic wastewater using constructed wetlands in the Mediterranean basin: the Zer0-m Experience. *Water Science and Technology*, *61*(1), 97-105. DOI 10.2166/wst. 2010.780

Mucha, J. & Jodłowski, A. (2010). Ocena możliwości wykorzystania wody szarej [Evaluation of possibility of using gray water]. *Gaz, Woda i Technika Sanitarna*, *7-8*, 24-27.

PN-78/C-04541. Woda i ścieki. Oznaczanie suchej pozostałości, pozostałości po prażeniu, straty przy prażeniu oraz substancji rozpuszczonych, substancji rozpuszczonych mineralnych i substancji rozpuszczonych lotnych [Water and sewages. Determination of the dry residue, residue on ignition, loss on ignition and solute substances, mineral solute substances and volatile solute substances].

PN-92/B-01706. Norma polska. Instalacje wodociągowe. Wymagania w projektowaniu [PN--92/B-01706. *Installations* for water supply. Design].

PN-C-04626:1976. Woda i ścieki. Oznaczenie zagniwalności i względnej trwałości [Water and sewages. Determination of the putrescibility and relative durability].
PN-EN 27888:1999. Jakość wody. Oznaczanie przewodności elektrycznej właściwej [Water quality. Determination of the specific electrical conductivity].
PN-EN 1899-1:2002. Biochemiczne zapotrzebowanie tlenu BZTn. Jakość wody. Oznaczanie biochemicznego zapotrzebowania tlenu po n dniach (BZTn). Część 1: Metoda rozcieńczania i szczepienia z dodatkiem allilotiomocznika [Biochemical oxygen demand BODn. Water quality. Determination of biochemical oxygen demand after n days (BODn). Part 1: Dilution and seeding method with allylthiourea addition].
PN-EN 1899-2:2002. Biochemiczne zapotrzebowanie tlenu BZTn. Jakość wody. Oznaczanie biochemicznego zapotrzebowania tlenu po n dniach (BZTn). Część 2: Metoda próbek nierozcieńczonych [Biochemical oxygen demand BODn. Water quality. Determination of biochemical oxygen demand after n days (BODn). Part 2: Method for indiluted samples].
PN-EN ISO 7027:2003. Jakość wody. Oznaczanie mętności [Water quality. Determination of the turbidity].
PN-ISO 15705:2005. Chemiczne zapotrzebowanie tlenu ChZT. Jakość wody. Oznaczanie indeksu chemicznego zapotrzebowania tlenu (SP-ChZT). Metoda zminiaturyzowana z zastosowaniem szczelnych probówek [Chemical oxygen demand COD. Water quality. Determination of the chemical oxygen demand index (ST-COD). Small-scale sealed-tube *method*].
PN-EN 806-3:2006. Wymagania dotyczące wewnętrznych instalacji wodociągowych do przesyłu wody przeznaczonej do spożycia przez ludzi. Część 3: Wymiarowanie przewodów. Metody uproszczone [PN-EN 806-3:2006. Specifications for installations inside buildings conveying water for human consumption – Part 3: Pipe sizing – simplified method].
PN-EN ISO 10523:2012. Jakość wody. Oznaczanie pH [Water quality. Determination of pH].
Oron, G., Adel, M., Agmon, V., Friedler, E., Halperin, R., Leshem, E. & Weinberg, D. (2014). Grey water use in Israel and worldwide: standards and prospects. *Water Research*, *58*, 92-101.
Rozporządzenie Ministra Środowiska z dnia 18 listopada 2014 r. w sprawie warunków, jakie należy spełnić przy wprowadzaniu ścieków do wód lub do ziemi, oraz w sprawie substancji szczególnie szkodliwych dla środowiska wodnego. Dz.U. 2014 poz. 1800 [Regulation of the Minister of Environment of 18 November 2014 on conditions for the introduction of sewage into water or soil and on the list of substances particularly harmful to water environment. Journal of Laws 2014, item 1800].
Rozporządzenie Ministra Zdrowia z dnia 7 grudnia 2017 r. w sprawie jakości wody przeznaczonej do spożycia przez ludzi. Dz.U. 2017 poz. 2294 [Regulation of the Minister of Health of 7 December 2017 on the quality of water intended for human consumption. Journal of Laws 2017, item 2294].
Šostar-Turk, S., Petrinić, I. & Simonič, M. (2005). Laundry wastewater treatment using coagulation and membrane filtration. *Resources, Conservation and Recycling*, *44*, 185-196.
Spychała, M. (2016). Skuteczność filtrów włókninowych do oczyszczania ścieków w warunkach stałego poziomu piętrzenia [Efficiency of textile filters for wastewater treatment in condition of stable wastewater table]. *Acta Scientiarum Polonorum – Formatio Circumiectus*, *15*(1), 19-34.
Ushijima, K., Ito, K., Ito, R. & Funamizu, N. (2013). Grey water treatment by slanted soil system. *Ecological Engineering*, *50*, 62-68.
Vakil, K.A., Sharma, M.K., Bhatia, A., Kazmi, A.A. & Sarkar, S. (2014). Characterization of greywater in an Indian middle-class household andinvestigation of physicochemical treatment using electrocoagulation. *Separation and Purification Technology*, *130*, 160--166.
Vuppaladadiyam, A.K., Merayo, N., Prinsen, P., Luque, R., Blanco, A. & Zhao, M. (2019). A review on grey water reuse: quality, risks, barriers and global scenarios. *Reviews in Environmental Science and Bio/Technology*, *18*(1) 77-99.

Wu, B. (2019). Membrane-based technology in greywater reclamation: A review. *Science of The Total Environment*, *656*, 184-200.
Yu, Z.L.T., Rahardianto, A., DeShazo, J.R., Stenstrom, M.K. & Cohen, Y. (2013). Critical review: regulatory incentives and impediments for onsite grey water reuse in the United States. *Water Environment Research*, *85*(7), 650-661.

Summary

Purpose of the housing double stage polypropylene-carbon cartridges filters usage in bath gray water treatment. Bath gray water organoleptically did not appear to be significantly contaminated liquid. However, in order to re-use them, they need proper treatment. When recirculated in a household, they cannot pose a threat to human life. Based on their appearance, it seems that the solution to the problem is the use of cartridges filter. The article presents the results of the filtration of gray water from the bath through the filtration system with a housing double stage polypropylene-carbon filter FCCA-STO and to determine the impact of individual filter layers on wastewater treatment, tests were carried out on a single polypropylene FCPS10 and carbon FCCA filtration cartridge. The aim of the study was to determine the suitability of the selected housing filter cartridges for the treatment of bathing gray water for their reuse. For the tests were used natural bathing gray water from a two-family building inhabited by seven people. Wastewater were fed to the filter with a constant flow rate of 0.1 $dm^3 \cdot s^{-1}$. The assessment of the work of the filters based on parameters such as: COD, BOD_5, suspension, dry residue, decay and turbidity. The conducted tests have shown a slight improvement in most of the quality parameters of gray water after filtration through selected housing cartridge filters. Only for turbidity, the reduction in the value of the pollution indicator was noticeable. The cartridge filters used in tests, acted like ordinary mechanical filtration cartridges. For the considered gray water, the use of analyzed cartridge filters can only be used for their initial purification.

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