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Removal of bacteria and pollutants from low susceptible to bio-decomposition septic tank effluent by textile filter

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ABSTRACT

The objective of the study was to assess the efficiency of the textile filter according to indicator bacteria removal. An additional goal was to determine the pollutants removal efficiency at relatively high chemical oxygen demand (COD) to 5 d biochemical oxygen demand (BOD_5) ratio of treated wastewater. The wastewater was taken from the septic tank effluent. The count of indicator microorganisms (*coliforms*, *Clostridium perfringens*, *Escherichia coli* and total mesophilic bacteria) was identified. The samples of wastewater were analyzed in terms of COD, BOD_5, total phosphorus, total nitrogen and ammonium nitrogen. The removal efficiencies of indicator bacteria were relatively high for *Escherichia coli* (2.1–2.5 log), differentiated for the other indicators: *Clostridium perfringens* (0.59–1.11 log), coliforms (0.58–1.55 log) and total mesophilic bacteria (0.56–0.97 log). In the first series (term I) the removal efficiency of *Escherichia coli* and total mesophilic bacteria was impossible to calculated due to the uncountable number of CFU. The removal efficiencies of pollutants were relatively high too (79.9% for COD_{Cr} and 71.0% for BOD_5). Despite the relatively high COD to BOD_5 ratio of inflowing wastewater, equal to 4.2, the organic dissolved compounds and nutrients removal efficiency was acceptable and met the requirements of Polish law.

Keywords: Indicator bacteria; Pollutants; Textile filter; Treatment; Wastewater

1. Introduction

Re-use of more than 50% of the total volume of water from wastewater treatment plants in Europe (e.g., for irrigation) would avoid over 5% of direct collection from surface and groundwater, thus by more than 5% reduce the overall water deficit. Presumably, wastewater reuse in agriculture will become more popular in some regions, for example, in Europe [1]. The need for treated wastewater disinfection, related to microbiological contamination is validated by law requirements in some countries [2].

In general, the efficiency of removal of indicator microorganisms during biological wastewater treatment processes (e.g., activated sludge) is differentiated according to different types of indicator organisms and has a relatively wide range: 90%–98% for the total number of bacteria, 55%–98% for *Salmonella* bacteria and only about 45% for tuberculosis

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bacilli. Both most popular treatment processes (activated sludge and conventional trickling filters) are almost equally efficient: 90%–98% and 90%–95%, respectively [3].

The small grain (particle) diameter filter media seem to be more effective in pathogenic organisms removal than conventional trickling filter material [4,5]. Dacewicz [5] reported that filters filled with fine grain natural material proved to be the most suitable for removal of indicator bacteria, removing coli group bacteria at a rate of 99.94% and *Escherichia coli* – at 99.98%.

The other studies argue that biofilm [4] or clogging layer (schmutzdecke) is one of the most important factors of indicator bacteria (e.g., *Escherichia coli*) removal by adsorption on the surface of the biofilm [6].

In some countries, for example, Italy [2], France, Germany, Spain, United States, the disinfection of treated wastewater is obligatory or recommended for selected use or reuse (recreation areas, protected areas, watering places, etc.)

The typical biological wastewater treatment plant effluent contains from several hundred thousand to about one million coliform bacteria per 100 cm^3 [7]. Lack of continuous disinfection of wastewater treatment plant effluent causes that the receivers (usually rivers), despite obtaining satisfactory physical and chemical indicators, are often out-of-class, which results from exceeding the microbiological indicators number [7].

Investigating new filtering materials, for example, zeolites, expanded clay aggregates, oyster shells, granular activated carbon [8], crushed polyethylene terephthalate [5] clinoptilolite layer [9] or wood-polymer composites [10] can allow removing pathogenic bacteria at a higher level of efficiency than filters filled with conventional materials.

Also, treatment process conditions can influence the pathogenic bacteria removal efficiency. Wąsik and Chmielowski [11] found a decrease in CFU of the coliform bacteria by one order of magnitude at pH about 4. Typical wastewater treatment plant effluent may still contain from a few dozen thousand to around a million of coliform bacteria [12]. Pathogenic bacteria, viruses, protists and invasive forms of parasitic worms can occur in domestic wastewater and be dangerous because of a direct epidemiological and allergic potential [7].

Many authors highlight that even treated wastewater outflowing from on-site wastewater treatment systems contains significant concentrations of pathogenic microorganisms [13,14]. In spite of the common opinion that wastewater treatment systems reduce pathogenic organisms concentration at least to some extent there are some notes that they can cause the increase in its concentration, for example, the growth of *E. coli* inside a septic tank [15].

The relatively long survival rate of pathogens in the soil, resistance to unfavorable environmental (weather) conditions, and the possibility of migration deeper into the soil profile and groundwater may cause microbiological contamination of the natural environment [16,17]. Recently, there have been more and more alarming reports of contamination of groundwater with pharmaceuticals and pathogenic bacteria as a result of their emission together with untreated, treated or pretreated wastewater (septic tank effluent, STE), discharged to the ground via soil infiltration systems (SIS) [18].

Finding a simple construction and technology useful for STE treatment would help to protect the environment from both physical–chemical pollution and pathogenic danger.

Textile filters have been found to be effective in the removal of physical and chemical pollution indicators [19–21]. However, one of their unidentified characteristics is the removal of bacteria, including pathogenic bacteria. It is important in regard to groundwater quality prevention and avoiding water well contamination.

These types of filters operating at a constant level of wastewater surface meet the requirements of the Polish regulation [22] on conditions to be met when introducing wastewater into waters or into the ground, and on substances particularly harmful to the aquatic environment) in reference to not exceeding the maximum permissible values of pollution indicators in terms of chemical oxygen demand (COD_{Cr}), BOD_5 and total suspended solids (TSS): 150 mg O_2 dm^{-3}, 40 mg O_2 dm^{-3} and 50 mg d.m. dm^{-3}, respectively [21].

BOD_5/COD ratio in wastewater is a popular and effective measure to assess biological stability. It fluctuates from 0.3 to 0.8 in raw domestic wastewater. However, this ratio is always changeable after a treatment process such as 0.4–0.6 and 0.1–0.3 in effluent of primary settling and final treatment, respectively [3]. The same result in the study of Abdalla and Hammam [23] that was the BOD_5/COD ratio dropped from 0.5 to 0.1 at a well-stabilized secondary effluent. The BOD_5/COD ratio also changes significantly in pond treatment and depends on the season [24].

The objective of the study was to assess the efficiency of textile filters according to indicator bacteria removal. This aspect is very important according to the possibility of treated wastewater reuse for flushing toilets supplying or plant irrigation.

An additional goal was to determine the pollutants removal efficiency at a relatively high COD_{Cr} to 5 d biochemical oxygen demand (BOD_5) ratio. This objective was justified by reports of high COD_{Cr}/BOD_5 ratios observed in field conditions at the high changeability of these pollution indicators [25].

2. Methods

In the research geotextiles made of polypropylene – an organic chemical compound, a polyolefin polymer – were used, due to the advantageous properties of this material (high chemical resistance, practical lack of wettability, the possibility of recycling after the end of use). Two filters (filter 1 and filter 2) made of eight layers of textile fabric TS 20 (8 × 0.9 mm = 7.2 mm thick) were used (Figs. 1 and 2). One of these two filters was treated as the main research object and the second one – only with the aim to verify the pollutants removal efficiency of the research filter. Construction and operation of textile filters for wastewater (STE) treatment were described in previous papers [19,21].

The level of wastewater surface was assumed to be steady as the fluctuations between the level of the overflow and the minimum level were no more than 5.0 cm (at the maximum level, from 32 to 35 cm).

The domestic wastewater used for the study came from a four-person household equipped with an on-site

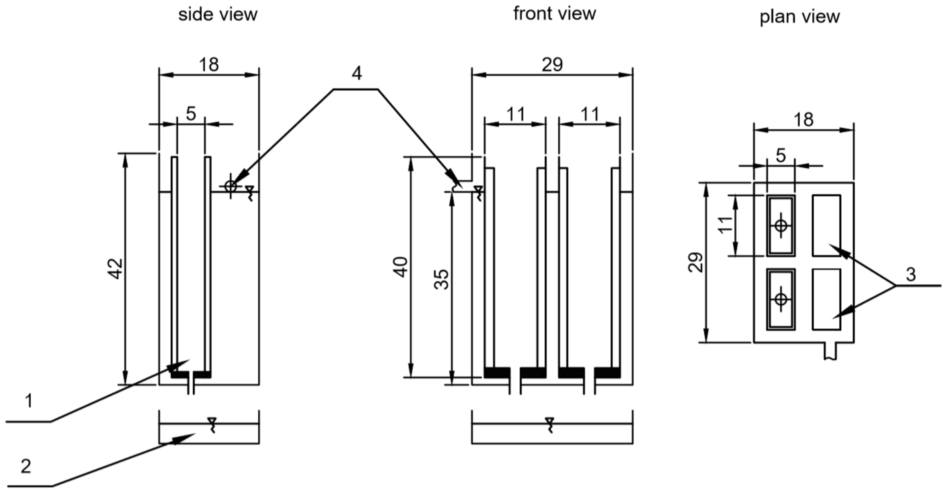

Fig. 1. Scheme of the filters (1 – non-woven textile filter; 2 – collecting tank for treated wastewater; 3 – space left after two filters dismantling; 4 – overflow; dimensions in cm).

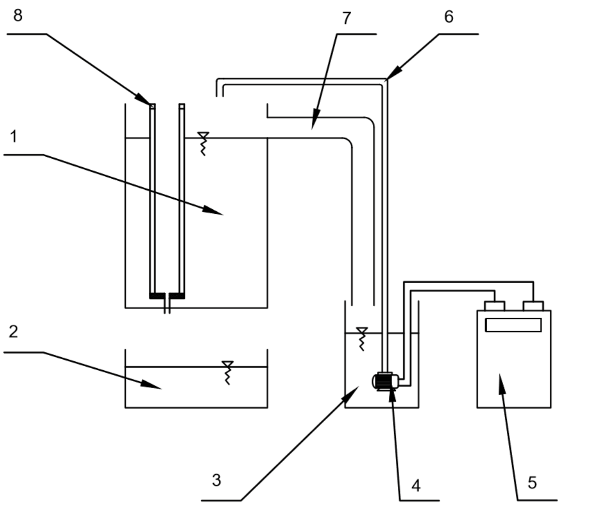

Fig. 2. Scheme of the experimental set-up (1 - reactor, 2 - collecting tank for filter outflow, 3 – storage tank, 4 – pump, 5 – controller , 6 – dosing pipe, 7 – overflow pipe, 8 - filter).

wastewater treatment plant consisting of a septic tank and SIS. The wastewater was taken from the STE in a period of several days, transported to the laboratory and stored in chambers of 20 dm^3 volume at room temperature.

Indicator bacteria were detected in a period of two weeks (12th–25th November). Five repetitions of each set of microbial analysis were performed. Three separate samples of the inlet wastewater (STE) and three samples of treated wastewater were collected for microbiological analyses once per week. The count of microorganisms in all samples was identified according to Lister's serial dilution method on the following selective substrates: *coliforms* – on ChromoCult® Coliform Agar ES (Merck KGaA, Darmstadt, Germany) substrate with peptone, galactopyranoside and glucuronic acid (Merck No. 1.00850.0500) at 37°C for 24 h; *Clostridium perfringens* – on Tryptose Sulphite Cycloserine (Merck, Warsaw, Poland) substrate with tryptose, sulfite and cycloserine (Merck No. 111972) under anaerobic conditions at 44°C for 24 h; *Escherichia coli* – on ENDO (Merck, Warsaw, Poland) (differentiating medium for *Enterobacteriaceae* bacteria, synonym: Endo C agar, Fuchsin lactose agar acc. to ENDO) agar with primary red (Merck No. 104044) at 35°C for 24 h; and total mesophilic bacterial count – on nutrient agar at 26°C for 48 h [26] (PN-EN ISO 6222:2004).

The *Escherichia coli* was finally identified biochemically by means of the Rapid ID 32E system (BioMérieux SA. Marcy-l'Etoile, France). The used set of indicator bacteria is comparable to ranges reported by other authors [27].

The samples of inlet and outlet wastewater (STE) were collected and analyzed once per week during the experimental period. The following parameters were analyzed: COD, BOD_5, total phosphorus, total nitrogen, ammonium nitrogen. COD was measured by the dichromate method (spectrophotometer Merck 142) and a direct reading from the spectrophotometer at 420 nm (DR/2000, HACH LANGE, Wroclaw, Poland). The BOD_5 was measured using the OxiTop® BOD system (WTW, Wroclaw, Poland). The total phosphorus, total nitrogen and ammonium nitrogen (N_{NH3}) concentrations were determined by (Merck, Germany) kits (Spectroquant® kits, Merck, Warsaw, Poland Nos. 14752 and 14773), respectively.

Determination of pollutants, defined as dissolved organic and nutrient compounds – chemical oxygen demand (COD_{Cr}), BOD_5, total nitrogen, ammonium nitrogen, and total phosphorus was performed for wastewater filtered through paper filters (with a pore size of 4–7 μm). The average values of pollution indicators in wastewater flowing into the filters were close to typical for the septic tank effluent: BOD_5: from 25.0 to 500.0 mg O_2 dm^{-3} (111.3 ± 39.6 mg O_2 dm^{-3} on average, n = 15); COD_{Cr}: 76.0 to 1,219.0 mg O_2 dm^{-3} (327.6 ± 84.2 mg O_2 dm^{-3} on average, n = 15); ammonium nitrogen: 16.4 to 129.0 mg N_{NH_4} dm^{-3} (45.36 ± 14.44 mg N_{NH_4} dm^{-3} on average, n = 8), total phosphorus: 4.1 to 37.2 mg P_{tot} dm^{-3} (13.43 ± 2.95 mg P_{tot} dm^{-3} on average, n = 15), total nitrogen: 12.0 to 28.0 mg N_{tot} dm^{-3} (20.33 ± 2.06 mg N_{tot} dm^{-3} on average, n = 9). The COD_{Cr}/BOD_5 ratio on average was 4.2.

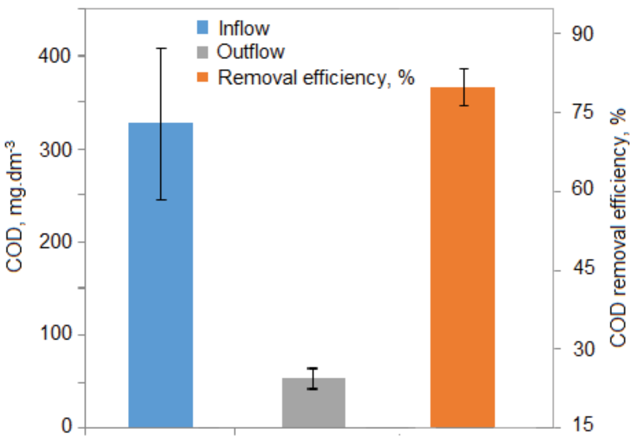

Fig. 3. Chemical oxygen demand (COD_{Cr}) removal efficiency.

The hydraulic capacity was measured as the averaged cumulated outflow volume for 4 h after every dose application. Bacteria and pollution indicators, and hydraulic capacities were measured from July 2017 to December 2018 with a short break between February 2018 and June 2018.

The obtained pollutant removal results were tested by using standard variance analysis (ANOVA) for the randomized complete block. Mean separations were made for significant effects with least significant difference (LSD) (Merck, Warsaw, Poland) and Tukey's test at the probability of $p = 0.05$. Statistical analyses in relation to indicator bacteria group removal were carried out using STATISTICA 10.0 software, license No JGNP 105B037825 AR-A from the University of Life Sciences.

3. Results and discussion

3.1. Bacteria removal efficiency

The filter inflow concentrations were 29.5 ± 0.2 – 388.4 ± 0.1 × 10^{-1} cfu mL^{-1}, 8.4 ± 0.2 – 21.7 ± 0.1 × 10^{-1} cfu mL^{-1}, 122 ± 0.1 – 453 ± 0.1 × 10^{-1} cfu mL^{-1}, 13.0 ± 0.1 – 190.1 ± 0.1 × 10^{-1} cfu mL^{-1}, for coliform bacteria, *Clostridium perfringens*, *Escherichia coli* and total mesophilic bacteria, respectively (excluding uncountable). The filter outflow concentrations were: undetected, 1.0 ± 0.1 – 7.2 ± 0.1 × 10^{-1} cfu m L^{-1}, 0–6.0 ± 0.1 × 10^{-1} cfu mL^{-1}, 3.7 ± 0.2 – 36.2 ± 0.2 × 10^{-1} cfu mL^{-1}, for coliform bacteria, *Clostridium perfringens*, *Escherichia coli* and total mesophilic bacteria, respectively (excluding uncountable). The results of indicator bacteria in inflow and outflow wastewater were shown in Tables 1–4.

The removal efficiencies of indicator bacteria were relatively high for *Escherichia coli* (2.1–2.5 log), differentiated for the other indicators *Clostridium perfringens* (0.59–1.11 log), coliforms (0.58–1.55 log) and total mesophilic bacteria (0.56–0.97 log). In the first series (term I) the removal efficiencies of *Escherichia coli* and total mesophilic bacteria were impossible to calculated due to the uncountable number of CFU.

3.2. Statistical analysis in relation to indicator bacteria groups

Statistical analyses in relation to indicator bacteria group removal were carried out using standard variance analysis (ANOVA) for the randomized complete block. Mean separations were made for significant effects with LSD and Tukey's test at the probability of $p = 0.05$, using Statistica 10.0 software, license No JGNP 105B037825 AR-A from the University of Life Sciences.

The results showed that the changeability of inflow indicator bacteria concentrations was slightly higher than the differences between outflow indicator bacteria concentrations (Tables 5–8). However, differences between inflow and outflow indicator bacteria concentrations for particular terms were in most cases statistically significant.

Table 1
Number of coliforms in inflow and outflow and removal efficiency

Sample of wastewater	I term	II term	III term
Inflow, 10^1 cfu mL^{-1} of wastewater (average ± SD)			
1	327.2 ± 0.1	45.1 ± 0.1	29.5 ± 0.2
2	359.9 ± 0.1	59.4 ± 0.2	42.2 ± 0.1
3	388.4 ± 0.1	54 ± 0.1	42.6 ± 0.1
Outflow, 10^1 cfu mL^{-1} of wastewater (average ± SD)			
1	0	0	0
2	0	0	0
3	0	0	0
Removal efficiency			
Average	1.55 log	0.72 log	0.58 log

Table 2
Number of *Clostridium perfringens* in inflow and outflow

Sample of wastewater	I term	II term	III term
Inflow, 10^1 cfu mL^{-1} of wastewater (average ± SD)			
1	21.7 ± 0.1	10.9 ± 0.2	21.1 ± 0.1
2	20.0 ± 0.1	8.4 ± 0.2	12.5 ± 0.2
3	20.7 ± 0.2	18.1 ± 0.1	16.1 ± 0.1
Outflow, 10^1 cfu mL^{-1} of wastewater (average ± SD)			
1	7.2 ± 0.1	0	0
2	3.5 ± 0.1	2.2 ± 0.1	2.0 ± 0.1
3	6.1 ± 0.2	1.6 ± 0.1	1.0 ± 0.1
Removal efficiency			
Average	0.59 log	0.89 log	1.11 log

3.3. Efficiency of organic compounds and nutrients removal

The effectiveness of the removal of dissolved organic substances expressed as COD_{Cr} was 79.88% ± 3.59% (n = 15) (Fig. 3). The inflow COD_{Cr} values were in the range between 76.0 and 1,219 mg O_2 dm^{-3} (n = 15). The outflow COD_{Cr} values were in the range between 5.0 and 119.0 mg O_2 dm^{-3}.

The effectiveness of the removal of dissolved organic substances expressed as BOD_5 was 71.02% ± 6.66% (n = 15) (Fig. 4). The inflow BOD_5 values were in the range between

Table 3
Number of *Escherichia coli* in inflow and outflow

Sample of wastewater	I term	II term	III term
Inflow, 10^1 cfu mL–1 of wastewater (average ± SD)			
1	Uncountable	122 ± 0.1	202 ± 0.1
2	Uncountable	145 ± 0.1	357 ± 0.1
3	Uncountable	125 ± 0.1	453 ± 0.1
Outflow, 10^1 cfu mL^{-1} of wastewater (average ± SD)			
1	5.0 ± 0.1	0	0
2	4.0 ± 0.1	0	0
3	6.0 ± 0.1	0	0
Removal efficiency			
Average	–	2.11 log	2.50 log

Table 4
Total mesophilic bacterial count in inflow and outflow

Sample of wastewater	I term	II term	III term
Inflow, 10^1 cfu mL^{-1} of wastewater (average ± SD)			
1	Uncountable	190.1 ± 0.1	145.1 ± 0.2
2	Uncountable	117.7 ± 0.1	45.1 ± 0.1
3	Uncountable	46.1 ± 0.1	13.0 ± 0.1
Outflow, 10^1 cfu mL^{-1} of wastewater (average ± SD)			
1	14.6 ± 0.1	3.7 ± 0.2	7.1 ± 0.1
2	36.2 ± 0.2	19.5 ± 0.2	21.0 ± 0.2
3	24.3 ± 0.1	17.3 ± 0.1	12.2 ± 0.1
Removal efficiency			
Average	–	0.97 log	0.56 log

25.0 and 500 mg O_2 dm^{-3}. The outflow BOD_5 values were in the range between 5.0 and 40 mg O_2 dm^{-3} (except one case of very high inflow value 500 mg O_2 dm^{-3} – the outflow BOD_5 was 60 mg O_2 dm^{-3}.

Total nitrogen (N_{tot}) removal efficiency was relatively low – 44.84% ± 3.76% (n = 9) (Fig. 5). The outflow N_{tot} values were in the range between 7.0 and 17 mg N_{tot} dm^{-3}. However the N_{NH_4} removal efficiency was relatively high – 80.39% ± 10.66% (n = 8) (Fig. 6). The outflow N_{NH_4} values were in the range between 0.39 and 32.1 mg N_{NH_4} dm^{-3}.

Effectiveness of total phosphorus removal (P_{tot}) was 44.14% ± 5.79% (n = 14) (Fig. 7). The outflow P_{tot} concentrations were in the range between 3.4 and 10.1 mg P_{tot} dm^{-3}.

3.4. Statistical analysis in relation to differences between filters efficiencies in pollutants removal

The statistical result showed that the outflow rate (hydraulic capacity) was not significantly different between both filters at 95% confidence interval (ANOVA for the randomized complete block, mean separations for significant effects with LSD and Tukey tests). The concentration of COD_{Cr}, BOD_5, P_{tot}, N_{NH_4}, N_{tot} outflow and their removal efficiency was not significantly different between both filters at a 95% confidence interval.

Table 5
Statistical analysis results related to coliforms in inflow and outflow

Sample of wastewater	I term	II term	III term
Inflow 1	a	a	a
Inflow 2	a	a	a
Inflow 3	a	a	a
Outflow 1	0	0	0
Outflow 2	0	0	0
Outflow 3	0	0	0

Average values in the columns marked with the same letter do not differ significantly at the level of probability $p = 0.05$.

Table 6
Statistical analysis results related to *Clostridium perfringens* in inflow and outflow

Sample of wastewater	I term	II term	III term
Inflow 1	b	b	c
Inflow 2	b	b	b
Inflow 3	b	c	b
Outflow 1	a	0	0
Outflow 2	a	a	a
Outflow 3	a	a	a

Average values in the columns marked with the same letter do not differ significantly at the level of probability $p = 0.05$.

Table 7
Statistical analysis results related to *Escherichia coli* in inflow and outflow

Sample of wastewater	I term	II term	III term
Inflow 1	n/a	a	a
Inflow 2	n/a	a	b
Inflow 3	n/a	a	c
Outflow 1	a	0	0
Outflow 2	a	0	0
Outflow 3	a	0	0

Average values in the columns marked with the same letter do not differ significantly at the level of probability $p = 0.05$.

3.5. Hydraulic capacity

The flow rate (hydraulic capacity) was relatively stable (Fig. 8). The average flow rate was 0.86 cm d^{-1} ± 0.036 (n = 15).

4. Discussion

4.1. Bacteria removal efficiency

The microbial investigation results showed that the population of microorganisms of the *Enterobacteriaceae*

Table 8
Statistical analysis results related to total mesophilic bacterial count in inflow and outflow

Sample of wastewater	I term	II term	III term
Inflow 1	n/a	e	d
Inflow 2	n/a	d	c
Inflow 3	n/a	c	a
Outflow 1	a	a	a
Outflow 2	b	b	b
Outflow 3	a	b	a

Average values in the columns marked with the same letter do not differ significantly at the level of probability $p = 0.05$.

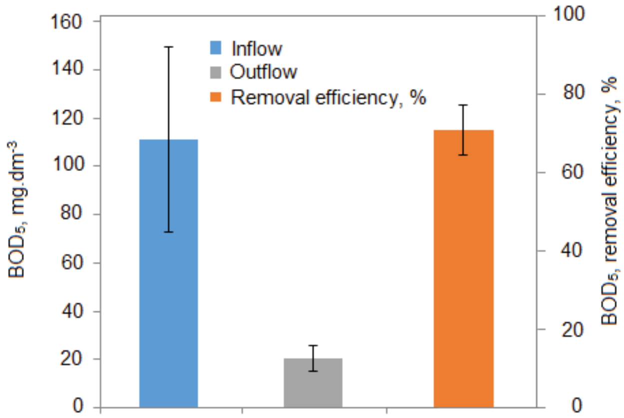

Fig. 4. Five-days biochemical oxygen demand (BOD_5) removal efficiency.

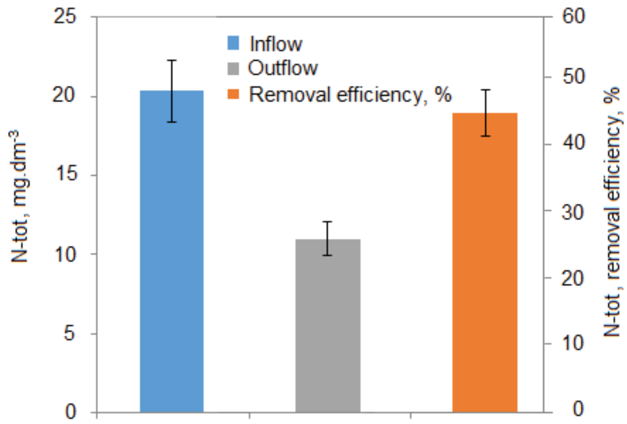

Fig. 5. Total nitrogen (N_{tot}) removal efficiency.

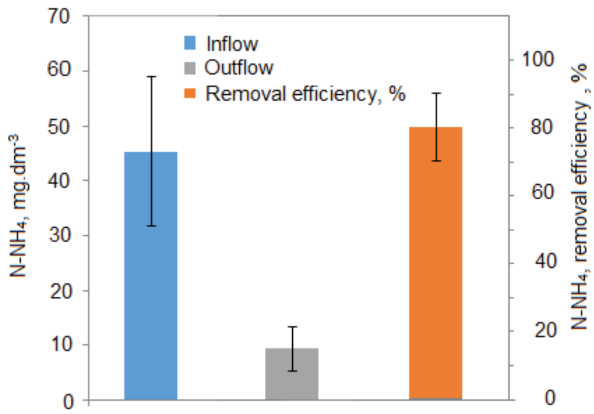

Fig. 6. Ammonium nitrogen (N_{NH_4}) removal efficiency.

family, *Clostridium perfringens* and *Escherichia coli* decreased with time. In the first term, the average count of this group of bacteria was two times greater than the average count in the second term. The analysis of the effect of the presented technology of STE biochemical treatment on the survival rate of selected microorganisms revealed that non-woven textile filtration is an effective method of elimination of these groups of bacteria. In comparison with the control sample, filtration eliminated nearly 100% of the rods in the first two terms of the experiment. A similar tendency of decreasing cell counts was observed in the case of total mesophilic bacteria.

It is worth noting that the high rate of indicator organisms and total mesophilic bacteria removal on textile filters could be related to the high number of heterotrophic bacteria inside and on the surface of textile filters detected during other studies carried out on this type of filters: 8.7×10^4 to 5.8×10^6 CFU cm^{-2} [28] and between 7.4×10^5 and 3.8×10^6 CFU on average per square centimeter [29]. Taking into account that the content of protozoa and metazoans was relatively high and abundant in different taxonomic groups [19], such as creeping ciliates ($4.1 \times 10^4 \pm 0.7 \times 10^4$ cm^{-2}), stalked ciliates ($3.1 \times 10^4 \pm 1.5 \times 10^4$ cm^{-2}) and nematodes ($8.3 \times 10^3 \pm 9.1 \times 10^2$ cm^{-2}) during studies carried out on this type of filters, one can assume that some pathogenic microorganisms could be trapped in the living biomass and subsequently eaten by higher taxonomic level groups.

There have not been established the requirements for on-site watering (irrigation) of plants (decorative plants and lawns) using treated domestic wastewater.

The results obtained in this study can be to some extend compared to Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse [30]. The proposal of this regulation determines four classes (A, B, C, D). For classes B, C and D, BOD_5 and TSS are determined according to Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment [31]. For class A they are determined as less than 10 mg dm^{-3} for the both indicators. Additional criteria are determined as *Legionella* spp. and intestinal nematodes. *Legionella* spp. indicator should be applied in case when there is risk of aerosolization (≤1,000 CFU dm^{-3}) and intestinal nematodes (helminth eggs) should be detected when irrigation of pastures or fodder for livestock (≤1 egg dm^{-3}). Polish requirements corresponding to Directive 91/271/EEC for wastewater flowing out from plants located outside 2000 PE agglomerations are: 40, 150 and 50 mg dm^{-3} for BOD_5, COD and TSS respectively, so the BOD_5 and COD content in treated wastewater obtained in this study are thus related to sanitary requirements included in Proposal for a Regulation of the European Parliament

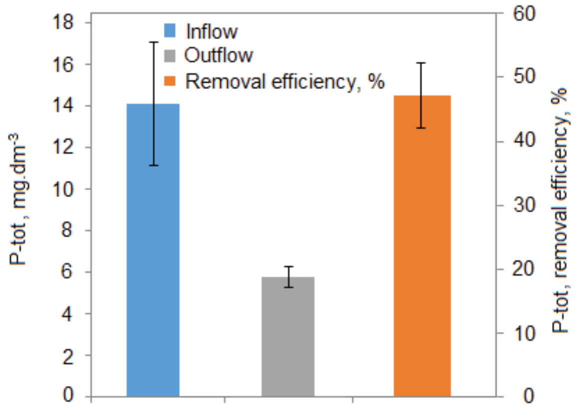

Fig. 7. Total phosphorus (P_{tot}) removal efficiency.

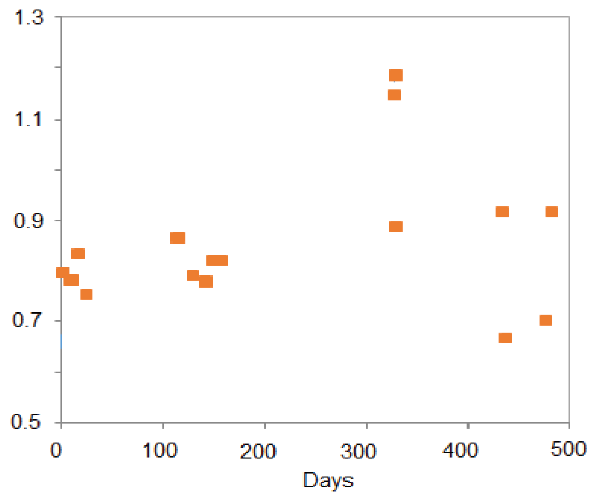

Fig. 8. Hydraulic capacity (cm d^{-1}).

and of the Council on minimum requirements for water reuse also.

In case of *E. coli* indicator – results obtained in this study fulfill the requirements for the all four classes – below 10 CFU in 100 cm^3 (class A), below 100 CFU in 100 cm^3 (class B), below 1,000 CFU in 100 cm^3 (class C) and below 10,000 CFU in 100 cm^3 (class D).

Seven samples from 24 of BOD_5 content in treated wastewater exceeded European Parliament recommended value – 10 mg dm^{-3}.

TSS was not detected in this study due to the difficulties related to differentiation of suspended solids originated from inflowing wastewater and biomass detached from textile layer. The high concentration of TSS occasionally observed in effluent from filters was probably related to the detachment of excessive biomass, rather than to the suspended solids inflowing to the filters with the STE, as was indicated periodically by higher concentrations of TSS in the outflow from filters than in STE.

The concentrations of bacteria were low at the inflow of the filter probably because of the long time of retention (inside the septic tank and in the laboratory), what caused decrease in the easy acceptable organic matter (confirmed by the high COD/BOD_5 ratio). Probably the concentration of bacteria in a fresh domestic wastewater would be much higher and the same bacteria removal efficiency would be higher in this case. It can be formed the hypothesis that there is some analogy between dissolved pollutants removal efficiency and bacteria removal efficiency - the higher removal efficiency was observed for higher inflow values, what could suggest that in both cases (dissolved pollutants removal efficiency and bacteria removal efficiency) the removal process rate is of one order.

4.2. Efficiency of pollutants removal

The efficiency of organic compounds removal was not the main goal of the study, but it was investigated with the aim of verification of this feature regarding the long-term operation effect. The relatively high COD_{Cr} to BOD_5 ratio of inflowing wastewater, equal to 4.2. was observed in this study. Such a ratio could occur in a wastewater filling septic tank when the users are not at home (e.g., during holidays) and then leaving the septic tank. Due to the several-day period of storage at a relatively high temperature (summer season) the easily biodegradable compounds (BOD_5) are degraded relatively fast comparing to the total organic compounds (COD_{Cr}), what causes that the COD_{Cr}/BOD_5 ratio increases from the typical about 2.0 up to 3.0 or even more.

The results of the effectiveness of removal of dissolved organic substances expressed as COD_{Cr} (79.88%) were even slightly better than those obtained during the previous study [21]: 76.0% for the eight-layer filter no. 1 and 75.1% for the eight-layer filter no. 2. The outflow COD_{Cr} values (5.0–119.0 mg O_2 cm^{-3}) meet the requirements of the regulation in terms of not exceeding the maximum permissible values (150 mg O_2 cm^{-3}) of pollutant indicators for wastewater introduced into surface waters or into the ground for PE below 2000 [22] (Ordinance of the Minister of Maritime Economy and Inland Navigation of 12 July 2019). It is worth noting that the lower limit of several (5–8) mg O_2 cm^{-3} resulted from biomass activity.

The results of the effectiveness of removal of dissolved organic substances expressed as BOD_5 (71.02%) were similar to the efficiencies of BOD_5 removal by the same (eight-layer) thickness filters (71.7% ± 3.7% and 73.1% ± 2.5%) investigated previously [21]. The outflow BOD_5 values (5–40 mg O_2 cm^{-3}) meet (excluding three values for one series when the inflow value was extremely high – about one order of magnitude than the average – 500 mg O_2 cm^{-3}) the requirements of the regulation in terms of not exceeding the maximum permissible values (40 mg O_2 cm^{-3}) of pollutant indicators for wastewater introduced into surface waters or into the ground for PE below 2000.

The BOD_5 removal efficiency was slightly worse than COD_{Cr} removal efficiency. It could be related to two factors. The first factor could be a relatively high concentration of microorganisms in inflowing wastewater (STE) and in the filtering layer, so the demand for oxygen might not be the result of organic pollutants only but also of high concentration of organisms. The second factor is related to the methodological procedure – the relatively low accuracy of BOD_5 measurements (±5.0 mg O_2 cm^{-3}), which could give a significant error at low BOD_5 inlet and outlet values.

The average biomass load of organic matter (expressed as BOD_5) was from 0.04 to 0.07 mg O_2 mg^{-1} d^{-1}, at the filtration velocity 0.90 ± 0.04 cm d^{-1}. A load of organic pollutants less than 0.1–0.2 mg O_2 mg^{-1} d^{-1} gives, according to literature data [32], the ability to remove organic compounds with high efficiency.

N_{tot} removal efficiency was relatively low (44.84%), but the N_{NH_4} removal efficiency was relatively high (80.39%). It means that the nitrification process was intensive and highly effective. Ammonium nitrogen removal efficiency was much better than the ammonium nitrogen removal efficiency obtained during the previous study carried out on this type of filter (28.8% ± 3.66%, *n* = 34) [21].

The effectiveness of the removal of P_{tot} (44.14%) was typical for bioreactors with attached biomass with natural ventilation (trickling filters). In one case the outflowing P_{tot} concentration value was higher than the inflow one, but the inflow value was very low (4.1 mg X cm^{-3}) and in these terms, at limited outflowing values due to the biological activity (between 3.4 and 10.1 mg P_{tot} cm^{-3} and about 5 mg P_{tot} cm^{-3} on average) no removal could be observed. Total phosphorus removal efficiency during the previous study was similar – 39.1% ± 2.8%, *n* = 14 for filter no. 1, and 37.6% ± 3.3%, *n* = 15 for filter no. 2 [21]. For all pollution indicators, the higher removal efficiency was observed for higher inflow values.

The statistical results showed that outflows from filters were not significantly different at a 95% confidence interval, which confirmed that removal of pollutants can be achieved by different filters of the same construction at the same removal efficiency.

4.3. Hydraulic capacity

It is worth noting that these filters, investigated previously, after a much shorter time of operation, were similarly effective according to the flow rate. It shows that for long-term operation the flow rate does not decrease and remains at about 0.9–1.0 cm d^{-1}. It is caused by gravitational removal of excess sludge (biomass) from the vertically situated filtering textile layer.

The hydraulic capacity did not change significantly during the period over 15 months. The results related to this technology were mentioned in the previous papers [19–21] and suggested long-term hydraulic capacity stabilization at a value of about 1–2 cm d^{-1}. This phenomenon can be explained by the excess biomass gravitational removal from the vertically situated filtering layer. The reactor also plays the role of a settler. However, it is difficult to calculate the real retention time because the rate of mixing during the application of doses is unknown. On the other hand, the low hydraulic capacity of the filter does not cause any local currents, and the time between dose applications is almost 4 h (dosing every 4 h and time of dosage equal to 10 s).

The changeability of filter capacity could be the result of *Psychoda* spp. larvae activity, which "drill" micro-canals in the filtering biomass. On the one hand, it can sometimes make the outflow quality worse and destabilize the capacity, but on the other hand, their activity can be considered as one of the main factors of clogging prevention. There are many literature reports indicating that these organisms perform such a function in wastewater treatment systems with relatively large pore sizes, such as conventional trickling filters [33].

The evaluation of the effectiveness of purification by the nonwoven filter was hampered by the periodic activity of flies, *Psychoda* spp.

5. Conclusions

Based on the results of this research the following conclusions can be drawn:

- The removal efficiencies of indicator bacteria were relatively high for *Escherichia coli* (2.1–2.5 log), differentiated for the other indicators *Clostridium perfringens* (0.59–1.11 log), coliforms (0.58–1.55 log) and total mesophilic bacteria (0.56–0.97 log).
- The removal efficiencies of organic pollutants (detected as COD_{Cr} and BOD_5) were relatively high (79.88% for COD_{Cr} and 71.02% for BOD_5) and were higher when the inflow concentrations were higher.
- The hydraulic capacity of the textile filter for wastewater (STE) treatment decreases with the time of operation, reaching the minimum value of long-term operation flow rate (after 2–3 y) about 0.9–1.0 cm d^{-1}, concentration in inflowing wastewater. This phenomenon can be explained by the excess biomass gravitational removal from the vertically situated filtering layer.
- Despite the relatively high COD_{Cr} to BOD_5 ratio of inflowing wastewater, equal to 4.2, resulting from simulation of several days storage of wastewater in ST in terms of users' absence (holiday trip), the organic dissolved compounds (detected as COD_{Cr} and BOD_5) and nutrients removal efficiency was acceptable and met the requirements of Polish law.

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