Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.25738

199 (2020) 241–251
September

Impact of artificial infiltration on removal of surfactants in surface water treatment process

Dorota Cierniak[a], Zbysław Dymaczewski[b,*], Joanna Jeż-Walkowiak[b], Aleksandra Makała[b], Bogdan Wyrwas[a]

[a]*Institute of Chemistry and Technical Electrochemistry, Poznan University of Technology, Berdychowo 4, 60-965 Poznań, Poland, emails: dorota.cierniak@doctorate.put.poznan.pl (D. Cierniak), bogdan.wyrwas@put.poznan.pl (B. Wyrwas)*
[b]*Institute of Environmental Engineering and Building Installations, Poznan University of Technology, Berdychowo 4, 60-965 Poznań, Poland, emails: zbyslaw.dymaczewski@put.poznan.pl (Z. Dymaczewski), joanna.jez-walkowiak@put.poznan.pl (J. Jeż-Walkowiak), aleksandra.makala@doctorate.put.poznan.pl (A. Makała)*

Received 25 September 2019; Accepted 12 February 2020

ABSTRACT

Surface-active compounds currently detected in natural waters pose a threat to the environment. Their presence negatively affects self-cleaning processes by foaming water, resulting in oxygen deficiency and eutrophication of water reservoirs. Getting into the human body with the consumed water, they can cause disease. Apart from adsorption, membrane filtration, and filtration through biologically active beds, the methods of removing surface-active compounds from treated water can also include the process of artificial infiltration. Infiltration is a process of pretreatment of captured surface water, using the forced flow of intaken surface water through the ground. The adsorption, filtration, and biodegradation processes occurring in the soil change the water quality characteristics from the surface to groundwater. In the infiltration process, organic, and biogenic admixtures, as well as color, are removed from the water and microbiological parameters are reduced. The paper presents the results of research on the artificial infiltration process in terms of removing non-ionic and anionic surfactants from the water taken. The study of the content of non-ionic surfactants was carried out using the iodobismutane method for the determination of oxyethylates with the final measurement of absorbance of bismuth-thiourea. A simplified method for the determination of anionic surfactants using methylene blue was used to measure the concentration of anionic surfactants. The tests were carried out on a field research installation, consisting of three piezometers drilled on the way of water flow from the infiltration pond to the well-receiving infiltration water. Water intake from subsequent piezometers allows the assessment of the effects of admixture removal as a function of the length of the infiltration path and the time of retention in the ground. A decrease in the concentration of test substances was observed during the migration of water from the infiltration pond to the collecting well.

Keywords: Infiltration; Anionic surfactants; Non-ionic surfactants; Surface water; Water treatment

---

1. Introduction

The common use of synthetic surfactants began in the middle of the 20th century. The intensive economic growth and demographic boom observed recently in some regions in the world resulted in an increased demand for surfactants in both household and industrial sectors [1,2].

Currently, anionic compounds are characterized by the highest market share among all the produced surfactants,

---

* Corresponding author.

Presented at the 14th Conference on Microcontaminants in Human Environment, 4–6 September 2019, Czestochowa, Poland

which covers almost 50% of the total global production. The share of the non-ionic surfactants is equal to approximately 30% and is constantly growing. The share of non-ionic surfactants in EU countries is currently estimated at approximately 50%, of which over 60% are oxyethylates. Participation of different regions in the global consumption of surfactants is also changing. Ten years ago, both USA and EU consumed one-third of the total production, while recently the Asia and Pacific regions became the biggest consumers, which utilize almost 40% of the global production that corresponds to over a dozen million tons per year [1,2].

The increased consumption of surfactants, result in their increased discharge to natural waters. The first negative effects on the environment, observed as foam on the surface of natural aquatic reservoirs and even in potable water, were noticed very soon. Increased amount of surfactants in water negatively influences the growth of algae and other microorganisms and interferes with the trophic chain of aquatic creatures [3]. Uncontrolled introduction of surfactants to natural water reservoirs causes the disruption of water self-cleaning processes and bioaccumulation of harmful substances in the environment, which – in consequence – may become dangerous for any life-forms, including humans. Most of the surface-active agents do not exhibit acute toxicity toward any organisms at concentrations usually found in the environment and chronic toxicity is usually above 0.1 mg/L [4]. However, the metabolites of non-ionic surfactants, especially alkylphenols, have been recognized as dangerous due to their high resistance on biodegradation, toxicity, and strong estrogenic activity [4–8]. Threats concerning the negative impact of micropollutants on the environment and human health have become more and more important along with the increase of social awareness and new results of scientific studies. This especially applies to situations when discharged sewage is introduced to rivers which are the source of potable water for cities [9]. This is one of major driving forces for monitoring of micropollutants in the environment and protecting against their migration to soil and water, although legal regulations in this regard are still imperfect [10,11].

The selection of appropriate technological processes in water treatment plants and water reclamation systems is associated with the presence of various organic micropollutants in raw water [12,13]. However, the most commonly used and simplest processes of surface water treatment are usually ineffective in terms of removal of micropollutants, especially in case of compounds which belong to the group of contaminants of emerging concern [11,14,15].

Numerous water treatment plants are based on a multibarrier approach, which ensures a high degree of operational safety in terms of removing biological and chemical contaminants from water during both normal operation and emergency situations [11,13]. Artificial infiltration may be considered as an additional barrier, which is a very effective and sustainable method of surface water treatment used worldwide [16–19]. The composition of surface water after infiltration becomes similar to groundwater in terms of quality. Implementation of the infiltration ponds into the treatment system reduces the color, turbidity, organic compounds content, and microbiological parameters, however, the iron and manganese concentrations may increase [18,20]. The temperature of water is more stable throughout the year. The quality of water is more uniform throughout the whole year. Artificial infiltration allows to notably simplify the treatment of surface water, usually in this case the technology consists of processes typical for groundwater treatment aeration and rapid filtration [21,22].

The goal of this research is to confirm the hypothesis that the infiltration combining biochemical and physical processes might be considered as an additional barrier for some emerging contaminants, such as surfactants. To confirm the hypotheses, the experimental approach focused on investigation of the effect of artificial infiltration on the removal of surfactants from surface river water and determination of conditions which affect the process. During the research, the removal of anionic and non-ionic surface active agents was investigated. The effectiveness of the process was related to the duration of water passage through the ground during infiltration.

2. Materials and methods, experimental installation

The research presented in this report was conducted at the Debina artificial infiltration intake which supplies the city of Poznan with water. The Warta River water is pumped with no treatment to the infiltration ponds at the intake.

The balance of raw water directed from Debina intake to the water treatment system is as follows: artificial infiltration – approximately 70%, riverbank infiltration – approximately 20%, groundwater – approximately 10% [23].

The experimental installation consisted of three metering wells (piezometers – marked as PP-1, PP-2, and PP-3 – located on the way between the bank of the infiltration pond (one of 27 operated ponds at the intake) and one of the intake wells included in the water collecting system – levar II. The levar II collects water from 92 wells with average capacity of 1,200 m^3/h. The infiltration pond is 750 m long and approximately 20 m wide at the bottom. The metering wells are 5.5, 7.5, and 9.5 m deep. The diameter of these metering wells is equal to 10 cm.

The cross-section of the infiltration path is shown in Fig. 1. The depth of piezometers is correlated with the infiltration water level in the ground.

The infiltration water passage starts at the bottom of the pond, enters the ground (aeration and saturation zones), with three piezometers on its way, and ends in the well S-48. The passage direction is perpendicular to the line of the pond bank and the line of collecting wells. The distance between the pond bank and each of the measuring points is given in Table 1.

During the research, samples of water were collected from the pond, three piezometers and the S-48 well. The samples were collected every 2–4 weeks starting from January to June 2019. The chemical analysis of water samples from the measuring points allowed to evaluate the changes of the concentration of selected contaminants during the infiltration process.

The analyses of surfactants were carried out using a V-530 UV-Vis spectrophotometer (Jasco, Japan) with the ability to acquire spectra in the range of 200–1,100 nm. The spectra were recorded using a standard PC. Glass cuvettes were used in the studies (10 mm × 10 mm × 30 mm) with a

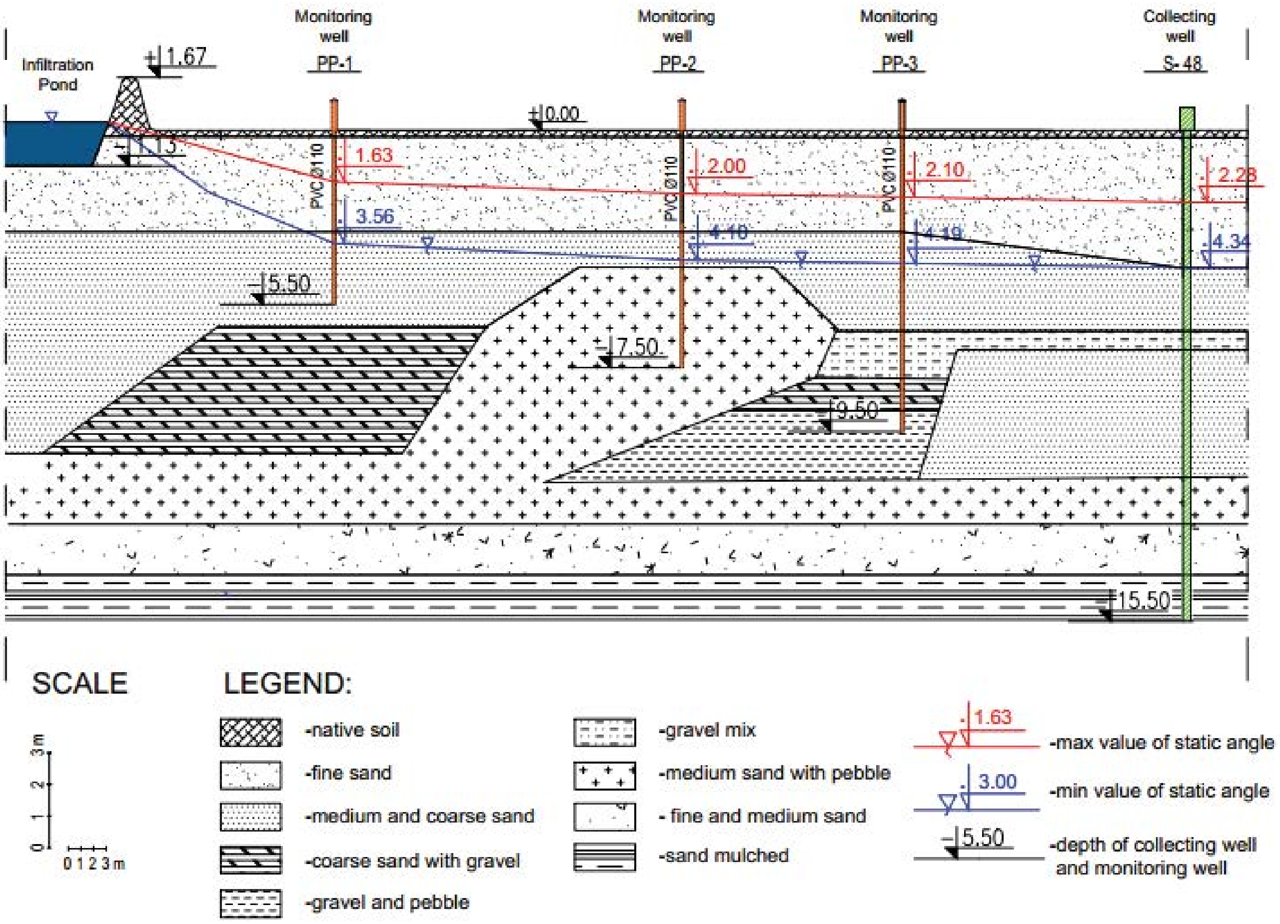

Fig. 1. Cross-section of the infiltration path.

Table 1
Distance of measuring points from the bank of the pond

Sampling points (Fig. 1)	Distance from pond bank (m)
PP-1	18.00
PP-2	45.50
PP-3	62.90
S-48 well	85.90

10 mm optical path length. The absorbance for wavelength λ_{max} = 650 nm was used as the analytical signal for determination of anionic surfactants, whereas the wavelength λ_{max} = 468 nm was used in case of non-ionic surfactants.

The Methylene Blue active substances (MBAS) method was used for determination of anionic surfactants based on Standard Methods and literature [24,25]. Demineralized water (100 mL), an appropriate amount of the sample containing anionic surfactants, 10 mL of carbonate buffer (pH = 10) and 5 mL of neutral methylene blue solution were introduced into a 250 mL separatory funnel. Next, chloroform was added in a stepwise manner using doses of 15, 10, and 10 mL. After each dose, the sample was shaken for 3 min and introduced to a second separatory funnel, which contained 110 mL of demineralized water and 5 mL of acidic methylene blue solution. After the shaking step, the chloroform phase from the first separatory funnel was introduced to a second separatory funnel, then shaken again in order to purify the blue chloroform extract. The extracts from the second separatory funnel were introduced to a volumetric flask (50 mL) and supplemented with chloroform to a final volume of 50 mL. The prepared solution was filtered using a paper filter to a glass cuvette and adsorption spectra were measured against chloroform at λ_{max} = 650 nm.

The mean result was obtained using three independent measurements for each sample. The relative standard deviation of the method is at 7.5%. Additionally, the correctness of the employed procedure was controlled by addition of a standard. The results of the measurements of anionic surfactants in the samples were investigated in relation to an anionic surfactant, sodium dodecylbenzenesulfonate.

In order to determine the limit of detection (LOD) (Table 2) and quantification (LOQ) of the method, the determination was repeated five times for blank samples and the parameters were determined based on the following relationships – Eqs. (1) and (2):

$$\text{LOD} = x_{\text{av}} + 3 \cdot \text{SD} \tag{1}$$

$$\text{LOQ} = 3 \cdot \text{LOD} \tag{2}$$

Table 2
Limit of detection and quantification of the MBAS method for blank samples

No.	Absorbance	Content (μg in the sample)
1	0.01899	1.177
2	0.02008	1.244
3	0.02139	1.325
4	0.02039	1.263
5	0.01771	1.097
Average value, x_{av}		1.221
Standard deviation (SD)		0.087
LOD		1.483
LOQ		4.450

where x_{av} is the mean value (mg in the sample); SD, standard deviation (mg in the sample).

In order to determine the precision of measurements (RSD, relative standard deviation) (Table 3), the analysis of a standard sample which included 10 mg of the analyte was repeated five times, and the parameter was determined based on Eq. (3):

$$\mathrm{RSD} = \frac{\mathrm{SD}}{x_{av}} \cdot 100\% \tag{3}$$

The modified BiAS-thio (Bismuth active substances) method was used for determination of non-ionic surfactants. The method is based on the formation of an oxyethylate precipitate using the Dragendorff's reagent which, after washing with glacial acetic acid, dissolves in an acidic thiourea solution and is subjected to spectrophotometric determination of bismuth as an equivalent of non-ionic surfactants. Approximately 1 mL of the solution including non-ionic surfactants and 1 mL of the modified Dragendorff reagent were introduced into centrifuge tubes. Next, the tubes were centrifuged (type 352 MPW, 12,000 rpm for 5 min). After precipitation and separation of the oxyethylate precipitate using the modified Dragendorff reagent, the solution was decanted and the orange precipitate was rinsed three times using 1 mL of glacial acetic acid in order to remove the residual Dragendorff reagent. The precipitate was dissolved in 2 mL of the dissolving-complexing solution (15% solution of thiourea in 1 M HNO_3) and placed in 1 cm glass cuvette. Absorbance was measured for λ_{max} = 468 nm against demineralized water. The relative standard deviation of the method is equal to 6.6%. The mean result was obtained using three independent measurements for each sample. Additionally, the correctness of the employed procedure was controlled by addition of a standard. The results were calculated using a model non-ionic surfactant – Triton X-100 [26–29].

In order to determine the LOD (Table 4) and LOQ of the method, the determination was repeated five times for blank samples and the parameters were determined based on the relationships given in Eqs. (1) and (2).

In order to determine the precision of measurements (RSD) (Table 5), the analysis of a standard sample which included 10 mg of the analyte was repeated five times, and the parameter was determined based on Eq. (3).

The determined precision for environmental samples in case of anionic surfactants was RSD = 6.75%, while in case non-ionic the value reached RSD = 9.59%.

The effect of infiltration process on the removal of organic contaminants was evaluated based on the following parameters: COD-Mn and TOC. The TOC analyses were carried out using the Multi N/C® 3100, Analytic Jena, Germany apparatus and MultiWin software. The chemical parameters of water quality were analyzed according to Standard Methods.

The retention time of infiltrated water in the ground was evaluated based on temperature measurements. The temperature of water was measured in the infiltration pond,

Table 3
Precision of the MBAS method, 10 μg DBSNa

No.	Absorbance	Content (μg in the sample)
1	0.15738	8.530
2	0.17159	9.410
3	0.18665	10.343
4	0.17785	9.798
5	0.16888	9.242
Average value, x_{av}		9.465
Standard deviation (SD)		0.673
RSD		7.11%

Table 4
Limit of detection and quantification of the BiAS-thio method for blank samples

No.	Absorbance	Content (μg in the sample)
1	0.01479	1.196
2	0.01418	1.146
3	0.01590	1.285
4	0.01734	1.402
5	0.01539	1.244
Average value, x_{av}		1.255
Standard deviation (SD)		0.097
LOD		1.547
LOQ		4.640

Table 5
Precision of the BiAS-thio method, 10 μg TX-100

No.	Absorbance	Content (μg in the sample)
1	0.13236	9.445
2	0.13458	9.625
3	0.15181	11.018
4	0.12811	9.102
5	0.12628	8.954
Average value, x_{av}		9.629
Standard deviation (SD)		0.821
RSD		8.53%

in piezometers, and in collecting well S-48 approximately 2 m below the water level, every 2–4 weeks.

3. Results, interpretation, and discussion

During the research conducted from January to June 2019, the quality of the Warta River was constantly monitored. The samples were collected every month. The values of selected water quality parameters are presented in Table 6 as arithmetic means and a range (minimum and maximum). The quality of water in the ponds is similar but not exactly the same as in the river, because of retention time and equalizing capabilities of the pond.

Seven research series were carried out during the entire study period. Each series consisted of six water samples (Warta, pond, three piezometers, and well), therefore 42 water samples were collected in total. The determined concentration values of anionic (AS) and non-ionic (NS) surface-active agents are listed in Table 7. The concentration of organic compounds in the collected samples was determined as chemical oxygen demand using potassium permanganate-$KMnO_4$ (COD-Mn) as a chemical oxidant and total organic carbon (TOC). The results of analyses are shown in Table 8. All results presented in Tables 7 and 8 are the arithmetic means calculated from two independent analyses.

The temperature of water was always measured in the infiltration pond, in the piezometers and in collecting well, approximately 2 m below the water surface. The temperature changes overtime during the research period are presented in Fig. 2. The upper graph is constructed based on temperature measurements from October 2018 to June 2019. To evaluate the retention time during the research regarding the removal of surfactants, the period starting from Spring 2019 was chosen as the most representative – lower graph. In spring, the temperature of water in the infiltration pond began to gradually increase with increasing air temperature. Each sampling point is represented by a separate line in the figure. The lines are inclined at a similar angle but shifted relative to each other. This observation allowed to estimate the approximate water flow time in the ground between particular points. The total retention time in the ground was estimated as 70 d.

The time of water passage through the ground results in water retention and creates the effects typical for slow sand filtration, in case of which biological processes play the main role in the removal of contaminants along with filtration, adsorption, and ion exchange. The water passes through the fine grains of soil and adsorption may occur [30].

The relationship between the concentration of surfactants and the infiltration distance for each research series was presented in Figs. 3 and 4. It is clearly visible that the

Table 6
Water quality of the Warta River during the research period

Parameter	Minimum	Maximum	Average
Anionic surfactant, mg/L	30.66	54.72	43.78
Non-ionic surfactants, mg/L	66.44	91.19	72.22
Colour, mgPt/L	15	50	37
Turbidity, NTU	2.52	4.35	3.44
COD-Mn, mgO_2/L	8.00	12.84	10.01
TOC, mg/L	8.54	25.98	14.90
Ammonium, $mgNH_4/L$	0.22	1.12	0.53
Nitrite, $mgNO_2/L$	0.04	0.42	0.23
Nitrate, $mgNO_3/L$	0.02	1.56	0.59
Orthophosphate, $mgPO_4/L$	0.004	0.033	0.018
pH	7.95	8.83	8.26

Table 7
Concentrations of anionic (AS) and non-ionic (NS) surfactants (mg/L) in all sampling points

Series no.	Date	Pond		PP-1		PP-2		PP-3		S-48	
		AS	NS	AS	NS	AS	NS	AS	NS	AS	NS
1	18.01.2019	25.58		15.18		12.42		8.42		13.61	
2	01.03.2019	43.50	100.47	10.36	98.33	17.20	91.97	14.23	83.8	11.44	92.83
3	15.03.2019	39.51	28.50	26.46	9.88	26.10	6.91	22.89	8.04	18.00	7.7
4	09.04.2019	57.91	50.65	27.07	36.80	36.70	26.79	35.49	28.42	30.17	24.80
5	16.04.2019	66.20	53.09	25.95	17.04	29.02	12.08	25.19	8.88		
6	14.05.2019	64.57	50.04	28.03	1.40	28.85	11.56	31.04	4.09	35.37	2.48
7	05.06.2019	49.90	50.18	25.56	4.90	30.00	5.01	30.67	7.08	29.24	8.64

Table 8
Organic compounds (mg/L) in all sampling points

Date	Pond		PP-1		PP-2		PP-3		S-48	
	COD-Mn	TOC	COD-Mn	TOC	COD-Mn	TOC	COD-Mn	TOC	COD-Mn	TOC
18.01.2019	6.80	4.56	5.00	1.82	5.10	0.83	4.80	0.00	4.10	0.38
01.03.2019	7.41	7.09	5.21	4.22	5.56	4.50	4.05	2.91	4.98	3.75
15.03.2019	8.80	9.23	5.50	5.32	5.00	3.72	4.50	3.13	4.70	4.98
09.04.2019	9.00	5.46	5.90	5.66	5.60	6.15	5.30	5.84	5.70	4.87
16.04.2019	8.20	8.97	5.20	4.82	5.00	5.50	5.00	5.27		
14.05.2019		8.86		4.53		3.90		4.46		4.97
05.06.2019	8.60	5.97	4.80	0.52	4.60	1.18	6.10	1.85	4.50	1.41

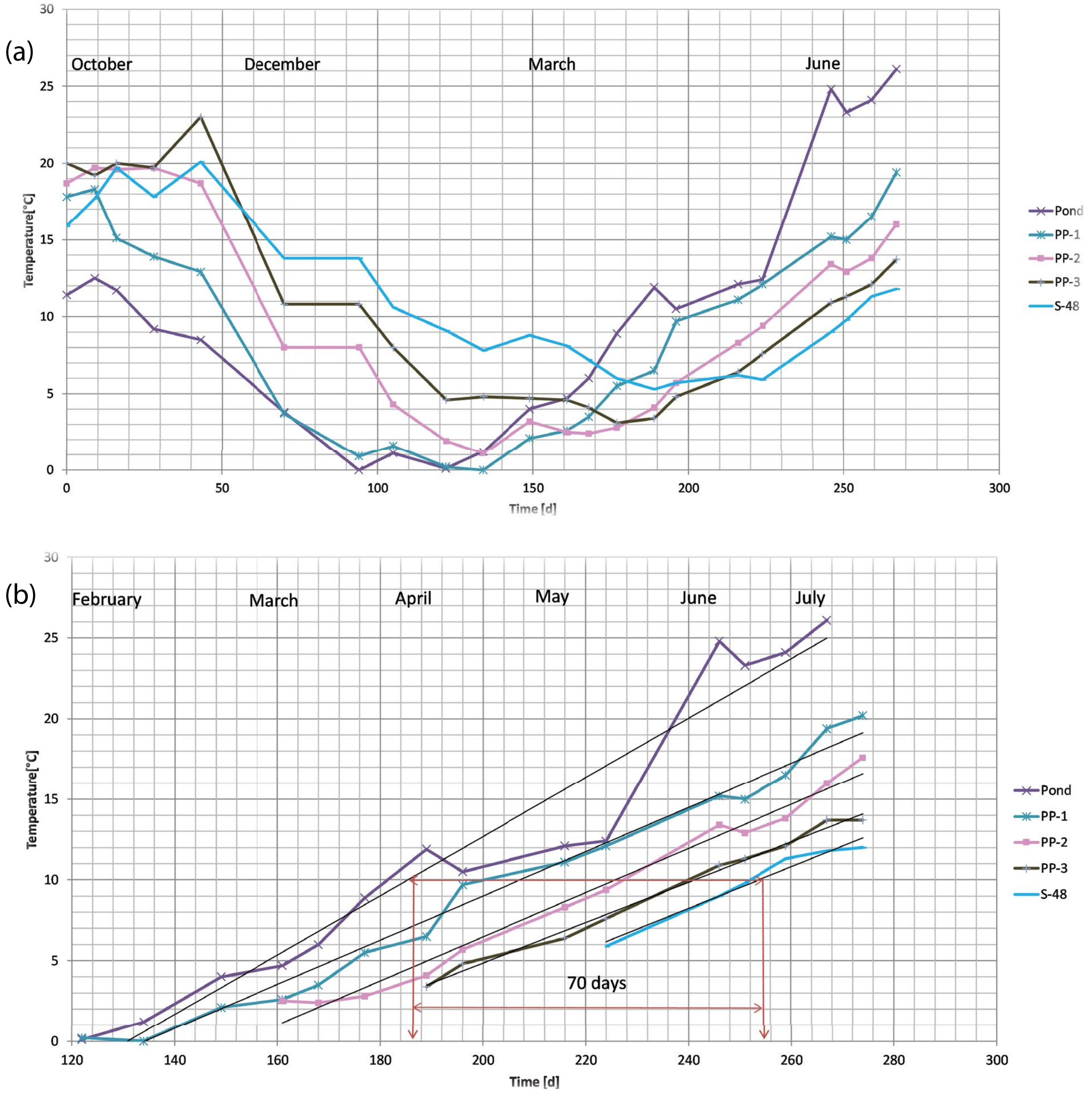

Fig. 2. Temperature changes in the sampling points during the research.

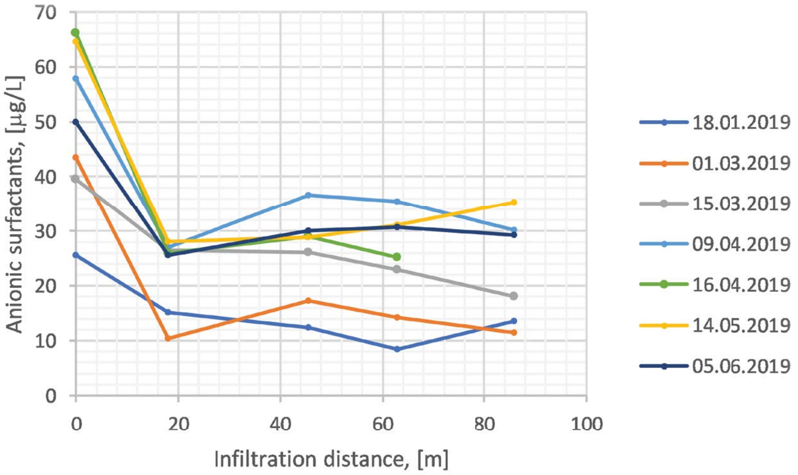

Fig. 3. Relationship between anionic surfactants concentration and infiltration distance.

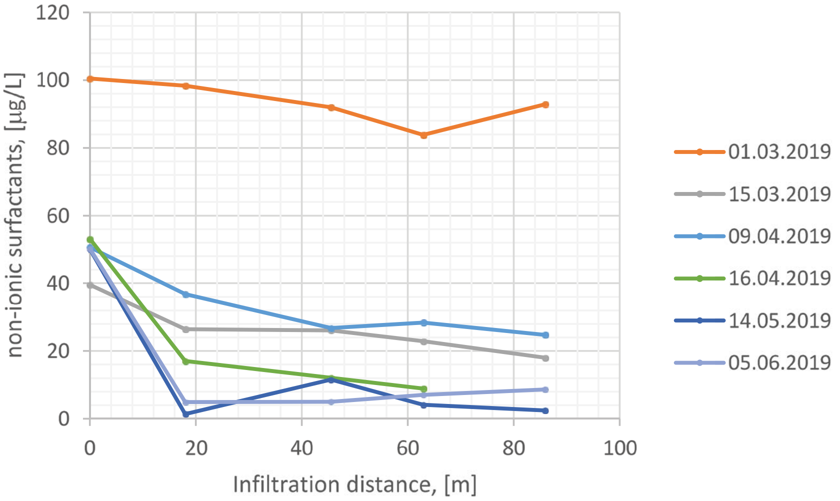

Fig. 4. Relationship between non-ionic surfactants concentration and infiltration distance.

most effective removal of both anionic (Fig. 3) and non-ionic (Fig. 4) surfactants occurred in the first part of the infiltration path between the pond and the monitoring well PP-1.

To quantify the results of infiltration with respect to the reduction of surfactant content, the removal efficiency of anionic and non-ionic surface active agents were calculated. The results presented in Table 9 show the efficiency of the process for the first part of infiltration distance from pond to the PP-1 (named E_{PP1}) and the total efficiency for the whole infiltration distance from the pond to the well S-48 (named E_{total}). The efficiency was calculated according to Eqs. (4) and (5):

$$E_{\text{PP1}} = \frac{C_{\text{pond}} - C_{\text{PP1}}}{C_{\text{pond}}} \cdot 100\% \tag{4}$$

$$E_{\text{total}} = \frac{C_{\text{pond}} - C_{\text{S48}}}{C_{\text{pond}}} \cdot 100\% \tag{5}$$

where C_{pond} is the concentration of surfactant in water from the infiltration pond, C_{PP1} is the concentration of surfactant in water from PP-1 monitoring well, C_{S48} is the concentration of surfactant in water from well S-48.

The temperature of water at the monitoring well PP-1 measured approximately 2 m below water level is also presented in Table 9. The temperature measured at PP-1 is representative for the conditions of the first part of infiltration distance in the ground.

The relationship between surfactants removal (E-PP1 and E-total) and water temperature in the ground is presented in Figs. 5 and 6. The effect of removal of non-ionic surfactants is correlated with temperature. The removal of non-ionic surfactants increased with the increase of water temperature. On the other hand, no strong correlation was established in case of removal of anionic surfactants and the temperature of water in the ground.

After penetrating into the ground, the water must pass the sediment layer formed at the bottom of infiltration ponds, which is usually characterized by a thickness of a few

Table 9
Surfactant removal efficiency calculated for the first and total distance of infiltration

Series no.	Date	Temperature of water in PP-1 (°C)	Anionic		Non-ionic	
			E-PP1 (%)	E-total (%)	E-PP1 (%)	E-total (%)
1	18.01.2019	0.9	41	47		
2	01.03.2019	2.1	76	74	2	8
3	15.03.2019	3.5	33	54	65	73
4	09.04.2019	6.5	53	48	27	51
5	16.04.2019	9.7	61	62	68	83
6	14.05.2019	12.1	57	45	97	95
7	05.06.2019	15.2	49	41	90	83

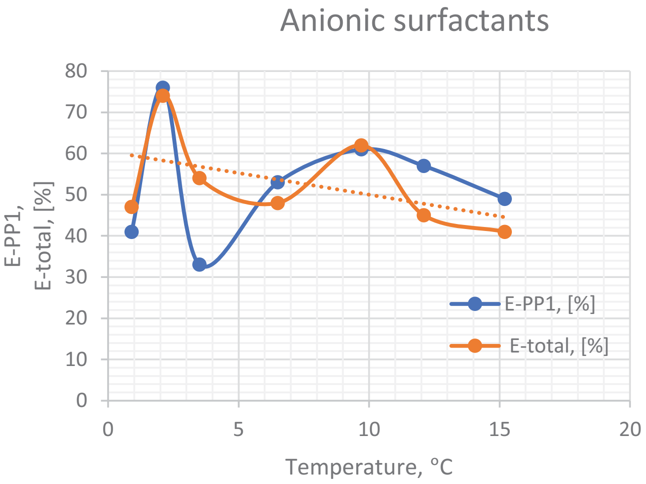

Fig. 5. Correlation between the removal of anionic surfactants and temperature of water in the ground.

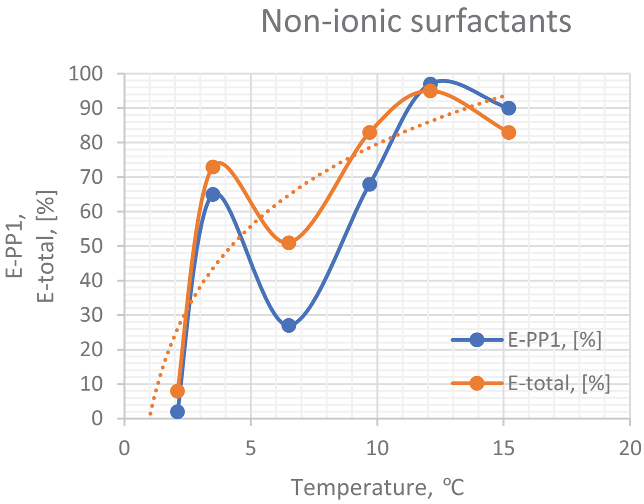

Fig. 6. Correlation between the removal of non-ionic surfactants and temperature of water in the ground.

centimetres. The sediment is a natural mineral and biological membrane at which mechanical filtration, ion exchange, adsorption, and biological processes occur and the majority of heterogeneous contaminants are separated [18,31]. Then, water passes through aeration and saturation zones. In the aeration zone, biochemical process, ion exchange, or adsorption occurs, resulting in the removal of organic and micropollutants. Afterwards, the concentration of organics and oxygen are diminished, autotrophic bacteria carry out the biodegradation process, and the concentration of carbon dioxide increases. The variety of treatment processes that occur during the infiltration allows for removal of different contaminants, including surfactants.

The correlation presented in Fig. 6 indicates the possible biodegradation of non-ionic surfactants because the effect of removal is strongly related to temperature. Non-ionic surfactants may be more readily biodegraded because there is no charge in the structure of the surfactant molecule and there is no interaction between the molecule and the cell wall of microorganisms with the negative charge, as in the case of anionic surfactants. Non-ionic surfactants are also considered less toxic than anionic surfactants. Non-ionic surfactant belongs to the V–VI class of toxicity. The observation of a very low removal effect at low water temperatures may confirm the significant role of biodegradation in the removal of non-ionic surfactants.

It can be observed that the concentration of anionic surfactants measured in the water from the metering wells (20 mg/L) is approximately two times higher compared to the concentration of non-ionic surfactants (10 mg/L). It may be because of the low biodegradability of anionic surfactants in anoxic conditions. This may result from the presence of an aromatic ring in the hydrophobic group of sodium dodecylbenzenesulfonate, which is constantly produced and used on a large scale, that impedes biodegradation, especially under anaerobic conditions, as well as the greater toxicity of anionic surfactants toward microorganisms and lower toxicity in case of non-ionic surfactants [32,33].

It should be noted that in surface waters anionic surfactants usually dominated in comparison to non-ionic surfactants. Production of surfactants is steadily increasing, and production of non-ionic surfactants has begun to outperform anionic production. Recent studies also confirm this and show the dominant content of non-ionic surfactants (74 mg/L on the average) compared to the average concentration of anionic surfactants (44 mg/L in

Warta River). In the infiltration pond, the concentrations of anionic and non-ionic surfactants remain at a similar level. A notable decrease of anionic surfactants content relative to non-ionic surfactants content occurs only at the PP-1 measuring point after passing through the bottom sediments and infiltration layers. This may result from the greater sorption of anionic surfactants relative to non-ionic surfactants [34].

The adsorption process is an effective method of removing contaminants of emerging concern from water. Adsorption allows to achieve a high removal efficiency of contaminants, but its performance depends on the type of adsorbent and parameters such as temperature, pH, and contact time [35,36]. The undoubted advantage is that adsorption is a physical process, which does not promote the formation of by-products that may be more toxic compared to the parent compounds [37–39].

The effectiveness of the adsorption process usually decreases with increasing temperature [30]. Since the effect of removal of anionic surfactants slightly decreases with temperature, it can be established that adsorption plays the main role in the removal of anionic surfactants, although biodegradation processes may occur as well.

The values presented in Table 8 as well as Figs. 5 and 6 indicate that the first part of the infiltration distance is crucial for removal of surfactants. The adsorption and biodegradation mainly occur in the sediment developed on the bottom of the infiltration pond. The role of the first distance from the pond to the PP-1 well is more visible in case of anionic surfactants than non-ionic surfactants.

The sediment deposited on the bottom of the infiltration pond also plays an important role in the removal of organic compounds. It may be illustrated by the decreasing content of organic compounds during the passage of water through the ground. The relationship of organic compounds concentration, measured as COD-Mn and TOC vs. infiltration distance is presented in Fig. 7. Values of TOC and COD-Mn presented in Fig. 7 are the average values of data collected in Table 8. The first part of the infiltration distance from the pond to the monitoring well PP-1 demonstrates the major removal of organic compounds as is in case of surfactant removal.

The majority of the commonly utilized anionic surfactants are relatively easily removed during pretreatment processes simultaneously with other pollutants. They are also readily biodegradable under aerobic conditions, resulting in low concentrations in the effluent from the wastewater treatment plant [40]. However, non-ionic surfactants, mainly oxyethylates, are only partially biodegradable by shortening their oxyethylene chain, which allows for the formation of more stable and toxic products. These metabolites are characterized by significant activity which disrupts the hormonal balance due to their similarity to natural estrogens [8,41].

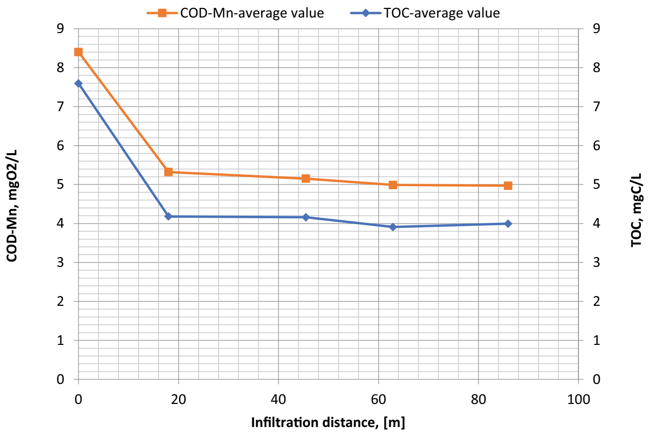

Fig. 7. Organic compound removal in infiltration process.

4. Conclusions

Numerous scientific reports confirm the presence of surfactant residues in surface waters and even groundwaters [4,42]. One of the main reasons is the insufficient removal of surface-active substances by commonly used wastewater treatment systems and formation of biodegradation metabolites, which are often much more hazardous for the environment than the parent pollutants. Usually, they are also more resistant to further biodegradation [43].

The contaminated surface water is the source used for the production of drinking water. The technological system of water treatment should be robust and consist of several barriers for contaminants such as surfactants and other emerging pollutants. The presented research confirms that artificial infiltration might be considered as an additional barrier with a potential for surfactant removal from natural surface waters.

The interpretation of results allowed to establish the following conclusions:

- the layer of sediment at the bottom of infiltration pond plays the main role in the removal of surfactants by adsorption and biodegradation processes. The major treatment effect occurs on the way from the pond to the first metering point – the PP-1 well. Further passage does not notably improve the quality of infiltrated water with respect to removal of surfactants as well as organic compounds.
- The results of the research indicate that the adsorption might be main process responsible for anionic surfactants removal in investigated infiltration process. The effect of removal decreases with the temperature, which is typical for the adsorption processes. However, biodegradation cannot be excluded. Literature reports confirm that anionic surfactants are readily biodegradable under aerobic conditions.
- In turn, biodegradation seems to be the main process responsible for removal of non-ionic surfactants in the infiltration process. The basis for this assumption is the correlation between non-ionic surfactant removal and the temperature of water in the ground. The effect grows with water temperature. If adsorption would be the leading process, the increasing temperature would rather inhibit surfactant removal. Another concern is the production of stable metabolites. The products of biodegradation may be toxic due to significant biological activity which disrupts the hormonal balance of organisms. The qualitative and quantitative characterization of metabolites is a goal for future studies.

- The overall removal efficiency is higher in case of non-ionic surfactants. The effectiveness of non-ionic surfactant removal at the temperature higher than 10°C was equal to 80%–100% for the investigated infiltration process, while the effectiveness of anionic surfactant removal was at the level of 40%–76%. The removal efficiency of non-ionic surfactants decreased to 8% only at a low temperature equal to 2°C–4°C, while removal of anionic surfactants at this temperature was equal 40%–46%, which is an additional confirmation that biodegradation of non-ionic surfactants occurred in the investigated infiltration system.

Acknowledgments

The research was financed from the PUT Research Project 01/13/SBAD/0913.

References

[1] M.I. Levinson, Surfactant Production: Present Realities and Future Perspectives, Vol. 142, U. Zoller, P. Sosis, Ed., Handbook of Detergents, Part F: Production, Surface Science Series, CRC Press, Boca Raton, 2008, pp. 1–38.

[2] CESIO, CESIO Industry Statistics, European Committee of Surfactants and their Organic Intermediates, 2017, Available at: https://www.cesio.eu/index.php/information-centre/industry-data (Accessed June 30, 2019).

[3] C.L. Yuan, Z.Z. Xu, M.X. Fan, H.Y. Liu, Y.H. Xie, T. Zhu, Study on characteristics and harm of surfactants, J. Chem. Pharm. Res., 6 (2014) 2233–2237.

[4] G.G. Ying, Fate, behavior and effects of surfactants and their degradation products in the environment, Environ. Int., 32 (2006) 417–431.

[5] G. Buttiglieri, T.P. Knepper, Removal of Emerging Contaminants in Wastewater Treatment: Conventional Activated Sludge Treatment, D. Barceló, M. Petrovic, Eds., Emerging Contaminants from Industrial and Municipal Waste, Springer, Berlin, Heidelberg, 2007, pp. 1–35.

[6] D. Barceló, M. Petrovic, Emerging Contaminants from Industrial and Municipal Waste: Removal Technologies, Vol. 5, Part S/2, Springer, Berlin, Heidelberg, 2008.

[7] S.K. Khetan, Endocrine Disruptors in the Environment, John Wiley & Sons, Hoboken, NJ, 2014.

[8] S. Siddique, C. Kubwabo, S.A. Harris, A review of the role of emerging environmental contaminants in the development of breast cancer in women, Emerging Contam., 2 (2016) 204–219.

[9] M.A.R. Cardenas, I. Ali, F.Y. Lai, L. Dawes, R. Thier, J. Rajapakse, Removal of micropollutants through a biological wastewater treatment plant in a subtropical climate, Queensland-Australia, J. Environ. Health Sci. Eng., 14 (2016) 14.

[10] N. Bolong, A.F. Ismail, M.R. Salim, T. Matsuura, A review of the effects of emerging contaminants in wastewater and options for their removal, Desalination, 239 (2009) 229–246.

[11] Y. Yu, Y.H. Choi, J. Choi, S. Choi, S.K. Maeng, Multi-barrier approach for removing organic micropollutants using mobile water treatment systems, Sci. Total Environ., 639 (2018) 331–338.

[12] R.I. Eggen, J. Hollender, A. Joss, M. Schärer, C. Stamm, Reducing the discharge of micropollutants in the aquatic environment: the benefits of upgrading wastewater treatment plants, Environ. Sci. Technol., 48 (2014) 7683–7689.

[13] D. Gologan, M.E. Popescu, The optimization of coagulation-flocculation process in a conventional treatment water plant, J. Environ. Sci. Toxicol. Food Technol., 10 (2016) 33–39.

[14] O.M. Rodriguez-Narvaez, J.M. Peralta-Hernandez, A. Goonetilleke, E.R. Bandala, Treatment technologies for emerging contaminants in water: a review, Chem. Eng. J., 323 (2017) 361–380.

[15] R. Tröger, P. Klöckner, L. Ahrens, K. Wiberg, Micropollutants in drinking water from source to tap-method development and application of a multiresidue screening method, Sci. Total Environ., 627 (2018) 1404–1432.

[16] R.R. Dash, J. Mehrotra, P. Kumar, T. Grischek, Lake bank filtration at Nainital, India, Hydrol. J., 16 (2008) 1089–1099.

[17] P.J. Dillon, M. Miller, H. Fallowfield, J. Hutson, The potential of riverbank filtration for drinking water supplies in relation to microsystin removal in brackish aquifers, J. Hydrol., 266 (2002) 209–221.

[18] S. Grünheid, G. Amy, M. Jekel, Removal of bulk dissolved organic carbon (DOC) and trace organic compounds by bank filtration and artificial recharge, Water Res., 39 (2005) 3219–3228.

[19] K. Dragon, J. Górski, R. Kruć, D. Drożdżyński, T. Grischek, Removal of natural organic matter and organic micropollutants during riverbank filtration in Krajkowo, Poland, Water, 10 (2018) 1457.

[20] W.J. Weiss, E.J. Bouwer, R. Aboytes, M.W. LeChevallier, C.R. O'Melia, B.T. Le, K.J. Schwab, Riverbank filtration for control of microorganisms: results from field monitoring, Water Res., 39 (2005) 1990–2001.

[21] I. Skoczko, J. Piekutin, K. Ignatowicz, Efficiency of manganese removal from water in selected filter beds, Desal. Water Treat., 57 (2016) 1611–1619.

[22] I. Skoczko, Efficiency estimation of water purification with various filtration materials, Desal. Water Treat., 134 (2018) 99–108.

[23] S. Kołaska, J. Jeż-Walkowiak, Z. Dymaczewski, Experiment in infiltration studies as a water treatment process, E3S Web Conf., 59 (2018) 01004-1–01004-11.

[24] M. Koga, Y. Yamamichi, Y. Nomoto, M. Irie, T. Tanimura, T. Yoshinaga, Rapid determination of anionic surfactants by improved spectrophotometric method using methylene blue, Anal. Sci., 15 (1999) 563–568.

[25] E. Jurado, M. Fernández-Serrano, J. Núñez-Olea, G. Luzón, M. Lechuga, Simplified spectrophotometric method using methylene blue for determining anionic surfactants: applications to the study of primary biodegradation in aerobic screening tests, Chemosphere, 65 (2006) 278–285.

[26] B. Wyrwas, Methodological Aspects of Surfactant Biodegradation Under Laboratory and Environmental Conditions, PUT Publisher, Poznań, 2012.

[27] K. Huszla, D. Cierniak, M. Wysokowski, B. Wyrwas, Non-biological methods for degradation nonionic surfactants in the aquatic environment, Chem. Ind. (London), 97 (2018) 2022–2025.

[28] B. Wyrwas, A. Zgoła- Grześkowiak, A new iodobismuthate method with a low volume filtration device as a new tool for the determination of microgram oxyethylate amounts, Tenside Surf. Deterg., 52 (2015) 213–218.

[29] B. Wyrwas, Ł. Chrzanowski, Ł. Ławniczak, A. Szulc, P. Cyplik, W. Białas, A. Szymański, A. Hołderna-Odachowska, Utililization of Triton X-100 and polyethylene glycols during surfactant-mediated biodegradation of diesel fuel, J. Hazard. Mater., 197 (2011) 97–103.

[30] I. Skoczko, Water Filtration in Theory and Practice, PAN Publishing, Series of Monographs of Environmental Engineering Committee, Warsaw, 2019.

[31] A. Hoffmann, G. Gunkel, Bank filtration in the sandy littoral zone of Lake Tegel (Berlin): structure and dynamics of the biological active filter zone and clogging processes, Limnologica, 14 (2011) 10–19.

[32] B. Wyrwas, I. Kruszelnicka, D. Ginter-Kramarczyk, Effects of selected anionic and nonionic surfactants on the operation of activated sludge, Przem. Chem., 90 (2011) 613–619.

[33] B. Wyrwas, I. Kruszelnicka, D. Ginter-Kramarczyk, Effect of concentration of anionic surfactant on the morphology of activated sludge, Przem. Chem., 90 (2011) 1743–1748.

[34] D. Cierniak, M. Woźniak-Karczewska, A. Parus, B. Wyrwas, A.P. Loibner, H.J. Heipieper, Ł. Ławniczak, Ł. Chrzanowski, How to accurately assess surfactant biodegradation - impact of sorption on the validity of results, Appl. Microbiol. Biotechnol., (2019), doi: 10.1007/s00253–019–10202–9.

[35] A. Tahar, J.M. Choubert, C. Miège, M. Esperanza, K. Le Menach, H. Budzinski, C. Wisniewski, M. Coquery, Removal of xenobiotics from effluent discharge by adsorption on zeolite and expanded clay: an alternative to activated carbon?, Environ. Sci. Pollut. Res. Int., 21 (2014) 5660–5668.

[36] T. Thiebault, R. Guégan, M. Boussafir, Adsorption mechanisms of emerging micro-pollutants with a clay mineral: case of tramadol and doxepine pharmaceutical products, J. Colloid Interface Sci., 453 (2015) 1–8.

[37] M. Grassi, G. Kazkioglu, V. Belgiorno, G. Lofrano, Removal of Emerging Contaminants from Water and Wastewater by Adsorption Process, Published in: Emerging Compounds Removal from Wastewater, Netherlands, Springer, 2012, pp. 15–37.

[38] S.C. Azimi, A. Pendashteh, Green Technologies for Wastewater Treatment, Second International Conference in New Research on Chemistry & Chemical Engineering, Iran, 2016.

[39] A.C. Sophia, E.C. Lima, Removal of emerging contaminants from the environment by adsorption, Ecotoxicol. Environ. Saf., 150 (2018) 1–17.

[40] K. McDonough, K. Casteel, N. Itrich, J. Menzies, S. Belanger, K. Wehmeyer, T. Federle, Evaluation of anionic surfactant concentrations in US effluents and probabilistic determination of their combined ecological risk in mixing zones, Sci. Total. Environ., 572 (2016) 434–441.

[41] J. Šíma, V. Holcová, Removal of nonionic surfactants from wastewater using a constructed wetland, Chem. Biodivers., 8 (2011) 1819–1832.

[42] F. Riva, S. Castiglioni, E. Fattore, A. Manenti, E. Davoli, E. Zuccato, Monitoring emerging contaminants in the drinking water of Milan and assessment of the human risk, Int. J. Hyg. Environ. Health, 221 (2018) 451–457.

[43] M. Palmer, H. Hatley, The role of surfactants in wastewater treatment: impact, removal and future techniques: a critical review, Water Res., 147 (2018) 60–72.