Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2020.25346

186 (2020) 297–308
May

Effect of PVC installation on quality and stability of tap water

Dorota Papciak[a], Barbara Tchórzewska-Cieślak[b], Andżelika Domoń[a,*], Anna Wojtuś[a], Jakub Żywiec[b]

[a]*Rzeszow University of Technology, Department of Water Purification and Protection, Powstancow Warszawy 6, 35–959 Rzeszow, Poland, emails: adomon@prz.edu.pl (A. Domoń), dpapciak@prz.edu.pl (D. Papciak), annawojtusss@gmail.com (A. Wojtuś)*
[b]*Rzeszow University of Technology, Department of Water Supply and Sewage Systems, Powstancow Warszawy 6, 35–959 Rzeszow, Poland, emails: cbarbara@prz.edu.pl (B. Tchórzewska-Cieślak), j.zywiec@prz.edu (J. Żywiec)*

Received 13 September 2019; Accepted 11 December 2019

ABSTRACT

The article presents the research into the effect of an experimental installation made of PVC, on the quality and chemical and biological stability of drinking water. Physicochemical and microbiological parameters of water remaining in the installation for 24 and 72 h were analyzed. Water leaving the experimental installation was characterized by changed parameters in relation to the water flowing into the installation. As a result of the contact with the PVC material, an increase in turbidity, content of organic compounds (TOC, oxidizability, UV absorbance) and nitrites. At the same time, a reduction in the content of chlorine occurred. The bacteriological quality of water also deteriorated, an increase in the number of mesophilic and psychrophilic bacteria occurred, and the presence of *Escherichia coli* was found. The obtained research results indicate that PVC materials release nutrients (C, P, N) that stimulate the growth of microorganisms in the experimental installation. Biological processes took place on the pipe surfaces.

Keywords: Biofilm; PVC; Tap water; Water quality

1. Introduction

The water supply system should be designed and made in such a way so as to reduce to a minimum the possibility of the water stability loss. Water is stable when there is a balance between processes of dissolving and precipitating chemical compounds on the boundary water-pipeline (the surface of armature of water supply devices) and there are no chemical or biological processes causing changes in the values of water quality indicators. Water biological stability is understood as the lack of susceptibility to the secondary regrowth of microorganisms in the water supply system [1,2].

Water biological stability is conditioned by both the content of non-organic nourishing substances, that is nitrogen and phosphorus, and the content of organic nutritional substrates creating conditions for the growth of heterotrophic organisms, including also pathogenic microorganisms [3]. The measure of water biological stability is achieving the threshold values of biogenic substances conditioning the lack of growth of microorganisms. The values limiting the secondary growth of microorganisms in the distribution systems are: biodegradable dissolved organic carbon (BDOC): <0.25 mg C/L [3], assimilable organic carbon (AOC): 10–20 μg C/L (in unchlorinated water) [4,5] and 50–100 μg C/L (in chlorinated water) [6], PO_4^{3-}: <0.03 mg P/L [3], $\sum N_{inorg}$: <0.2 mg N/L [3].

The intensity of the biofilm growth in the water distribution system depends on many factors, among which there are the quality of water introduced into the system, the amount of disinfectant and hydrodynamic conditions in the water supply network [7–13]. The type of material the water supply pipes are made of also significantly affects the rate at which biofilm forms, its structure and biodiversity [14–19]. Chemical composition of the installation material, as well as

* Corresponding author.

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

its properties, that is roughness and susceptibility to corrosion are considered as one of the basic causes of the increased colonization of microorganisms [16,20,21]. The multiplicity of factors conditioning the formation and growth of biofilm makes the prevention of this phenomenon very troublesome [19,22–25].

In the recent years, more and more often, the construction of new water supply pipelines involves the use of materials made of plastics, that is polyethylene, polyvinylchloride, polypropylene and polybutylene. It was expected that synthetic materials, characterized by a slight roughness would decrease the risk of the secondary contamination of water. The exploitation of pipelines made of plastics did not allow to confirm this thesis. The research conducted so far indicates that biofilm is formed on all installation materials, but each of them creates different conditions for the regrowth of microorganisms [24].

While selecting materials for the construction and modernization of the water supply networks and installations, the current knowledge on causes of the loss of chemical and biological stability of water in the water supply systems must be taken into account. During the selection of materials, not only easily corrosive materials must be avoided but also attention should be given to leaching of non-organic and organic substances from pipelines. They increase the rate of chlorine disappearance in the water supply network and contribute to the biofilm growth [26,27].

Secondary bacterial growth in the distribution system is a major problem that water treatment plants are trying to deal with. Particular danger is associated with the presence of growths of biofilms in the water supply systems of hospitals and nursing homes, where patients with reduced immunity reside [28]. Tap water is a source of microorganisms that mainly cause gastrointestinal or respiratory diseases when inhaled. The entry of microorganisms into the body through damaged mucous membranes can result in a multifocal infection. It is estimated that in the United States, 560,000 people get waterborne diseases each year, 7.1 million people get infections, with 12,000 deaths annually [29]. Biofilm constitutes an undoubtedly serious risk to the human health; therefore, effective methods allowing to prevent this phenomenon are being searched for [3]. Water delivered to water consumers must be characterized by the appropriate quality not only at the moment of its supplying into the water distribution network but also at the moment of delivery to consumers. The increase in the effectiveness of water purification, and particularly, the elimination of biogenic substances may contribute to the reduction of the secondary growth of microorganisms in the water supply network [8,19]. However, there is not sufficient and unambiguous information on the effect of materials used in the construction of water distribution systems on changes in the quality of water being in contact with them and the rate of the biofilm growth on internal surfaces of pipes.

The article presents the research into the effect of the internal installation made of PVC on the quality and biological stability of drinking water.

2. Materials and methods

The research installation used in the study consisted of three main parts: (1) a tap water connection, (2) circulation in the experimental system, and (3) discharge of water from the system. Two ball valves and a water meter measuring the fresh tap water flow were installed on the connection conduit. The experimental water supply system is a closed circuit made of PVC DN 32 pipes with a length of 6.8 m. In the installation, the circulation is ensured by an installed pump. The circuit is equipped with a separate water meter, drain and vent lines, flow decrease installation, and disinfectant injection point (Fig. 1).

Before the commencement of the research, the installation was disinfected by means of sodium hypochlorite, and then rinsed and filled with tap water. The experimental installation was supplied with surface water treated on water treatment plant based on the processes: pre-ozonation, coagulation (using PAX-18), sedimentation, fast filtration, intermediate ozonation, sorption on activated carbons and disinfection (using ClO_2/Cl_2). The treated water met the quality requirements for drinking water.

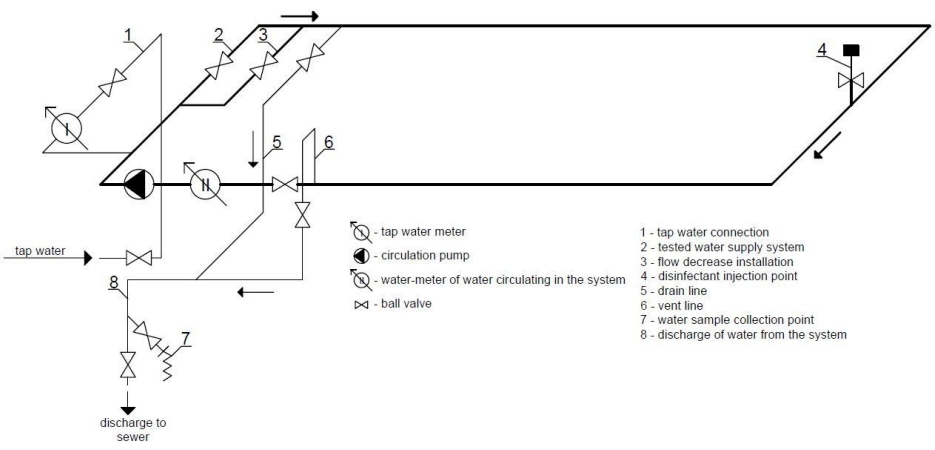

Fig. 1. Scheme of a research installation.

Due to the consumption of large amounts of water with continuous flow, water in the installation was changed once a day (Monday to Friday). Therefore, the water remained in the experimental installation for 24 h and 72 h in the forced flow with the speed of 0.3 m/s. Changes in the quality of water leaving and supplying the experimental installation were checked three a week for the period of 3 months.

The following were subjected to the physicochemical and bacteriological analyses:

- water after the final disinfection from the tank of water treated at the water treatment plant (directed to the water supply network),
- water before the experimental installation – taken from the internal installation of a building at a distance of about 5 km from the water treatment station,
- water after remaining for 24 h (Monday–Tuesday), and 72 h (Friday–Monday) in the experimental installation.

Samples of water were taken three a week in the period from November till February. Physicochemical parameters were determined in the laboratory tests (Table 1).

The analyzes allowed to determine the biological and physicochemical stability of water. Unstable water causes overgrowth of deposits of calcium carbonate in water pipes and contributes to corrosion of deposits. There are many parameters which determine the corrosive properties of water, among them are those related to the state of calcium carbonate equilibrium: the Langelier saturation index (I_L) (1) and the Ryznar Index (I_R) (2):

$$I_L = [pH]_O - [pH]_s \quad (1)$$

$$I_R = 2[pH]_S - [pH]_O \quad (2)$$

where $[pH]_O$ – pH of the examined water sample, $[pH]_s$ – pH in saturated state [30].

3. Research results

During the transport of water to the building in which the experimental installation was placed the quality of water changed: turbidity, oxidizability, absorbance UV and content of phosphorus compounds increased, the content of nitrogenous total organic carbon and conductivity decreased. An increase in the number of mesophilic and psychrophilic microorganisms was also found (Tables 2 and 3). Water leaving the experimental installation was characterized by the changed parameters in relation to the water supplying the installation (Tables 2 and 3). As a result of the contact with the PVC material, an increase in turbidity, content of organic compounds (TOC, oxidizability, UV absorbance) and nitrites. At the same time, a reduction in the content of chlorine (total and free chlorine) compounds occurred.

Table 1
Analytical methods and procedures used in research

Parameter	Analytical method/standard
pH	Multifunction meter CX-505
Conductivity, μs/cm	Multifunction meter CX-505
Turbidity, NTU	2100P ISO TURBIDIMETER HACH (Düsseldorf, Germany)
Oxidizability, mg O_2/L	Permanganate method with $KMnO_4$
TOC, mg C/L	TOC analyzer Sievers 5310 C (SUEZ, Boulder, CO, USA)
UV absorbance	Spectrophotometric method using Hach-Lange DR 5000 spectrophotometer
Dissolved oxygen, mg O_2/L	Electrochemical method using a Hach-Lange oxygen probe (Düsseldorf, Germany)
Ammonium nitrogen, mg $N\text{-}NH_3^+$/L	Spectrophotometric method 8155 (sachet tests – ammonia salicylate(1) and cyanurate(2)) using Hach-Lange DR 500 spectrophotometer (Düsseldorf, Germany)
Nitrite nitrogen, mg $N–NO_2^-$/L	Colorimetric method by nitrite test Merck 1.14408 (Darmstadt, Germany)
Nitrate nitrogen, mg $N–NO_3^-$/L	Spectrophotometric method 8039 (sachet tests – NitraVer5) using Hach-Lange DR 500 spectrophotometer (Düsseldorf, Germany)
Phosphates, mg PO_4^{3-}/L	Spectrophotometric method 8048 (sachet tests – PhosVer3) using Hach-Lange DR 500 spectrophotometer (Düsseldorf, Germany)
Total chlorine, mg Cl_2/L	Spectrophotometric method 8167 (sachet tests – DPD reagent) using Hach-Lange DR 500 spectrophotometer (Düsseldorf, Germany)
Free chlorine, mg Cl_2/L	Spectrophotometric method 8021 (sachet tests – DPD reagent) using Hach-Lange DR 500 spectrophotometer (Düsseldorf, Germany)
Total number of bacteria at 37°C (mesophilic bacteria) and at 22°C (psychrophilic bacteria), CFU/mL	Heterotrophic plate count (HPC) method using R2A Agar (CM0906) manufactured by Oxoid Thermo Scientific (UK) (incubation 7 d) and an A Agar (P-0231) manufactured by BTL Sp. z o.o., Department of Enzymes and Peptones (Poland) (incubation 2-d mesophilic bacteria and 3 d psychrophilic bacteria)
Escherichia coli, CFU/100 mL	Membrane filtration procedure using Chromocult® Coliform agar (CCA) manufactured by Merck (Darmstadt, Germany)

Table 2
Values of parameters for water treatment plant and for inlet/outlet water from experimental installation after 24 h

		Water treatment plant	Inlet				Outlet			
Parameter		M	Min	Max	Me	M ± SD	Min	Max	Me	M ± SD
Temperature, °C			14.40	20.30	17.80	18.01 ± 1.73	21.0	23.90	22.40	22.5 ± 0.86
Dissolved oxygen, mg O_2/L		–	12.56	16.30	14.47	14.32 ± 1.13	5.83	10.25	9.78	9.25 ± 1.23
pH		7.59	7.01	7.69	7.56	7.54 ± 0.17	7.17	7.74	7.62	7.60 ± 0.14
Conductivity, μs/cm		564	383	506	426	429 ± 35.31	475	662	533	543 ± 53.07
Turbidity, NTU		<0.20	0.16	1.33	0.25	0.40 ± 0.35	0.58	4.50	1.10	1.41 ± 0.35
Oxidizability, mg O_2/L		1.05	0.50	2.10	1.20	1.27 ± 0.42	1.00	2.60	1.80	1.87 ± 0.47
TOC, mg C/L		2.16	0.98	2.05	1.56	1.50 ± 0.30	1.99	5.00	2.20	2.44 ± 0.86
UV absorbance		2.06	1.48	2.76	2.16	2.15 ± 0.35	2.42	3.70	2.78	2.89 ± 0.36
Ammonium nitrogen, mg N–NH_4^+/L		0.09	0.00	0.07	0.00	0.018 ± 0.028	0.00	0.11	0.01	0.019 ± 0.03
Nitrite nitrogen, mg N–NO_2^-/L		<0.015	0.00	0.037	0.00	0.003 ± 0.010	0.001	0.037	0.002	0.007 ± 0.011
Nitrate nitrogen, mg N–NO_3^-/L		0.87	0.30	0.90	0.60	0.61 ± 0.210	0.10	1.50	0.20	0.40 ± 0.39
Phosphates, mg PO_4^{3-}/L		0.027	0.020	0.190	0.040	0.053 ± 0.047	0.000	0.150	0.030	0.038 ± 0.037
Total chlorine, mg Cl_2/L		–	0.010	0.210	0.080	0.103 ± 0.068	0.01	0.070	0.02	0.025 ± 0.017
Free chlorine, mg Cl_2/L		–	0.010	0.080	0.030	0.033 ± 0.021	0.000	0.040	0.01	0.012 ± 0.011
Mesophilic bacteria	A agar CFU/mL	0	0	3	1	1.15 ± 1.14	0	56	2	8 ± 15.10
	R agar CFU/mL	1	3	110	17	31 ± 34.17	300	5,200	2,800	2,393 ± 1,561
Psychrophilic	A agar CFU/mL	1	1	6	3	4 ± 1.94	2	160	20	37 ± 30.39
bacteria	R agar CFU/mL	0	5	150	38	49.46 ± 43.25	450	16,500	4,899	5,544 ± 4,500
Escherichia coli, CFU/mL		0	0	0	0	0 ± 0	0	200	11	41 ± 59.15

M – average value; Me – median; SD – standard deviation.

Table 3
Values of parameters for water treatment plant and for inlet/outlet water from experimental installation after 72 h

Parameter		Water treatment plant	Inlet				Outlet			
		M	Min	Max	Me	M ± SD	Min	Max	Me	M ± SD
Temperature, °C			15.60	22.60	19.15	18.81 ± 2.07	19.00	24.8	22.15	22.02 ± 1.45
Dissolved oxygen, mg O_2/L		–	12.24	15.20	13.79	13.75 ± 1.02	6.14	10.43	9.52	9.05 ± 1.20
pH		7.59	7.46	7.76	7.57	7.59 ± 0.10	7.38	7.72	7.64	7.60 ± 0.11
Conductivity, μs/cm		564	347	648	399	422 ± 77.73	378	533	433	448 ± 44.34
Turbidity, NTU		<0.20	0.14	1.14	0.25	0.31 ± 0.27	0.37	7.61	1.50	2.28 ± 2.01
Oxidizability, mg O_2/L		1.05	0.40	2.60	1.45	1.46 ± 0.85	0.90	3.20	2.45	2.33 ± 0.78
TOC, mg C/L		2.16	1.24	1.78	0.25	1.52 ± 0.16	1.68	4.09	3.21	3.26 ± 0.64
UV absorbance		2.06	1.84	2.42	2.13	2.16 ± 0.19	1.74	4.94	3.13	3.25 ± 0.87
Ammonium nitrogen, mg N–NH_4^+/L		0.09	0.00	0.09	0.00	0.020 ± 0.31	0.00	0.23	0.01	0.043 ± 0.07
Nitrite nitrogen, mg N–NO_2^-/L		<0.015	0.00	0.007	0.00	0.001 ± 0.002	0.002	0.008	0.002	0.003 ± 0.002
Nitrate nitrogen, mg N–NO_3^-/L		0.87	0.30	1.00	0.75	0.708 ± 0.23	0.10	0.70	0.35	0.39 ± 0.21
Phosphates, mg PO_4^{3-}/L		0.027	0.005	0.120	0.040	0.049 ± 0.034	0.020	0.090	0.050	0.048 ± 0.023
Total chlorine, mg Cl_2/L		–	0.020	0.290	0.065	0.099 ± 0.089	0000	0.080	0.02	0.026 ± 0.02
Free chlorine, mg Cl_2/L		–	0.010	0.080	0.025	0.032 ± 0.020	0.000	0.020	0.010	0.007 ± 0.006
Mesophilic bacteria	A agar CFU/mL	0	0	3	0	0.75 ± 1.06	0	39	2.5	9.83 ± 13.20
	R agar CFU/mL	1	3	90	10.5	29 ± 31.66	400	6,700	225	2,329 ± 1,859
Psychrophilic	A agar CFU/mL	1	1	6	2	2 ± 1.48	1	150	20	36.83 ± 46.16
bacteria	R agar CFU/mL	0	4	550	44.5	96 ± 150.16	500	20,500	3,595	6,373 ± 6,239
Escherichia coli, CFU/mL		0	0	0	0	0 ± 0	0	150	0	19 ± 45.59

M – average value; Me – median; SD – standard deviation.

In the first days after the installation start-up, the concentration of PO_4^{3-} ions increased systematically from the value of 0.05–0.15 mg PO_4^{3-}/L (for the third analysis), after 26 d no further increase in this parameter was observed (Fig. 2). Phosphorus leached into water in a smaller amount was used by the increased number of bacteria developed in the installation. A similar dependence was noted in the case of total organic carbon (TOC). The concentration of TOC after the 72 h-long flow through the installation increased from 1.52 mg C/L to the value of 3.26 mg C/L (Table 3). Organic compounds feed and develop bacteria and different other organisms [31].

The bacteriological quality of water also changed, the increase in the number of mesophilic and psychrophilic bacteria occurred. Despite the earlier disinfection of the installation, the presence of *Escherichia coli* (0–200 CFU/mL) was noted (Figs. 3–5).

Changes in parameters of water leaving the installation indicated the biological processes occurring inside pipes. The concentration of total chlorine (Fig. 6) and free chlorine was significantly reduced below the normative value of 0.3 mg Cl_2/L (Fig. 7).

The water residence time in the PVC installation did not affect the majority of physicochemical parameters. The noted differences between water circulating for 24 and 72 h concerned turbidity (Fig. 8), content of TOC (Fig. 9), nitrogenous compounds (Fig. 10), phosphorus compounds and the number of microorganisms.

Data included in Table 4 prove that the admissible concentrations of nutritional substrates N, P, C were exceeded in water introduced into the experimental system, which could significantly affect the water biological stability loss. Biodegradable dissolved organic carbon (BDOC) content was estimated on the basis of data published by Wolska [30]. Studies have shown that in the case of surface waters, a non-biodegradable fraction is the dominating DOC fraction, and the content of BDOC constitutes about 10.6% DOC [32]. During water residence in the PVC installation, the risk of the biological stability loss increases due to leaching organic and phosphorus compounds from the material used for the construction of the installation.

The analyses concerning changes in the chemical stability of the examined water indicated that tap water supplying the experimental installation is chemically unstable water with a tendency to dissolve sediments (the Langelier index values averaged 0.03 and 0.06). Moreover, with the possibility of the occurrence of a delicate corrosion (the Ryznar index values averaged 7.49 and 7.46) (Table 5). For the water outflow from the experimental installation, the Ryznar index value did not change (after 24 h and 72 h I_L was 7.41 and 7.40, respectively; Table 5). On the other hand, the analysis showed an increase in the Langelier index value (after 24 and 72 h I_L was 0.09 and 0.1, respectively). This indicates that the installation experienced the phenomenon of a delicate section reduction of pipes. Although for the assessment of water corrosiveness

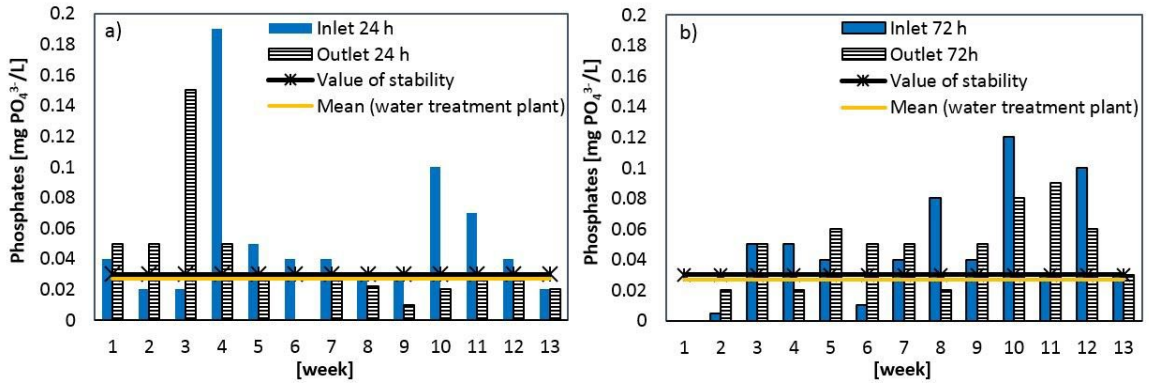

Fig. 2. Change of phosphates content after (a) 24 and (b) 72 h.

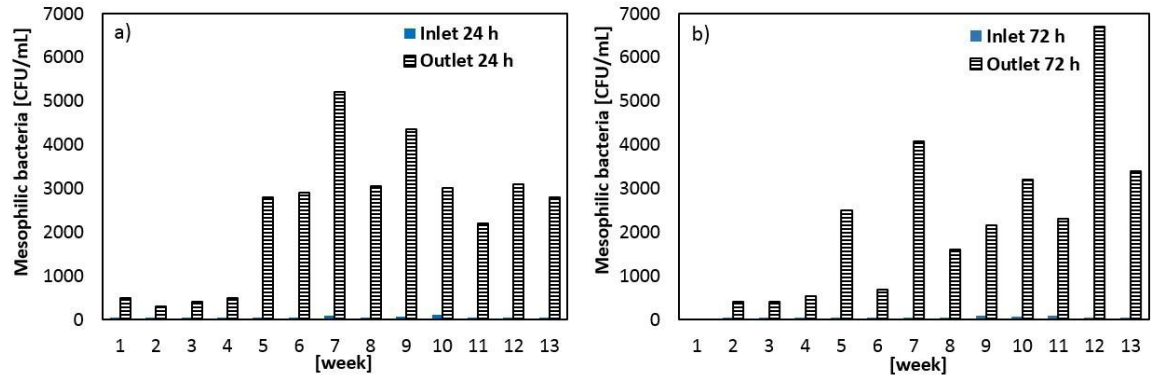

Fig. 3. Change of total number of mesophilic bacteria after (a) 24 and (b) 72 h.

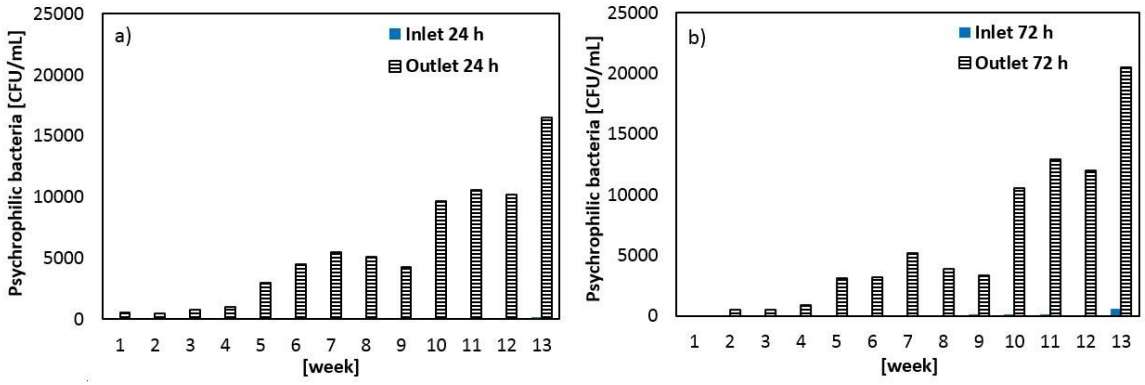

Fig. 4. Change of total number of psychrophilic bacteria after (a) 24 and (b) 72 h.

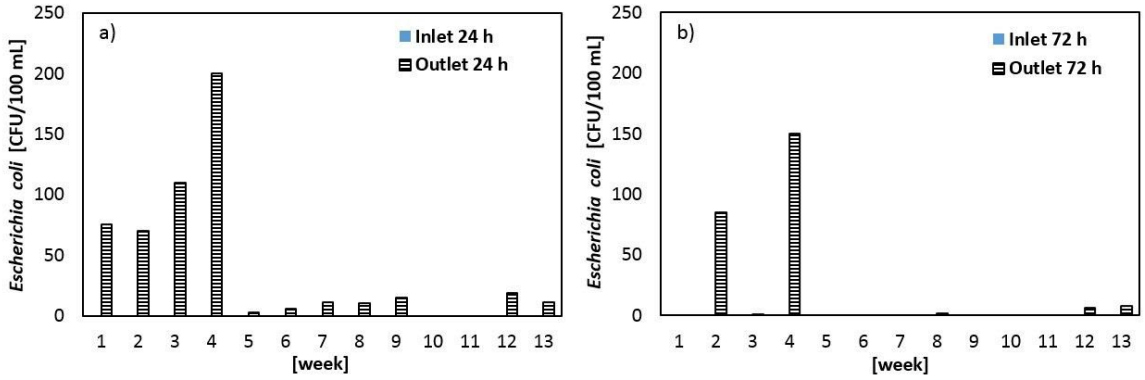

Fig. 5. Change of total number of *Escherichia coli* after (a) 24 and (b) 72 h.

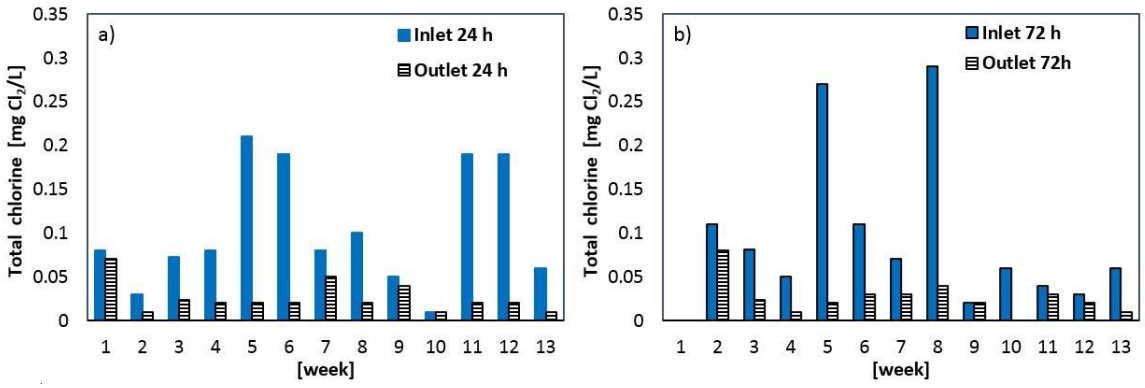

Fig. 6. Change of total chlorine concentration after (a) 24 and (b) 72 h.

the numerous indices are used, due to the complexity of the corrosion process, none of them provides a complete assessment of the rate of corrosion in aquatic environment. The calculation formula of I_L and I_R are the simplest one among other indicators, and considers only water pH [33].

4. Discussion

In accordance with the adopted parameters of risk assessment criteria presented in Pietrucha-Urbanik et al. [30], the analysis showed that the quality of waters at the inflow and outflow from the experimental installation are at the level of controlled risk. The level of controlled risk means the possibility of changes in the chemical stability of water in the water supply network and the need to control and reduce corrosivity parameters. The phenomenon of corrosion facilitates the biofilm formation [26] and creates the additional risk of the loss of biological stability of tap water [1]. Striving for achieving water biological stability is connected to the need to ensure the extremely low content of nutritional substrates

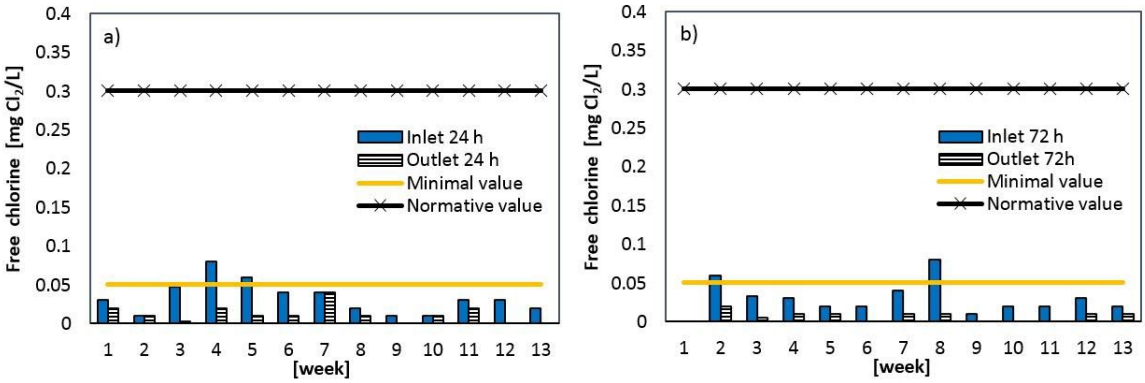

Fig. 7. Change of free chlorine concentration after (a) 24 and (b) 72 h.

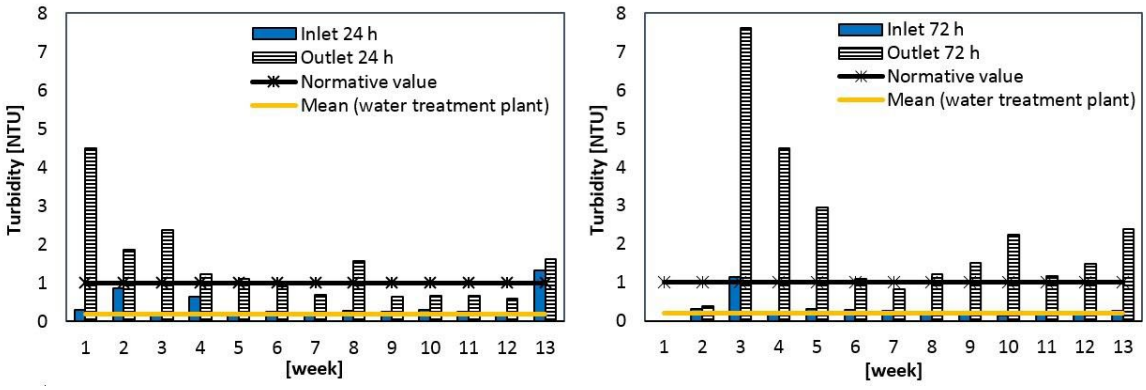

Fig. 8. Change of turbidity after (a) 24 and (b) 72 h.

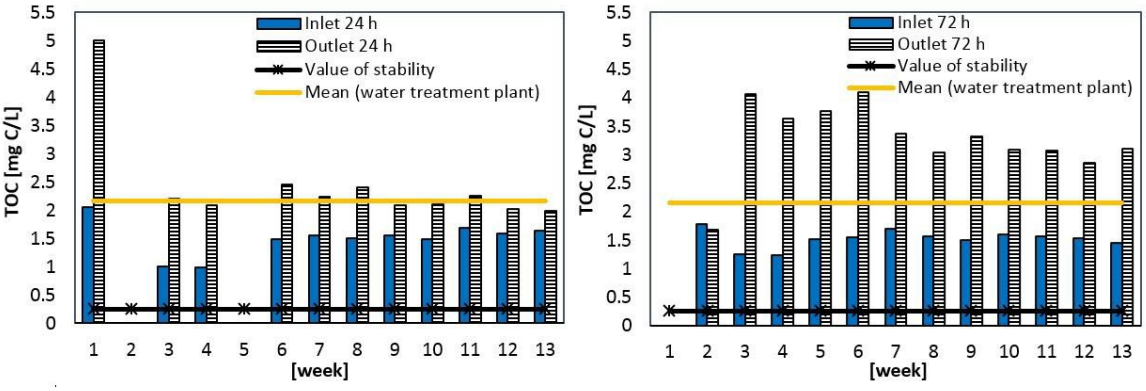

Fig. 9. Change of total organic carbon content after (a) 24 and (b) 72 h.

for microorganisms developing on the surface of pipelines. This is a very difficult task, especially in the case of water subjected to purification in conventional systems (chemical oxidation, coagulation, filtration, disinfection). The effective elimination of organic substances and biogenic elements: nitrogen and phosphorus is necessary to ensure water biological stability [32]. To maintain the stability and reduce to a minimum the risk of the secondary bacteriological contamination of water, two out of three biogens determining the regrowth of microorganisms must be eliminated [1].

In the case of water containing NOM and non-organic nitrogen, phosphorus ions are of the basic importance [16,20]. Their too low content hinders the growth of microorganisms to a significantly larger extent than it is the case for the remaining biogens [34]. Lehtola [35] inform that due to the lowest required content of phosphorus, it is this element that limits the growth of microorganisms [35]. Attention should be given also to the fact that phosphorus as well as other nourishing substances in the first days of the use of systems and water installations made of plastics, can be leached

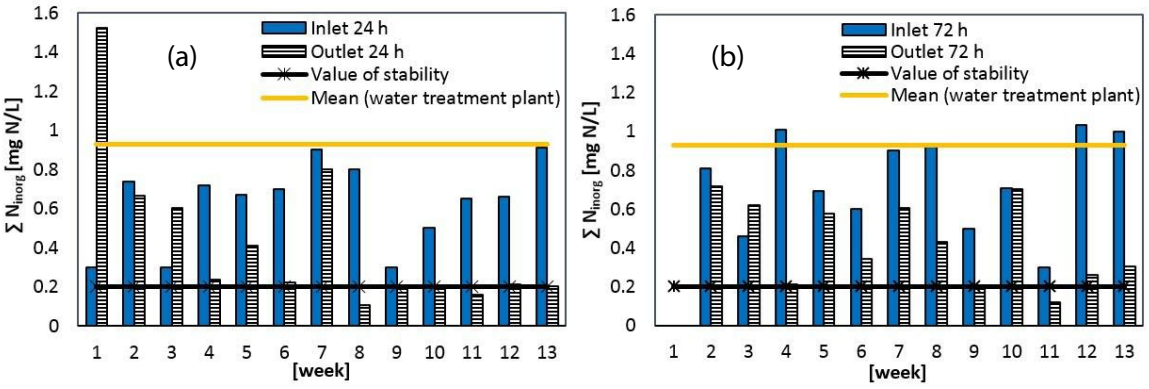

Fig. 10. Change of inorganic nitrogen content after (a) 24 and (b) 72 h.

Table 4
Acceptable values and average concentrations of N, P, C in the test water

Stability criterion	Water treatment plant	Inlet (24 h)	Outlet (24 h)	Inlet (72 h)	Outlet (72 h)
			Mean		
$\Sigma N_{inorg} \leq 0.2$ mg N/L	0.930	0.629	0.425	0.627	0.556
$PO_4^{3-} \leq 0.03$ mg PO_4^{3-}/L	0.027	0.053	0.038	0.049	0.048
Dissolved organic carbon (DOC) mg C/L	2.160	1.500	2.440	1.520	3.260
Biodegradable dissolved organic carbon (BDOC) BDOC = 10.6% DOC BDOC ≤ 0.25 mg C/L	0.229	0.159	0.259	0.161	0.346

Table 5
Descriptive statistics of the Langelier index (I_L) and Ryznar index (I_R) values

	Water treatment plant	Inlet 24	Outlet 24	Inlet 72	Outlet 24
			Value of Langelier index – I_L		
Min	–	–0.63	–0.34	–0.14	–0.17
Max	–	0.30	0.29	0.34	0.35
M	–0.17	0.03	0.09	0.06	0.10
Me	–	0.05	0.14	0.07	0.11
SD	–	0.24	0.17	0.14	0.17
			Value of Ryznar index – I_R		
Min	–	7.06	7.13	7.08	6.98
Max	–	8.27	8.21	7.94	7.99
M	7.67	7.49	7.41	7.46	7.40
Me	–	7.44	7.32	7.41	7.37
SD	–	0.36	0.29	0.24	0.29

from these materials causing the quicker biofilm growth [16,19,36,37]. Precisely such a situation could have taken place in the discussed case.

The increase in biofilm depends on water temperature, residence time in the system, as well as on the type and concentration of disinfectant used [38–40]. Due to the fact that the research was conducted in the winter-spring period, temperature of water influenced greatly the growth of microorganisms. Temperature of water flowing into the installation changed within 14.4°C–22.6°C. Additionally, temperature of water after its passage through the installation increased to 24.8°C. Zamorska [38] by means of the analysis of the

temperature (5°C, 15°C and 22°C) effect on the microbiological quality of water additionally confirmed the lack of stability of water introduced into the water supply network. According to literature data, metabolic activity of microorganisms increases along with temperature, at temperature of 17°C it is higher by 50% than at temperature of 7°C [8].

The study also observed an increase in turbidity to 1.41 NTU (after 24 h) and 2.28 NTU (after 72 h). Water with high turbidity may pose an epidemiological hazard due to suspended particles used as a support for pathogenic bacteria. Water turbidity results from suspended substances such as organic substances, small inorganic substances, finely divided suspensions or microorganisms [31]. The number of microorganisms at the outflow increased 80 times for mesophilic bacteria (their number was on average 2,393 and 2,329 CFU/mL after 24 and 72 h, respectively). In contrast, the average number of psychrophilic bacteria after 24 h circulation in the installation increased from 50 to 5,544 CFU/mL, and after 72 h from 96 to 6,373 CFU/mL. The deterioration of bacteriological quality was also confirmed by a 35% reduction in dissolved oxygen in water. The highest number of *Escherichia coli* was recorded during 4 weeks. This could be due to the highest concentration of nutrients in the water flowing into the installation. In particular the increased content of phosphorus compounds 0.19 mg PO_4^{3-}/L (C:N:P ratio was 100:74:20, respectively). In addition, leaching of phosphorus compounds from the experimental installation was observed for the 4 weeks. Despite the fact that no *Escherichia coli* were found in the incoming water, they could have been found in the installation in a persistent form (despite disinfection).

The concentration of total chlorine and free chlorine in water leaving the research system in comparison with water flowing into the system lowered to the value of, accordingly: 0.025 and 0.012 mg Cl_2/L (after 24 h) and 0.026 and 0.007 mg Cl_2/L (after 72 h). Total chlorine concentration decreased by 74% on average after 24 and 72 h, while free chlorine by 63% after 24 h and 79% after 72 h. Chlorine is a disinfectant and guarantor of the microbiological safety of water which in this case was clearly impaired. In Poland, there is no specified admissible residence time of water in the water supply network, called the water age; however, it is a fact that along with the water age, the risk of its stability loss increases. Computer simulations allow to separate these sections of water supply networks in the water supply system in which the water residence time in pipelines is longer due to low water consumption, and taking the kinetics of chlorine and chlorine dioxide disappearance into account it is possible to determine areas vulnerable to the secondary growth of bacteria in water [6,9,41].

In Poland, the required concentration of free chlorine in water directed to the water supply network should be equal to 0.2–0.5 mg Cl_2/L. According to WHO recommendations, residual chlorine should be maintained throughout the entire distribution system. At the point of consumption by the consumer, the minimum free chlorine concentration should be 0.2 mg Cl_2/L. However, the drinking water supplier is not required to maintain a minimum amount of free chlorine in the water supply, and factors such as pipe length and chlorine demand mean that the actual concentration of free residual chlorine may be less than the recommended value [42]. It was demonstrated that in the distribution systems of water with the concentration of free chlorine below 0.5 mg Cl_2/L, water contained a greater number of bacteria cells [14]. Francisque et al. [43] also shows that the number of heterotrophic bacteria was significantly higher in samples of water with the chlorine content <0.3 mg Cl_2/L.

The phenomenon of insufficiently effective influence of chlorine on microorganisms in the water supply network may constitute a danger to the health of consumers. *Helicobacter pylori* bacteria occurred in biofilm at the concentration of chlorine of 0.2–1.2 mg Cl_2/L even to 26 d, and microorganisms of faecal origin remained resistant to the concentration of 1 mg Cl_2/L [44]. Bacteria resistance to disinfectants can be significant at a small content of biogenic compounds; it was found that, among others, *Legionella pneumophila* was six- to nine-times less sensitive than other bacteria strains, more demanding in terms of the content of nutritional compounds [44]. Also, the presence of filamentous fungi, yeast, amoeba and other pathogenic protozoa was found in chlorinated water [45]. The research results presented in the article confirm the research by Grabińska-Łoniewska and Siński [46], Sokołowska and Olańczuk-Neyman [47]. Authors indicated that a 100-fold increase in the number of microorganisms at the ends of the water supply network caused a three-fold increase in TOC, released from the deposited sediments inside pipes. At the same time, a decrease in the concentration of chlorine and chlorine dioxide to 0.03 mg Cl_2/L and 0.027 mg ClO_2/L was observed [46,47]. In our case also an increase in the content of TOC and phosphorus as a result of leaching from the PVC installation was observed. During the materials contact with water, phosphorus or carbon being nutritional substances for microorganisms may be passed into water in the form of microbiologically available phosphorus (MAP) [16] or AOC [21], accelerating the biofilm formation.

Although the material may influence the biofilm formation [48–50], in the case of research by Inkinen et al. [51] conducted on the actual sections of pipes after a year of contact with tap water, no such a dependence was noted. However, it was found, that water temperature and conditions of flow had a particular influence on the process of biofilm formation [51]. The use of concentrations of disinfectants greater than recommended is dangerous to health. The by-products of disinfection cause cancer, gastritis, anemia, damage to neural system, eye and skin irritations [48].

In conclusion, it should be noted that despite numerous studies, the problem of effective disinfection ensuring the removal of pathogenic microorganisms and achieving biological stability still exists. Studies on the biofilm formation should include measurements of quantities by methods other than the culture identification method due to the fact that only 2%–26% bacteria forming biofilm is capable of growing on cultivation media. Hydraulic parameters affecting the growth of biofilm inside pipes and uncontrolled detachment of biofilm fragments increasing the risk of drinking water contamination should also be taken into account.

5. Conclusions

The research confirmed the results obtained by other researchers that not only the parameters of water introduced into the installation (i.e., content of nutrients, disinfectant)

determine its biological stability. The material from which the installation is made also affects the formation of biofilm and the quality of water at the consumer.

It was also confirmed that as a result of contact of PVC pipes with tap water, its quality and stability deteriorated, despite the absence of phosphorus compounds in the incoming water. An increase in turbidity and leaching of phosphorus and organic compounds from the installation was observed, which affected the microbiological contamination of water. There was a significant increase in the number of mesophilic and psychrophilic bacteria and *Escherichia coli* was found in the water leaving the installation. The obtained research results indicate that PVC materials release nutrients (C, P, N) that stimulate the growth of microorganisms. The residence time of the water in the installation had an impact on the increase in turbidity (increase by 38%) and the TOC content (increase by 25%). It should be emphasized that the number of mesophilic and psychrophilic bacteria and *Escherichia coli* increased in the first 24 h, further water retention in the installation up to 72 h did not affect the bacteriological quality of the water.

Obtained research results indicate the need to search for installation materials that are not only resistant to corrosion but also do not change the biological stability of water. The problem of disinfection efficiency and maintaining the biostability of tap water still exists.

References

[1] D. Papciak, B. Tchórzewska-Cieślak, K. Pietrucha-Urbanik, A. Pietrzyk, Analysis of the biological stability of tap water on basis of risk analysis and parameters limiting the secondary growth of microorganisms in water distribution system, Desal. Wat. Treat., 117 (2018) 1–8.

[2] E.I. Prest, F. Hammes, M.C.M. van Loosdrecht, J.S. Vrouwenvelder, Biological Stability of Drinking Water: Controlling Factors, Methods, and Challenges, Front. Microbiol., 7 (2016) 1–24.

[3] M. Wolska, Removal of nutrients in the technology of purification of water intended for human consumption, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław, 2015.(in Polish).

[4] M.W. LeChevallier, N.E. Shaw, L.A. Kaplan, T.L. Bott, Development of a rapid assimilable organic carbon method for water, Appl. Environ. Microbiol., 59 (1993) 1526–1531.

[5] M.W. LeChevallier, N.J. Welch, D.B. Smith, Full-scale studies of factors related to coliform regrowth in drinking water, Appl. Environ. Microbiol., 62 (1996) 2201–2211.

[6] M.W. Lechevallier, T.M. Evans, R.M. Seidler, Effect of turbidity on chlorination efficiency and bacterial persistence in drinking water, Appl. Environ. Microbiol., 42 (1981) 159–167.

[7] R. Boe-Hansen, H.-J. Albrechtsen, E. Arvin, C. Jørgensen, Dynamics of biofilm formation in a model drinking water distribution system, J. Water Supply. Res. Technol., 51 (2002) 399–406.

[8] N.B. Hallam, J.R. West, C.F. Forster, J. Simms, The potential for biofilm growth in water distribution systems, Water Res., 35 (2001) 4063–4071.

[9] J. Łomotowski, Z. Siwoń, Assessing the chemical stability of tap water by means of the software for ionic composition simulation, Ochrona Środowiska, 4 (2004) 13–16 (In Polish).

[10] T. Dippong, C. Mihali, G. Ardelean, Seasonal variation of physico-chemical parameters in the drinking water supply network of satu city, NW Romania, EEMJ, 18 (2019) 1–10.

[11] T. Dippong, C. Mihali, D. Năsui, Z. Berinde, C. Butean, Assessment of water physicochemical parameters in the Strîmtori-Firiza Reservoir in Northwest Romania, Water Environ. Res., 90 (2018) 220–233.

[12] Z. Tsvetanova, Quantification of the bacterial community of drinking water-associated biofilms under different flow velocities and changing chlorination regimes, Appl. Water Sci., 10 (2020) 1–11.

[13] T. Dippong, C. Mihali, E. Cical, A. Avram, Influence of precipitation quantities on the strâmtorifiriza raw water quality indicators, Stud. Univ. Babes-Bol. Chem., 61 (2016) 251–262.

[14] M. Łebkowska, E. Pajor, A. Rutkowska-Narożniak, M. Kwietniewski, J. Wąsowski, D. Kowalski, Microbial growth in cement-lined ductile cast-iron water-pipe networks, Ochrona Środowiska, 33 (2011) 9–13. Available online: http://www.os.not.pl/docs/czasopismo/2011/3–2011/Lebkowska_3-2011.pdf (accessed on 7 May 2019) (in Polish).

[15] B. Kołwzan, Analysis of biofilms - their formation and functioning, Ochrona Środowiska, 33 (2011) 3–14. Available online: http://www.pzits.not.pl/docs/Kolwzan.pdf (accessed on 1 May 2019) (in Polish).

[16] M.J. Lehtola, I.T. Miettinen, M.M. Keinanen, T.K. Kekki, O. Laine, A. Hirvonen, T. Vartiainen, P.J. Martikainen, Microbiology, chemistry and biofilm development in a pilot drinking water distribution system with copper and plastic pipes, Water Res., 38 (2004) 3769–3779.

[17] T.M. Traczewska, M. Sitarska, Substrate physical structure impact on the development of biofilm, Ochrona przed korozją, 55 (2012) 15–19 (in Polish).

[18] M. Szczotko, B. Krogulska, A. Krogulski, W. Kurzątkowski, M. Staniszewska, Biofilm on the surface of materials contacting with drinking water. Comparison of structure and growth rate, Gaz, Woda i Technika Sanitarna, 11 (2012) 498–502 (in Polish).

[19] J. Yu, D. Kim, T. Lee, Microbial diversity in biofilms on water distribution pipes of different materials, Water Sci. Technol., 61 (2010) 163–171.

[20] M.J. Lethola, I.T. Miettinen, T. Lampola, A. Hirvonen, T. Vartiainen, P.J. Martikainen, Pipeline materials modify the effectiveness of disinfectants in drinking water distribution systems, Water Res., 39 (2005) 1962–1971.

[21] M. Bucheli-Witschel, S. Kötzsch, S. Darr, R. Widler, T. Egli, A new method to assess the influence of migration from polymeric materials on the biostability of drinking water, Water Res., 46 (2012) 4246–4260.

[22] T.M. Traczewska, M. Sitarska, I. Biedroń, Ecological and technical aspects of the formation of biofilms in water, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław, 2014 (in Polish).

[23] D. Papciak, J. Kaleta, A. Puszkarewicz, B. Tchórzewska-Cieślak, The use of biofiltrationproces to remove organic matter from groundwater, J. Ecol. Eng., 17 (2016) 119–124.

[24] A. Pietrzyk, D. Papciak, The influence of water treatment technology on the process of biofilm formation on the selected installation materials, JCEEA, XXXIV, 64 (2/II/17) (2017) 131–143.

[25] I. Douterelo, M. Jackson, C. Solomon, J. Boxall, Microbial analysis of in situ biofilm formation in drinking water distribution systems: implications for monitoring and control of drinking water quality, Appl. Microbiol. Biotechnol., 100 (2016) 3301–3311.

[26] D. Kowalski, B. Kowalska, M. Kwietniewski, Analysis of changes in chlorine concentration for the purpose of water quality modeling in a water supply network. Conference materials on New technologies in water supply and sewage networks and installations, The Silesian Technical University, Institute of Water and Wastewater Engineering, Gliwice, 2012, pp. 35–50.

[27] A. Deb, S. B. McCammon, J. Snyder, A. Dietrich, Impacts of lining materials on water quality, Water Research Foundation and Drinking Water Inspectorate USA, 2010.

[28] J. Falkinham, A. Pruden, M. Edwards, Opportunistic premise plumbing pathogens: increasingly important pathogens in drinking water, Pathogens, 4 (2015) 373–386.

[29] J.P.S. Cabral, Water microbiology. Bacterial pathogens and water, Int. J. Environ. Res. Public Health, 7 (2010) 3657–3703.

[30] K. Pietrucha-Urbanik, B. Tchórzewska-Cieślak, D. Papciak, I. Skrzypczak, Analysis of chemical stability of tap water in terms of required level of technological safety, Arch. Environ. Prot., 43 (2017) 3–12.

[31] T. Dippong, C. Mihali, M-A. Hoaghia, E. Cical, A. Cosma, Chemical modeling of groundwater quality in the aquifer of Seini town – Someș Plain, Northwestern Romania, Ecotoxicol. Environ. Saf., 168 (2019) 88–101.
[32] M. Wolska, M. Mołczan, Stability Assessment of Water Introduced into the Water Supply Network, Ochrona Środowiska, 37 (2015) 51–56.
[33] I. Skoczko, E. Szatyłowicz. Treatment Method Assessment of the Impact on the Corrosivity and Aggressiveness for the Boiler Feed Water, Water, 11 (2019) 1965.
[34] C. Chu, C. Lu, Effects of acetic acid on the regrowth of heterotrophic bacteria in the drinking water distribution system, World J. Microbiol. Biotechnol., 21 (2005) 989–998.
[35] M. Lehtola, Microbially available organic carbon, phosphorus, and microbial growth in ozonated drinking water, Water Res., 35 (2001) 1635–1640.
[36] M.J. Lehtola, M. Laxander, I.T. Miettinen, A. Hirvonen, T. Vartiainen, P.J. Martikainen, The effects of changing water flow velocity on the formation of biofilms and water quality in pilot distribution system consisting of copper or polyethylene pipes, Water Res., 40 (2006) 2151–2160.
[37] T.M. Traczewska, M. Sitarska, Synthetic materials as a substrate for the development of biofilms in water distribution systems, Ecotoxicology in environmental protection: collective work: Matt. II Conf. Sciences, Szklarska Poręba, 2017, pp. 443–450.
[38] J. Zamorska, Biological Stability of Water after the Biofiltration Process, J. Ecol. Eng., 19 (2018) 234–239.
[39] K. Lautenschlager, N. Boon, Y. Wang, T. Egli, F. Hammes, Overnight stagnation of drinking water in household taps induces microbial growth and changes in community composition, Water Res., 44 (2010) 4868–4877.
[40] D. Van der Kooij, Potential for biofilm development in drinking water distribution systems, J. Appl. Microbiol., 85 (1999) 39–44.
[41] J. Łomotowski, Reasons for Changes in Water Quality in Water Supply Systems, Monographs of the Institute of Systemic Research of the Polish Academy of Sciences. System Test Series, Vol. 55, 2007.
[42] Guidelines for Drinking-Water Quality, Fourth Edition Incorporating the First Addendum; https://apps.who.int/iris/bitstream/handle/10665/254637/9789241549950-eng.pdf;jsessionid=72D49BCC93BEB968B6E9B742650B10D9?sequence=1 (Accessed on 2 November 2019).
[43] A. Francisque, M. Rodriguez, L.F. Miranda-Moreno, R. Sadiq, F. Proulx, Modeling heterotrophic bacteria counts in a water distribution system, Water Res., 43 (2009) 1075–1087.
[44] D. Mara, N. Horan, Handbook of Water and Wastewater Microbiology. Academic Press, London, 2003.
[45] J. Wingender, H.C. Flemming, Biofilms in drinking water and their role as reservoir for pathogens, Int. J. Hyg. Environ. Health, 214 (2011) 417–423.
[46] A. Grabińska-Łoniewska, E. Siński, Pathogenic and potentially pathogenic microorganisms in aquatic ecosystems and water supply networks, Wydaw. Seidel-Przywecki Sp. z o.o., Warsaw, 2010 (In Polish).
[47] A. Sokołowska, K. Olańczuk-Neyman, Microbiological water quality in the water-pipe network of the Gdańsk district, Ochrona Środowiska, 31 (2009) 15–19. Available online: file:///C:/Users/HP/Downloads/Sokolowska_4-2009.pdf (Accessed on 2 May 2019) (in Polish).
[48] S. Chowdhury, Heterotrophic bacteria in drinking water distribution system: a review, Environ. Monit. Assess., 184 (2012) 6087–6137.
[49] L.P. Waines, R. Moateb, A.J. Moodya, M. Allenc, G. Bradleya, The effect of material choice on biofilm formation in a model warm water distribution system, Biofouling, 27 (2011) 1161–1174.
[50] T. Schwartz, S. Hoffmann, U. Obst, Formation and bacterial composition of young, natural biofilms obtained from public bank-filtered drinking water systems, Water Res., 32 (1998) 2787–2797.
[51] J. Inkinen, T. Kaunisto, A. Pursiainen, I.T. Miettinen, J. Kusnetsov, K. Riihinen, M.M. Keinänen-Toivola, Drinking water quality and formation of biofilms in an office building during its first year of operation, a full scale study, Water Res., 1 (2014) 83–91.