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Preliminary microbiological screening of internal water supply installations considering the material structure of pipelines

Karolina Czerwińska[1*], Emil Kuliński[1], Anna Grobelak[1]

[1] Czestochowa University of Technology, Faculty of Infrastructure and Environment, ul. Generała Jana Henryka Dąbrowskiego 73, 42-202 Czestochowa, Poland

* Corresponding author's e-mail: karolina.czerwinska@pcz.pl

ABSTRACT

The quality of drinking water consumed by end users largely depends on the technical condition of internal water supply installations. The aim of the study was to assess the impact of factors such as the technical state of the installation as well as the type of materials used on the growth and abundance of microorganisms. The research was conducted on water samples collected from internal water supply systems. The analyses involved quantification of the total number of bacteria at 22 °C and 36 °C. The obtained results indicated a correlation between the type of material (e.g., plastics, copper) and the technical condition of the installation, as well as the occurrence of specific microbial groups. The study highlighted the importance of regular monitoring of the condition of internal plumbing systems and the appropriate selection of construction materials to ensure high microbiological quality of domestic water and microbiological safety. The findings are also of practical importance, as they may contribute to the development of recommendations for the design, construction, and operation of water supply installations that minimize the risk of water contamination.

Keywords: biofilm, internal water supply system, pipe material, water quality, drinking water.

INTRODUCTION

The presence of microorganisms, particularly pathogenic ones, in drinking water supply systems raises concerns among users due to the associated health risks. Clean water, free from pathogenic bacteria and harmful substances, is fundamental to public safety. Waterborne bacteria can proliferate rapidly, leading to deterioration of water quality, including undesirable taste and odour, the formation of toxic compounds, and the occurrence of secondary contamination. The quality of drinking water is also influenced by the material used in the construction of the water supply system. Depending on the type of material, various reactions may occur, such as leaching from the pipe surfaces, which can result in the release of harmful chemical compounds, pipe corrosion, or the development of biofilm (1). The factors influencing the development of microbial communities in drinking water distribution systems include pH level, temperature, the concentration and type of disinfectant used, availability of nutrients and the presence of biofilm or corroded layers on the internal pipe surfaces (2). Drinking water distribution systems are constructed from a variety of materials, including lead, cement, copper, iron, steel, and polymers.
The studies that included analysis of the mechanisms of corrosion of the internal surface of pipes in the water distribution system showed that the main factors promoting corrosion are dissolved oxygen, calcium carbonate, TDS (total dissolved solids), chlorine dioxide, and low water resistivity. These factors contribute to the formation of electrochemical cells that promote pipe degradation (3).

Currently, sources of lead in drinking water include lead pipes and soldered joints containing lead. Lead concentrations may vary depending on the sampling point, for example, internal plumbing systems or taps at the water treatment plant. Today, lead is no longer used in new pipeline construction, and older installations are typically replaced only when elevated lead concentrations are detected (4). The release of lead into water is influenced by multiple factors, among which pH plays a critical role, as a decrease in pH value contributes to an increase in lead concentration (5).

The research conducted by Trueman and Gagnon (6) indicated a correlation between the occurrence of elevated lead concentrations and simultaneously high levels of iron. Both elements, in the presence of organic matter, are readily released into water supply systems. To control the corrosion of lead pipes, methods such as pH and alkalinity adjustment, the addition of orthophosphates or orthophosphate/polyphosphate blends as corrosion inhibitors and softening using $Ca(OH)_2$ are applied (7).

Cement is used in the production of pipes themselves or as a lining material on the internal surfaces of cast iron or steel pipes. Due to the high pH of cement, an alkaline environment is created, which in turn limits the corrosion of metal pipes (8). Cement pipes are susceptible to a leaching, which is most intense during the initial phase of operation. (9). The research conducted by Mlynska et al. (10) showed that calcium, aluminum, chromium, lead, and cadmium ions are most readily leached from cement-coated cast iron/steel pipes. The type of disinfectant used in drinking water treatment also influences the leaching of harmful substances from cement.

The studies also conducted by Mlynska et al., demonstrated that (10), the rate of compound from cement is inversely proportional to the concentration of the disinfectant used. Although cement pipes are no longer manufactured or sold, the continued use of existing installed pipes is permitted until their decommissioning or reaching the end of their service life (11). Copper pipes used in drinking water distribution systems are covered with a layer of copper oxide. This layer protects against corrosion; however, in the presence of soft water, the degradation of the copper oxide layer begins to degrade. Detached copper oxide crystals are further transported with the water, leading to the formation of pitting corrosion on the inner pipe walls. Corrosion of copper pipes is influenced by such factors as pH, temperature, total organic carbon content, the presence of carbonates, disinfectants, microorganisms, as well as sulfates and polyphosphates/orthophosphates used as corrosion inhibitors (12).

Iron is used in the production of pipes for water supply systems in the form of cast iron pipes, galvanized iron pipes, and ductile iron pipes. Corrosion of such pipes can lead to cracking and the formation of pits. The parameters influencing corrosion include alkalinity, pH, the presence of chloride and sulfate ions, as well as corrosion inhibitors, such as orthophosphates (13–15). The coating limits the access of oxidizing agents, thereby protecting the pipe from further corrosion progression (16).

Studies analyzing the impact of disinfectants on the corrosion of iron pipes have shown that both sodium hypochlorite and liquid chlorine increase iron corrosion. At the same time, sodium hypochlorite enhances the deposition of calcium carbonate over time (17). The rate of iron release from corroded pipes primarily depends on pH, water hardness, nitrate ion concentration, the Larson index, and the level of dissolved oxygen (18). The impact of corroded iron pipes on water quality is also associated with the presence of so-called tubercles on the pipe walls. The water trapped inside these tubercles has a low pH, typically around 5–6, and prolonged water stagnation further reduces the pH to around 4 (19). Long-term use of steel pipes can lead to the formation of corrosion deposits, which often contain significant amounts of chromium compounds (20). As with iron pipes, the corrosion of steel pipes is affected by the presence of disinfectants (21). The corrosion process is also slower under the conditions of continuous water velocity, compared to stagnant water (22). Polymer pipes are also used in water supply systems and include materials such as PE (polyethylene), PEX (cross-linked polyethylene), LDPE (low-density polyethylene), HDPE (high-density polyethylene), PVC (polyvinyl chloride), PVC-U (unplasticized polyvinyl chloride), and Hi-PVC (high-impact polyvinyl chloride). These pipes do not generate corrosion deposits, have reduced heavy metal content, and are lighter than concrete or iron pipes, making them suitable for use in buildings. However, they exhibit lower mechanical strength and provide a favorable surface for the formation of biofilm and organoleptic compounds (23, 24). Iron and manganese originating from various components of the water supply system can dissolve and deposit onto polymer pipes, to which they readily adhere, but can also be easily released back into the water (25). In the case of PVC pipes, various additives are used in their production, such as organotins or lead-based compounds, which may be released during use. Therefore, additional flushing of such pipes is required before they are implemented (26). A biofilm in drinking water distribution systems is defined as a structure composed of microorganisms that forms through adhesion, nucleation, and surface growth. It consists of a bacterial population embedded in a matrix, where microorganisms adhere to each other and to the pipe surfaces. Most biofilms are composed of approximately 90% extracellular polymeric substances (EPS), which are conglomerates of various types of biopolymers produced by the organisms themselves (27, 28). The quality of drinking water depends primarily on the presence and type of biofilm that forms within the system. Biofilm contributes to the deterioration of water quality, corrosion of metal pipes, increased leaching processes in concrete pipes, and the proliferation of pathogens. The presence of scale on the inner pipe walls also promotes microbial growth. The biofilm formed on the internal surfaces of pipes is more diverse and contains a higher number of microorganisms than the biofilm found in continuously flowing water (29). Biofilm can also detach spontaneously as a result of water velocity, leading to an increased concentration of microorganisms in the transported water. Its presence negatively affects the organoleptic properties of water and may pose a threat to human health as well as life due to the presence of pathogenic bacteria such as *Legionella pneumophila* and *Pseudomonas aeruginosa* (30). The role of biofilm in drinking water distribution systems is of critical importance, while also being problematic, as the accumulated microorganisms serve as carriers of various bacteria, including pathogenic ones. Biofilm formation can also contribute to the corrosion of components within the water supply network (27, 28, 31–33). The presence of microorganisms in water is undesirable, yet unavoidable. They serve as a reservoir for pathogenic species, posing a threat to human health and safety. Microorganisms can lead to microbiologically influenced corrosion (MIC), in which the interaction of cells and their metabolic by-products contributes to the degradation of materials used in water supply systems. Proliferating microorganisms cause biofouling and biodeterioration of manufactured products, resulting in negative environmental consequences (27, 33, 34). The continuous proliferation of microorganisms in water leads to changes in the quality of drinking water. The accumulating biofilm on the inner surfaces of pipes reduces pipeline capacity while increasing the concentration of free-floating bacteria in the water, thereby deteriorating drinking water quality. On the other hand, biofilm formation serves a protective function for bacteria, allowing them to survive under the conditions of low nutrient availability essential for growth and development. It shields microorganisms from oxidizing agents, enhances the retention of organic matter, and isolates them from adverse conditions such as disinfectant use, dehydration, or temperature fluctuations (31, 35, 36).

The bacteria forming biofilm utilize carbohydrates, lipids, and proteins present in water. This enables them first to attach to pipe surfaces, then to develop and release EPS, as well as finally to modify their environment in order to either inhibit or promote the growth of other microorganisms. All stages of biofilm formation are influenced by (a) the source of the water supply, (b) the concentration of nutrients, (c) the level of disinfectant present, (d) the age of the pipe, (e) the material from which the pipe is made, and (f) the duration of water stagnation (37–43). Biofilm causes a heterogeneous distribution of the corrosion process due to its non-uniform composition, which includes, among others, sulfate-reducing bacteria, nitrate-reducing bacteria, acid-producing bacteria, and metal-oxidizing bacteria (44, 45, 46). By developing on concrete pipes, biofilm contributes to their degradation. The formed layer can reach a thickness of 2–5 mm. In this process, microorganisms produce fatty acids that locally lower the pH, leading to the leaching of free lime. The resulting microcracks create a favorable environment for microbial proliferation, while simultaneously weakening the material structure, which begins to deteriorate and release specific components into the water, ultimately reducing the mechanical strength of the pipes (47, 48). Metal pipes are also subject to corrosion induced by the presence of biofilm. In the research conducted by Hyun-Jung et al. (49), comparing four types of pipe materials (steel, copper, stainless steel, and polyvinyl chloride), it was shown that microorganisms were more diverse and proliferated more frequently on steel and copper pipes than on polymer and stainless steel pipes.

The aim of the conducted research was to check the influence of the material structure of internal water supply installations on the development of heterotrophic bacteria growing at temperatures of 22 °C and 36 °C. These measurements help assess the microbiological water quality and the potential presence of pathogenic bacteria in water distribution systems.

MATERIALS AND METHODOLOGY

The water sampling locations included four selected DMAs (district metered areas), which were selected based on the assessment of the stability of the water supply network operation and having a single supply source (no variability of water quality parameters). A total of 50 samples were analyzed, which were taken between March 2025 and May 2025 from internal water supply systems directly from consumers' taps. The samples were collected in sterile 200 ml glass bottles containing sodium thiosulfate to neutralize residual chlorine. The samples were transported to the laboratory in a cooled container (4±2 °C) and analyzed within 4 hours of collection to maintain the viability of microorganisms. The samples were taken in accordance with the procedures, i.e., according to PN-EN ISO 19458:2007, and without following the procedures, i.e., without unscrewing the strainer/aerator, without rinsing the internal water supply system for 2–3 min., and without disinfecting the tap.

The water samples were suspended in the amount of 1 ml on Yeast Extract Agar medium and incubated for 48 h at 36 °C and 72 h at 22 °C. After a specified incubation time, the colonies that grew were counted. The counting range was assumed to be 0–300 CFU/ml. For each series of tests, a plate with clean agar was additionally incubated to control sterility and ensure that the medium was not contaminated. Each water sample was analyzed in triplicate.

Samples collection

The stability of hydraulic conditions in the zones was analyzed using TelWin, a SCADA software that allows for data collection, archiving, reporting and visualization, as well as process control and alarming. In the analyzed zones, water velocity [m^3/h] and pressure [MPa] were checked several days before and on the day of water sampling.

Figures 1, 2, 3, and 4 show two series of time-based data from the measurements taken in the analyzed zones. The data concern the pressure in the network – marked in green and the water velocity – red/purple. In all analyzed zones, the pressure in the system was stable a few days before and on the day of sampling. The water velocity with regular fluctuations is related to the periodic demand for water. Detailed information on the technical and hydraulic parameters of the selected zones is presented in Table 1.

Table 1 summarizes the technical and hydraulic parameters of the analyzed zones, including the average pipe diameter, the length of the water supply network in a given zone, the average pressure and water velocity. Hydraulic parameters in individual zones show significant differences. The highest pressure and water velocity were observed in zone A, which is a relatively short network. Zone D is characterized by the longest network and the lowest pressure, while zone B, being the largest network among the analyzed zones, and is characterized by the most diverse pipe diameters.

The percentage share of individual materials used to build the water supply network of selected zones was analyzed in the study, which is presented in Figure 5.

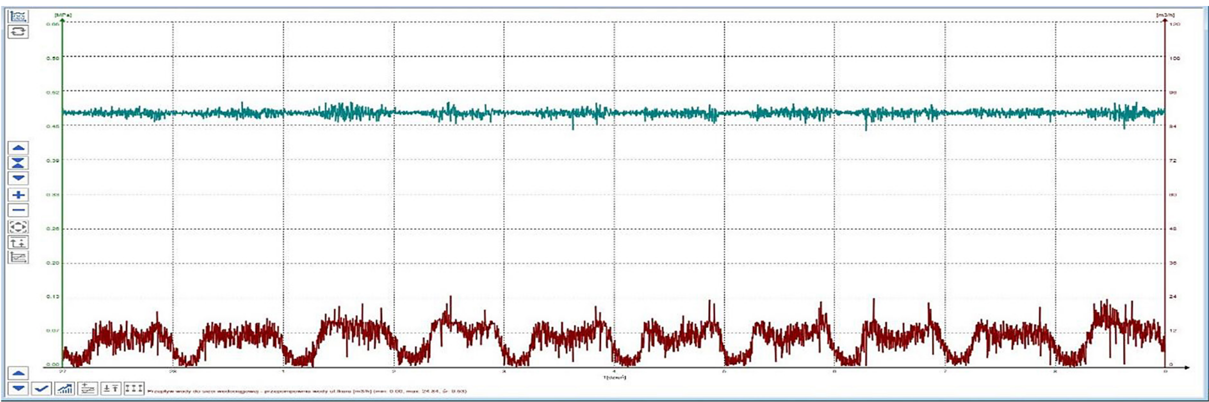


Figure 1. Consistent hydraulic conditions of zone A (screenshot from TelWin)

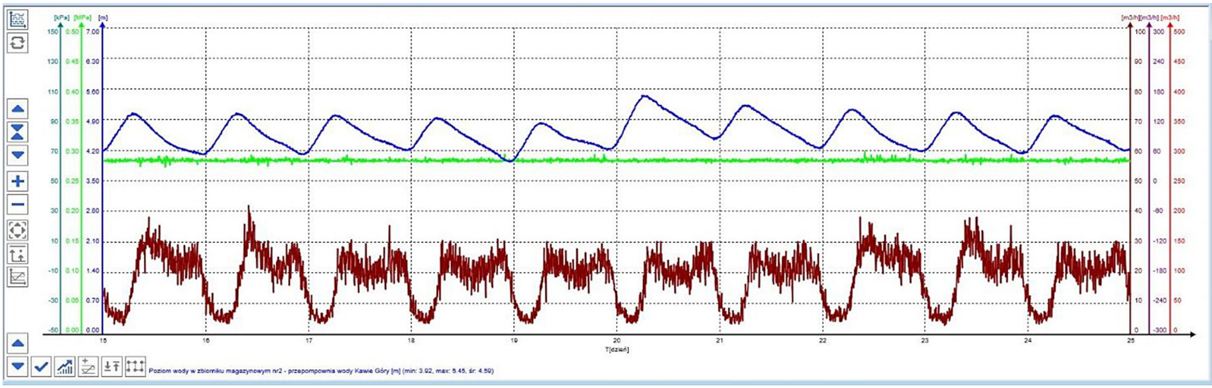


Figure 2. Consistent hydraulic conditions of zone B (screenshot from TelWin)

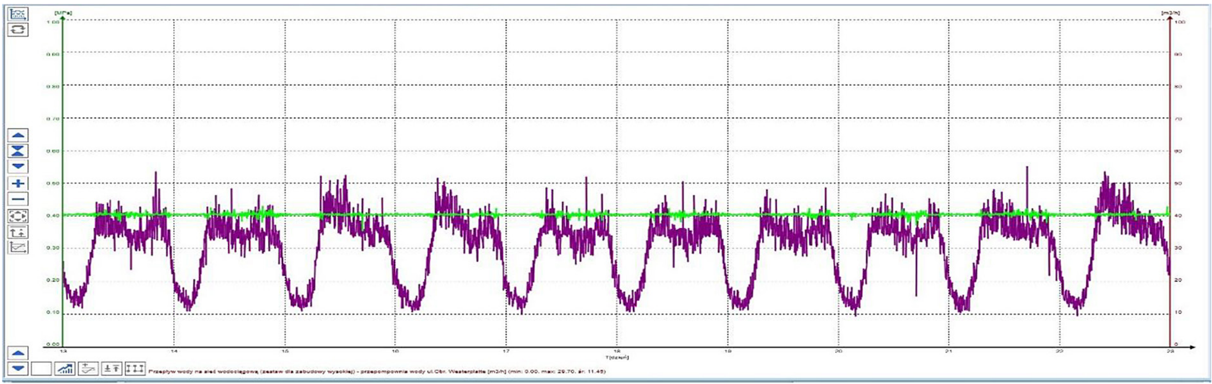


Figure 3. Consistent hydraulic conditions of zone C (screenshot from TelWin)

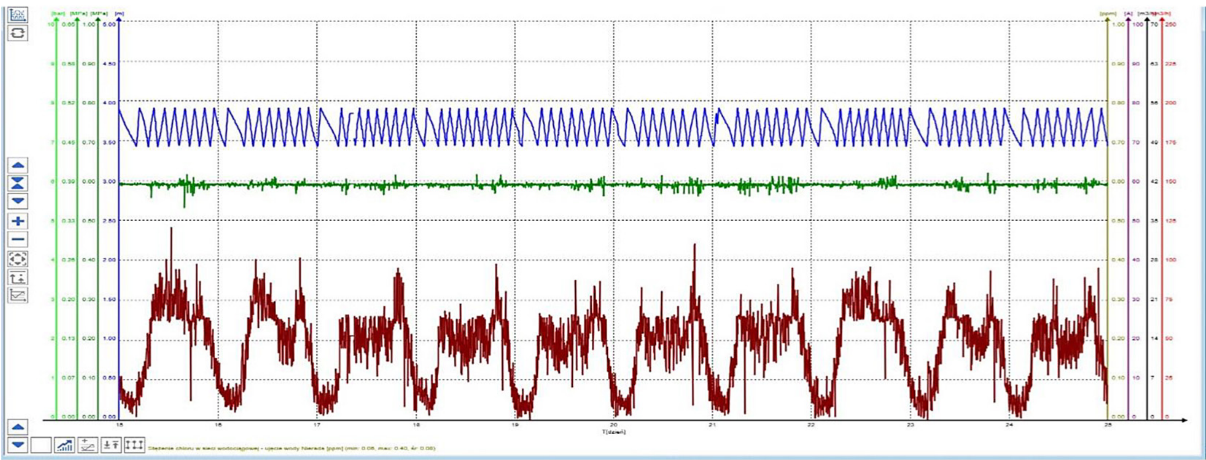


Figure 4. Consistent hydraulic conditions of zone D (screenshot from TelWin)

In zone A, the largest part of the materials was iron (64%), and the smallest was PE (12%). PE pipes accounted for 24% of all materials used. In zone A, there are no stainless steel or asbestos-cement pipes. In zone B, the most pipes are made of PE (38%), and the least of stainless steel (4%). There are also cast iron (31%) and PVC (27%) pipes. There are no asbestos-cement pipes. In zone C, the most is cast iron (52%), the least is PE (19%). There are also PVC pipes (29%). There are no stainless steel or asbestos-cement pipes. In zone D, the largest share is PVC (45%), the smallest is stainless steel (1%). The composition of this zone also includes PE (34%) and cast iron (20%) pipes. No asbestos-cement pipes.

Table 1. Technical and hydraulic parameters of the zones

Parameter	Zone			
	A	B	C	D
Mean diameter value [mm]	122	144	123	118
Length of pipelines [m]	12899	25184	13496	37099
Network pressure [MPa]	0.48	0.38	0.40	0.39
Water velocity [m³/h]	0–16	4–35	10–50	0–28

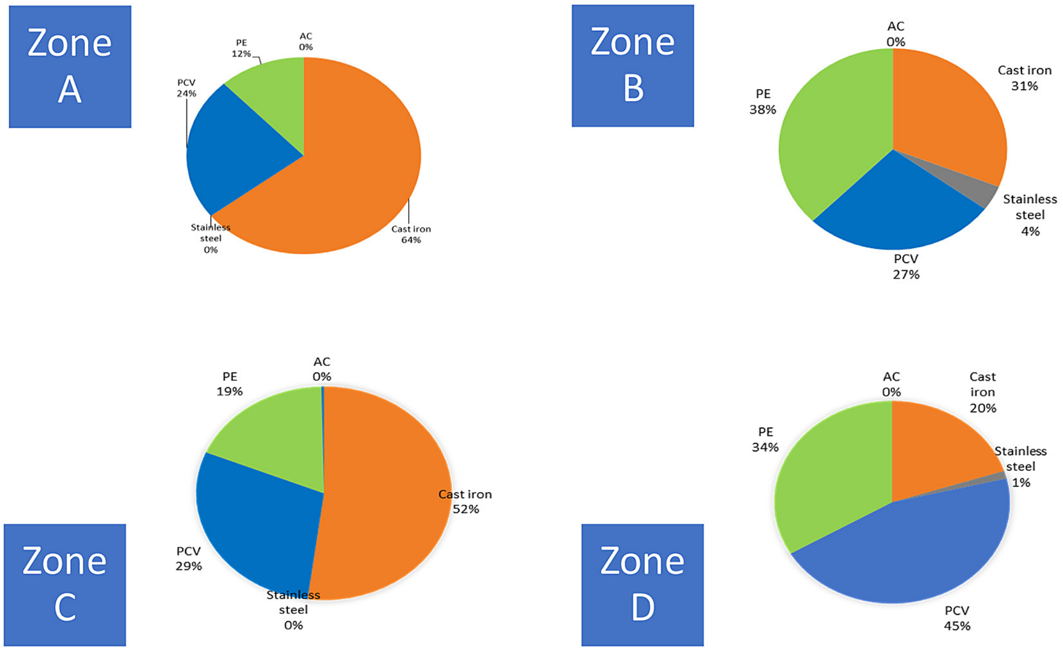


Figure 5. Percentage composition of materials in zones A, B, C, and D

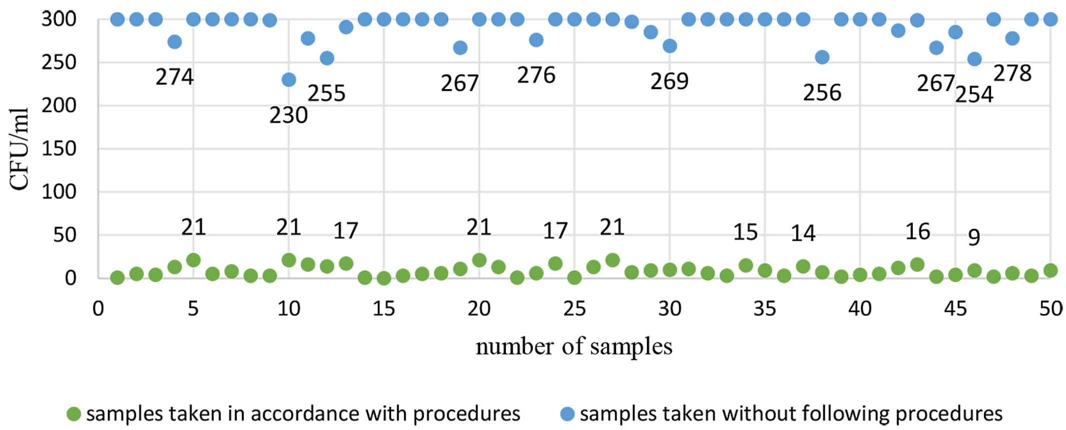
RESULTS

The results of microbiological analyses of the water samples taken with and without observing appropriate procedures according to the PN-EN ISO 19458:2007 are presented in graphs 1 and 2. The limits of bacterial colony countability were assumed as 0–300 CFU/ml. The samples with a result >300 CFU/ml are presented on the graph as a value = 300 CFU/ml.

Figure 6 shows the result of the total number of microorganisms growing at 36 °C, depending on the compliance with the sampling procedures. The vast majority of samples (64%) taken without following the procedures were beyond or at the limit of quantification. The number of bacteria in the samples taken without following the procedures was within the range of 230 to >300 CFU/ml. Despite the sample with the lowest result, this value exceeds the standards for water intended for consumption (up to 200 CFU/ml in the water in the water supply network, up to 100 CFU/ml in the water from the treatment plant). The number of bacteria in the samples taken by the PN-EN ISO 19458:2007 standard was within the range of 0–21 CFU/ml.

Figure 7 shows the result of the total number of microorganisms growing at 22 °C depending on the compliance with the sampling procedures. A larger percentage of samples exceeded or were at the limit of quantification (68%). The number of bacteria in the samples taken without following the procedures was in the range of 257 to > 300 CFU/ml. The sample with the lowest result exceeds the standards for water intended for consumption (up to 200 CFU/ml in water in the water supply network). The number of bacteria in samples taken by the PN-EN ISO 19458:2007 standard was in the range of 2-131 CFU/ml.

The graph shows the percentage of the water samples taken from internal water installations made of different materials, in which the number of bacteria growing at 36 °C exceeded the limit of detection (Figure 8). The highest percentage of



Fiure 6. Total number of microorganisms at 36 °C depending on the sampling procedures

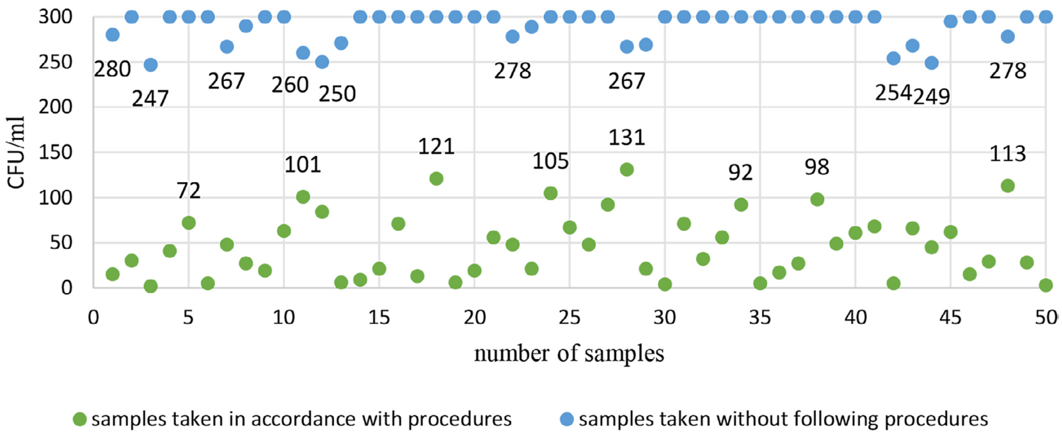


Figure 7. Total number of microorganisms at 22 °C depending on the sampling procedures

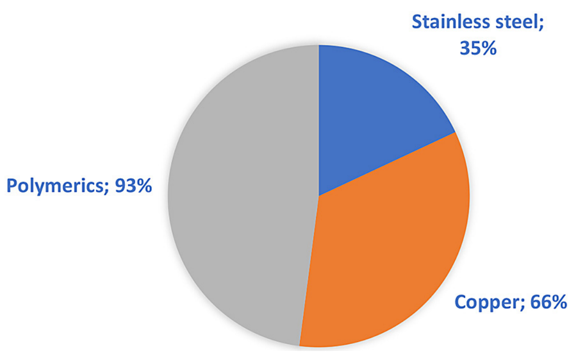


Figure 8. Percentage of the samples with exceeded detection limit of bacteria growing at 36 °C depending on the material of the internal water installation

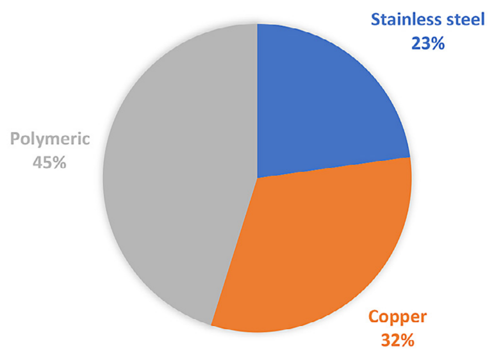


Figure 9. Percentage of the samples with exceeded detection limit of bacteria growing at 22 °C depending on the material of the internal water installation

such cases was recorded in the installations made of plastics (93%). In the case of copper, the exceedance was detected in 66% of samples, while in stainless steel installations – in 35% of cases. The chart shows the percentage of water samples in which the number of bacteria growing at 22 °C exceeded the detection limit, depending on the material of the pipeline (Figure 9). The largest number of samples was observed in plastic installations (45%). In the samples taken from copper installations, this percentage was 32%, while in the case of stainless steel pipes, it was 23%.

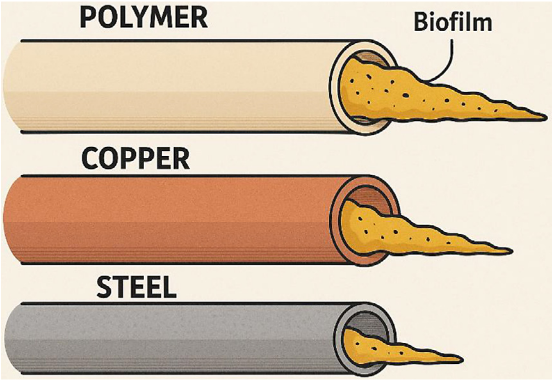


Figure 10. Biofilm growth depends on the material of the internal plumbing system

Figure 10 shows a cross-section of three pipes made of polymer, copper, and steel materials. The polymer pipe exhibits the highest biofilm growth, covering a substantial portion of its internal surface. The copper pipe contains a visible, but thinner, biofilm compared to the polymer pipe. The steel pipe has minimal biofilm. Two-way ANOVA and Tukey HSD post-hoc tests were performed for the data on microorganism counts at 22 °C and 36 °C, depending on the material and temperature, as shown in Table 2. After conducting the analysis, it can be observed that:

- there is a statistically significant effect of material on the number of microorganisms ($p = 0.000385 < 0.05$),
- there is no statistically significant effect of temperature on the number of microorganisms ($p = 0.759757 > 0.05$),
- there was no statistically significant interaction effect between material and temperature ($p = 0.201678 > 0.05$).

Significant statistical differences based on the Tukey HSD post-hoc Test results presented in Table 3 were found between the following materials:

- copper and steel ($p = 0.0403$),
- polymers and steel ($p = 0.001$).

The analyses based on the Tukey HSD post-hoc test results, presented in Table 4, showed: there was no significant difference in the number of microorganisms between temperatures of 22 °C and 36 °C ($p = 0.7854$).

The statistical analysis performed indicates that the type of material used in internal plumbing systems is crucial for microbial growth at 22 °C and 36 °C. Steel may exhibit the properties that limit bacterial growth, as evidenced by the lower microbial counts compared to copper and polymer systems. It was also noted that temperature had no significant effect on the number of microorganisms, either in interaction with the material or on its own. Within this temperature range, it is not a limiting factor for bacterial growth. Furthermore, the results of post-hoc tests confirmed that the differences in microbial counts are due to material properties, not temperature. The differences between copper and steel, as well as polymers and steel, are statistically significant. The lack of a significant material-temperature interaction indicates that these factors are independent.

Table 2. ANOVA results table

Source	Sum of Squares	df	F-value	P-value
C(Material)	3850.42	2.0	8.557851	0.000385
C(Temperature)	21.16	1.0	0.094059	0.759757
C(Material):C(Temperature)	732.78	2.0	1.628667	0.201678
Residual	21146.64	94.0	NaN	NaN

Table 3. Tukey HSD post-hoc test for 'Material'

Group 1	Group 2	Meandiff	P-Adj	Lower	Upper	Reject
Copper	Polymers	6.55	0.1875	-2.2918	15.3918	False
Copper	Steel	-8.8676	0.0403	-17.4211	-0.3142	True
Polymers	Steel	-15.4176	0.001	-24.3769	-6.4584	True

Table 4. Tukey HSD post-hoc test for 'Temperature'

Group 1	Group 2	Meandiff	P-adj	Lower	Upper	Reject
Total number of microorganisms at 22 °C	Total number of microorganisms at 36 °C	0.92	0.7854	-5.511	7.351	False

The aim of the conducted research was to check the influence of the material structure of internal water supply installations on the development of heterotrophic bacteria growing at temperatures of 22 °C and 36 °C. Samples were taken between the hours of 8:00 and 12:00 directly from consumers' taps, immediately after turning on the cold water. The main materials from which the analyzed internal water supply installations are made included stainless steel, copper and polymeric materials such as PVC, PE.

The samples were also analyzed depending on compliance with the sampling procedures. The obtained results showed that the water samples taken without following the procedures have a significantly greater growth of bacteria at 22 °C and 36 °C compared to the samples taken by the standard PN-EN ISO 19458:2007. Failure to follow the procedures and take care of the internal installation leads to overstated microbiological results, which may indicate the condition of the internal water supply installation, posing a threat to the health of users.

The conducted analysis also took into consideration the material composition of the entire individual zones. Despite the presence of various materials in the entire water supply system (PE, PVC, steel, cast iron), the development of microorganisms is primarily influenced by the type of material from which the internal water installation is made.

Increased pressure and water velocity in zone A with the shortest network can promote better sediment flushing and less stagnation. In zone D, which is the longest zone, local water stagnation may occur due to lower water pressure. Lower water velocity in zone B, which has the most diverse pipe diameters, can contribute to the formation of biofilm in the places with the largest cross-sections. Maintaining proper hydraulic conditions is crucial to ensuring good drinking water quality and limiting the development of biofilm in drinking water distribution systems.

Stable pressure in the network on the days of sampling for analysis indicates the lack of sudden changes caused by e.g., fires or sudden failures in the analyzed zones. Small variability of water velocity in the analyzed zones was related to the periods of sampling and water rest (day/night). Analysis of the results showed that the largest percentage of samples in which the number of bacteria growing at temperatures of 22 °C and 36 °C exceeded the detection limit came from the installations built of polymer materials, then from copper installations, and the least from stainless steel installations (Figure 6). The material of the pipeline has a significant effect on the multiplication of microorganisms.

DISCUSSION

The material structure of pipelines can affect the development of microorganisms in various ways. Polymer pipes, such as PVC or PEX can leach out bioavailable organic carbon, which is a source of energy for bacterial growth and development, while also promoting biofilm formation. The use of such pipes is also associated with increased biofilm biomass and higher levels of opportunistic pathogens compared to copper pipes (50– 52). The studies comparing polyethylene pipes have shown greater adhesion and growth rate of microorganisms compared to polypropylene pipes. The use of plastic pipes, which often contain various additives – such as those enhancing flexibility – can further support biofilm development. The specific chemical composition of these pipelines may absorb or sustain microorganisms that do not thrive in metal or concrete pipes (50).

The presence of biofilm contributes to the reduction of disinfectant concentration. Depending on the type of disinfectant used, different byproducts are formed as a result of microbial transformation. This phenomenon also depends on the material from which the installation is made. Research by Hang et al. (30) showed that ductile iron and stainless steel pipes produced significantly greater amounts of 2,4,6-TCA than PE pipes in the case of using 2,4,6-trichlorophenol (2,4,6-TCP).

Biofilm can affect chlorine stability, as demonstrated in various studies. Researchers analyzed carbohydrate concentrations, biofilm thickness, biofilm mass, and EPS (extracellular polymeric substances) under varying water velocity rates (0.08–0.20 L/min) and free residual chlorine levels ranging from 0.05 to 0.7 mg/L in a reactor containing segments of HDPE and PVC pipes. The studies showed that both types of polymer pipes were equally susceptible to biofilm formation, with chlorine primarily present in the form of organic chloramines (53). Compared to free-floating microorganisms, biofilm offers a less favorable environment for genetic material exchange, thereby reducing microbial sensitivity to antibiotics and disinfectants. The presence of biofilm can also cause water discoloration, resulting from its corrosive effect on pipe surfaces. This leads to the formation and accumulation of loose sediments to a degree that hydraulic changes are insufficient to remove them. Over time, the accumulated deposits – containing elements such as calcium, iron, and manganese – combined with physical and biochemical processes, contribute to the discoloration of drinking water (28). Development in drinking water distribution systems can promote the growth of *Legionella pneumophila* bacteria. Initially, it develops at room temperature under stagnant water conditions, but its concentration increases only under flowing water conditions (54, 55). The formation of microbial communities in drinking water distribution systems depends on the surface of the material from which they are made. The key role is played by such features as roughness, surface energy and hydrophobicity/hydrophilicity. Under the conditions favorable to the adhesion of proteins, carbohydrates and other organic and inorganic compounds, a conditioning layer is formed, creating optimal conditions for the formation of biofilm on the surface. The conditioning layer also fulfills protective functions for bacteria (56). Several studies have been conducted to analyze the growth of microbial communities depending on the pipe materials used (57, 58). Studies (32) have shown different numbers of microorganisms with different morphology depending on the pipe material and conditioning. Biofilm development occurred at lower water velocity and inhibition of its development at higher flows, which indicates the effectiveness of shear forces on the ability of biofilm to attach to pipe walls. Some species of bacteria, i.e. *Sphingomonas* and *Pseudomonas*, were abundantly present in the biofilms formed at higher flows inside pipes made of rough materials such as PVC and Str-HDPE (32). The microorganisms in drinking water that form biofilm contribute to the release of corrosion products from pipe materials, providing a substrate that promotes further biofilm formation and influences the composition of microbial communities. The smooth surface of plastic pipes allows for the easy removal of biofilm, thereby exposing a larger surface area available for re-colonization by bacteria. A more stable microbial community is favored in environments where corrosion deposits are present, as these deposits offer protection, similar to the case of iron-metabolizing bacteria living on iron pipes. Under such conditions, biofilm is less exposed to disinfectants, which in turn promotes its continued development (31). The material from which the water installation is made influences the development of various bacterial communities. In studies (42), comparing PVC-U, PE-HD and cast iron pipes, it was shown that the dominant bacteria on polymer pipes were *Proteobacteria* and on cast iron pipes *Nitrospirae*, thus indicating that polymer pipes create a more favorable environment for pathogenic species compared to cast iron pipes. In other studies (59), microbial communities growing on PVC, PEX and HDPE pipes were compared. HDPE pipes were characterized by the largest number of microorganisms, including those attached to sediments, while PEX pipes contained the largest number of non-aggregating bacteria. On the other hand, PVC pipes were characterized by the largest number of pathogenic bacteria of the *Pseudomonas aeruginosa* species. Studies (50) have shown that under semi-stagnant conditions, the greatest microbial growth occurred on the surface of pipes made from PVC-P, while the least was observed on copper pipes. PVC-P and PE pipes promoted the growth of species such as *Legionella spp., Mycobacterium spp., Pseudomonas spp., Aeromonas spp.*, fungi, and *Vermamoeba vermiformis*. The same study also demonstrated that under intermittent flow conditions, there was an increase in *Legionella pneumophila* on the surface of copper pipes compared to stainless steel, CPVC, and glass pipes. Species capable of growing on corroding copper likely utilize low-molecular-weight carboxylic acids as substrates for metabolic processes. The studies comparing PE, steel and ductile iron pipes have shown more favorable conditions for bacterial growth on the surfaces of ductile iron pipes. This is due to the higher concentration of proteins and polysaccharides in EPS (37). Other studies have shown that *Azospira* and *Dechloromonas* bacteria were more numerous on cast iron pipes compared to PE pipes due to the presence of iron as a substrate for the production of iron oxides, which results in/leads to corrosion (60).

Increased biofilm biomass is associated with numerous negative effects on human health and safety. The harmfulness of microbial activity largely depends on the species composition of the microbial community. Among the pathogenic bacteria that pose a risk in drinking water are *Stenotrophomonas maltophilia, Ralstonia pickettii, Pseudomonas stutzeri, Pseudomonas putida, Pseudomonas fluorescens*, and *Pseudomonas* *aeruginosa* (51). The studies analyzing PE pipes have shown an increased presence of *Mycobacterium* and *Mycobacteroides*, which are organisms resistant to chlorine disinfection (61). The presence of biofilm in drinking water distribution systems poses a risk related to the formation of disinfection byproducts (DBPs) because biofilm – a structure composed of microorganisms embedded in a matrix of organic substances – acts as both a reservoir of DBP precursors and a site for local chemical reactions involving disinfectants. In addition, biofilm impedes the even distribution of disinfectant in the water supply network, which can result in local zones of elevated DBP concentrations and increased microbiological risk (62). The species *Ralstonia pickettii* is found in the biofilms forming on the surfaces of PE and cast iron pipes (51). The presence of biofilm in drinking water distribution systems poses a risk associated with the formation of disinfection byproducts (DPBs). Depending on the type of material used in the pipelines, the potential for the formation of DPBs by microorganisms is different. In the studies (24) biofilms on ductile iron pipes were characterized by the highest potential for the formation of disinfection by-products, compared to stainless steel and polyethylene. The polymeric substances forming the biofilm matrix have a greater potential for the formation of DPBs than bacteria themselves, with particular emphasis on the amino acids histidine, alanine and tryptophan among all EPS components (24).

CONCLUSIONS

In microbiological analysis, the sampling procedures prescribed in the PN-EN standard have a limiting effect on the correct interpretation of microbiological analysis results; water samples collected under non-prescribed conditions demonstrated bacterial colonies at significantly higher levels, exceeding acceptable standards for potable water. It was found that microorganisms will grow within the internal installations of plastic materials (e.g., PVC, PE) to a markedly greater extent than copper installations, and at a lower level than stainless steel installations, because plastic pipes enable the adhesion of the bacteria to the defected surface area and the brick feature the ability for bacteria to form biofilms based on its physical surface features and chemical composition. In the conducted study, it is evident that the composition of materials for internal water supply systems affects the spread of heterotrophic bacteria, as shown by the number of times the bacterial detection limit was exceeded for concentrations above the maximum acceptable concentration. This was highest for the internal installations made with plastic materials and copper, and the lowest for internal installations made of stainless steel. Moreover, the hydraulic conditions (i.e., water velocity and pressure) within the different sectors of the network also affect the ability to spread microorganisms. Long pipe networks or those with variable diameters are also those where biofilm will develop preferentially due to water stagnation of particular diameters and sedimentation of dead objects, such as biofouling or exoenzyme substances. In addition to causing microbial contamination, biofilm will also cause chemical changes to the water, such as increased formation of disinfection byproducts (DBPs). Higher DBP rates of formation will occur in parts of the water supply network at further distances from the microbial biofouling. The most significant higher EP may occur in water supply systems manufactured from plastic pipes. Although the material properties of the pipes or pipe sections must be considered in microbiological analysis, not to be excluded from consideration are all accessories that are made from the same material.

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