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INVESTIGATION OF THE IMPACT OF THE TECHNICAL CONDITION OF WATER SUPPLY SYSTEMS ON DRINKING WATER QUALITY

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Abstract

This study investigates the impact of pipeline corrosion on drinking water quality, with a focus on secondary contamination caused by metal ion release and biofilm formation. The technical condition of water supply systems was assessed using metallographic and elemental analyses, while the presence of corrosion products was examined through spectroscopic. The results confirm that corrosion of pipelines contributes to the accumulation of iron oxides and the formation of microbial biofilms, leading to deterioration in water quality. It has been established that damage to protective coatings on steel pipes accelerates oxidation, increasing the risk of microbiological contamination. Additionally, disruptions in water supply schedules contribute to water stagnation, further intensifying contamination risks. Furthermore, the release of heavy metal ions from corroded pipelines poses potential long-term health risks for consumers. To mitigate these issues, a water purification system is proposed at the consumer supply stage, integrating multi-stage filtration, sorption technologies, and disinfection methods. This approach enhances the removal of corrosion byproducts and microbiological contaminants, ensuring safer drinking water. The study highlights the necessity of corrosion control strategies, regular pipeline maintenance, and systematic monitoring to reduce contamination risks and improve water supply quality and public health safety.

Keywords: water supply; pipeline corrosion; secondary contamination; iron oxides; drinking water; microbiological safety; filtration; disinfection.

ДОСЛІДЖЕННЯ ВПЛИВУ ТЕХНІЧНОГО СТАНУ СИСТЕМ ВОДОПОСТАЧАННЯ НА ЯКІСТЬ ПИТНОЇ ВОДИ

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Анотація

У цьому дослідженні вивчається вплив корозії трубопроводів на якість питної води з акцентом на вторинне забруднення, спричинене виділенням іонів металів та утворенням біоплівки. Технічний стан систем водопостачання оцінювався за допомогою металографічного та елементного аналізу, а продукти корозії досліджувалися методами спектроскопії. Результати підтвердили, що корозія трубопроводів сприяє накопиченню оксидів заліза та формуванню мікробних біоплівки, що призводить до погіршення якості води. Встановлено, що пошкодження захисних покриттів на сталевих трубах прискорює окиснення, підвищуючи ризик мікробіологічного забруднення. Крім того, порушення графіків подачі води спричиняє застій у трубопроводах, що посилює ризики забруднення. До того ж, вивільнені важкі метали з кородованих трубопроводів можуть становити довгострокову загрозу здоров'ю споживачів. Для вирішення цих проблем запропонована система очищення води на етапі подачі споживачам, яка включає багатоступеневу фільтрацію, сорбційні технології та методи знезараження. Такий підхід сприяє ефективному видаленню продуктів корозії та мікробіологічних забруднень, забезпечуючи підвищену безпеку питної води. Дослідження підкреслює необхідність контролю корозійних процесів, регулярного технічного обслуговування трубопроводів та систематичного моніторингу, щоб зменшити ризики забруднення і покращити якість водопостачання та безпеку здоров'я населення.

Ключові слова: водопостачання; корозія трубопроводів; вторинне забруднення; оксиди заліза; питна вода; мікробіологічна безпека; фільтрація; знезараження.

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Introduction

The vast majority of Ukraine's population consumes water from centralized water supply systems: 99.1 % of cities, 89.8 % of urban-type settlements, and 30.1 % of rural settlements (according to the National Report on Drinking Water Quality and the State of Drinking Water Supply in Ukraine in 2018). At the same time, only 69% of the population has access to centralized water supply systems, while 47.8 % have access to centralized wastewater disposal systems.

The total length of water supply networks (excluding Donetsk and Luhansk regions) amounts to 102,759 thousand kilometers, including 34,216 thousand kilometers, or 33.3 %, classified as obsolete and emergency pipelines [3].

The quality of drinking water from centralized water supply systems does not meet established standards in many settlements across the regions. The deterioration of drinking water quality is primarily associated with the condition of water supply networks, particularly internal building pipelines, which are about 80% worn out, as well as numerous unauthorized connections of new construction projects to the water supply network [1; 2].

Water contamination by corrosion products and other toxic elements is one of the major environmental issues affecting modern water supply systems. At the same time, the significant deterioration of pipelines, particularly internal building networks, creates conditions that intensify corrosion processes, potentially leading to additional drinking water contamination [3;4]. In Ukraine, approximately 40% of water supply networks have reached a critical level of wear, and around 35% of drinking water treatment facilities require modernization, directly impacting water quality and public health [5].

Corrosion processes occurring in both metal pipeline components and nickel-coated surfaces result in water contamination with metal ions and corrosion products, negatively affecting the hygienic properties of water. Corrosion not only degrades the mechanical properties of pipes but is also a primary cause of secondary water contamination by corrosion byproducts such as metal ions, oxides, and hydroxides. These substances can enter drinking water, posing a health risk to consumers [6; 7].

Furthermore, corrosion damage and the formation of rough surfaces inside pipes create a favorable environment for biofilm development, which can harbor pathogenic microorganisms. Biofilms in water supply pipes can serve as a

source of infections, such as *Legionella* and other harmful bacteria, posing a serious bacteriological threat [8].

Research on corrosion processes and their impact on water contamination is not only a scientific necessity but also crucial for developing effective water purification methods, improving water supply systems, and reducing public health risks [9]. The issue of corrosion and water contamination remains highly relevant in the context of modern water supply infrastructure, as existing anti-corrosion methods do not always yield the desired results, and the search for new water treatment technologies requires ongoing attention and research.

Analysis of Recent Studies and Publications. Recent research in the field of metal corrosion and its impact on water quality highlights the importance of monitoring the processes occurring in water supply pipelines. As noted by the authors [7], steel corrosion in various environments significantly affects the mechanical properties of metals [10] and contributes to the accumulation of corrosion products in water. Therefore, water contamination can pose a serious health risk to consumers, especially if corrosion leads to the formation of hazardous compounds, such as iron ions.

Fig. 1 illustrates the mechanism of secondary contamination of tap water due to corrosion processes. The corrosion of metal pipelines occurs through the anodic oxidation of iron ($\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$) and the cathodic reduction of dissolved oxygen ($\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$). The corrosion products formed as a result of these reactions include iron hydroxides $\text{Fe}(\text{OH})_2$, $\text{Fe}(\text{OH})_3$, and other compounds that either precipitate in water or form deposits on the inner walls of the pipes. As a result of these processes, water becomes contaminated with corrosion product particles, and favorable conditions for microbial growth are created, potentially leading to microbiological contamination.

The quality of water in supply systems depends on a complex set of factors that determine its physicochemical and microbiological composition. As shown in Fig. 2, malfunctions in the water supply system, particularly power supply failures and disruptions in the water distribution schedule, lead to changes in consumption patterns, the formation of stagnant zones, and, consequently, increased water contamination. Corrosion processes occurring in both centralized and in-building pipelines result in water contamination with corrosion

byproducts and contribute to the development of biofilms containing pathogenic microorganisms [11; 12]. This, in turn, deteriorates water quality by altering its color, odor, and taste, while also increasing turbidity due to sediment accumulation and microbiological pollution. As a result, consumers may be exposed to hazardous chemical and biological factors, increasing health

risks and necessitating additional water purification measures, such as filtration, disinfection, or the use of bottled water. Therefore, pipeline corrosion and water supply disruptions are key factors that directly affect water quality and pose potential health threats to the population.

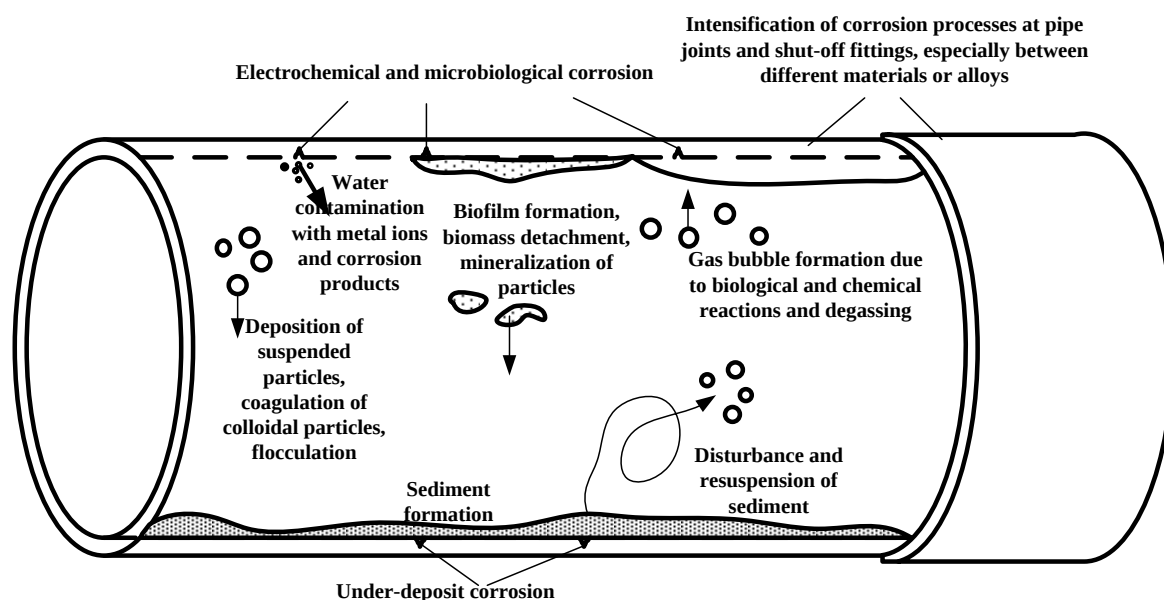


Fig. 1. The process of secondary water contamination in water supply systems

The study [13] examined the corrosion potential of water in the Iranian city of Rafsanjan, revealing a high level of corrosion in urban water pipelines due to the elevated content of iron and chloride ions in the water. This confirms the existence of a correlation between the chemical composition of water and the intensity of corrosion processes. The authors note that corrosion processes not only affect the physical properties of pipes but also cause the dissolution of heavy metals in water, increasing the risk of diseases such as lead and cadmium poisoning.

Currently, [14] considers the use of coatings to improve the corrosion resistance of steel pipes. However, it highlights that even high-quality coatings cannot fully protect against the effects of aggressive chemical compounds present in water, especially under conditions of temperature and humidity fluctuations. This fact confirms the necessity of continuous monitoring of water supply networks to detect corrosion products at early stages.

Additionally, detecting pathogenic microorganisms that accumulate on rough pipe surfaces due to corrosion processes is crucial. As researchers [15] point out, microcracks and pores on metal surfaces serve as ideal sites for the development of biofilms, which may contain dangerous bacteria such as *Legionella*, posing a serious health threat to water consumers.

Previous research has addressed the issue of pipeline corrosion and its effect on material durability. However, insufficient attention has been given to its consequences for water quality, particularly secondary contamination by corrosion products and the microbiological risks arising from biofilm formation in damaged areas. Despite the existence of scientific studies focusing on specific aspects of corrosion processes in water supply systems, the comprehensive impact of these processes on changes in the chemical and microbiological composition of water under disrupted water supply conditions remains insufficiently explored [16; 17].

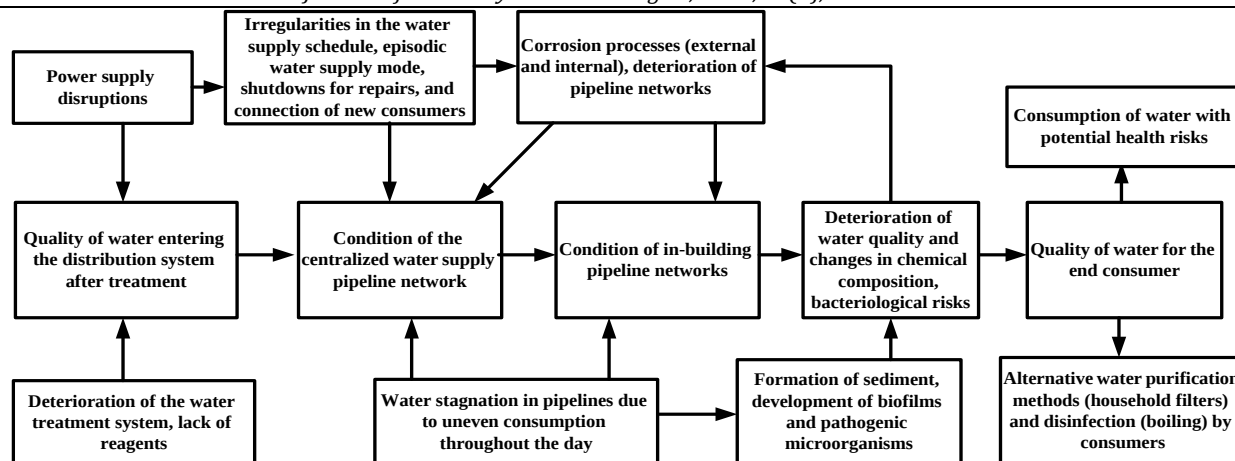


Fig. 2. Analysis of factors affecting water quality in pipelines

In particular, there is a lack of systematic research on the interrelation between corrosion-induced pipeline degradation, the accumulation of corrosion products, and biofilm formation, which may contain pathogenic microorganisms [18]. Identifying this relationship is crucial for developing effective methods of water quality control and minimizing the negative impact of corrosion processes in water supply systems, which is the primary objective of this study.

This study comprehensively examines the impact of corrosion processes on water quality in pipeline systems, with a focus on secondary contamination by corrosion products and microbiological risks arising from biofilm formation in damaged pipeline sections. Unlike previous research, which primarily focused on corrosion mechanisms and material degradation, this study establishes the relationship between pipeline coating integrity disruption, the accumulation of corrosion products in water, and conditions that promote the proliferation of pathogenic microorganisms [19; 20]. A key distinction of the proposed approach is its consideration of dynamic changes in water supply, which enhances water purification efficiency and minimizes the negative effects of corrosion processes in distribution networks.

The aim of this study is to comprehensively assess the impact of the technical condition of water supply systems on drinking water quality, with a focus on corrosion processes that cause secondary contamination. Special attention is given to the experimental detection of corrosion products in water after water supply interruptions and their impact on microbiological safety. The obtained results provide a basis for developing recommendations to improve water supply quality and reduce the risks of secondary water contamination in distribution networks.

Experimental

Elemental analysis of the samples was conducted using the optical emission method on a Spectro device, which provides accurate data on the elemental composition of the surface layer. This information is essential for further assessment of material properties, including potential factors influencing corrosion behavior.

Metallographic studies were carried out using a ZEISS AIXO Ver.1 metallographic microscope, enabling a detailed examination of the microstructure of the samples after corrosion testing and the identification of defects or damage.

Microscopic analysis, performed using the XS-3330 LED MICROMed microscope, included the study of iron complex sediment in water formed due to disruptions in the water supply schedule, as well as corrosion changes on the surface of the nickel coating and faucet elements after two years of operation.

Results and discussion

Based on the conducted research, it has been established that the significant wear of pipeline systems leads to the intensified development of corrosion processes. One of the key targets of corrosion damage is water treatment station equipment (Fig. 3a), particularly storage and transportation reservoirs, pipelines, and pumping systems. The corrosion of this equipment occurs due to prolonged contact with water containing aggressive ions, such as chlorides, sulfates, and dissolved oxygen [21; 22]. Additionally, temperature fluctuations and mechanical impact from hydrodynamic loads accelerate the surface degradation of metals. As a result, rust deposits form, serving as a source of secondary water contamination.



Fig. 3. Examples of corrosion during water transportation: (a) corrosion of equipment at a water treatment station; (b) corrosion of faucets in centralized water supply; (c) corrosion of faucets in centralized water supply

Shut-off valves and faucets used in centralized water supply systems are among the most vulnerable elements to corrosion damage. Corrosion in these components has a mixed nature: in addition to general electrochemical metal degradation, localized pitting corrosion occurs due to the uneven distribution of stresses at connection points (Fig. 3b, c). The presence of corrosion products in the sealing areas leads to a loss of joint tightness, increasing the likelihood of leaks and requiring regular maintenance [23]. Additionally, metal oxide deposits on the internal surfaces of the fittings create conditions for microbiological contamination of water.

Metal pipes and faucets with a protective nickel coating exhibit reduced corrosion resistance during long-term operation. Specifically, the

results of metallographic analysis confirm that after two years of use, the nickel coating undergoes degradation at bending points and areas of mechanical stress (Fig. 4a). This is due to the formation of microcracks in mechanically deformed areas, which become active anodic zones for the corrosion process. Under these conditions, the base material, which is low-carbon steel, begins to oxidize actively, leading to the further degradation of the surface layer (Fig. 4b, c) and the release of metal ions into the water. This phenomenon creates additional risks of drinking water contamination with nickel and iron ions, which may have toxic effects on human health if maximum permissible concentrations are exceeded.

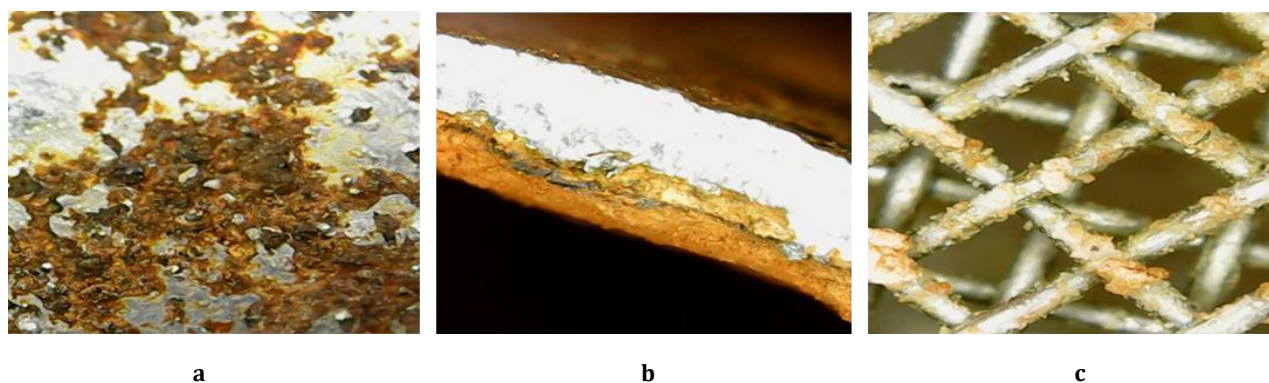


Fig. 4. Corrosion changes in the nickel coating and faucet elements after 2 years of operation: (a) surface of the nickel coating applied to steel 10; (b) cross-section of the faucet body showing corrosion damage; (c) aerator mesh at the water outlet affected by corrosion.

Elemental analysis demonstrated that the faucet material is made of low-carbon steel with a nickel coating (Table 1) approximately 7 μm thick. Corrosion damage is primarily observed at

bending points, where technological deformation occurs, likely leading to the destruction of the protective coating (Fig. 5).

Table 1

Elemental composition of the water tap (%)

Таблиця 1

Елементний склад водопровідного крану (%)

Sample	C	Mn	Cr	Ni	S	P	Material
Tap	0.11	0.15	-	-	0.021	0.031	Steel 10
Coating	-	-	3.67	96.33	-	-	Ni

During the study, an analysis of changes in the chemical composition of water in the pipeline system was conducted under different operating conditions: normal operation mode and after water supply shutdown and restoration. Water samples were collected at control points before

the water supply was interrupted and after it was restored. The research results showed a significant increase in the concentration of corrosion products, particularly iron ions, as well as an increase in water turbidity in the first hours after the supply was resumed.

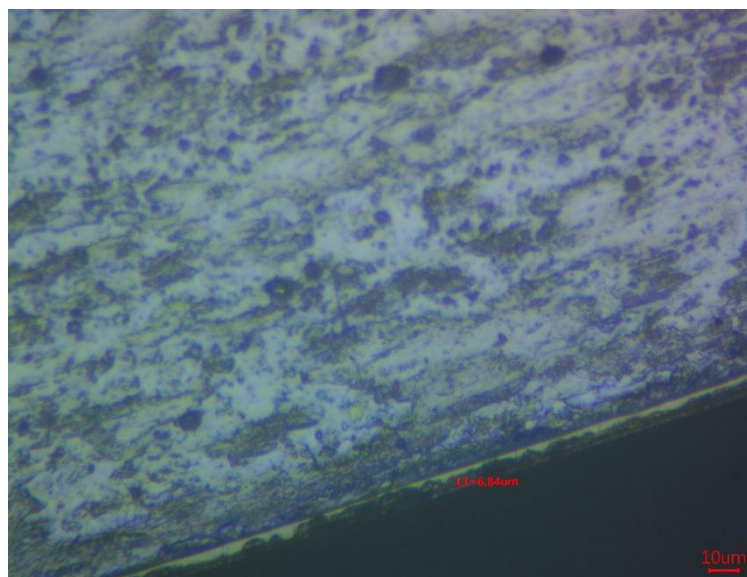


Fig. 5. Partially damaged coating (x500)

Before the shutdown, the physicochemical properties of the water remained stable: the pH level ranged from 7.2 to 7.5, and the Fe^{2+} concentration did not exceed 0.1 mg/L. In terms of organoleptic characteristics, the total suspended solids content ranged from 2 to 5 mg/L.

After the shutdown and restoration of water supply, a sharp increase in the concentration of corrosion products was observed. The following changes were recorded:

1) The concentration of Fe^{2+} ions increased to 0.7–1.2 mg/L, exceeding the upper threshold of the recommended range for total iron (0.2–1.0 mg/L) as defined by DSanPiN 2.2.4-171-10, which regulates hygienic requirements for drinking water intended for human consumption.

Water turbidity more than doubled (from 0.7–1.1 mg/L to 2.5–3.2 mg/L).

Presence of brown sediment after settling water samples, confirming the formation of iron hydroxides $\text{Fe}(\text{OH})_2$ and $\text{Fe}(\text{OH})_3$.

Detection of small fragments of corrosion deposits in water samples, indicating the shedding of oxide films from the inner surface of pipelines.

Analysis also showed that 4–6 hours after water supply restoration, the concentration of corrosion products gradually decreases; however, during the first 1–2 hours, it remains elevated. This confirms that at the moment of system restart, a massive washout of corrosion products accumulated in stagnant zones of the pipeline occurs.

The obtained results indicate that periodic interruptions in water supply can significantly affect drinking water quality, increasing the risks of secondary contamination and deteriorating its organoleptic properties. Additionally, sediment deposits can serve as a medium for the development of biofilms containing pathogenic microorganisms, including *Legionella* species, which pose serious health risks.

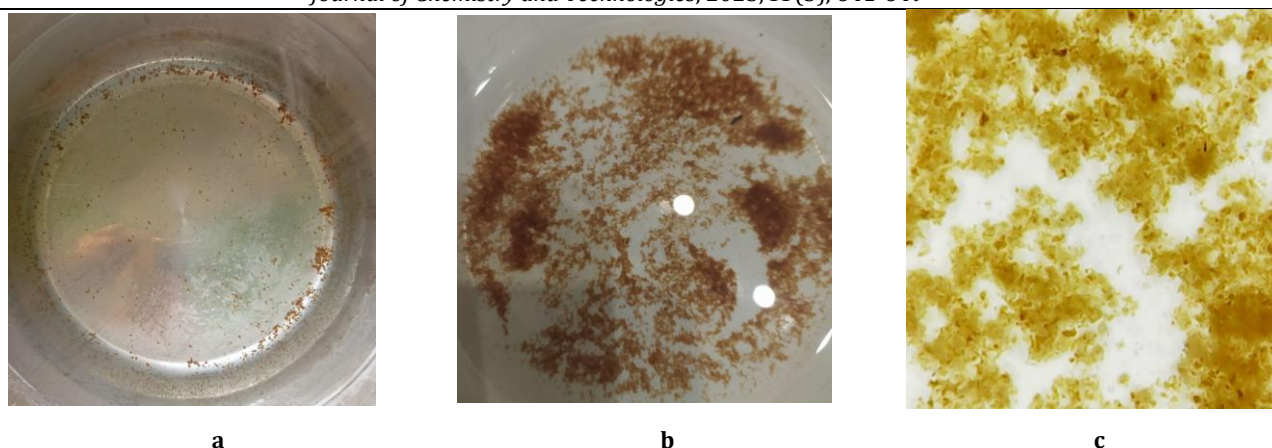
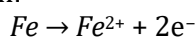
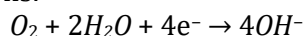


Fig. 6. Examples of water quality deterioration due to water supply disruptions: (a) sediment after water shutdown (after settling 3 liters of water, Kharkiv, 10.07.2024); (b) photograph of collected sediment; (c) iron complex sediment under a microscope

Corrosion processes in metal pipelines develop according to the anodic-cathodic mechanism. At the sites of anodic oxidation, iron, as known [24], dissolves with the formation of Fe^{2+} ions, which enter the solution:



At the same time, in the cathodic areas, dissolved oxygen is reduced with the formation of hydroxide ions:



The further interaction of iron ions with the products of the cathodic reaction leads to the formation of insoluble oxide-hydroxide complexes, which deposit on pipe surfaces and contribute to drinking water contamination. These processes are particularly intense under uneven water flow distribution, which promotes the formation of stagnant zones and localized depassivation of the metal surface.

Corrosion processes in pipeline systems not only alter the chemical composition of drinking water but may also contribute to microbiological risks under certain operational conditions. Degradation of protective coatings and the formation of surface irregularities on the inner pipe walls facilitate the accumulation of organic and inorganic deposits, which may act as substrates for microbial adhesion and growth. Although biofilm formation was not experimentally confirmed in the present study, this assumption is supported by previous research indicating that stagnation zones, uneven flow conditions, and deteriorated surfaces can promote biofilm development in distribution networks [17].

In well-regulated centralized water supply systems, microbial contamination is effectively controlled through chlorination. According to DSanPiN 2.2.4-171-10, the residual free chlorine

concentration in drinking water must be maintained within the range of 0.3–0.5 mg/L to ensure microbiological safety throughout the distribution process. Residual chlorine serves as a critical barrier, preventing bacterial regrowth in transit.

The ultraviolet (UV) disinfection unit integrated into the proposed purification system is intended as an additional safeguard in cases where residual chlorine levels are insufficient or absent, such as during emergency supply interruptions or in decentralized water sources. While not a substitute for chlorination in municipal systems, UV treatment enhances the microbiological protection of the system under variable or uncontrolled operating conditions, contributing to its flexibility and reliability.

The proposed water purification system is an autonomous device that combines multi-stage filtration, ozonation, and ultraviolet disinfection for the effective removal of corrosion products and microbiological contamination. The system's design is optimized for operation in emergency situations, making it particularly effective for use in regions with unstable water supply.

Main components of the device:

- 1) Inlet water supply unit, ensuring a steady flow of raw water to the first purification stage.
- 2) Filtration module, consisting of a multi-layer filtration system that removes mechanical impurities and corrosion products.
- 3) Storage tank for purified water, which prevents recontamination and maintains a continuous purification process.
- 4) Ozonator, responsible for the oxidation of dissolved metals, the breakdown of organic contaminants, and partial disinfection, serving as a chemical-free pretreatment stage.

5) Ultraviolet disinfection unit, operating at a wavelength of 220 nm and an intensity of 16 mW/cm², provides an immediate and highly effective inactivation of pathogenic microorganisms, including those potentially resistant to chemical oxidants.

The combination of ozonation and UV treatment ensures a multi-barrier disinfection approach. This integration enhances overall system reliability and safety, especially in decentralized or emergency water supply conditions, where residual disinfectant levels may be insufficient or absent. Moreover, the sequential application of ozone followed by UV disinfection maximizes the removal of both chemical and biological contaminants from the treated water.

6) Circulation and process control system, enabling automated water recirculation to enhance purification efficiency.

The compact modular design allows for easy integration into various water supply systems, while the use of energy-efficient components minimizes electricity consumption. A detailed analysis of the system's structural features, as well

as its schematic representation, is provided in study [25].

Conclusions

1. Studies confirm that the technical condition of pipelines plays a crucial role in determining drinking water quality, particularly due to the corrosive degradation of metal components and the leaching of corrosion products. Research has demonstrated that water passing through damaged pipeline sections experiences a 3–5 times increase in iron concentration, often exceeding permissible limits.

2. An analysis of water composition before and after a water supply shutdown revealed significant changes in physicochemical parameters. After water supply restoration, an increase in turbidity and suspended particles is observed, which is associated with the leaching of sediments and corrosion deposits.

3. The obtained results confirm the necessity of monitoring the physicochemical and microbiological parameters of water in supply systems, especially after shutdowns and emergency repairs.

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