FEATURES OF THE OPERATION OF COLD AND HOT WATER SUPPLY SYSTEMS REGARDING THE CORROSION ACTIVITY OF ZINC-PLATED PIPES IN WATER SUPPLY

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The exploitation of zinc-plated household water supply systems is associated with the problem of the development of local corrosion processes on the inner surface of steel pipes. Research on this topic is quite relevant, as evidenced by the analysis of articles on short-term use of zinc-plated pipes in water supply systems. The work presents aspects of consideration of the influence of water treatment, operational parameters and the presence of zinc coating on the performance of the system from the point of view of the development of local corrosion processes. The need for control by comparing water quality indicators "before and/or after water treatment" and "water in the system", was highlighted. This makes it possible to detect an aggressive corrosive environment already at the beginning based on the indicators of dissolved oxygen, free carbon dioxide and the index of equilibrium saturation of water with calcium carbonate and to establish the state of the inner wall ("active / passive") based on the presence of an increased concentration of iron, oxygen, and zinc ions. It was established that the presence of molecular oxygen dissolved in tap water in the hot water supply system in the temperature range of 60...70 ºC leads to the loss of protective properties by zinc due to the formation of a surface passive film of the ZnO, which leads to a shift in the corrosion potential of zinc to a more positive region, compared to the protective potential of iron, values. Cold water supply systems are characterized by the electrochemical nature of corrosion processes with oxygen cathodic depolarization. On top of that, the inadmissibility of direct contact of zinc-plated pipes with fittings elements and shut-off valves that made of brass, bronze and copper due to the contact corrosion, has been proven - the potential difference of these galvanic elements is from 0.570 to 0.854 V.

Key words: *water supply system, tap water, water quality, corrosion, zinc-plated pipes, electrochemical research*

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1. Introduction

The thermodynamic instability of pipe metals used in water supply systems leads to the occurrence of intra-pipe corrosion processes. Failures of water supply systems due to the course of such processes are one of the important aspects of ensuring uninterrupted functioning of the entire system as a whole. This is primarily related to ensuring water quality. The main attention in solving this issue is focused on finding effective ways to clean water, investigating the causes and preventing the development of corrosion processes (Klymenko et al., 2023; Bolshak et al., 2022; Bolshak et al., 2020; Vasyliev, 2021; Yanushevska, 2023; Vasyliev et al., 2018; Vasyliev et al., 2020; Klymenko et al., 2020).

The most widespread method of protecting the metal surfaces of pipes of water supply systems is still the application of zinc coating, in particular the method of hot-dip galvanizing and galvanizing in the vapor phase, which ensures complete surface alloying with the formation of Fe–Zn intermetallic phases (Marder, 2000; Jordan et al., 1993; Petit et al., 2019). Wide use of pipes with a layer of zinc coating in domestic water supply systems is primarily due to the environmentally safe nature of zinc (Matviienkiv et al., 2016; Jain et al., 2018). In addition, the ability of zinc to exhibit long-term protective properties in relation to the steel surface both in atmospheric conditions and in aqueous solutions, acting as an anode in case of coating damage, is taken into account (Lins et al., 2016; Gomatin, 2019). They act as an adhesive barrier layer (Raja, 2006). The electrode potential of zinc-saturated coatings is in the range from -0.9 to -1.1 V relative to the chlorine-silver reference electrode (CHE), both on the surface of the coating and in the places of its cohesive damage, providing an effective protective effect on the metal against corrosion destruction (Klymenko et al ., 2020; Saeedikhani et al., 2020; Polyakov et al., 2007).

At the same time, the operation of galvanized systems is associated with the problem of the development of local corrosion lesions of internal surfaces in contact with the water environment (Klymenko et al., 2020; Yadav et al., 2007; Desalegn, 2022; Ghalia et al., 2023; Marjanowski et al. ; Delaunois et al., 2014; Makisha et al., 2023; Pawłowski et al., 2020). And they are more severe against lesions of external surfaces exposed to internal conditions (Shams et al., 2019). As for the corrosion destruction itself, the sequence of stages of the process is determined, namely: thinning of the coating due to dissolution with the formation of corresponding Zn-containing corrosion products, which at the same time inhibit the overall corrosion rate of the coating itself; corrosion of the bare metal base in places of local intensive wear of the zinc coating; corrosion of the steel metal base under a layer of formed corresponding corrosion products in the complete absence of zinc coating (Lins et al., 2016). Among the factors affecting the general corrosion behavior of galvanized steel, the following are distinguished: water preparation and composition of tap water in relation to the presence of components aggressive from the point of view of corrosion, the presence of deposits and accumulation of iron in the circulation circuit; oxygen concentration; temperature, which can affect the kinetics of dissolution, changing the diffusion coefficient of soluble forms of Zn(II); stray currents; microbiological corrosion (Klymenko et al., 2020; Ghalia et al., 2023; Marjanowski et al.; Delaunois et al., 2014; Makisha et al., 2023; Shams et al., 2019; Nakhai et al., 2020) . At the same time, the duration of operation of internal water supply systems of tap water before destruction can be as little as 18 months to 4 years (Klymenko et al., 2020; Pawłowski et al., 2020).

The goal of this study was to establish the causes of deterioration of water quality and loss of performance due to the destruction of galvanized internal water supply systems for short-term operation, which did not exceed two years, as well as to determine the rational conditions for their operation. From our point of view, when investigating the causes, it is necessary to apply a comprehensive approach, which should include successive stages of water treatment analysis (water quality at the stages before and after water treatment and circulation in the network according to the consumption system), determination of the nature of destruction and factors affecting the kinetics of corrosion processes and determining rational conditions of operation with regard to influencing factors.

2. Materials and Methods

Samples of tap water taken from various points of operating internal circulation systems of cold (CWS) and hot (HWS) water supply were used as the investigated solutions: water supply network, after the water treatment system, internal circulation system of consumption. Sampling of water samples for analysis was carried out in accordance with DSTU ISO 5667-3-2001, chemical analysis of water - in accordance with DSanPiN 2.2.4-171-10. The concentration of molecular oxygen in water was determined by a CyberScan PD300 oximeter. Chemical analysis of deposits of corrosion products was carried out using micro-X-ray spectral analysis on a Camebax FX-50 device.

Determination of the rate of corrosion of steel in the corresponding samples of tap water was carried out by polarization resistance (static and dynamic environment) and gravimetric methods. Measurements by the method of polarization resistance (i_k) were carried out using a universal corrosion rate meter UISK-101 using a flat coplanar two-electrode sensor with the size of one electrode 30×7×3 mm, made of the metal of pipe samples, the duration of the tests was 60 minutes. Gravimetric studies on the change in the mass of the samples before and after the tests (Δm) with the determination of the mass index of the corrosion rate (K_m) were performed on samples with the removed coating size 20×6×3 mm, the duration of the tests was 284 hours. The samples were weighed on analytical scales with an accuracy of 0.00005 g. The values of the indicators were calculated according to the formulas (Gerasimenko et al., 2012; Nyrkova et al., 2024):

$$i_k = \frac{K}{R_p} = \frac{K \cdot \Delta I}{\Delta E},\ (mm \cdot year^{-1}) \qquad (1)$$

$$K_m = \frac{\Delta m}{S \cdot \tau},\ \left(\frac{g}{m^2 \cdot year}\right) \qquad (2)$$

where:

- K – estimated sensor coefficient (for steel – 167, for zinc – 214), $\Omega\ mm \cdot year^{-1}$;
- ΔI – current arising between the electrodes, A;
- ΔE – potential difference, V;
- R_p – polarization resistance, Ω;
- Δm – weight loss of the sample after testing, g;
- S - sample area, m^2;
- τ - duration of tests, hours.

Electrochemical studies on the corrosion activity of pipe metal and the protective properties of zinc coating (applied by hot-dip galvanizing) in the studied solutions were carried out with free aeration by methods of measuring potentials (external and internal surfaces of samples with a duration of measurements at one point of 1 hour) and removing volt-amperage dependences (three-electrode measuring scheme). Polarization studies were carried out on the MTech PGP-550F potentiostat relative to the HSE comparison (Ag/AgCl), the speed of the potential sweep was 1 $mVs^{-1.}$

As a working electrode, a sample made of the studied steel with a working surface area of 10^{-5} m² was used, which was kept in the solution for 30 minutes until a stationary electrode potential was established with subsequent polarization. For HWS pipes, the protective properties of the zinc coating were determined at 20 °C, 40 °C, 60 °C, 70 °C and 90 °C in a sample of water from the internal circulation system of consumption with an additional measurement of the current between the zinc and the steel surface for one hour at each temperature The probability of the occurrence of galvanic corrosion was determined taking into account the contacts between galvanized pipes, the base metal of the galvanized pipe (since contact corrosion of steel is possible in the system after the contact corrosion of the zinc coating has occurred) and the copper, bronze and brass connecting fittings available in the engineering design of the CWS system by difference values of their stationary electrode potentials ($\Delta E = E_{сплав} - E_{Zn(Fe)}$).

Samples made from fragments of pipes of operating internal circulation water supply systems were used as experimental samples, namely:

- fragments of structural carbon steel pipes 18 kp Ø76×3.5 mm CWS (CWS Ø76);
- fragments of galvanized pipes made of structural carbon steel 08kp Ø25×2.4 mm CWS (CWS Ø25) and Ø42×3.5 mm HWS (HWS Ø42), zinc coating applied by hot-dip galvanizing method.

3. Results and Discussion

3.1. Analysis of water samples of water supply systems.

Results of chemical analysis of CWS water samples taken from different points (sample 1,2 - internal circulation system of consumption - flowing water and stagnant zone of the system, respectively; sample 3 - before the water treatment system, external urban water network; sample 4 - immediately after the water treatment system) are given in Table 1.

Table 1. *Chemical analysis of water quality CWS*

Test water	pH	Total hardness, mg-eq L^{-1}	Ca^{2+}, mg L^{-1}	Mg^{2+}, mg L^{-1}	Cl^{-}, mg L^{-1}	O_2, mg L^{-1}	HCO_3^{-}, mg L^{-1}	$Fe^{2+,3+}$, mg L^{-1}	CO_{2free}, mg L^{-1}	Equilibrium saturation index of calcium carbonate
DSanPIN	6.5 - 8.5	7.0	-	-	350	-	-	0.3	< 5	from 0.1 to 0
1	7.4	4.0	52.1	17.02	19.8	5.2	170.8	0.20	8.8	-0.3
2	7.45	3.8	56.1	12.16	28.4	6.27	158.6	0.19	10.56	-0.3
3	7.4	3.5	50.1	12.16	28,4	7.72	158.6	0,20	10.56	-0.5
4	7.35	3.6	52.1	12.16	28.4	6.45	158.6	0.18	10.12	-0.25

According to the results of the water quality analysis, it is worth noting the inefficiency of the filtration system for cleaning the tap water from iron ions (almost the same concentration of ions at all sampling points. In addition, it was established that the water samples according to the indicators of the content of dissolved oxygen, free carbon dioxide and the equilibrium index of carbonate saturation calcium do not meet the requirements of DSanPIN 2.2.4-171-10, and their level is sufficient for the course of intensive oxygen corrosion of steel pipes. Thus, oxygen dissolved in water is one of the main causes of local corrosion of steel because it causes the formation of differential aeration vapors, which leads to destruction of areas of metals in contact with water less saturated with oxygen. The rate of corrosion of steel is directly proportional to the concentration of oxygen dissolved in water. According to the theory of macrogalvanic pairs (Evans, 1971), side processes under the action of oxygen on steel are the formation of aeration pairs - pairs of uneven (differential) aeration and a sharp decrease in the content of ferrous iron Fe^{2+} as a result of their oxidation to Fe^{3+}. In addition, free dissolved carbon dioxide determines the corrosivity and stability of water, since excess aggressive carbon dioxide converts alkaline carbonates into bicarbonates, which leaves the metal without a protective surface layer, lowers the pH of the water, and serves as a catalyst for oxygen corrosion of steel.

For HWS, a significant deviation of water quality was detected only in relation to the indicator of the total amount of iron, the content of which in the circulating internal system of consumption increased 40 times (from 0.05 mg/dm^3 to 0.7 - 2.4 mg/dm^3) compared to the similar indicator in the sample of water from the external city water network, which indicated an intensive corrosion process of the main metal of the pipeline.

3.2. Chemical analysis of corrosion products.

The image of fragments of CWS and HWS galvanized pipes damaged during operation is presented in Fig. 1.

a) b) c)

Fig. 1. *Image of the inner surface of fragments of CWS Ø25 (a), CWS Ø76 (b) and HWS Ø42 (c) pipes damaged during operation.*

The sediments revealed during a visual inspection of the inner wall of the pipeline fragments had a structure of insoluble red-brown sediments characteristic of the formation of corrosion products, characteristic of iron corrosion products (Fig. 1 a – c) and a finely dispersed structure of white color (Fig. 1a), characteristic of products of corrosion oxidation of zinc.

Table 2 shows the results of micro-X-ray spectral chemical analysis of deposits of corrosion products of the inner wall of pipelines CWS Ø25 from the circulation system of internal water consumption (A), CWS Ø76 immediately after water treatment

(B) and from the circulation system of internal water consumption HWS Ø42 (C). .

Table 2. *Chemical composition of CWS and HWS corrosion products*, %

Система		**Si**	**Mn**	**S**	**Cr**	**Al**	**Ca**	**Fe**	**Zn**	**Mg**	**O**
CWS Ø25	A	0.719	0.059	0.139	-	0.375	0.153	33.86	19.9	0.6	44.195
CWS Ø76	B	0.936	0.021	0.642	0.021	0.291	0.126	47.309	1.125	0.4	49.53
HWS Ø42	C	0.700	0.056	0.121	-	0.358	0.155	34.01	19.9	0.5	44.200

According to the results of the analysis of corrosion products, the main part of ~98 wt. % was iron, zinc and oxygen for galvanized pipes of the CWS Ø25 (A) and HWS Ø42 (C) systems and iron and oxygen for steel pipes CWS Ø76 (B). This made it possible to assume that the corrosion products for the pipelines of the CWS Ø76 (B) system consist mainly of iron oxides and hydroxides $Fe(OH)_2$, $Fe(OH)_3$, and for the galvanized pipes of the CWS Ø25 (A) and HWS Ø42 (C) – additionally from zinc oxidation products (Zn(OH)2 hydroxide).

3.3. The corrosion rate of steel of polarization resistance and gravimetric methods.

To conduct a comparative analysis according to the "speed of corrosion" parameter, the "0" sample of water (pH 6.7) was used in CWS, taken directly from the sampling point of the city network, which is independent and separate from the investigated circulation system of the water supply, the chemical analysis of which showed full compliance with all indicators of water quality according to with the requirements of DSanPIN 2.2.4-171-10. The results of corrosion rate measurements in a static (without mixing) and dynamic (with mixing) environment of various CWS and HWS water samples (sample 1,2 – internal circulation system of consumption, flowing water and stagnant zone of the system, respectively; sample 3 – to the water treatment system, external urban water supply network; sample 4 - immediately after the water treatment system) are shown in Table 3.

Table 3. *The corrosion rate of steel*

Water sample		K_m, $\frac{g}{m^2 \cdot year}$	i_k, $mm \cdot year^{-1}$	
			static	**dynamic**
CWS	«0»	0.052	0.057	0,007
	1	0.117	0.142	0.08
	2	0.093	0.083	0.118
	3	0.086	0.116	0.012
	4	0.099	0.128	0.035
HWS	1	0.075	0.097	0.010
	4	0.073	0.095	0.009

The increase in the rate of steel corrosion in static conditions by 1.5÷10 times compared to dynamic conditions in both CWS and HWS is explained by the transition in the presence of an oxidant of iron ions Fe^{2+} to Fe^{3+}, which assimilate electrons in the cathodic areas of corrosion pairs and are reduced to Fe^{2+}. However, in the dynamic flow, there is a constant removal of Fe^{2+} ions from the surface, and therefore the corrosion rate is lower. Therefore, as expected after conducting a chemical analysis of water quality (Table 1), the content of dissolved oxygen and free carbon dioxide, due to which the rate of corrosion in CWS increases, namely:

- in static conditions ~1.5 times (from 0.097 $mm \cdot year^{-1}$ up to 0.142 $mm \cdot year^{-1}$) and ~2.5 times (from 0.057 $mm \cdot year^{-1}$ up to 0.142 $mm \cdot year^{-1}$) against to HWS and independent CWS, respectively;

in dynamic conditions ~8 times (from 0.01 $mm \cdot year^{-1}$ up to 0.08 $mm \cdot year^{-1}$) and ~11 times (0.007 $mm \cdot year^{-1}$ up to 0.08 $mm \cdot year^{-1}$) against to HWS and independent CWS, respectively.

At the same time, for HWS it was established that an increase in water temperature from 20 °C to 60 °C increases the increased indicator almost twice from 0,09 $mm \cdot year^{-1}$ to 0,148 $mm \cdot year^{-1}$.

When using zinc-filled protective protection systems, it is necessary to obtain their ability to form finely dispersed powdery deposits on surfaces, products of zinc oxidation under the influence of the operating environment, which leads to changes, partial or complete loss of protective properties, namely: grinding, reduction of adhesiveness, partial / complete cohesive destruction, loss of power defenders due to passivation. Thus, to increase the temperature of the zinc coating from 20 °C to 60 °C led to an acceleration of the corrosion process with an increase in the corrosion rate of zinc from 0,068 $mm \cdot year^{-1}$ to 0,099 $mm \cdot year^{-1}$ and its subsequent decrease to 0,048 $mm \cdot year^{-1}$ due to the formation of a passive film of zinc hydroxide $Zn(OH)_2$. The latter is a negative factor that leads to both partial and complete passivation of the zinc coating and the loss of its protective protective properties when attributed to the steady further development of local corrosion processes in the form of pitting corrosion.

3.4. Volt-ampere characteristics

The main cause of steel corrosion is due to its thermodynamic instability - the tendency of the metal to change from the metallic state to the ionic state (that is, to dissolve). Ionization occurs with an increase in free energy (ΔG) from –48.6 kJ/mol to –127.3 kJ/mol, which indicates a tendency for the metal to transition into an oxidized state, and a negative value of the indicator ($\Delta G<0$) indicates an electrochemical mechanism of corrosion process

The results of the investigation of corrosion behavior (anodic dissolution and cathodic depolarization) of the inner steel surface of CWS Ø76 samples by the method of removing polarization curves in water samples are shown in Fig. 2.

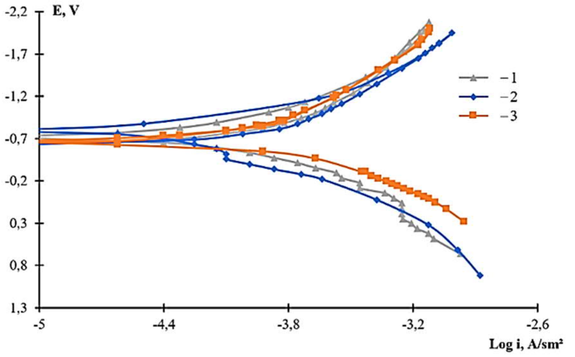


Fig. 2. *The results of measuring the corrosion potential on the CWS pipe Ø76 in water samples taken from the CWS external urban water supply network (1), the internal circulation consumption system (2) and after water treatment (3).*

According to the current-current characteristics (Fig. 2), the value of the stationary electrode potential of the base metal CWS Ø76 in a neutral medium (pH 7.0...7.1) is from -0.404 V to -0.505 V, which corresponds to the state of active ionization of the metal – active dissolution. Under the conditions of anodic polarization (displacement of the potential in the region of positive values), initially only electrochemical dissolution of the inner surface occurs - metal ions from the crystal lattice pass into water in the form of hydrated ions:

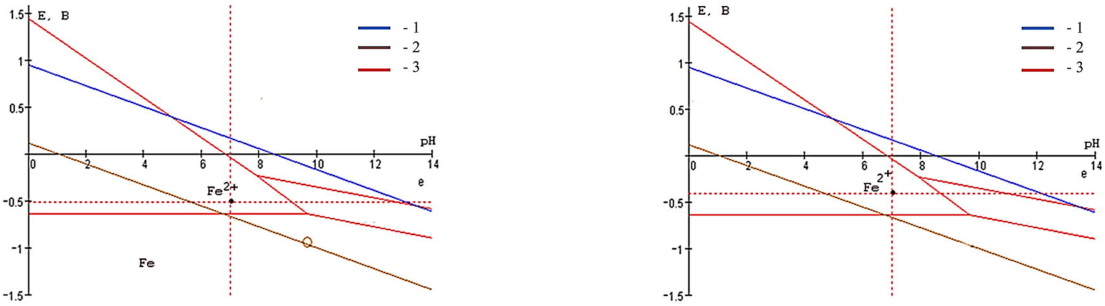
$$Fe + mH_2O = Fe^{2+} \cdot mH_2O + 2\bar{e} \qquad (3)$$

At the same time, an equivalent number of electrons remains in the metal and the inner surface of the metal of the pipe acquires a negative charge, and the water - a positive one. Electrons released in the anodic process are joined by an oxidizing agent (depolarizer), whose role is oxygen dissolved in water. At the cathode, molecular oxygen is regenerated - ionization:

$$O_2 + 2H^+ + 4\bar{e} = 2OH^- \qquad (4)$$

The values of the reverse oxidation-reduction potential of oxygen ($\mathrm{E}_{\mathrm{OH}^-/\mathrm{O}_2}$) and the electromotive force ($(E_{298})_{rev}$) of a corrosion galvanic cell are, respectively, for pH 7.1 pH 7.1 $\mathrm{E}_{\mathrm{OH}^-/\mathrm{O}_2}$=0,811 V та $(E_{298})_{rev}$ = 1,215 V, для pH 7 $\mathrm{E}_{\mathrm{OH}^-/\mathrm{O}_2}$= 0,817 V та $(E_{298})_{rev}$ = 1,221 V. And the values of $\mathrm{E}_{\mathrm{OH}^-/\mathrm{O}_2}$ themselves are more positive than the value of the reverse potential of the steel pipe under these conditions ($\mathrm{E}_{Fe/Fe^{2+}} = -0{,}404 \ldots - 0{,}505\,V$). Therefore, the inner surface of the test tube corrodes by an electrochemical mechanism with oxygen cathodic depolarization, as a result of which the concentration of hydrogen ions decreases and the water becomes more alkaline. The presence of electronic conductivities of metal and water determines the course of anodic and cathodic processes both territorially separated and on the same surface, alternating in time. Thus, corrosion occurs only on the anodic areas of the inner surface of the steel pipe, and on the cathodic areas, which may include graphite C_{gr}, cementite FeC_3, etc., only depolarization occurs without loss of metal. This explains the presence on the inner surface of the steel pipe of local areas with formations in the form of "growths" of corrosion products - rust.

According to the state diagram of Fe – H_2O (Pourbet diagram) (Fig. 3a, b), the region of the corresponding pH values and the stationary electrode potential of the metal from $\mathrm{E}_{Fe/Fe^{2+}} = -0{,}404\,V$ (pH 7) to $\mathrm{E}_{Fe/Fe^{2+}} = -0{,}505\,V$ (pH 7.1) corresponds to the state of the Fe^{2+} ion in the research sample of CWS water.



a) *b)*

Fig. 3. *State diagram of the Fe – H_2O system for $\mathrm{E}_{Fe/Fe^{2+}} = -0{,}505\,V$ (a) and for $\mathrm{E}_{Fe/Fe^{2+}} = -0{,}404\,V$ (b): oxygen electrode equilibrium diagram (1); equilibrium diagram of the hydrogen electrode (2); boundaries of separation of the equilibrium regions of the steel electrode (3).*

Based on the state of iron ions in the form of Fe^{2+} in water, in addition to cathodic and anodic processes, the course of secondary chemical reactions takes place with the formation of $Fe(OH)_2$ (due to the increase in the concentration of hydroxide ions due to the course of cathodic processes) and $Fe(OH)_3$, formed by further oxidation of $Fe(OH)_2$, with the formation of surface layers of iron corrosion products in the form of rust on the inner surface of CWS Ø76.

3.5. Protective properties of the zinc coating of the CWS and HWS system.

Table 4 illustrates the results of measurements of potentials (E) on the internal galvanized surface covered with corrosion products of zinc (c. p.) and steel 08kp of CWS and HWS pipe fragments, as well as active zinc in water samples from the circulation system of internal consumption.

Table 4. *Comparison table of potentials of CWS and HWS galvanized pipes*

System	**E of the surface at temperature, V**				
	20 ˚C	40 ˚C	60 ˚C	70 ˚C	90 ˚C
CWS Ø25 (c. p.)	-0.730	-	-	-	-
HWS Ø42 (c. p.)	-0.702	-0.775	-0.612…-0.791	-0.555…-0.634	-0.66…-0.812
Zn active	-0.976	-0.985	-0.931	-0.969	-0.947
Steel 08kp	-0.681	-0.684	-0.68	-0.707	-0.688

According to the tabular data, the value of the potential of the inner galvanized surface of the HWS Ø42 pipe (p.c.) at temperatures of 20 °C and 40 °C (-0.702 V and -0.775 V, respectively) is more negative against the base metal and is between the potentials of pure zinc and of the base metal (-0.976 V and -0.681 V, respectively), and therefore minimal protective protection of the base metal of the pipe is provided. At temperatures of 60 °C, 70 °C and 90 °C, passivation of the inner surface of the galvanized pipe occurs and the potential, at some moments of time, becomes more positive than the potential of the base metal (-0.612 V, -0.555 V and -0.66 V, respectively) that is, the zinc coating loses its protective properties.

The data of potential measurements regarding the loss of the protective properties of the zinc coating are additionally confirmed by the results of measuring the current flowing between zinc and steel in the HWS system at different temperatures, graphically shown in Fig. 4.

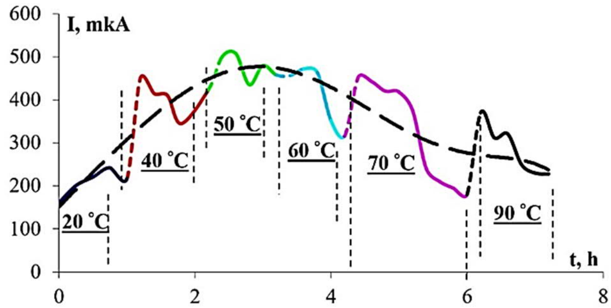


Fig. 4. *Effect of temperature on the magnitude of current between zinc and steel in HWS*

Thus, according to the obtained data, temperatures of 40 °C and 50 °C correspond to the highest value of the current, and therefore zinc actively dissolves, providing protective protection against steel. At temperatures of 60 °C, 70 °C and 90 °C, active dissolution of zinc (preserving protective properties) occurs at the initial moment, followed by passivation of the surface of the zinc coating due to the formation of zinc oxidation products ($Zn(OH)_2$), and the current decreases (the protective properties of zinc decrease). Obviously, this behavior makes it possible to make an assumption that with further aging of zinc and steel under the influence of the specified temperatures, a drop in the current to zero and a change in its polarity will be observed, which will lead to the loss of the protective properties of the zinc coating and the active local dissolution of steel in the operating HWS water supply .

3.6. Probability of galvanic corrosion.

The stationary electrode potential relative to Ag/AgCl of the reference electrode of the base metal (steel) of the pipe fragment of the CWS system was $E_{Fe} = -0.634\,V$,, zinc coating in a passive state (passivation due to the formation of zinc oxidation products) $E_{Zn} = -0.73\,V$,, in an active state (protective protection) $E_{Zn} = -0.909\,V$. The results of the study of the probability of the course of galvanic corrosion in CWS due to the presence of contacts between copper, bronze and brass connecting shaped products with a galvanized pipe (zinc coating active and passive), carried out in a water sample taken immediately after the system water treatment, presented in Table 5.

Table 5. *The difference in potentials of the "zinc coating / steel - shaped product" system.*

Shaped product alloy	E_{alloy}, **V**	**ΔE of the system, V**		
		Zinc active	Zinc passive	Steel
Copper	-0.055	0.854	0.675	0.579
Bronze	-0.125	0.784	0.605	0.509
Brass	-0.160	0.749	0.570	0.474

Thus, the values of the potential difference obtained (from 0.474 V to 0.854 V) are quite sufficient to ensure the course of galvanic corrosion in CWS in the presence of direct contact between the galvanized pipe, its base metal (steel) and brass, bronze and copper connectors shaped elements.

4. Conclusions

According to the results of the chemical analysis of water quality, it was established that the level of indicators of the content of dissolved oxygen (5.2 … 7.72 mg L^{-1}), free CO_2 (8.8 … 10.56 mg L^{-1}) and the equilibrium index of calcium carbonate saturation (-0.25 ... -0.5) in water CWS is sufficient for the course of intensive oxygen corrosion of steel pipes, and the value of the indicator of the total amount of iron (0.7 ... 2.4 mg/dm^3) indicates the intensive course of the corrosion process of the main metal of the HWS pipeline.

Chemical analysis of corrosion products showed that their main part (~98 wt. %) was iron, zinc and oxygen for galvanized pipes CWS Ø25 and HWS Ø42 and iron and oxygen for pipes CWS Ø76, mainly compounds $Fe(OH)_2$, $Fe(OH)_3$ and zinc oxidation products $Zn(OH)_2$ for galvanized pipes.

For CWS and HWS pipes, the increase in the rate of steel corrosion in static conditions by 1.5÷10 times compared to dynamic conditions, which ensure the constant removal of Fe^{2+} ions from the surface, is due to the transition in the presence of an oxidant of iron ions Fe^{2+} to Fe^{3+}, which assimilate electrons in the cathode areas of corrosion pairs and are reduced to Fe2+. Against HWS and independent CWS, respectively, the presence of dissolved oxygen and free carbon dioxide in the studied CWS water samples contributes to an additional increase in the corrosion rate under static conditions by ~1.5 times (from 0.097 $mm \cdot year^{-1}$ to 0.142 $mm \cdot year^{-1}$) and ~2.5 times (from 0.057 $mm \cdot year^{-1}$ to 0.142 $mm \cdot year^{-1}$), and under dynamic conditions - by ~8 times (from 0.01 $mm \cdot year^{-1}$ to 0.08 $mm \cdot year^{-1}$) and ~11 times (from 0.007 $mm \cdot year^{-1}$ to 0.08 $mm \cdot year^{-1}$). At the same time, for HWS, the increase in water temperature to 60 °C contributes to the growth of the value of the indicator from 0,09 $mm \cdot year^{-1}$ to 0,148 $mm \cdot year^{-1}$.

For the zinc coating, the increase in water temperature from 20 °C to 60 °C led to an increase in the corrosion rate of zinc from 0,068 $mm \cdot year^{-1}$ to 0,099 $mm \cdot year^{-1}$, followed by a decrease to 0,048 $mm \cdot year^{-1}$ due to the formation of a passive film of zinc hydroxide Zn(OH)2.

Based on the results of polarization studies, it was established that the CWS Ø76 metal in the studied neutral environment (pH 7.0...7.1) is in a state of active ionization (dissolution). The value of the stationary electrode potential of the base metal ($\mathrm{E}_{Fe/Fe^{2+}}$), the reverse oxidation-reduction potential of oxygen ($\mathrm{E}_{\mathrm{OH}^-/\mathrm{O}_2}$) and the electromotive force ($(E_{298})_{\mathrm{rev}}$) of a corrosion galvanic element were, respectively, 〚 $\mathrm{E}_{Fe/Fe^{2+}} = -0{,}404 \ldots -0{,}505\,V$, $\mathrm{E}_{\mathrm{OH}^-/\mathrm{O}_2}$=0,811…0.817 V та $(E_{298})_{\mathrm{rev}}$ = 1.215…1.221 V. And the values of $\mathrm{E}_{\mathrm{OH}^-/\mathrm{O}_2}$ are more positive than the value of the reverse potential of the steel pipe under these conditions. The inner surface of the test tube corrodes locally by an electrochemical mechanism with oxygen cathodic depolarization, as a result of which the concentration of hydrogen ions decreases and the water becomes more alkaline. In addition, the ionic state of iron Fe^{2+} also contributes to the course of secondary chemical reactions with the formation of $Fe(OH)_2$, followed by its oxidation to $Fe(OH)_3$ and the formation of surface layers of iron corrosion products in the form of rust on the inner surface of the steel pipe.

Regarding the protective properties of the internal zinc coating of CWS and HWS, it was established that the temperature increase to 60 °C, 70 °C and 90 °C leads to partial passivation of the inner surface of the galvanized pipe at some moments of time and the potential becomes more positive than the potential of the base metal (respectively -0.612 V, -0.555 V and -0.66 V against -0.681 V), that is, the zinc coating loses its protective properties.

It was also established that the potential difference from 0.474 V to 0.854 V, which occurs in the presence of direct contact between the galvanized pipe (steel) and the shaped elements in the CWS (brass, bronze, copper), is quite sufficient to ensure the course of galvanic corrosion.

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ОСОБЛИВОСТІ ЕКСПЛУАТАЦІЇ СИСТЕМ ХОЛОДНОГО ТА ГАРЯЧОГО ВОДОПОСТАЧАННЯ ЩОДО КОРОЗІЙНОЇ АКТИВНОСТІ ОЦИНКОВАНИХ ТРУБ В ВОДОГІННІЙ ВОДІ

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Експлуатація оцинкованих систем побутового внутрішнього водопостачання пов'язана з проблемою розвитку локальних корозійних процесів на внутрішній поверхні сталевих труб. Дослідження цієї теми є досить актуальним про що свідчить аналіз статей щодо малотривалої експлуатації оцинкованих труб в системах водопостачання. У роботі наведено аспекти розгляду питання щодо впливу водопідготовки, експлуатаційних параметрів, наявності цинкового покриття на працездатність системи з точки зору розвитку корозійних процесів. Виділено необхідність контролю шляхом порівняння показників якості води «до / після водопідготовки», «вода в системі». Це дозволяє вже на початку виявити агресивне корозійне середовища за показниками розчинений кисень, вільна вуглекислота та індекс рівноважного насичення води карбонатом кальцію та встановити стан внутрішньої стінки («активний / пасивний») за наявністю підвищеної концентрації іонів заліза, кисню, цинку. Встановлено, що наявність молекулярного розчиненого у водогінній воді кисню в системі гарячого водопостачання в діапазоні температур 60 °С…70 °С призводить до втрати цинком протекторних властивостей через утворення поверхневої пасивної плівки ZnO, яка призводить до зміщення потенціалу корозії цинку в область більш позитивних, порівняно до захисного потенціалу заліза, значень. Для систем холодного водопостачання характерний електрохімічний характер перебігу корозійних процесів з кисневою катодною деполяризацією. Окрім того, доведено неприпустимість безпосереднього контакту оцинкованих труб з фасонними елементами та запірною арматурою, виготовленими з латуні, бронзи та міді через руйнування стінки металу труби за рахунок контактної корозії – різниця потенціалів даних гальванічних елементів складає від 0,570 до 0,854 В.

Ключові слова: *система водопостачання, водогінна вода, якість води, корозія, оцинковані труби, електрохімічні дослідження.*