The suitability of galvanized steel water piping system

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The main aim of this study was to investigate the corrosion behaviour of zinc in drinking water systems, using waters with different pHs and temperatures. The goal was also to present the problem of the use of galvanized steel water piping system in Slovenian public buildings.

In this study the basic electrochemical tests (linear polarization resistance, potentiodynamic curves) were performed in order to show the basic corrosion behaviour of Zn and how strongly its corrosion resistance depends on water pH and its temperature. Three different simulated tap waters (very hard pH 7.1, soft pH 6.7 and soft pH 8.4) at two different temperatures (25 °C and 70 °C) were used for the corrosion tests.

The results showed that the use of Zn in waters with higher temperatures cause the decrease in its corrosion resistance. That information could be important when selecting material for hot water supply systems and systems. The pH of waters used for corrosion tests does not seem to be an important parameter, while the hardness of water could play more important role in corrosion resistance of Zn.

Key words: water piping system, drinking water system, materials in contact with drinking water, galvanized steel, corrosion, electrochemical corrosion tests, deterioration of water piping system

1. Introduction

Construction materials which come in contact with drinking water are one of the main parameters that define the durability of the water supply systems and may consequently also affect the quality of drinking water.

In EU, the installations inside buildings conveying water for human consumption have to be designed and implemented according to the standards of the series EN 806 [1]. However, these standards only cover a basic level of this field and therefore some supplementary standards and guidelines should be used, e.g. DIN norms, DVGW and VDI working sheets and guidelines [2-4].

On the other hand, there is currently no unified approach in EU to deal with materials and products that come into contact with drinking water, so this area is regulated individually by each country. In 2011, France, Germany, the Netherlands and the United Kingdom (4 Member States, hereinafter referred to as "4MS") adopted a decision to unify the procedures for assessing the adequacy and approval of materials and products coming into contact with drinking water [5]. Their approach defines a set of policies and practices that can be adopted within national frameworks. Belgium has introduced self-certification of materials and products that come into contact with drinking water, independent of the country of production [6]. The Nordic countries have merged into a joint project "Materials and Products Innovation through Knowledge-based Standardization in the Drinking Water Sector" [7], where they explore methods of testing.

Even though Slovenian Rules on drinking water [8] from year 2004 contains Article 33, which says that “Materials and substances in contact with drinking water must not affect the conformity of drinking water with respect to physical, chemical or microbiological properties.”, Slovenia started solving this issue only a few years ago. In 2016, at the initiative of the Ministry of Health and the Ministry of Economic Development and Technology, three national institutes (Slovenian National Building and Civil Engineering Institute – ZAG, National Institute of Public Health – NIJZ and National Laboratory of Health, Environment and Food – NLZOH) issued the “Recommendations for evaluation of the materials and products for the contact with drinking water” (hereinafter: Recommendations) [9] which address the issue of the material in contact with drinking water. The basis for the Recommendations was the "4MS" scheme [10] and describes the procedure for assessing the suitability of products made of different materials (metal, cement, organic) and the methodology for testing their chemical and microbiological properties.

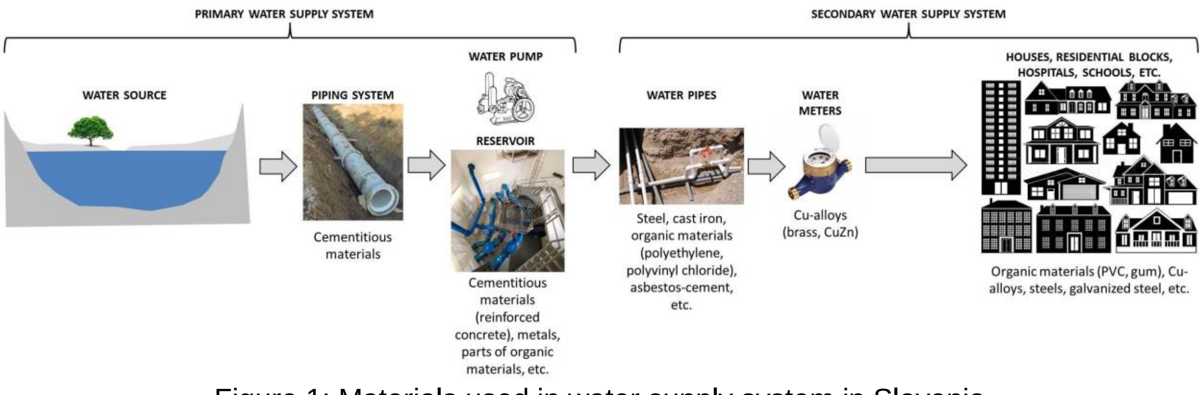

Figure 1: Materials used in water supply system in Slovenia.

Carbon steel and cast iron without permanent protective layers is not suitable for use in contact with drinking water, while the galvanized steel is not suitable for use with all drinking waters in Europe [10]. Member States may need to impose restrictions for the use of galvanized steel pipes depending on the local drinking water composition. Concerning the suitability of galvanized steel for Slovenian drinking water systems, the Recommendations are quoting the 4MS documents [10]. However, regardless our long-term (bad) experience of use of these materials, the galvanized steel pipes are still used in Slovenia.

The main aim of this study was to investigate the corrosion behaviour of zinc in drinking water systems. The goal of this paper was to study the electrochemical corrosion behaviour of zinc in simulated tap waters with different pHs and temperatures, and also to present the problem of the use of galvanized steel water piping system in selected Slovenian public building.

2. Electrochemical corrosion tests

3.1 Experimental

The sample of pure zinc (Zn) was prepared for basic electrochemical tests in simulated tap waters. Sample was tablet shaped with exposed surface area of 0.785 cm^2. Surface was ground before the experiments by means of SiC paper grit 360/P600 and cleaned with ethanol in ultrasonic bath.

Simulated tap water samples were prepared from deionized water by controlling alkalinity, Cl^- content and pH, according to the standard EN 15664-2 [11]. Three different simulated tap waters were chosen for this study (Table 1).

Table 1: The different simulated tap water samples.

	Water 1 **Very hard, neutral**	**Water 2** **Soft, weekly acidic**	**Water 3** **Soft, alkaline**
pH	7.1	6.7	8.4
Alkalinity [mg HCO_3^-/L]	305	50	50
Cl^- [mg/L]	30	30	30

Basic electrochemical corrosion measurements were performed in each simulated tap water at two different temperatures, 25 °C (room temperature) and 70 °C (water bath). The electrochemical tests were performed as follows: 1-h stabilization at open circuit potential (OCP), with linear polarization (LP) measurements at ± 20 mV vs. OCP at a scan rate 0.1 mV/s. The potentiodynamic measurements were then performed starting from −0.25 V vs. OCP, and progressing in the anodic direction up to +1.0 V at a scan rate of 1 mV/s. All potentials are reported with respect to the Ag-Ag/Cl scale.

Standard three electrode corrosion cell was used: Zn sample was used as a working electrode, Ag-AgCl as a reference electrode and graphite rod as a counter electrode.

3.2 Results

Electrochemical tests were performed in each simulated water solution (Table 1) at two different temperatures (25 °C and 70 °C).

Open circuit potential (OCP) was measured before each linear polarization tests (LP) and potentiodynamic polarization measurements (PD), until steady state conditions were achieved. OCP values of each system are presented in Table 2.

Table 2: OCP of each tested systems.

E [mV]	**Water 1** **Very hard, neutral** (pH7.1)	**Water 2** **Soft, weekly acidic** (pH6.7)	**Water 3** **Soft, alkaline** (pH8.4)
25 °C	–1080	–1050	–1090
70 °C	–910	–740	–970

Curves of measured LP are presented in Figure 2. Polarization resistance (R_p) for Zn in very hard / neutral water (pH 7.1) at 23 °C is 1.2 kΩ cm^2. At higher temperature (70 °C), R_p in in hard / neutral water increases to 2.1 kΩ cm^2, most probably due to ZnO formation at higher temperatures. In soft / alkaline (pH 8.4) environment at lower temperature (25 °C) have steeper slopes and therefore higher R_p values (11 kΩ cm^2) than the one obtained at higher temperature (1.5 kΩ cm^2 at 70 °C). That indicates that Zn in soft / alkaline water (pH 8.4) has significantly higher corrosion resistance at lower temperature. The influence of temperature on R_p values measured in hard / neutral environment (pH 7.1) and soft / weekly acidic (pH 6.7) waters is not so evident (Table 3).

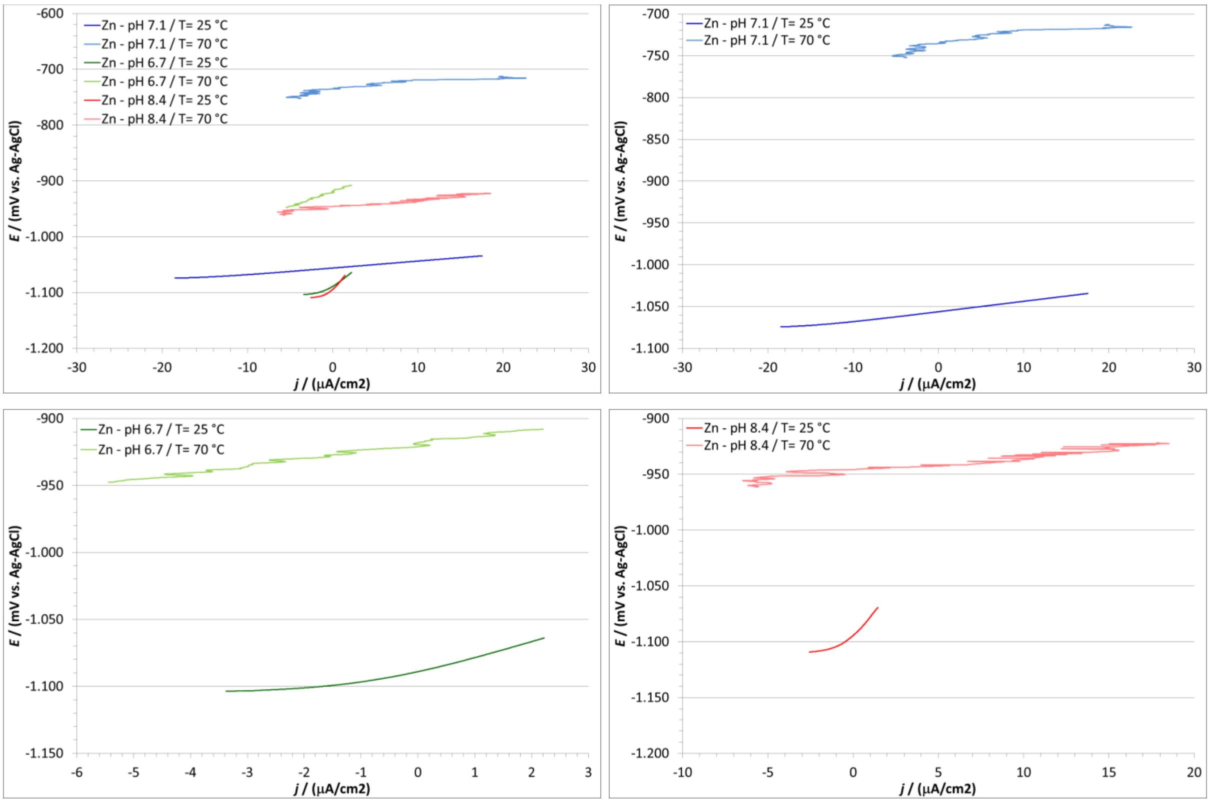

Figure 2: Linear polarization (LP) measurements on Zn electrode in 3 different simulated tap waters (Table 1) at 2 different temperatures (25 °C and 70°C).

Table 3: Polarization resistance (R_p) values estimated from linear polarization (LP) curves.

R_p [kΩ cm^2]	**Water 1** **Very hard, neutral** (pH7.1)	**Water 2** **Soft, weekly acidic** (pH6.7)	**Water 3** **Soft, alkaline** (pH8.4)
25 °C	1.2	7.4	11
70 °C	2.1	5.1	1.5

Measured potentiodynamic scans are presented on Figure 3. Electrochemical parameters were obtained from each curve, which are presented in Table 4.

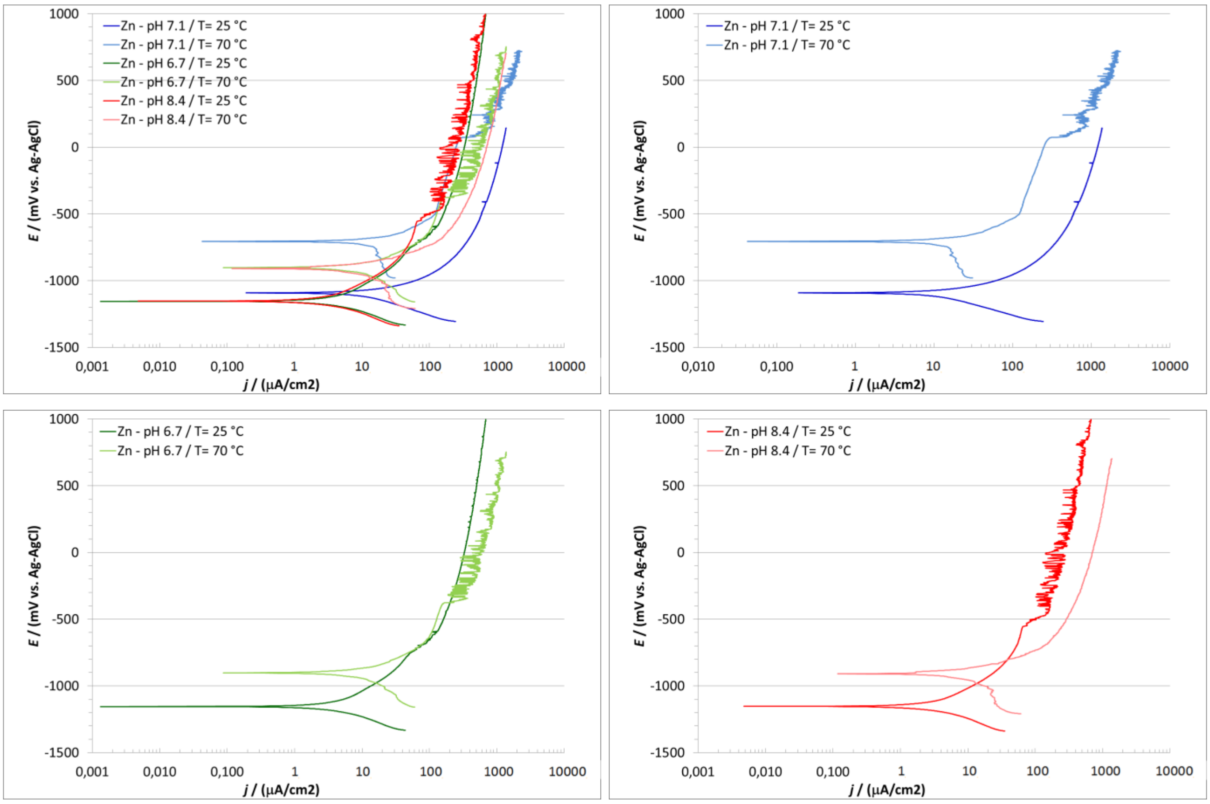

Figure 3: Potentiodynamic (PD) measurements on Zn electrode in 3 different simulated tap waters (Table 1) at 2 different temperatures (25 °C and 70°C).

Table 4: Electrochemical parameters for the investigated Zn electrode estimated from potentiodynamic (PD) curves.

	Water 1 Very hard, neutral (pH7.1)		**Water 2 Soft, weekly acidic** (pH6.7)		**Water 3 Soft, alkaline** (pH8.4)	
	25 °C	70 °C	25 °C	70 °C	25 °C	70 °C
E_{corr} [mV]	–1090	–705	–1150	–901	–1094	–908
j_{corr} [μA/cm^2]	18	18	5	15	2	11

It can be seen from the PD curves and obtained parameters that even though corrosion current density values (j_{corr}) do not differ much (2-18 µA in all systems), the corrosion potential (E_{corr}) values indicate better corrosion resistance of Zn at low temperatures. The corrosion behaviour of Zn seems to be very similar in soft / weekly acid (pH 6.7) and soft / alkaline environment (pH 8.4), while in hard / neutral conditions (pH 7.1) Zn actually shows slightly poorer corrosion behaviour, which is consistent with higher j_{corr} values measured in these conditions. There are some differences in the shape of PD curves measured in different simulated tap waters; the most obvious difference is probably the occurrence of meta-stabile pitting in all three tested pHs at higher temperature (70 °C). Break down potential (E_b) values in these tests do not seem to be influenced by pH nor the temperature.

3. Water supply systems in Slovenian public buildings

In the past few years, there were several cases of problems with secondary water supply systems in Slovenian public buildings. Each case was evaluated individually and the most optimal rehabilitation of each system was proposed.

Standards, guidelines and recommendations [1-4] allow the use of galvanized pipes for drinking water installations only when compatibility of material with disinfection methods is determined. However, standards do not provide instructions or procedure on how such evaluation should be performed. Since this type of steel pipes has been banned in more developed EU countries, there is also a lack of scientific research in this topic [12-17].

3.1 Near-future case-study

Recently, ZAG received a request to perform an evaluation of a water supply system of a public building, built in 1992. There is very little information available on the materials used and the design of the system, since the detailed construction plan is not available. Drinking water system was made from galvanized steel pipes, while accessories, fittings and valves, were most probably made from brass. For the last 10 years a water softening system was used to prevent the accumulation of limescale on the heaters. No chemical or thermal disinfection of the system was additionally used.

The problems on the installation became obvious in 2016, when boiler room was renewed and all old taps and showers were replaced with automatic (water saving) ones. The high amount of solid material in the water is causing the failures of these sensitive taps on a daily basis. However, no leakage was noticed in the last 10 years.

In the first phase of this investigation the general inspection of the building and its water supply system will be performed. Visual part of the system will be inspected and the places for water pipes sampling will be determined. In parallel, the sampling of drinking water will be performed on several locations, to cover cold/hot and flowing/standing water parts of the system.

In the second phase of the investigation, samples of pipes will be collected and subjected to detailed analyses. The identification of water pipes properties will be performed by cross-sectional metallographic analysis (type, seams), chemical analysis and determination of Zn coating thickness. The current state of a drinking water system will be evaluated by determination of the thickness of the remaining inner Zn coating, observation of the corrosion products (visual, SEM/EDS analysis, Raman analysis), assessment of the extent and type of corrosion damage under corrosion products (visual and SEM/EDS analysis). Water analysis on chemical and microbiological properties will be presented and the relation of corrosion to water chemistry will be shown. FTIR analysis will be performed in order to investigate biofilm formation in cold and hot water systems.

On the basis of all investigations, the most optimal rehabilitation will be proposed.

4. Conclusions

According to the results of this study, the following major conclusions can be given:

- In general, lower temperature (25 °C) of all tested waters represents milder corrosion conditions for Zn than higher temperature (70 °C) with exception at very hard waters.
- Zn experienced the lowest corrosion protection in very hard / neutral simulated tap water (pH 7.1) at both temperatures (25 °C and 70 °C). The best corrosion behaviour of Zn was measured in soft / alkaline water (pH 8.4) at room temperature (25 °C).
- The results of electrochemical tests suggest that hardness of the water (content of HCO_3^-) has a greater impact on corrosion resistance of Zn than pH of water, i.e. harder water ~ lower corrosion resistance.
- Electrochemical tests performed in this study have certain limitations and can not take into account the formation of calcium carbonate layer on galvanized steel surface and its influence on the corrosion protection of Zn.
- Slovenian reality often shows the selection of materials for water supply systems that are not appropriate for the designated use. The problems can show already at the beginning or in several years when some changes (renovations) of the system are made.

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