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CORROSION IN THE PERIPHERAL PART OF THE HOT WATER DISTRIBUTION SYSTEM IN THE TOWN OF BOR – A CASE STUDY

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Abstract

This study presents preliminary research on corrosion conditions and mitigation strategies in the hot water distribution system in the town of Bor, Serbia. It aims to provide a foundation for further investigations into corrosion rates, the feasibility of cathodic protection for the system's pipes, appropriate water treatment, and the use of suitable inhibitors. The paper characterises pipe material and water in the secondary network. In the peripheral parts of the network, the heat-transfer water is not of adequate quality, resulting in corrosion acceleration and leaks in the system during the heating season.

***Keywords**: corrosion, steel pipes, urban heating network, feed water quality*

1. INTRODUCTION

Corrosion in iron pipes used in heating distribution systems presents a common issue for local public municipal companies (district heating plants). This is especially true if the system is old and the pipe network is highly branched, as it was in the study. The investigation was conducted in the town of Bor, the capital of Bor district in northeastern Serbia. Bor is located at 44° 04′ N, 22° 05′ E, having an area of 47,62 km² and a population of 28.822 (Census 2022), with a population density of ~605/km² [1,2]. The Bor heating plant began operating in 1973 and expanded during the 1970s and 1980s, reaching 95% coverage of the city today [3]. Although a major reconstruction of the heating network (more than 15 km) and 53 heating substations (HS) was carried out in 2024 and 2025 [4], the ends of the network remained in their original state (from the 1980s). This study focused precisely on these locations.

Corrosion has been, and still is, the main factor in failures of Distributive Heating Systems (DHS) [5,6]. It causes frequent pipe leaks that require many interventions by repair crews during the heating season. It is not only workforce-intensive and costly, but it also interrupts heat distribution, which is not only unpleasant for customers but also

increases the carbon footprint. Although corrosion-resistant flexible PE pipes have been used in DHS for a few decades, pre-insulated rigid steel pipes still have the largest share for the purpose [5]. Among the factors that influence steel pipe corrosion, water (thermal medium) quality was found (by fuzzy hierarchy analysis) to be the most important, while pipe-related factors (material itself, age, contact with dissimilar metals, etc.) are the most overlooked and least studied [6]. For these reasons, the study focuses attention on these two factors.

Water quality influences on corrosion of steel pipes of DHSs are widely investigated, with known effects of dissolved oxygen, aggressive anions Cl^-, NO_3^- and SO_4^{2-}, CO_2, turbidity, etc. [7,8,9]. High F^- or Cl^- concentrations, combined with elevated water temperatures (~80 °C), can cause pitting corrosion or stress corrosion cracking in even AISI 304 stainless steel (SS) [10,11]. Hard feedwater deposit scale and corrosion products on the pipe surface [12], and the presence of Cl^- ions, led to under-deposit corrosion, which can affect highly corrosion-resistant materials such as AISI 316Ti SS [13]. Increased corrosion rates under different iron oxide deposits covering steel pipes were found to increase failure risk in DHS [14]. This significant factor is taken as the third subject of this study, along with pipe material and feedwater composition.

2. EXPERIMENTAL

A water sample from the DHS (in the city of Bor) was taken from the secondary circulation (network), within the individual consumer system at the very end of the city network (the "GHI" block, individual houses), from the aluminium radiator flushing (at the start of the process to avoid mixing with pure tap water). A piece of steel pipe was taken just before the radiator during the repair (welding) of the rupture. Pipe material was standard mild unalloyed steel (JUS Č0361, equivalent to S235JR (material number 1.0038) EN 10025-2), which is confirmed by the chemical analysis using Spark-OES (Spectro, model MaXx LMF06) for the low-content components and EDS (Oxford Instruments X-Max, attached to the SEM JEOL JSM IT 300LV) for the (high) Fe concentration. The results are given in Table 1.

Table 1. *Chemical analysis of the cleaned steel pipe sample*

Element/material	Fe, %	C, %	Mn, %	Cu, %	P, %	S, %	Si, %
Mild (low carbon) steel	98.45	0.12	0.81	0.33	0.016	0.022	0.15

XRD analysis was performed on a Rigaku MiniFlex 600 instrument with a D/teXUltra 250 detector. The imaging conditions were: angle range 3-90° (in the paper, 10- 70° was shown), step 0.02°, scanning speed 10 °/min. The X-ray tube voltage was 40 kV, and the current was 15 mA. Mineral identification was performed in the PDXL 2 Version 2.4.2.0 software.

3. RESULTS AND DISCUSSION

Table 2 presents the chemical composition of this field sample and compares it with the standard for recommended water quality for use in closed heating systems (up to 110 °C).

It should be stressed that TD shows that the water in the secondary circuit is not softened, which is not the case for the whole system, because reconstructed substations have softeners. This type of water treatment has been shown to reduce suspended limescale (or its deposits), which can indirectly influence Fe oxide precipitation and cause very dangerous under-deposit corrosion; combined with a rise in pH, it is beneficial for mitigating pipe corrosion. Nevertheless, ion exchange softeners can increase the possibility of microbiologically influenced corrosion (MIC).

Table 2. *Comparative analysis of water from the Bor heating plant pipeline with the standard [15]*

Standrad: EN 14868			Bor heating plant/field sample
pH (25 °C)	–	8.5 – 9.5	7.8
Total hardness (TH)	°dH	≤ 0.05	6.83
Dissolved oxygen (DO)	mg/L	≤ 0.10	5.8
Electrical conductivity (EC)	µS/cm	≤ 100	299.8
Chlorides (Cl^-)	mg/L	≤ 50	1.76
Sulfates (SO_4^{2-})	mg/L	≤ 150	74.6
Iron (Fe)	mg/L	≤ 0.10	1800
Aluminium (Al)	mg/L		0.07
Copper (Cu)	mg/L	≤ 0.05	<0.005
Oils and fats	–	not allowed	<0.008
Suspended materials	mg/L	≤ 5	6780

MIC should be considered very seriously, especially at temperatures between 40 and 60 °C [16], which provide an ideal environment for microbial proliferation and are common in the secondary system during most of the heating season.

The most important result of the study is the finding of a very high content of suspended material in heating water and deposits on the pipe surface. Their mineral compositions, determined by XRD, are shown in Figure 1.

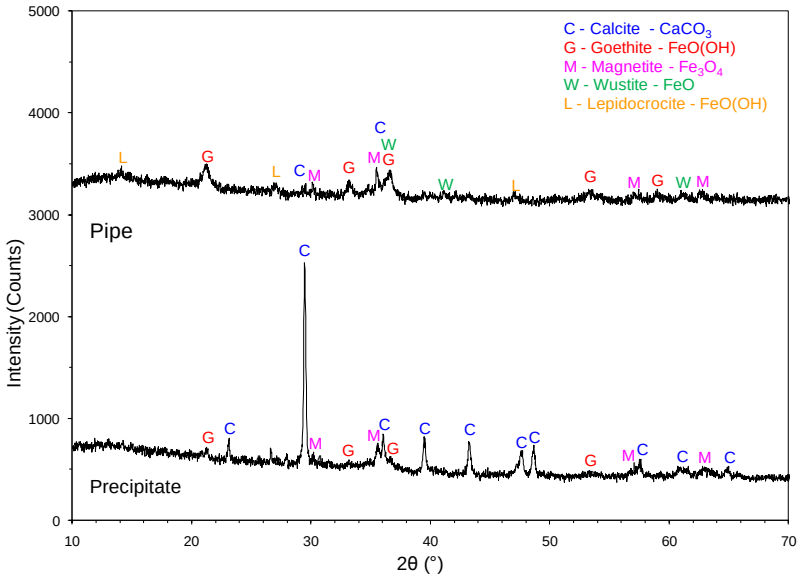


Figure 1. *X-ray diffraction pattern for filtered suspended material from heating water and on the steel pipe*

Calcite ($CaCO_3$), magnetite (Fe_3O_4), and goethite (FeOOH) were identified in the precipitate (sediment) sample. The most abundant mineral is calcite, while magnetite and goethite are less abundant. Magnetite is a spinel mineral, and the peaks of spinel minerals occur at close 2θ angles, so other spinel minerals may also be present in the sample. Analysis of the diffractogram indicates that the sample may also contain amorphous material. At the pipe surface (second sample, upper XRD pattern), wustite (FeO) was also identified as a corrosion product, and a lower presence of calcite was evident. The XRD analysis is significant because the presence of FeOOH (both detected forms) indicates progressive oxidation and material degradation [17]. Magnetite and goethite (α-FeOOH) deposits increased the cathodic and anodic reactions [14].

4. CONCLUSION

Based on the results of the study, the following conclusions can be drawn:

Water from the secondary DHS network did not meet the requirements of the relevant EN 14868 standard, which is a consequence of corrosion processes and (for the purpose) high hardness (significant excess of Fe concentration and suspended matter). On the other hand, an increase in these two parameters leads to the formation of (corrosion) layers on the pipe surface and progressive under-deposit corrosion, creating a feedback loop and accelerating the material degradation process. Fortunately, the water had low concentrations of aggressive ions (chloride and sulfate), a relatively high pH, a relatively low concentration of dissolved oxygen, and moderate hardness (121 mg/l $CaCO_3$), so the pipe perforated only after many years of use.

Fe oxides were identified in the sediment from the feed water, but calcite was in the highest concentration. Less abundant calcite, along with FeO and other Fe oxides from precipitates, was found at the pipe surface as a corrosion layer. Although Fe_2O_3 was not identified in the mineral state (hematite or maghemite), the XRD analysis leaves the possibility that it was present in an amorphous state. Although Fe_3O_4 has certain protective properties, the presence of FeOOH (α and γ) indicates degradation (corrosion) processes, which was the actual consequence (leakage at the pipe seam).

This provided the basis for further corrosion testing of the materials used in the system (various steels, including "boiler" (low alloy) steels, aluminium (radiators) and brass (e.g. boiler taps)) in different corrosive environments (feedwater of different quality and treatment methods). This could identify weak points in the system, assess the life of individual components and indicate possible protective measures, such as cathodic protection.

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