

INFLUENCE OF WATER VELOCITY AND NOM COMPOSITION ON CORROSION OF IRON PIPES

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Abstract

The effect of water velocity on the corrosion rate of new iron pipes was studied in the full scale. Sets with four rigs operated under different flow regimes (high, low, variable, stagnant) were installed in two locations (chemically treated surface water and groundwater) of a drinking water supply networks, and weight loss of the iron coupons was monitor over the period of one year. During the initial phase of corrosion (about 200 days), the results showed that in water which can be considered more corrosive (undersaturated in respect to calcium carbonate, high sulphate concentration) the corrosion rate of iron increased by 20-50% at low or variable flow regimes compared to at high flow rate. The chemical water quality was less important for the overall corrosion of iron coupons at high flow rate, however, it was very important for the occurrence of pitting and localized corrosion. Pitting of iron surface occurred in the more corrosive water. The influence of natural organic matter (NOM) on the corrosion of iron was studied in batch experiments by measuring the weight loss of coupons after three weeks of exposure to water containing similar concentrations but different types of NOM. The results showed that the composition of NOM affected the corrosion rate of iron pipes. Non-humic hydrophilic NOM fractions were more corrosive than humic substances towards iron pipes at stagnant conditions. Comparing to copper pipes, iron were more affected by the type of NOM. The study allowed us to conclude that high corrosion rate and corrosion problems (new or aggressively cleaned old pipes) are more likely to occur in service pipes (low or variable flow rate) supplied with water containing high level of NOM composed of non-humic compounds. Pitting corrosion and risk of pipe failure increase having the more corrosive water.

INTRODUCTION

Corrosion is one of the most important problems in the drinking water industry as it is compromising the public health (both due to release of heavy metals from pipes and due to pipe damage and ingress of contaminated water into the pipes), public acceptance of water quality and increased costs of providing safe water. Deterioration of materials resulting from corrosion creates economical losses due to repairs and pipe replacements.

To mitigate these problems there are large number of studies that have been carried out aiming at determining water qualities which are less aggressive towards the pipes. Most of these studies are considering the influence of inorganic ingredients (hardness, alkalinity, saturation, sulphate, chloride, etc.), whereas the effect of natural organic matter (NOM) has been studied only by a few authors [1, 2, 3]. Consequently, there is a need to better understand the influence of NOM on the corrosion of cast iron, especially, the role of the organic substances composition as it can be very different depending on the source and the water treatment methods being used.

Another factor which has not received significant attention is the influence of water flow regimes on the pipe corrosion. This is surprisingly, since the flow velocity in the water distribution networks is very different depending on the part of the networks considered. Flow is relatively high and stable at transport mains, but it is very variable at service pipes.

The aim of this study was to determine the effect of the water flow regime and the type of NOM on the corrosion rate of iron.

The velocity effect was studied in full scale at the water distribution networks in Riga (Latvia), whereas the influence of the composition of NOM was examined in laboratory scale. The study was focusing on the corrosion process occurring in new pipes before they are covered with corrosion and deposit layer.

MATERIALS AND METHODS

Tests with corrosion rigs in full scale to study the velocity effect

Two corrosion test rigs have been placed in the Riga water supply system, one at the surface treatment plant (D) and another in the distribution system supplied from groundwater (B). The test rigs are designed to measure corrosion rate of iron by determining weight loss of coupons which are made of low grade steel (st37).

Figure 1 shows the schematic sketch of the corrosion test rigs which were installed at the location D and B. Each test rig had 4 parallel columns in which 12 steel coupons (st37) were placed parallel to water flow. The coupons were cleaned, degreased and weighed prior to installation.

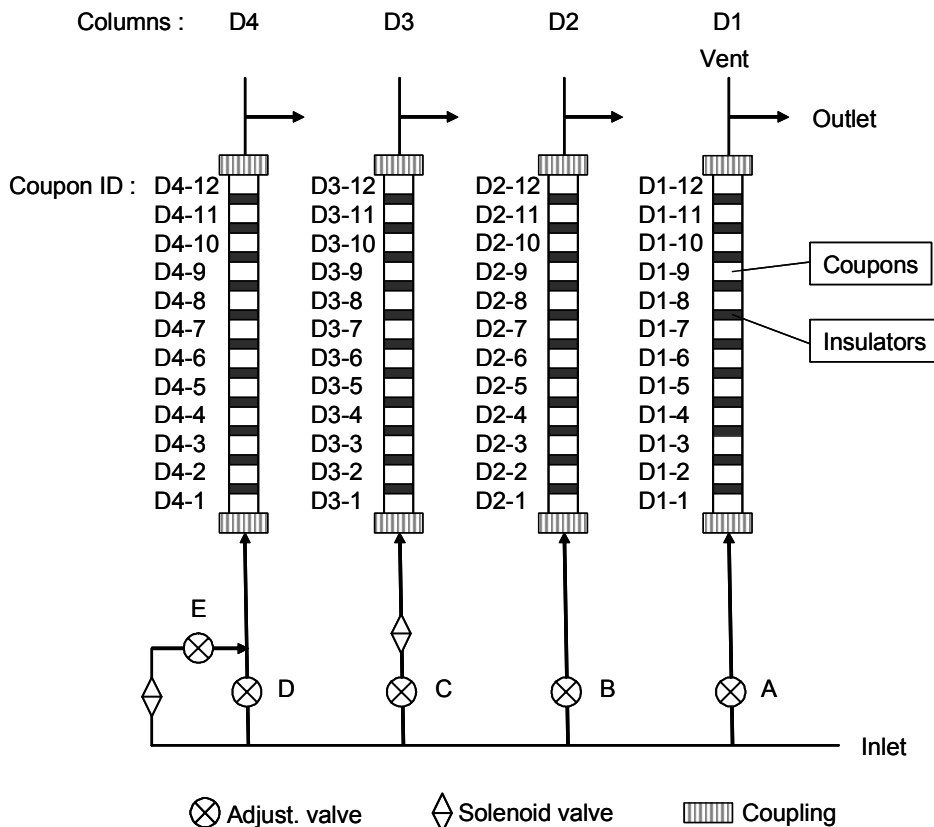


Figure 1. Rigs used to study the effect of water velocity on the corrosion rate. Sets of the rigs were installed in two location (B and D) of the drinking water distribution system.

The flow rate of column one (D1) was adjusted by valve A, and it was $3.8 \text{ L/min} \pm 0.38 \text{ L/min}$ (high flow rate $\sim 0.35 \text{ m/s}$). The flow rate of column two (D2) was adjusted by valve B, and it was $0.6 \text{ L/min} \pm 0.06 \text{ L/min}$ (low flow rate $\sim 0.05 \text{ m/s}$). The flow rate of column three (D3) was alternating between high flow rate and stagnation. The alternation was determined by the timer which controls the solenoid valve. The timer was set to 11 hrs of stagnation followed by 13 hrs of flow in a 24 hrs period. The flow rate during the flowing period was adjusted by valve C, and it was $3.8 \text{ L/min} \pm 0.38 \text{ L/min}$ ($\sim 0.35 \text{ m/s}$). The flow rate of column four (D4) was alternating between high and low flow rate. The alternation was determined by the same timer that controlled column three, which also controlled the solenoid valve in column four. The low flow rate has to be adjusted first with the solenoid valve closed. The

low flow rate was then adjusted by valve D, and it was 0.6 L/min \pm 0.06 L/min (\sim 0.05 m/s). After that the high flow rate was adjusted with the solenoid valve open. The high flow rate was then adjusted by valve E, and it was 3.8 L/min \pm 0.38 L/min (\sim 0.35 m/s). The high flow rate was the sum of water flowing through valve D and E.

Every third month, 3 coupons were extracted from each column. Before the coupon extraction the feed line valve of the test rig (not shown in the figures) was closed, shutting down the water feed to the rig without affecting the flow rate adjustments of the columns.

The corrosion products/deposits were removed in ultrasonic bath followed by cleaning in concentrated HCl. The coupons were then dried (i.e. at 60°C for at least 4 hrs) and weighted.

Batch scale test for NOM composition effect on iron and copper

Experiments were carried out in batch scale. One group of samples contained steel (st 37) coupons, other – copper coupons. Prior to the experiment, the steel coupons were immersed in hydrochloric acid to remove any oxide layer from the coupon surface, and then washed with distilled water to remove traces of acid. The coupons were then dried and weighted. Water for the experiment was prepared by adding salts into pure distilled water to make water composition similar to that from location B. pH was adjusted to 7.4 -7.6. All the coupons were left in the water samples for three weeks. The samples were capped and placed on a shaker which was covered with aluminium foil to avoid light influence. After three weeks, the coupons were extracted, sonicated for 1 min and dried for 8 hours at 60°C. Then the coupons were weighted and weight loss was calculated.

All the glass bottles, flasks used in these experiments were heated for 6 h at 250 °C to avoid organic carbon contamination from glassware. Water was sterilized for 20 minutes at 121°C and filtered through 0.45 μ m pore size membrane filters. To the water samples it was added aliquots of charged hydrophilic acids (CHA) or very hydrophobic acids (VHA), which were isolated from drinking water at site D by using NOM fractionation technique which was developed by Christopher et al [4]. CHA were used as model of non-humic substances and VHA for humic substances.

Dissolve organic carbon (DOC) measurements were performed with a TOC-5000A Analyzer (Shimadzu Corporation, Kyoto, Japan) [5]. The blank and control solutions were analyzed with each series of DOC sample in order to verify the accuracy of the results obtained by the method. Every DOC sample was tested in duplicate and the mean value calculated ($CV \leq 2\%$). The reported DOC values are the mean of three samples.

RESULTS AND DISCUSSION

The effect of water quality and velocity on the corrosion rate of iron

The experiments were carried out during 327 days by measuring weight loss of coupons which were placed in locations B and D of the drinking water distribution networks in Riga, Latvia. The average values of the water quality parameters from both locations are summarized in Table 1. In both locations the water was moderately hard with relatively high alkalinity. According to calculation of corrosion indexes, Langelier saturation index (LSI) and Larson ratio (LR), the water in location D were more corrosive and with a higher potential to induce pitting type corrosion.

The initial weight loss of the iron coupons was rapid, about 0.2-0.4 mg/cm²/d, during the first 200 days, where after it slowed down resulting in a overall weightloss of about 0.11-0.25 mg/cm²/d for the entire experimental period (Figure 2). This is caused by an initially high corrosion rate of bare metals which then decreases as the scale layer of iron oxides grows and provides increasing resistance to the corrosion reaction [6]. At high flow rates (0.35 m/s) the overall corrosion rates were similar in water from both locations, even though water from location D could be considered as more corrosive. In all other cases, namely at low (0.06 m/s), variable and high/stagnant flow conditions, the corrosion rates in the water at location D increased by some 20-50%, while in location B it decreased by some 10-30% compared to at high flow conditions. The literature reports that in relatively noncorrosive, balanced waters

higher flow rates decrease the iron corrosion rates [7], even though there are opposite findings available as well [8].

However the water quality and velocity also affect the type of corrosion (Figure 3). The more corrosive water quality from location D facilitates pitting type of corrosion, which was not the case for coupons from location B. In particular at high flow rate, the pitting attack was severe at location D, and only 10-30% of the surface was corroded. Since the overall corrosion were about the same at location D and B at high flow rate, the actual corrosion rate was much higher at location D than at location B where the entire surface was corroded. This results in a much more severe corrosion attack at location D with respect to corrosion damages and pipe life time, whereas the difference between location D and B may not be significant with respect to water quality deterioration.

Table 1. Average values of water quality from locations B and D collected during 327 days

Water quality parameter	B		D	
	Average	SD ±	Average	SD ±
pH	7.57	0.15	6.91	0.26
Ca, mg/l	63.36	5.75	52.13	6.28
Alkalinity, mg/l	184.00	10.16	130.13	29.77
temperature, °C	10.62	2.59	8.65	8.03
SO ₄ ²⁻ , mg/l	62.26	3.85	80.74	4.94
Cl ⁻ , mg/l	119.00		8.56	
Mg, mg/l	17.74	1.14	12.48	1.63
Mn, mg/l	0.07	0.03	0.01	0.01
Si, mg/l	2.99	0.79	2.15	1.13
Conductivity, µS/cm ²	754.06	105.63	358.45	152.56
Turbidity, NTU	0.54	0.09	0.20	0.11
Fe-tot, mg/l	0.21	0.08	0.05	0.00
Redox, mV vs AgCl	257.82	30.80	260.61	127.02
Dissolved oxygen, mg/l	7.91	1.34	22.96	11.45
DOC, mg C/l	5.03	1.02	5.84	1.13
BDOC, mg C/l	0.47	0.35	0.58	0.26
P-tot, mg/l	0.01	0.01	0.02	0.04
N-tot, mg/l	0.49	0.21	1.11	0.77
Cl ₂ -tot, mg/l	0.13	0.07	0.02	0.01

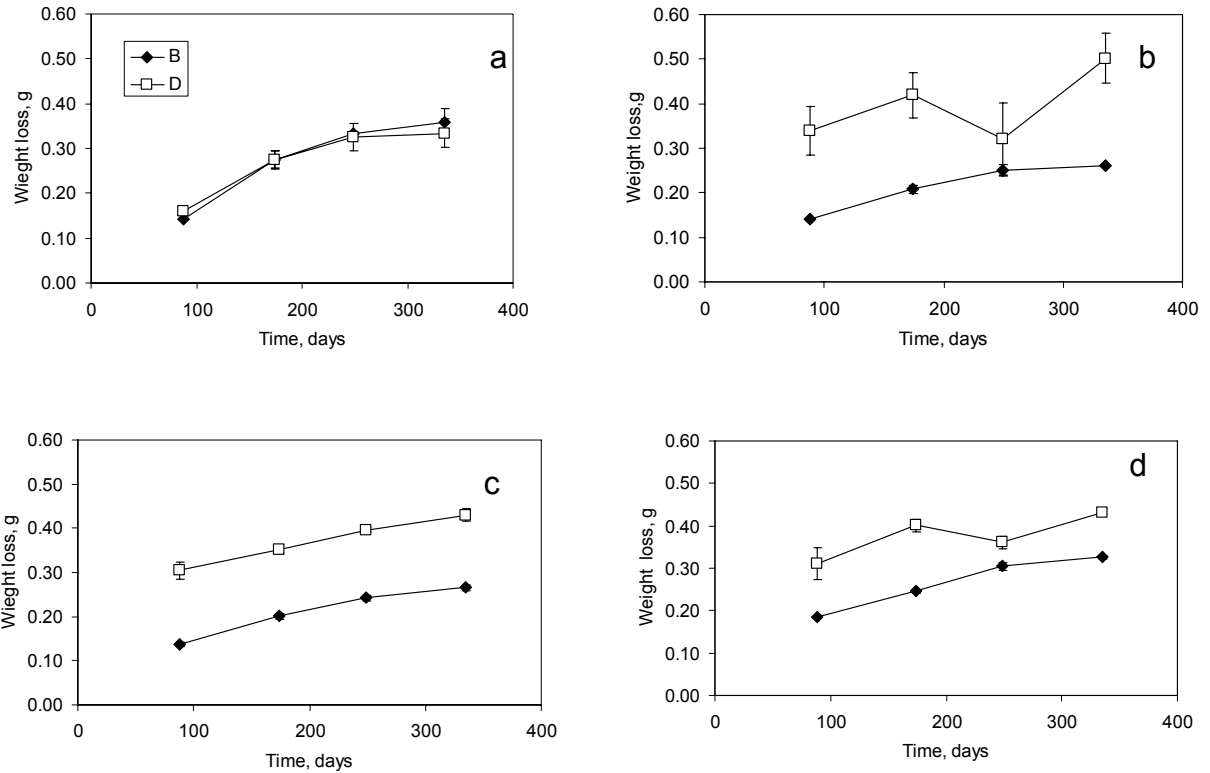


Figure 2. Weight loss of coupons at high flow rate of 0.35 m/s (a), low flow rate of 0.05 m/s (b), high flow rate of 0.35 m/s and stagnant conditions (c), and high / low flow rate (d), over the period of 327 days.

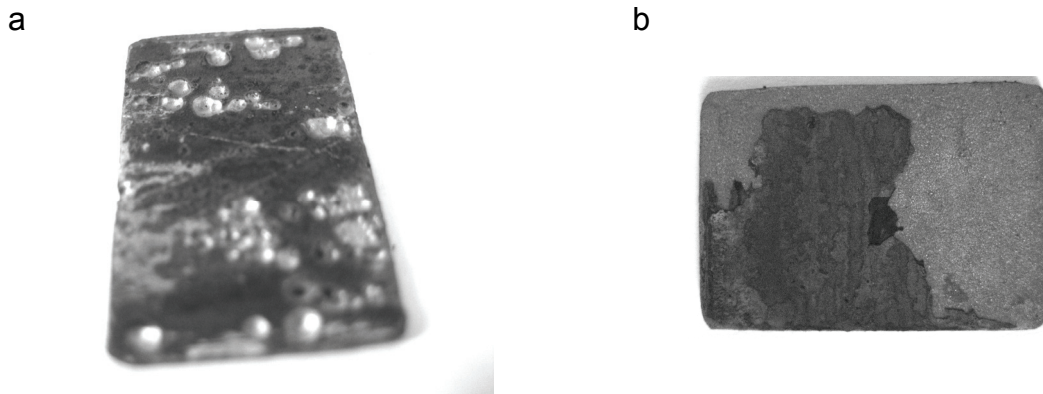


Figure 3. Coupons from site D (a) and B (b) after three month expose to water under high flow rate conditions.

The effect of NOM composition on the corrosion rate of iron and copper

The NOM composition affected the corrosion rate of iron and copper (Figure 4). An increase in the concentration of NOM which were composed of very hydrophobic acids (VHA), mainly humic substances, did not have any significant effect on the iron corrosion, whereas more charged hydrophilic (CHA) substances increased the corrosion rate at higher concentrations.

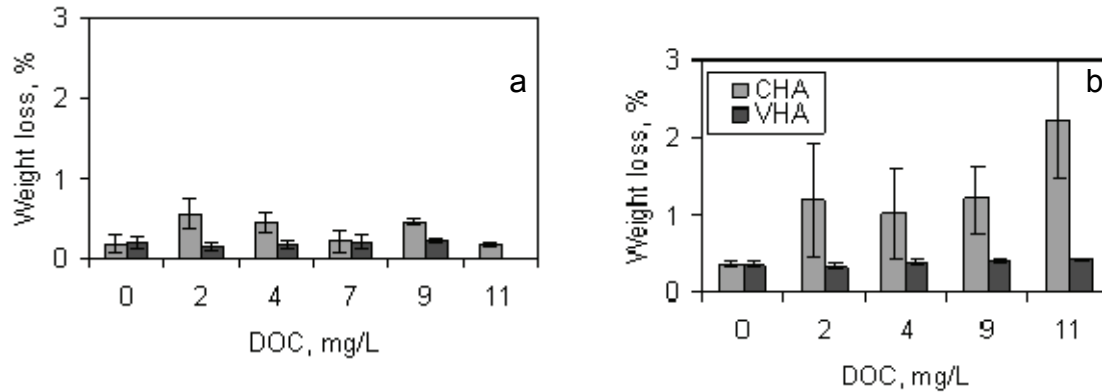


Figure 4. Weight loss of copper (a) and iron (b) coupons after exposure to NOM composed of very hydrophobic acids (VHA) (humic substances) or charged hydrophilic acids (CHA) (non-humic substances) during three weeks in stagnant conditions.

Organic matter has an indirect influence on the corrosion, by complex formation with free iron. This complex formation changes the precipitation rate and the structure of the precipitates in the protective layer. NOM has been reported in the literature to encourage the formation of more protective scales [9]. The results obtained in this study show that hydrophilic non-humic substance most likely facilitate dissolution of iron and inhibits the formation of protective iron oxide layer. The role of complexation between iron and NOM was stressed by Broo et al. [10] who revealed that NOM increased the corrosion rate at low pH values, but decreased it at high pH values. The authors concluded that this opposite effect was due to different surface complexes formed under different pH conditions.

CONCLUSIONS

The conclusions from this study can be summarized as follows:

- The flow regime and the water quality affect the corrosion type and rate of iron pipes;
- At low or variable flow rate the corrosion rate of iron pipes increases by some 20-50 % in less corrosive water (making corrosion problems more likely in service pipes);
- Chemical water quality was less important for the overall corrosion of iron pipes at high flow rates (e.g. transition mains), however, it is very important for the occurrence of pitting and localized corrosion;
- Pitting and localized corrosion occurs in more corrosive waters (thus increases the risk of pipe failures);
- The composition of NOM affects the corrosion rate of iron and copper pipes;
- Non-humic hydrophilic NOM fractions were more corrosive than humic substances to copper and iron pipes at stagnant conditions; this effect was much stronger for iron pipes.

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