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TEMPORAL CHANGES OF CORROSION LOSSES AND CORROSION RATES IN WATER PIPES

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Abstract: *Water distribution systems are often constructed of metal tubes, which in addition to its good properties, especially mechanical, has also tendency to corrosion. Increased activity of corrosion processes significantly affect not only the time- life of the pipe, its failure rate and reliability, but also changes hydraulic conditions of water supply system and may result in poor water quality. Price increase of the water caused a reduction of water consumption and the extension of the travel time of the water in distribution system. This also influences the interaction of the transported water and pipe material. For the reasons, stated above, we observed the corrosive effect of the water from water source Pernek on the pipe with the short- and long- term corrosion tests. Tests are based on measurements of the weight loss difference of the test sample after 30 and 60 day exposure to flowing water. Since short time (30-60 day) test does not always give an accurate picture of the interaction between water and pipe, we extend the test up to two years. During these long term test we have observed not only the corrosion losses and the corrosion speed, but also the formation of the corrosion layer and its thickness. Corrosion losses between 30 and 60 day were almost in linear course, but during longer tests corrosion losses speed decreases and the average corrosion rate for 2-year test reached only about 39% of the corrosion rate determined from short term tests.*

Keywords: *corrosion of water pipes, corrosion rate, corrosion losses, corrosion layer*

1. Introduction

During the transport of drinking water to the consumer, an interaction between transported water and pipe material occurs, which often results in increased activity of the corrosion process. Increased activity of corrosion processes significantly affect not only the lifetime of the pipeline, its failure rate and reliability, but also changes the hydraulic conditions of water supply system and may result in a poor water quality. In general it can be stated that the problems caused by corrosion cause problems for all operators of water supply systems, whether in the public drinking water supply or the industrial water supply and therefore the interaction of water and transported material pipe should be in spotlight of all water systems operators [1-5].

2. Matherials and methods

Determination of water aggressiveness – used materials and methods

One of the most important chemical equilibrium in water chemistry and water technology and water is calcium- carbonate balance, which is important in assessing the aggressive and incrusting effects of water [6, 7, 8, and 9].

Water aggressiveness can be determined from chemical analyses of water, direct test for solid $CaCO_3$ (Heyer’s test), by a variety of formulas and tables, or corrosion tests [6]. Since the calculations of water aggressiveness, according to various authors [8,9] take into account only the water aggressiveness caused by CO_2, but do not consider the amount of dissolved oxygen in the water, which may be the dominant factor in the corrosion rate or the flow velocity of the water. Because these factors substantially affect the corrosion processes, results of direct corrosion tests are the most objectives, but very troublesome and also highly time-consuming [10].

The test methodology is presented in the Slovak Technical Standard (STN) 75 7151 "Quality requirements for water transported in pipes" [12] and is based on weight loss measurement of the test sample after 30 and 60 days after exposure of the sample to the flowing water [11].

The measured corrosion losses (g / sample) can be converted to the unit g/m^2 using following equation:

$$K_i = \frac{(m_0 - m)}{S} \qquad (1)$$

Where m_0 is the weight of the sample before exposure in grams, m is the weight of the sample after exposure in grams, S is the surface area of the sample in square meters.

Following, using the steel density (7.86 g.cm^{-3}), the corrosion losses can be converted from unit g.m^{-2} to the unit µm/(exposure time) (10^{-6} m / exposure time).

This means that the conversion of corrosion losses from unit g/sample to µm/exposure time (10^{-6} m/exposure time) leads to idealization in which a corrosion loss is equal over the sample surface (uniform corrosion). Actually, this is not true in generally, because in most cases non-uniform corrosion occurs and local losses are greater.

According to Slovak Technical Standard STN 75 7151 for each experiment / measurement shall be 5 test samples used, each with dimensions 42 x 42 x 1 mm, and the averaged value is used to calculate the corrosion rate.

Based on the measured corrosion losses the corrosion rate is calculated, which basically means the thickness reduction of the pipe wall, related to the original thickness. Based on the corrosion rate (expressed in in micron for 1 year between the 30th and 60 day), the level of water aggression is determined. STN 75 7151 recognises the three levels of water aggressiveness and their assessment (Table 1):

Table 1

Water categorisation according the aggressiveness level

Aggressiveness level	**Corrosion rate (µm. year^{-1})**	**Assessment**	**Anticorrosive measures:**
I.	Less than 50	Moderate aggressiveness	Not required
II.	From 50 up to 150	Medium aggressiveness	Based on results of technologic and economic analysis
III.	More than 150	Heavy aggressiveness	Necessary

If we want to check also the corrosion type (in addition to the corrosion loses), ie whether the pipeline corrosion is uniform (areal - flat) or non-uniform (local, in-depth), respectively, what type of corrosion layer will be formed, the test period shall be extended up to one year. Advantage of the test is that the water complex effect on the test specimen as the pipe.

3. Results and discussion

Field experiments were carried out in cooperation with the Bratislava water Company, Inc. (BVS, a.s.). Corrosion tests were performed on the water source Pernek, whose water shows relatively high aggressive effects. The water source Pernek supplied water in the past to the Záhorský water system. After interconnection of the Záhorský water system with the Bratislava water system, the Záhorský water system is supplied with water of very high quality from the water resources in the Bratislava region. From the Pernek water source is currently only one well used (HL-1) to supply municipalities Jablonové and Pernek. [11].

Corrosion tests on the wells were started in April 2010 and conducted two years long.

During the experiments, groundwater has shown following ranges of parameters (parameters related to the calcium carbonate equilibrium of the water):

Saturation index: -0.52 till -0.74

Free CO_2: 6.60 till 10.12 $mg.l^{-1}$

Balanced CO_2: 2.9 till 4.52 $mg.l^{-1}$

Aggressive CO_2: (aggressive to iron, Fe):4.41 till 5.60 $mg.l^{-1}$

Aggressive CO_2 (aggressive to marble, $CaCO_3$) 2.58 till 3.24 $mg.l^{-1}$

Groundwater pH value was in range from 7.30 till 7.42, groundwater temperature was 9.8 till 10.5 ^{o}C, acid neutralization capacity ($ANC_{4.5}$) 2.10 till 2.43 $mmol.l^{-1}$, base neutralization capacity ($BNC_{8.3}$) 0.15 till 0.23 $mmol.l^{-1}$, Fe concentration was below 0.03 $mg.l^{-1}$, Mn below 0.01 $mg.l^{-1}$, Ca^{2+} concentration was 69 till 74 $mg.l^{-1}$, NH_4^+ below 0.02 $mg.l^{-1}$, NO_3^- 18 till 22 $mg.l^{-1}$, SO_4^{2-} 74 till 78 $mg.l^{-1}$, a Cl^- 10 till 14 $mg.l^{-1}$.

In the well HL-1 we installed a test device with a 1.5 m long glass tube, into which we put up to 6 racks of test samples. 5 samples were retracted into each rack, and each sample was separated with a non-conductive cylinder. The samples were made of class 11 steel, 1 mm thick, with the size of 42 x 42 mm. Water in the test device was pumped out from the well and after flowing through the racks (experiment device) water flow out through an outlet to a surface infiltration ditch.

All corrosion tests were evaluated in accordance with STN 75 7151 for corrosion losses, corrosion rate, corrosion layer as well as the velocity of water flowing in the test facility.

Under the corrosion layer we understand a poorly adhered layer of corrosion products, which includes also substances from water in addition to corroded pipe material.

The method of determining the amount of corrosion products permanently attached on test samples was performed according to STN 75 7151. After finishing the exposure of the samples, the rack with the five samples was taken out of the glass pipe. The test samples were carefully removed from the rack in order to avoid loss due to fractions peel-off or fall-off from the corrosion layer. The samples with corrosion layer are dried in an oven at the temperature of 105° C until the weight was constant. After weighting the samples (with corrosion layer) the corrosion layer has been mechanically removed from the samples and the test samples were cleaned same way as during the procedure for the corrosion losses determination (5-minute submerging in 20% hydrochloric acid solution with a concentration of hexamethylenetetramine 5 $g.l^{-1}$, rinsing with distilled water and ethanol, subsequent drying at 105 ° C and weighing). The amount of corrosion products permanently attached on a test samples were calculated from the difference of the test sample weight (with corrosion layer and weight of the test sample after cleaning).

Following measurements have been completed and evaluated so far: two - two-year, three one-year, three six-month, one four-month, one three-month, eight 60-day and sixteen 30-day measurements, respectively. Each 60-day test consists of two 30-day and one 60-day measurement. The 60-day tests two highest placed racks of samples were used, which were after removal being replaced by racks with new samples. For the six- month tests the third rack and for the annual test the fourth racks were used, with samples that have also been replaced after removal by new samples. The fifth and sixth racks were used for the two- year tests.

With the aim to check, if there isn't a gross fault in the corrosion measurements (whether the minimum or maximum) and thus avoid a possible distortion of the results of the average corrosion loss of the tests, the measured values of corrosion losses (g per sample, respectively. $g.m^{-2}$), were checked by the extreme deviations tests. We used the Dixon and Grubbs test. Of the total of 170 tested values 8 values did not comply with the tests criteria and were excluded from further evaluation (whereas all values were close to the maximum).

Measurements results are shown in tab. 2 and on the Fig. 1 and Fig. 2.

Table 2

Corrosion rates achieved during the test period

days	**Corrosion speed v_t ($\mu m.year^{-1} = 10^{-6} m.\ year^{-1}$)**		
	interval	**average**	**%**
30 - 60	90.94–219.14	134.86	100.0 %
30 - 180	48.31 – 87.92	73.00	54.1 %
30 - 365	59.85 – 67.27	63.10	46.8 %
30 - 730	50.29 – 53.84	52.23	38.7 %
365 – 730	41.52 – 43.54	42.25	31.3 %

In Table 2 the ranges of corrosion speed as well as the average corrosion speed obtained during the two-year corrosion tests are presented. The biggest and significant variance of corrosion rates was found during the short 30 to 60 day corrosion tests (Fig. 1); whereas with increasing time of the test period variance of determined corrosion speed decreased significantly.

This is due to the forming of the corrosion layer, which creates a barrier between the transported water and pipeline and thus reduce the corrosion rate.

As can be seen on Figure 1, water aggressiveness changes during the test period. A significant increase in the corrosion rate occurred mainly during the second 60-day test, which was probably due to the significant increase of the groundwater level due to long-term heavy rainfalls. In contrast, the corrosion rates measured in the same month, but with annual shift (experiment Nr. 1 and 7) are very similar. The completed and evaluated 60-day measurements have shown that the tested water is classified in II. and III. aggressiveness level.

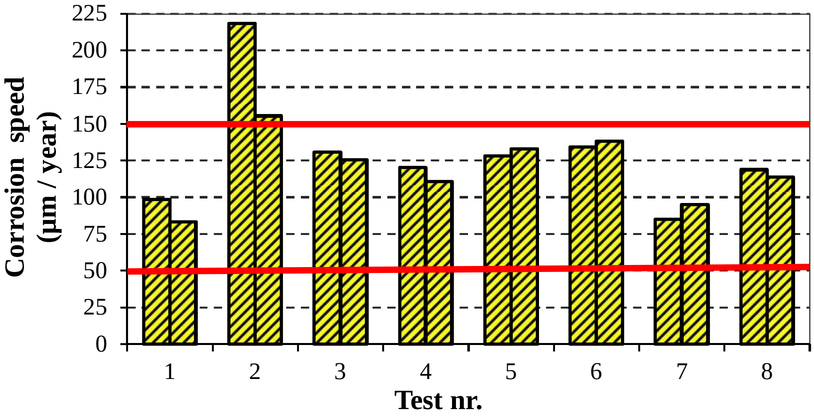

Figure 1. Achieved corrosion rates during I. -VII. 60-day cycle

Increases of the corrosion losses and corrosion products are not linear, but are decreasing with increase of the exposure time. Their trends are shown in Fig. 2. However, the chart shows that the measured amounts of corrosion products and corrosion losses were during the 30 or 60- day measurements not the same, but changed significantly during the year, and these changes were not influenced by the flow rate. E.g. for eight 60-day tests were standard corrosion losses determined in the range from 0.397 to 0.804 g / sample and corrosion products in the range from 0.479 to 1.095 g / sample. Significantly smaller variance occurs during annual tests, the corrosion losses ranged from 1.755 to 1.974 g / sample and corrosion products from 2.815 to 2.978 g / sample.

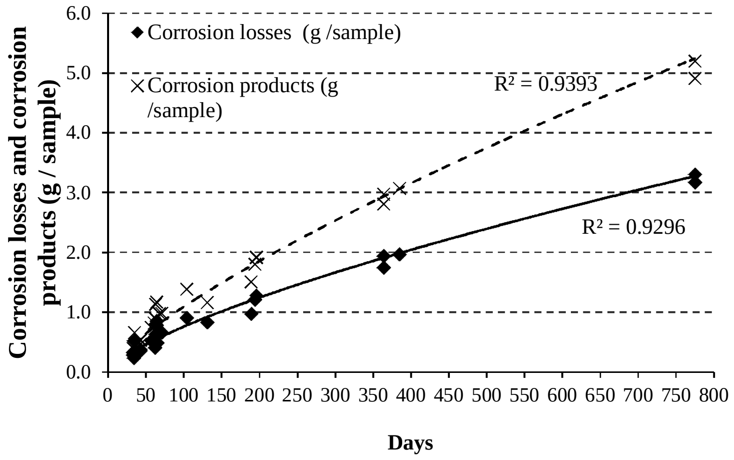

Figure 2. Trend of corrosion losses and corrosion products

The corrosion rates for long term annual test are significantly lower than corrosion rates of the short tests (30 - 60 days test), which are required by the standard STN 75 7151. Short test results of the corrosion speeds are more than half lower then long-term tests and water can be classified just above the criteria for the 2nd aggressiveness level, respectively in the bottom range of the 2nd aggressiveness level. In the two-year test the results even decreased to the criteria between the 1st and 2nd aggressiveness level and represents only 39% of the results from short tests (30-60 day tests). There is approximately double increase of the values of corrosion losses and corrosion products between 30 and 60-day tests. The decrease of the corrosion losses shows that during the long-term tests the corrosion layer takes some protective effect, although usually there is only a poorly adherence and the corrosion layer fall off very easily even with a careful handling with the samples.

In terms of the corrosion rate development and corrosion losses the formation of corrosion layer and its protective effects is important. This layer changes the hydraulic roughness and cross-section of the pipe; therefore we focused our research also on the mapping of their development. The thickness of the corrosion layer was determined with use of the digital photo - microscope (180 up to 300 times magnification). The corrosion layer is not uniformly distributed across the test samples surface, but mostly concentrated along the samples edges, on places, where the samples are attached to the frames. With increasing exposure duration during the corrosion tests increases the area of corrosion layer with bigger thickness. Averaged surface "with" and "without" of samples with thick corrosion layer are shown in Table 3.

Table 3

Average area, covered with thick corrosion layer

Exposure time	**Sample area without thick corrosion layer (%)**	**Sample area with thick corrosion layer (%)**
30 days	68	32
60 days	51	49
6 months	35	65
1 year	22	78
2 years	17	83

Assuming development according (Fig. 3), the average corrosion loss, which represents uniform corrosion, reached after 10 years, the value of about 9.9 g/sample, respectively 357 µm/10 years. In fact, the local corrosion losses are several times larger.

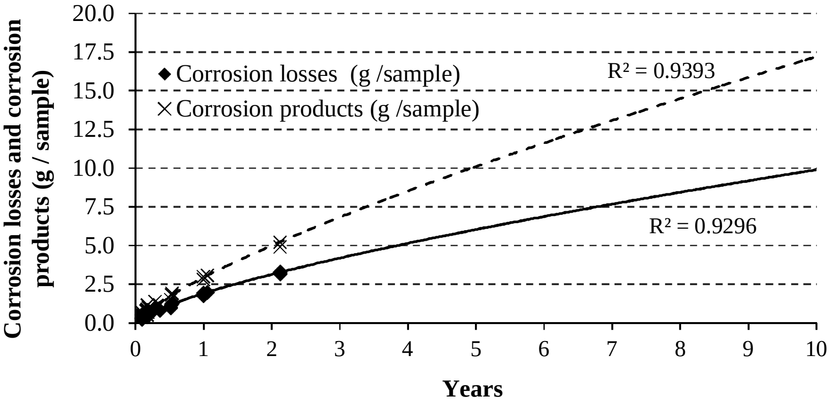

Figure 3. Trend of corrosion losses and corrosion products and their extrapolation

Figure 4. Development of corrosion layer over time (30, 60, 180, 365 days). Plastic racks with samples are ordered by exposure time, whereas the lowest is the shortest time exposure (30 days).

Figure 5. Detail of the corrosion layer after two years exposition.

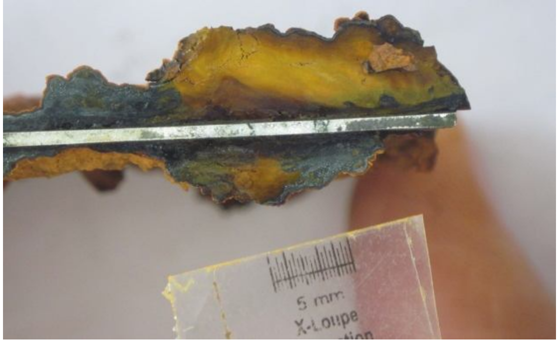

Figure 6. Photomicroscope's detail of the corrosion layer after two years exposition.

Figure 7. Comparison of the amount of peeled-off fragments from corrosion layer after 30, 60, 180 and 365 days of exposition of the test samples in water.

4. Conclusion

From the measured corrosion rate, it is clear that the aggressiveness of the tested water varied during the test period. The results of the two-year monitoring of the water aggressiveness of the water source Pernek show a decrease in the corrosion rate during the long-term tests (30 to 730 day tests) compared to a standard tests (30 - 60 days). While in normative tests, corrosion rates classified the water to the 2nd up to the 3rd level of aggressiveness and therefore it is seriously suggested to consider and adopt some anti -corrosive measures, for longer-term corrosion tests the speed decreased significantly and also the water aggressiveness decreased to the 1st up to the 2nd level of water aggressiveness. The average corrosion rate measured during the annual test reached only 48.4% of the corrosion rate of 30-60 days test (and only 38.75% for the two years test)

Even on the basis of these tests, we can conclude, that the 30-60 day corrosion tests may overestimate the aggressiveness of the water. If the water shows in a standard test significant effects of aggressiveness, we recommend to perform long-term measurements to examine these aggressive effects to confirm it or to modify the original test results.

With increasing exposure time during the corrosion tests increases also the sample surface, which is covered with thick corrosion layer. After one- year tests the thick corrosion layer covered in average 78% of the samples surfaces and after two-years tests up to 83% of the sample surfaces were covered with thick corrosion layer. These values are more than 2.5 times bigger than the 30-day test results and more than 1.5 times comparing with the 60-day tests. So far, the corrosion layer on samples after 60 days, 4 and 6 months exposition were documented with photo microscopic snapshots. In April will be the tests completed, that should demonstrate, how thickness of corrosion layer and its shape changes on samples from annual and biennial tests.

Although corrosion losses between the 30th and 60th day shows nearly a linear dependency and corrosion layer after two-years exposure was only poorly adhered on the samples surface, during the longer test the growth of corrosion losses and hence the corrosion rate was slowing down.

5. Acknowledgment

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