CORROSION TESTS AT THE WATER TREATMENT PLANT IN JAKUBANY

KORÓZNE SKÚŠKY NA ÚPRAVNÍ VODY JAKUBANY

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Abstract

External corrosion, which depends on environmental and operating conditions, is the main cause of structural deterioration of all metallic mains. Internal corrosion, on the other hand, can cause significant functional (hydraulic, water quality) deterioration within a distribution system. This work deals with the corrosion of water pipes which greatly affects the durability and failure rate of water systems. The test is evaluated in accordance with STN 75 7151 and ASTM D2688-11. The corrosion tests were carried out on raw and treated water at the water treatment plant in Jakubany.

Abstrakt

Hlavnou príčinou poškodenia konštrukcie všetkých kovových sietí je vonkajšia korózia, ktorá je závislá od prostredie a prevádzkových podmienok. Vnútorná korózia môže spôsobiť významné funkčné zhoršenie (hydraulické, kvalita vody) v rámci distribučného systému. Táto práca sa zaoberá koróziou vodovodného potrubia, ktorá výrazne ovplyvňuje odolnosť vodovodných systémov. Skúška je hodnotená v súlade s STN 75 7151 a ASTM D2688-11. Korózne testy boli vykonané na surovej a upravenej vode na úpravní vody Jakubany.

Key words: The corrosion, water treatment, incrustations, change in water quality

1 INTRODUCTION

A water supply system represents a complex mechanism which is affected by many factors. In terms of economy, it is also an exacting system whose service life is limited by the durability of used materials. The durability of materials has a significant impact on reliability of water supply systems and on the quality of supplied water for human consumption.

The majority of water supply systems were built in past when increasing water consumption was assumed. Therefore, the water supply systems are overdesigned. By decreasing the water consumption in overdesigned water supply systems, the extension of water retention period occurs and it may negatively affect the sensorial character of supplied water as well as result in microbial contamination.

The interaction between water and pipeline materials occurs during the transport of water in water supply network, which may lead to a decrease in water quality (Vreeburg 2007) [1]. Water supply operators (companies) often deal with this problem in water supply systems which consist of metal pipelines. In water supply systems, corrosion processes occur which have a negative impact on water quality (Munka 2005) [2]. The corrosion is mainly caused by electrochemical processes which are formed at the water and pipe material interface. The basis of all these reactions consists in oxidation-reduction (redox) reactions which lead to the degradation and depreciation of material (Slavíčková, 2006) [3].

Lytle et al. [4] found that metal levels rapidly increased with respect to stagnation time. High flow velocities can assist the formation of protective coatings by diffusing effectively protective ingredients to the metal surface. However, high flow velocities can mechanically remove the protective wall coating and pipe material, resulting in erosion corrosion or impingement attack. High flow velocities increase the rate, at which dissolved oxygen comes into contact with pipe surfaces, which can affect corrosion rates due to the involvement

of oxygen in the corrosion chemical reactions. Volk et al. [5] and Fang et al. [6] studied the effect of temperature on the corrosion of iron in water and clearly demonstrated that the corrosion increased as a function of temperature.

Many other authors who monitored the course of processes corrosive to water pipes made of iron came to the conclusion that corrosion is a major cause of colour changes in water piping [7],[8].
The negative effects of corrosion are mainly expressed by:

- Decreasing the water quality (by its secondary ferrization, decreasing the content of solved oxygen, leaching of lead, zinc, copper and other substances from armature into water),
- Deterioration of hydraulic conditions of water flow
- Reduction of pipeline service life
- Increase in number of disorders and water decrements of pipeline
- Increasing costs of water pumping (Singley et al, 1984) [9].

The corrosion of pipeline has a significant impact on water supply system reliability. Specifically, it is just a reliable and sustained drinking water supply system which represents the basic requirement for social and economic development of a certain area.

Corrosion costs encountered in the water distribution division included expenditure for replacing aging infrastructure, lost water from unaccounted-for leaks, corrosion inhibitors, internal mortar linings, external coatings, and cathodic protection (Devietti 2011) [10].

This study aimed at quantifying key water quality parameters, such as flow velocity, pH, biofilm growth, temperature, and evaluating the influence of these parameters on corrosion and iron release in a drinking water distribution system. The test is evaluated in accordance with STN 75 7151 and ASTM D2688-11. The corrosion tests were carried out on raw and treated waters at the water treatment plant in Jakubany.

2   WATER AGRESIVITY DETERMINATION

It is possible to determine whether the water has corrosive effects or not by using chemical water analyses through a direct $CaCO_3$ test, by means of various calculations or corrosion tests. Determining the water aggressivity based on chemical analyses represents some advantages, such as a relatively quick way of obtaining results, possibility of periodical testing, which means regular control of water quality. The changes in water quality and the results of the tests can be compared. On the other hand, the water aggressivity calculations count only the water agsressivity that is caused by aggressive CO_2, which represents a disadvantage described by many authors. No calculation takes into account the amount of dissolved oxygen in water or the velocity of flowing water which may represent two dominating factors in influencing the corrosion progress significantly.

The method for the corrosion test is mentioned in the standard STN 75 7151 "Requirements for quality of water in piping systems" [11] and is based on measuring differences in mass decrease of tested samples on the 30th and 60th day after their exposition to the effects of flowing water. For the tests, 42x42 mm coupons with a thickness of 1 mm are used.

From the obtained results of corrosion decrement, corrosion velocities are calculated. The velocities show the reduction in pipe wall thickness. If it is necessary to determine the corrosion type in addition to the corrosion decrement, the time period of the test is prolonged to one year. The advantage of this test lies in the effect of water on testing samples which is as complex as the effect of water on the pipeline. The impact of dissolved oxygen in water may occur and be denoted as the dominating factor causing the corrosion or as the positive factor causing the passivation of metal by forming a layer with a good protective properties which separates the transported water from the pipeline surface (Dubová et al, 2010) [12].

From the decrement of testing coupons, the corrosion velocity was determined according to the formulas of STN 75 7151:

Average corrosion decrement (g.m^{-2}) is calculated as an arithmetic average of 5 testing coupons fixed in one coupon holder according to the following formula:

$$K' = \frac{1}{n} \sum_{i=1}^{n} K_i$$

(1)

The calculation of corrosion decrements of particular samples in g·m^{-2}:

$$K = \frac{m_1 - m_2}{s}$$

(2)

Where:

m_1 – weight before exposition $\left[\dfrac{g}{m^2}\right]$,

m_2 – sample weight after exposition $\left[\dfrac{g}{m^2}\right]$,

S – sample surface $[m^2]$.

The calculation of corrosion decrements, U_t, in μm during exposition:

$$U_t = \frac{1}{7.86}.\left(\bar{K} - K'\right) \tag{3}$$

Where:

$\bar{K}$ - average of corrosion decrements of 5 samples $\left[\dfrac{g}{m^2}\right]$,

K' - decrement of sample during the blank sample test, which is performed for controlling the possibility of testing samples dissolution in removal process of corrosion waste products in HCL, $\left[\dfrac{g}{m^2}\right]$,

7.86 - specific weight of steel $\left[\dfrac{g}{cm^3}\right]$,

The calculation of corrosion velocity, v_u, in μm in 1 year time period:

$$v_u = \frac{365.(U_{t2} - U_{t1})}{t_2 - t_1} \tag{4}$$

Where:

t_1 – shorter exposition time of sample [d],

t_2 – longer exposition time of sample [d],

Ut_1 – corrosion decrement of sample in shorter exposition time [μm],

Ut_2 - corrosion decrement of sample in longer exposition time [μm].

Based on the corrosion test results obtained between the 30th and 60th day, the water is classified by the aggressivity level depending on the corrosion velocity in μm for 1 year as shown in Tab. 1.

Tab. 1 Water aggressivity level classification according to corrosion velocity [11].

Aggressivity level	Corrosion velocity v_t [μm.year^{-1}]	Classification
I	<50	moderately aggressive
II	50 until 150	medium aggressive
III	>150	strongly aggressive

The water is classified according to the aggressivity levels into three following categories:

    I. No anti-corrosion precaution required

    II. Considered individually; the decision about anti-corrosion actions is made with regard to required pipeline service life and based on the results of technical and economic analyses

    III. Anti-corrosion actions must be provided with regard to required pipeline service life

As the next equipment for classification of aggressive properties of transported water, an ASTM D2688-11 [13] device was used, in which the testing coupons were installed. The coupon size was 74x9 mm and the thickness 1 mm. The corrosion velocity was calculated according to the following relations.

The calculation of corrosion decrements of particular samples in mg:

$$W = W_i - W_f \tag{5}$$

Where:

W_i – sample weight before exposition [mg],

W_f – sample weight after exposition [mg].

The obtained weight values are put into the calculation of corrosion velocity:

$$KR = \frac{\Delta m}{\Delta t}.factor \qquad (6)$$

Where:

Δm – determined decrement of weight [mg],

Δt – onset period of coupon [day],

factor – 0.025 (for steel of class 11).

3 CORROSION TEST AT THE WTP JAKUBANY

The corrosion tests were performed in cooperation with the company PVPS, a.s. (Podtatranská Water Operating Company) at the water treatment plant (WTP) in Jakubany, a village in the Stará Ľubovňa District (Fig. 1). Raw water for treatment is sampled directly from the Jakubianka brook and is transported by gravity through a DN 500 pipeline to the water treatment plant. The treatment plant is capable to produce 150 liters per second. Currently, the production is about 60 liters per second. The water treatment technology at the Jakubany treatment plant varies according to season. Over the winter, the brook water quality is at a very high level and the detritus tank is weaned because of ice-cover formation and the only treatment of water by using pressure filters is provided.
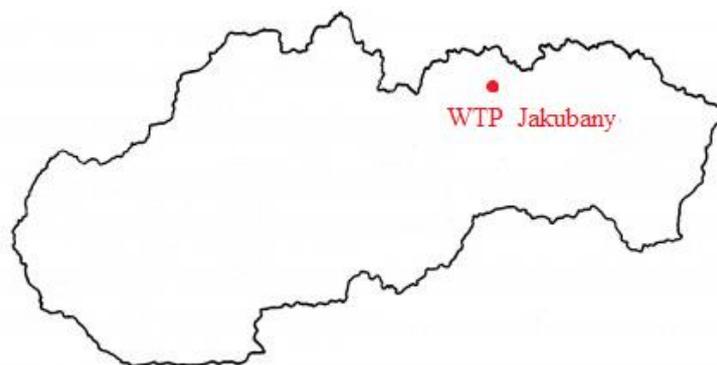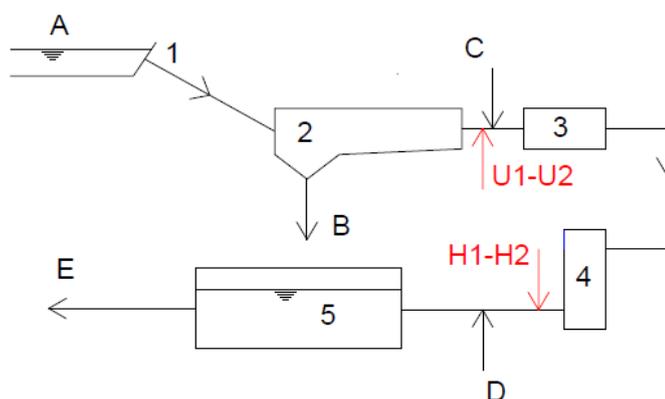

Fig. 1 WTP in Jakubany.

The treatment process at the WTP in Jakubany is chosen with regard to the quality of water input. Therefore, the processes used at the WTP in Jakubany include mechanical precleaning, simple sedimentation and consequent 1-step coagulative filtration which is used only in case of impaired raw water quality. In case of need, aluminium sulphate, a coagulation reagent, is added to pressure mixing tanks and the consequently formed flocks are removed by means of pressure sand filters.

Health safety of filtered water is ensured by gaseous chlorine, or by chloramination, which is accumulated in a tank with a capacity of 2500 m³. The water is transported from the tank through gravity pipes to the consumption area.

This work consists in long-time monitoring of corrosion in the water supply pipeline. Measurements were performed from 11ᵗʰ May 2013 to 12ᵗʰ May 2014. Two devices for monitoring the corrosion velocity were used in order to make the operational classification of aggressive character of water. Testing coupons (according to STN) were used for tests performed on one of the devices and coupons according to ASTM were used for the tests on the other one. These devices were placed into a raw water intake location of the WTP, downstream the pressure filters and upstream the disinfection (Fig. 2).

Fig. 2 Technological scheme of WTP in Jakubany

A – Jakubianka water source, B – draining of settled sludge, C – aluminium sulphate dosing, D – water disinfection, E – conduit to water storage, U1,H1 – corrosion equipment according to STN, U2, H2 – corrosion equipment according to ASTM, 1 – sampling object, 2 – sedimentation tank, 3 – pressure mixing tank, 4 – pressure sand filter, 5 – accumulation tank

The water quality was monitored also during the change of testing coupons in corrosion devices. In terms of chemical changes, the quality of water at the WTP in Jakubany did not change significantly. The quality values were: pH 7.22-8.32, temperate 0.2 – 17 $^{\circ}$C, $KNK_{4,5}$ 1.4-2.2 mmol.l^{-1}, ZNK4,5 below 0.06 mmol.l^{-1}, Fe 0.008-0.067 mg. l^{-1}, Mn below 0.01 mg. l^{-1}, Ca^{2+} 28.1-40.5 mg.l^{-1}. Turbidness of raw water was observed in a range of 0.00-1.60 ZF. Fig. 3 shows the temperature progress during the measurement. The average year temperature was 7.6 °C.
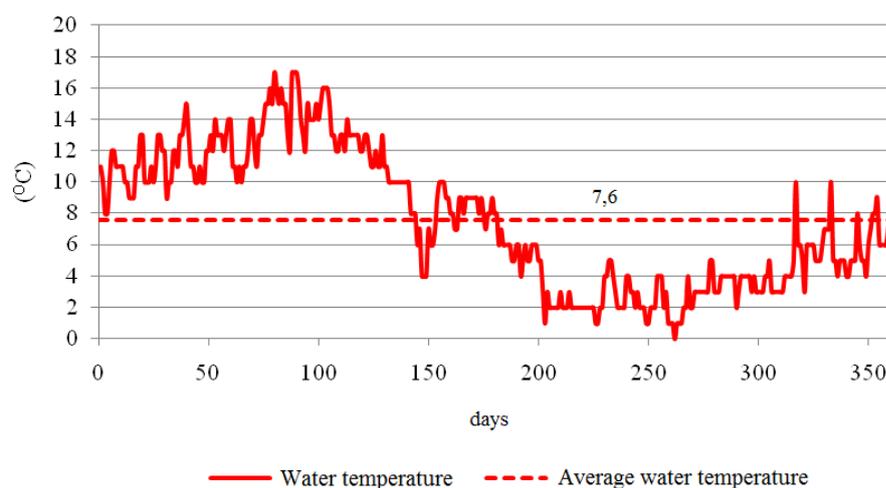

Fig. 3 Water temperature progress in a period of 11.5.2013 - 12.5.2014

4   RESULTS

4.1 Results according to STN

From the performed measurements, it is obvious that the progress of corrosion velocities of raw water and treated water is a bit different. Fig. 4 shows the consideration of corrosion velocities between 30 and 60 days of measuring. Due to these standardized results, the water is classified into I and II aggressivity levels. During the first two tests (5/13 and 6/13), the corrosion velocity of raw water showed a higher value as it was in case of using the water that passed the treatment process. This was probably induced by a water flow decrease (down to stopping) through the corrosion equipment, which was caused by strong storm-related turbidity. During the 5th and 9th tests, the corrosion velocity also increased.

In case of seven tests, the corrosion velocity of water that passed the treatment process was higher than the velocity of raw water which might be caused by a higher flowing velocity, disinfection reagent (gaseous chlorine), using which the pre-disinfection before the filter is provided, or which might be caused by coagulant (aluminium sulphate).
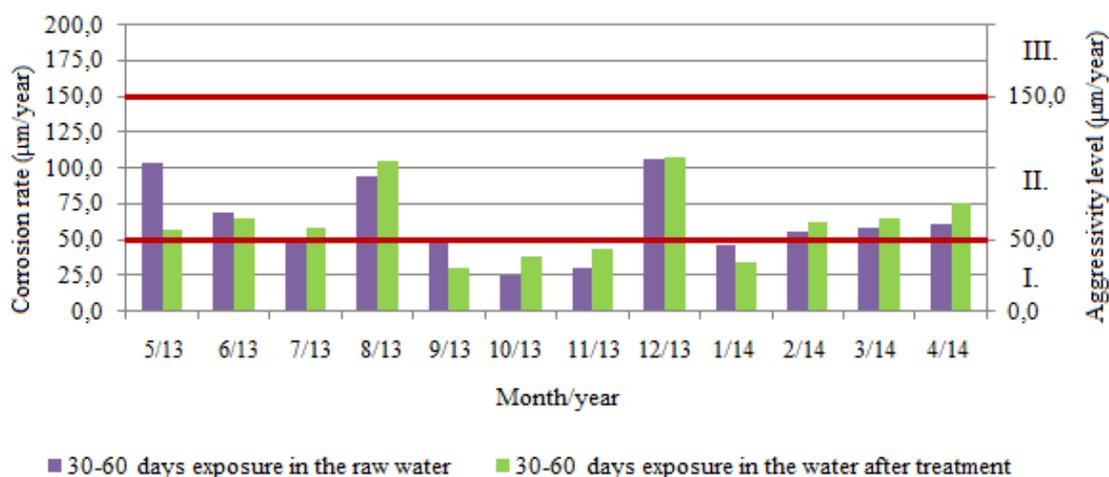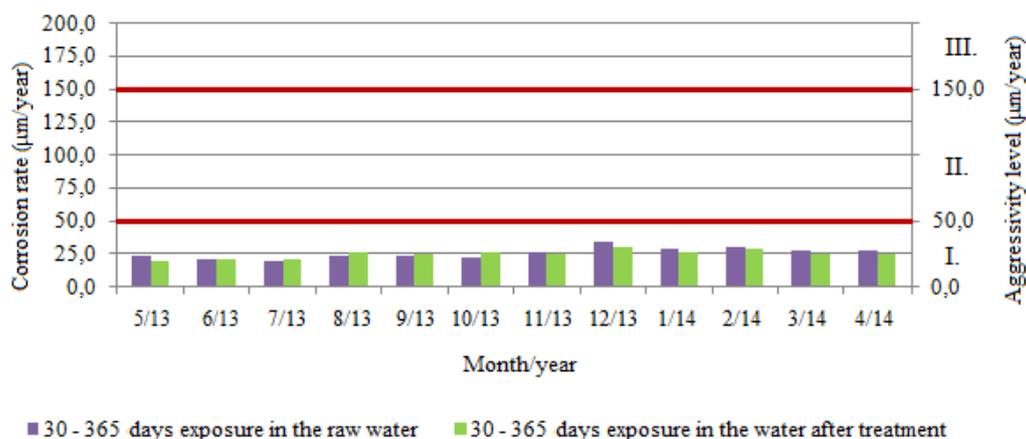
Fig. 4 Consideration of corrosion velocities of raw water and water which passed treatment after 30-60 days of measurements
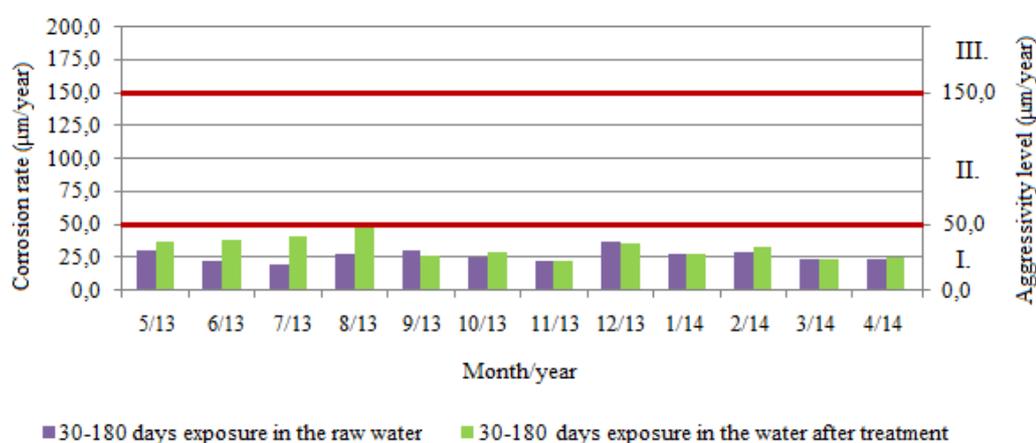
Fig. 5 Comparison of corrosion velocities of raw water and water after treatment during 30-80 days of measurements

Fig. 5 shows the comparison of corrosion velocities when using the raw water and the water after treatment during 30-180 days of measurements. The results refer to the linear progress of corrosion velocity, just in case of water after treatment tests numbered 5/13-8/13 when a moderate increase is presented. In comparison with standardized 30-60 days of measurement, the lower corrosion velocity of water classifies the aggressivity to level I.

Fig. 6 Comparison of corrosion velocities of raw water and water after treatment during the 30-365 days of measurements

The progress of corrosion velocities of raw water and water after treatment during 30-365 days of experiment/measurements is shown in Fig. 6. With regard to the annual results of corrosion velocities, the water

is classified into the aggressivity level I which represents the lowest value in comparison with the measurements during 30-60 and 30-180 days. The comparison of corrosion velocities for 30-60 days of measurements of raw water and water after treatment after filtration with a change in water temperature during the monitoring period is shown in Fig. 7.
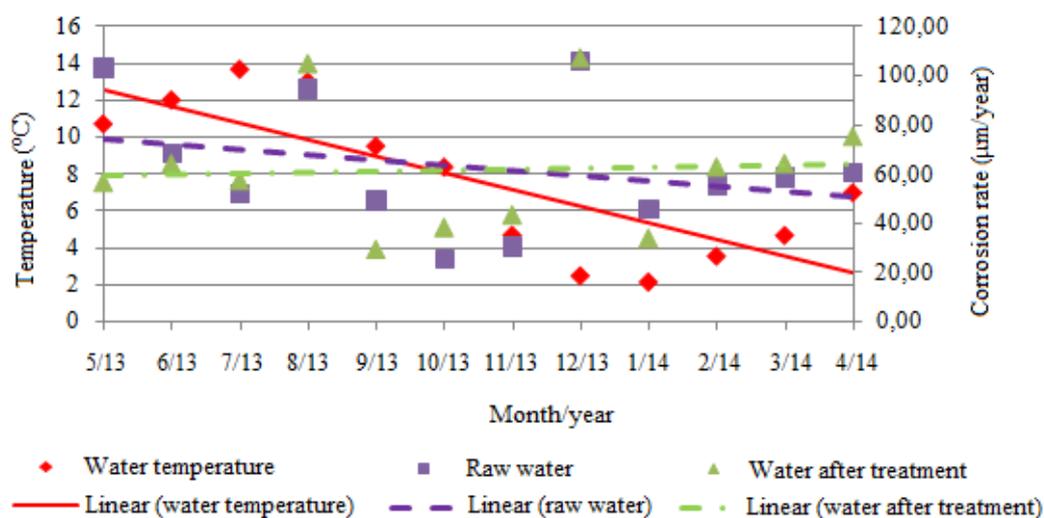
Fig. 7 Corrosion velocities of raw water and water after treatment after filtration during 30-60 days of measurements in comparison with temperature progress

The estimations of service life of pipeline were calculated from the obtained results (annual exposition) for raw water and water after treatment. The service life estimations are listed in Tab. 2. In the tests performed with raw water, the value of estimated service life fell within a range of 14.57-19.50 μm.year^{-1} (annual average of 16.57 μm.year^{-1}), and with water after treatment, after filtration 14.54-23.52 μm.year^{-1} (annual average of 19.19 μm.year^{-1}).

Tab. 2 Estimation of service life of pipeline

| Period of corrosion tests	Estimation of service life of pipeline $v_{u(\check{z})}$ (μm/year)	
	Raw water	Water after treatment
11.5.-10.7.2013	14,74	14,54
10.7.-8.9.2013	14,57	16,18
8.9.-7.11.2013	19,50	22,26
7.11.2013-6.1.2014	17,41	20,59
6.1.-7.3.2014	18,39	23,52
7.3.-12.5.2014	14,81	18,03

According to our results, it is obvious that the aggressivity of water was changing over the testing period. A significant variation of velocities mainly occurred during 30-60 days of measurement. Short-time measurements showed much higher aggressivity of water than it was in case of long-time measurements. Therefore, it is necessary to perform measurements for a longer time in order to obtain more exact results or support the short-time measurement results. The corrosion velocities within 30-180 days of measurements of raw water had almost linear progress, while the measurements of water after treatment decreased moderately. In case of 30 – 365 days of measurement, both water types reflected linear progress of their corrosion velocities. Therefore, it may be asserted that the short-time (30-60 days) measurements may overvaluate the water aggressivity.

The impact of a change in water temperature was found mainly within short-time standardized measurements (60 days), while during long-time (30-180, 30-365 days) measurements, the variation of corrosion velocities was not significant.

4.2 Results according to ASTM

The corrosion test assemblies and corrosion specimens employed in the study were prepared according to the ASTM D2688-11 standard "Test Method for Corrosivity of Water in the Absence of Heat Transfer" (Weight Loss Method). This test method covers the determination of water corrosivity by evaluating pitting and by measuring a weight loss of metal specimens. Pitting is a form of localized corrosion: the weight loss is a measure of the average corrosion rate. The rate of corrosion of a metal immersed in water is a function of the tendency of the metal to corrode and is also a function of the tendency of water and materials contained to promote (or inhibit) corrosion. The test method employs flat, rectangular-shaped metal coupons which are mounted on pipe plugs and exposed to water flowing in metal piping in municipal, building, and industrial water systems using a side stream corrosion specimen rack [13].

The comparison of corrosion velocities in testing raw water and water after treatment during the 30-day experiment is shown in Fig. 8. The corrosion velocity is higher in the raw water experiment. In comparison with the 60-day experiment, the corrosion velocities were lower in the short-time 30-day experiment (Fig. 9).
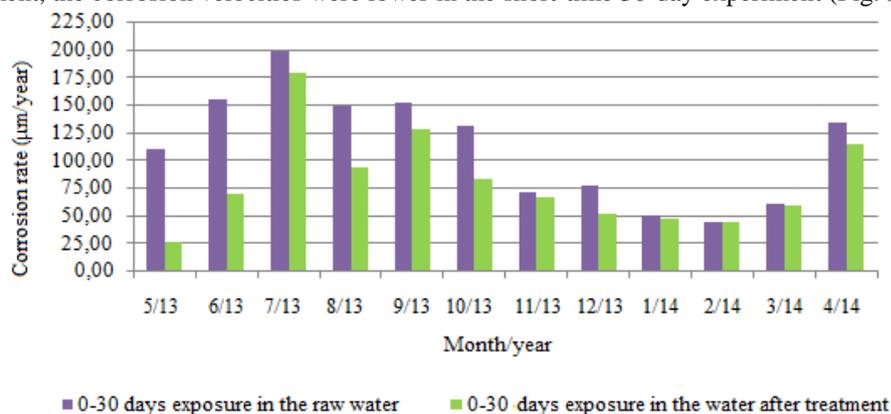
Fig. 8 Comparison of corrosion velocities for raw water and water after treatment during 30-day experiment/measurements
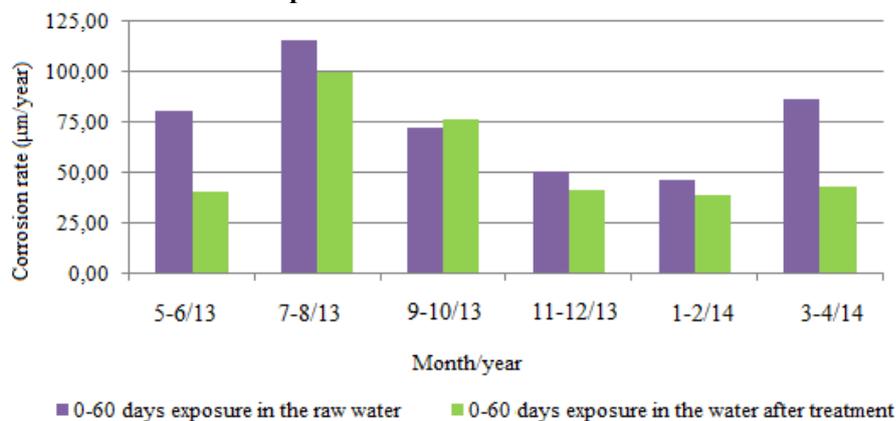
Fig. 9 Comparison of corrosion velocities for raw water and water after treatment during 60-day measurements

The comparison of corrosion velocities of 30-day measurement (Fig. 10) and 60-day measurement for both type of water with water temperature pointed out the impact of temperature on water aggressivity. Following the comparison of corrosion velocities, it may be asserted that the raw water seems to be more aggressive than the water after treatment. In the case of 60-day measurements, the corrosion velocities decreased twice compared to normal (Fig. 11).
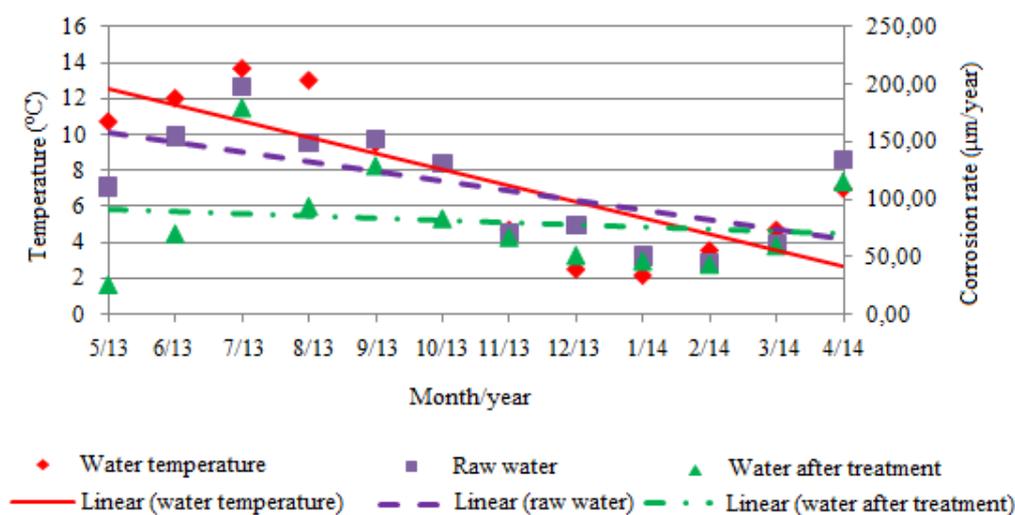
Fig. 10 Corrosion velocities after 30-days of measurements for raw water and water after treatment after filtration in comparison with water temperature progress
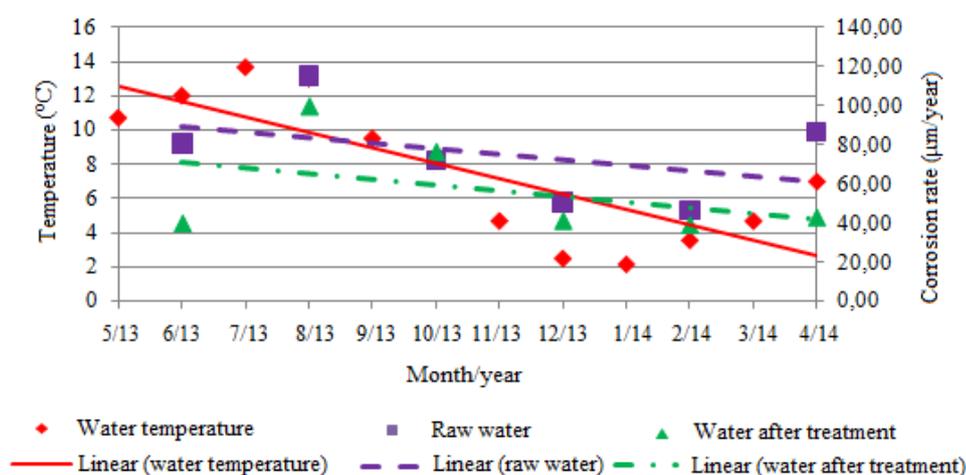

Fig. 11 Corrosion velocities after 60-days of measurements for raw water and water after treatment after filtration in comparison with water temperature progress

5 DISCUSSION

According to the STN 75 7151 and ASTM D2688-11 results, the difference between short-time measurements is obvious. But long-time (annual) measurements show almost similar corrosion velocities. A higher average corrosion velocity in the raw water tests than in the tests for water after treatment (water after filtration) was observed in both types of measurements. From the temperature change progress over the seasons, it is obvious that the change in temperature of flowing water through the testing corrosion devices influenced the corrosion progress of tested samples. The most significant impact of water on corrosion was observed within short-time measurements (30-60 days), while in half-year and annual measurements the impact was minimal.

Annual measurement results refer to the possibility to classify the water (both types, raw water and water after treatment after filtration) as the water of the first aggressivity level (moderately aggressive water – corrosion velocities to 50 $\mu m.year^{-1}$). The type of corrosion was determined based on annual testing coupons. In case of raw water, surface area corrosion and sporadically point corrosion prevailed, while in case of water after treatment, more significant point corrosion in combination with fewer area corrosion prevailed. The estimation of service life of pipeline system was calculated by using the annual test results. The annual average of service life estimations was 16.57 $\mu m.year^{-1}$ for raw water and 19.18 $\mu m.year^{-1}$ for water after treatment (after filtration).

6 CONCLUSIONS

Iron corrosion is an extremely complex process. Because of the large variability in distribution system conditions, a particular factor may by critical in one system but relatively unimportant in another system. Iron pipe corrosion is extremely complicated and is affected by practically every physical, chemical, and biological

parameter in water distribution systems. Because distribution system pipes are in place for long periods of time (> 50 years), corrosion control is critical to maintain microbial, water quality and pipe integrity.

This work consists in long-time monitoring of corrosion in the water supply pipeline. It showed that corrosion rates were strongly related to water temperature (and/or other seasonal factors). According to the obtained results of corrosion velocities, it is obvious that water aggressivity varied over the monitored period of time. The results obtained from annual monitoring of water aggressivity point out a decrease in corrosion velocity in long-time tests in comparison with short-time tests for both types of water. This implies that further arrangements for decreasing the corrosion formation of pipeline system are not required.

Acknowledgement

REFERENCES

[1] VREEBURG, J.,H.,G., *Discolouration in Drinking Water Systems: A Particular Approach*. Department of Water Management. Delft, Delft University of Technology, The Netherlands, 2007, ISBN 978-90-74741-91-0

[2] MUNKA, K., KARÁCSONYOVÁ, M., GAJDOŠ, Ľ., *Poloprevádzkové hodnotenie vplyvu kvality vody na vybrané materiály prichádzajúce do styku s pitnou vodou*. In: Voda Zlín 2005. Sborník příspěvků IX. mezinárodní vodohospodářské konference. Zlín, 7.-8.4.2005. Zlín: Zlínská vodárenská, a.s., 2005. s. 85-90. ISBN 80-239-4453-3

[3] SLAVÍČKOVÁ, K., *Meření a hodnocení rychlosti koroze při procesu úpravy vody*, In: Zborník príspevkov X. Medzinárodnej vodohospodárskej konferencie, Voda Zlín 2006, s. 143-148. ISBN 80-239-6523-9

[4] LYTLE, D. A., SCHOCK, M. R., *Impact of Stagnation Time on Metal Dissolution from Plumbing Materials in Drinking Water*. Journal of water supply research and technology, 2000, AQUA 49(5):243-257.

[5] VOLK, CH., DUNDORE, E., SCHIERMANN, J., LECHEVALLIER, M., *Practical evaluation of iron corrosion control in a drinking water distribution system*, Water Research, Volume 34, No.6., Elsevier Science Ltd, 2000, s. 1967-1974, ISSN 0043-1354(99)00342-5

[6] FANG, C. S., LIU, B., (2003). *Hydrodynamic and temperature effects on the flow induced local corrosion rate in pipelines*, Chemical Engineering Communications, Vol. 190, s. 1249-1266, ISSN 0098-6445

[7] SMITH, S.E., BISSET, A., COLBOURNE, J.S., HOLT, D.M., LLOYD, B.J., 1997. *The occurrence and significance of particles and deposits in a drinking water distribution system*. Journal of the New England Water Works Association, 1997, Vol. 111 (2), 135-150

[8] MCNEILL, L.S., EDWARDS, M., 2001. *Iron pipe corrosion in distribution system*, Journal – American Water Works Association, July 2001, s 88-100,

[9] SINGLEY, J.,E., BEAUDET, B.,A., MARKEY, P.,H., *Corrosion Manual for Internal Corrosion of Water Distribution System*, Environmental Science and engineering, INC., Florida, 1984, ESE No. 81-227-260

[10] DEVIETTI, J.,L., *Modelling water quality in tropical water distribution systems*. PhD thesis, James Cook University, 2011

[11] STN 75 7151 Kvalita vody. Požiadavky na kvalitu vody dopravovanej potrubím

[12] DUBOVÁ, V., ILAVSKÝ, J., BARLOKOVÁ, D., *Sledovanie agresivity vody na VZ Pernek*, Konferencia vodohospodárov v priemysle, Liptovský Ján, 2010, s. 217-224, ISBN 978-80-227-3393-6

[13] ASTM D2688-11 „Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer" (Weight Loss Method)