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APPLICATION OF CORROSION PLATES IN DRINKING WATER

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Abstract. Drinking water has always been, is and will be a strategic raw material. Stopping corrosion or at least minimisation of its impact while keeping quality drinking water supplies is a big challenge for the future. That is why the corrosion monitoring in the drinking water pipe system is one of the essentials for dealing with the issue.

Areas of South Bohemia that were fitted with corrosion coupons and subsequently evaluated by the aggressiveness of water were chosen as examples for the study. The corrosion rate was monitored in drinking water during 35 and 82-day exposures. It was found that water in this part of the distribution system has the II. degree of the distribution system, i. e. medium. The evaluation of the corrosion rates also corresponds with the evaluation of the corrosion type using the Matlab. The impact of the corrosion plates on the general corrosion is slightly above 50 %. The occurrence of the pitting corrosion during such short disposure to a flowing drinking water in the pipeline is also significant.

Keywords: corrosion; drinking water; water distribution system; pipe; small metal plate.

1. Introduction

These days, drinking water and corrosion are worldwide discussed issues not only in the science field. The modern human can hardly imagine few hours without an unlimited access to a drinking water, let alone a day or a week. Corrosion causes significant daily financial losses. They are costs connected to maintenance, reconstruction or total equipment renewal in the automotive, shipbuilding, engineering and aerospace industries and in the rail transport [1, 2].

When we combine the two phenomena into one, we will get the important issue of these days — the corrosion within the drinking water distribution system. It may look like an easy matter, which has been solved long ago. The opposite is true. We need to realize that this is a form of food distribution, which must meet the strictest hygiene requirements and have all the qualitative characteristics.

Corrosion monitoring is a diagnostic tool, which collects information to solve the corrosion problems. There is no such monitoring method that provides all necessary data for a factual evaluation of the effectiveness of the water treatment process. The choice depends on the usability in the system and on the expected results. Some of the monitoring setups provide results immediately applicable in practice, other informs about the corrosion rate, or about the overall corrosion. The coupon test is an example of the direct way.

Quality of the water in the distribution network can vary depending on the speed of the delivered water, on the type and the delivery of the disinfectant, on the delay in the network, water temperature, pH and other significant influences.

A non-negligible factor is, of course, the selected material, which distributes the water, including its surface finish. It must not only meet the hygiene requirements for a contact with drinking water but also to be resistant to the external (stray currents, external pressures, temperature, . . .) and internal (chemical composition of water, speed, pressure, . . .) environment.

Drinking water has always been, is and will be a strategic raw material. Stopping corrosion or at least minimisation of its impact while keeping quality drinking water supplies is a big challenge for the future. That is why the corrosion monitoring in the drinking water pipe system is one of the essentials for dealing with the issue.

2. Literature survey

The degradation of the quality of treated water in the distribution networks can take place at different rates depending on the composition of the transported water, the type and the supply of the disinfectant, the retention time of water in the network or the temperature depending on the season. A similar paper discusses the corrosion and scaling potential of the Tabriz drinking water distribution system in Northwest of Iran. The aim of this study was to determine the corrosion and scaling potential in the potable water distribution system of Tabriz during the spring and summer in 2011. Methods: This study was carried out using Langlier Saturation Index, Ryznar Stability Index, Puckorius Scaling Index, and Aggressiveness indices. Eighty samples were taken from all over the city within two seasons, spring and summer. By a survey of corrosion indices, it was found that Tabriz drinking water is corrosive [5]. Radiography (neutron, gamma, X-ray) has long been used as a technique for pipe inspection and corrosion monitoring [4]. But the use of this method is still too expensive in drinking

Figure 1. Four testing plates mounted in a holder and prepared to be put into the pipeline

water conditions. For example, in the article: In-pipe water quality monitoring in water supply systems under steady and unsteady state flow conditions: A quantitative assessment, the study demonstrates:

- the significant impact of the unsteady-state hydraulic conditions on the disinfectant residual, turbidity and colour caused by the re-suspension of sediments, scouring of biofilms and tubercles from the pipe and increased mixing, and the need for further experimental research to investigate these interactions;
- important advances in sensor technologies, which provide unique opportunities to study both the dynamic hydraulic conditions and water quality changes in operational systems [2]. A study biofilm demonstrated that, compared to a sterile water, the existence of the biofilm in a reclaimed water promoted the corrosion process significantly. The results demonstrated that the corrosion process was influenced by the settled bacteria, EPS, and corrosion products in the biofilm comprehensively. But, the corrosion mechanisms were different with respect to time [5].

Aggression causes an erosion of pipe materials, facilities and equipment, namely corrosion, it is a violation of materials produced by the interaction of materials and the environment. It will create an inlay or an adhesive layer of solids excluded from water. When distributing the treated water, the quality changes due to chemical, physico-chemical and biological processes. This occurs both in the directly conveyed drinking water and in the interaction with the changes on the walls of pipes, reservoirs and fittings.

Evaluating the aggressiveness is also covered by an article by A.M.Shams El Din and directs attention to three practical strategies. The theoretical background of the three strategies is described in short and is referred to in terms of indices: the Hardness Index, Oxygen Index and Corrosion Index. The advantages and drawbacks of each strategy are mentioned [6]. Corrosion in a distribution system: Steady water and its composition proves the existence of a layer of steady water surrounding and partly filling corrosion scale in corroded water pipes. Steady water is rich in ions and has reductive properties that cause quick disappearance of nitrates and unwanted ammonia formation [7]. The drinking water quality is one of the basic prerequisites of the modern society. That is the reason why the extraordinary attention is paid to both drinking water resources and crude water treatment.

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3. Procedure

This test is based on the long-term exposure of coupons from defined materials to the floating water. It is suitable for an evaluation of the initial corrosion, because the surface of the metal is "active" due to the surface adjustment. According to the TNV 75 71 21 coupons, made from carbon steel with the dimensions 42×42 mm and 1 mm in thickness with non corroded surface, were used. The commonly used exposure time for little corrosive waters is 30 days. Exposure time lesser than 30 days can lead to misconceptions. A longer test time is usually required — up to 90 days. During this testing period, 3 sets of coupons are being placed into the holder and are changed after 30, 60 and 90 days [3]. The longer is the exposure time the lower is the measured average corrosion rate and the more the coupons reflects the conditions in the system.

The essence lies in studying the corrosion in the drinking water distribution system. To monitor the corrosion rate, testing plates were used in a pipeline with an unaltered water flow. The detailed description is described at the standard TNV75 71 21 — Requirements for water quality transported in the pipeline [4, 5].

The standard includes the unified, binding, methodical procedure for both experimental corrosion tests and also for their final evaluation.

At the beginning the steel plates from carbon steel are weighed accurate to the nearest 0.0005 g and are fastened to the holder by 4 pieces (Figure 1).

Holders with testing plates are then installed at the prepared place of the distribution system (Figure 2).

During the testing, the flow is measured and written down into the records. At the same time, the temperature at the tributary is measured and the free chlorine concentration is determined. During the mounting and removal of the coupons (Figure 3) the chemical values were measured by portable meter Hach HQ40d

Figure 2. Placement of the plates

Figure 3. Removal of the plates after the required exposure time

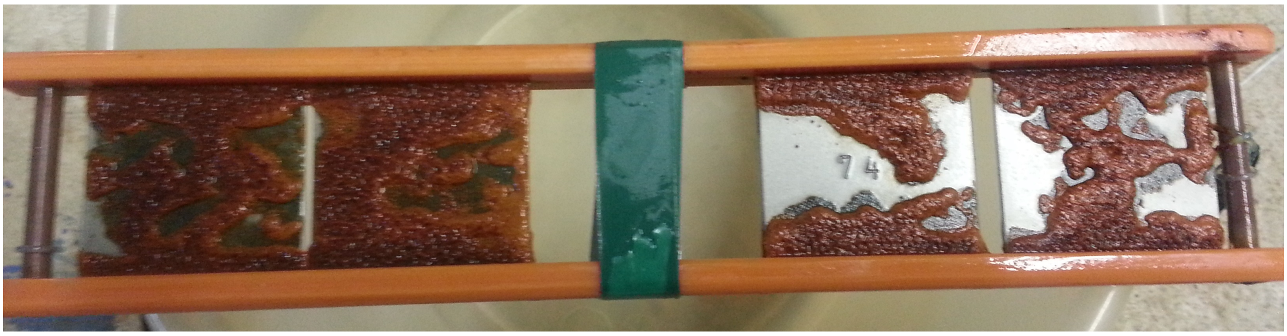

Figure 4. Testing plates after extraction from the pipeline

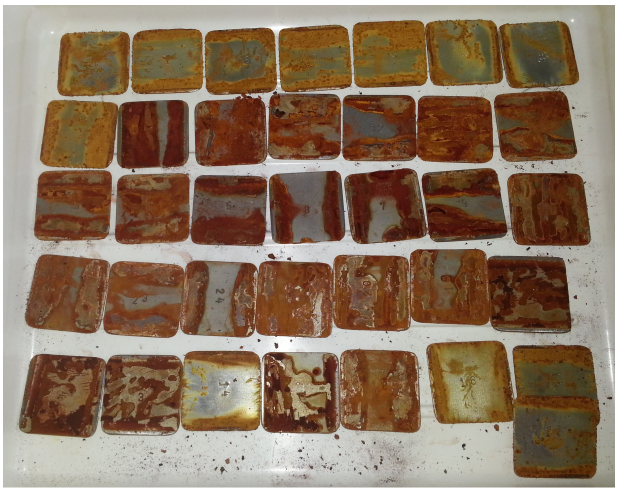

Figure 5. Coupons before staining in hydrochloric acid

Figure 6. Coupon after exposure

portable (pH, conductivity, temperature and the dissolved oxygen content) and portable chlorine meter EUTECH INSTRUMENTS Colorimeters C401 (free active chlorine and total active chlorine).

After the required time, the plates with an inlay are removed (Figure 4), dried (THE LAB DRYING ROOM KBC G 100/250) and placed to the desiccator.

The plates are then weighed including the loose incrustation (incrustation in the water pipeline system rises by corrosion of the pipe material of insoluble corrosion products on the pipe walls, precipitation and crystallization of insoluble compounds on the pipe walls, or by coagulation of particles present in the water on the pipe walls [11]) accurate to the nearest 0.0005 g. The incrustation is removed from the plates (Figure 5) and the plates are again weighted accurate to the nearest 0.0005 g (Figure 6). The incrustation removal is carried out by staining in a solution of hydrochloric acid followed by rinsing with both distilled water and ethanol and drying with hot air.

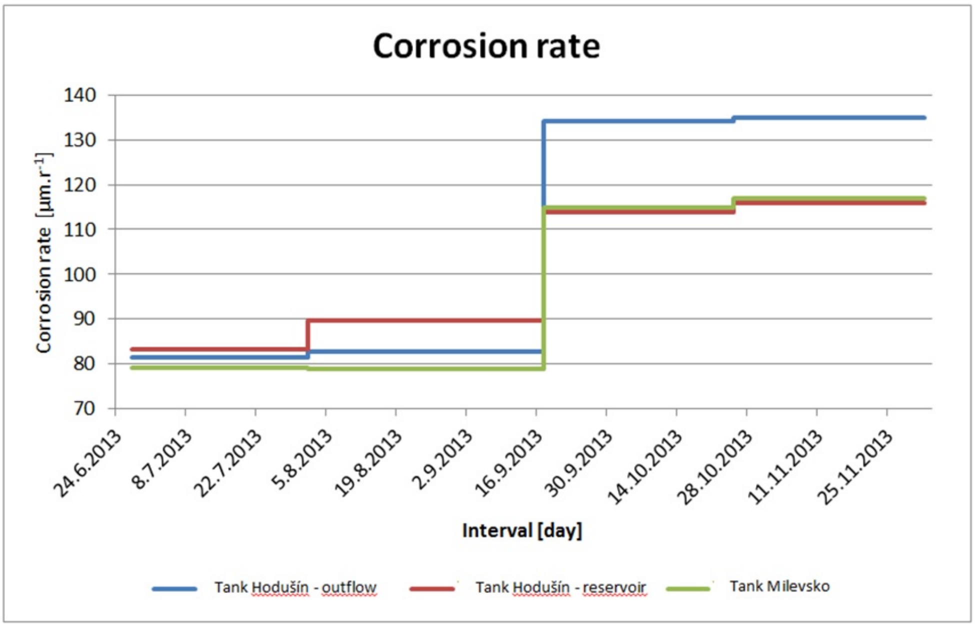

Figure 7. Corrosion rate evaluations according to consecutive intervals — June 25th–September 17 2013 (0–82 days) and September 17th–December 2nd 2013 (0–76 days)

The corrosion loss was reported from the measured values (1), the amount of the corrosion products captured on the plates (2), the corrosion rate was calculated (3) and the weight of the incrustation captured on the plates (4) [4].

For the evaluation of the aggressiveness of the tested water, the values of the average corrosion rate v_u, from the four determinations for each exposure interval between 30th and 60th day of the test with the carbon steel coupons (each having an exposed area of 37 cm^2), were used. Based on the corrosion rate, a data classification into one of the three degrees of aggressiveness is made according to the classification chart.

The results are expressed by the dimensional corrosion rate v_u [µm year^{-1}] calculated from the weight corrosion losses k [g m^{-2}] [4].

The corrosion rates are evaluated from the plate weight losses according to these relationships [6]. Corrosion loss (U_t):

$$U_t = \frac{1}{7.86}(k - k_0)\ [\mu\text{m}], \tag{1}$$

where k – the average value of corrosive discharges [g m^{-2}]; k_0 – corrosion loss of plates during a blind test [g m^{-2}]; 7.86 – density of steel [g cm^{-3}].

Corrosion loss of individual plates (k):

$$k = \frac{(m_0 - m_t)}{S}, \tag{2}$$

where k – plate corrosion loss [g m^{-2}]; m_0 – weight of the plate before the exposure [g]; m_t – weight of the plate after exposure and after incrustation removal [g]; S – the total surface area of the plate before the exposure.

Corrosion rate (v_u):

$$v_u = \frac{365(U_{t_2} - U_{t_1})}{t_2 - t_1}, \tag{3}$$

where v_u – corrosion rate in [µm year^{-1}]; t_1 – shorter exposure time [d]; t_2 – longer exposure time [d]; U_{t_1} – corrosion plate loss in the shorter exposure time [µm]; U_{t_2} – corrosion plate loss in the longer exposure time [µm].

Weight of the incrustation captured on the plates [m]:

$$m = (m_i - m_t), \tag{4}$$

where m – incrustation weight [g]; m_i – weight of the plate including incrustation [g]; m_t – weight of the plate after the exposure after removing the incrustation [g].

4. Evaluation of corrosion

Steel plates are exposed to the environment while installed and the pitting corrosion occurs. Based on the standard TNV 75 7121 Requirements for quality of water transported by pipeline, we determined the corrosion rate by calculating coupons' weight difference before and after the installation in the pipeline. However, we are not able to determine whether it is a general corrosion or pitting corrosion unless we use the sensory evaluation of the impact. For this evaluation, the Matlab software method was chosen.

4.1. Matlab

The Matlab programming language is an integrated environment designed for science-technical purposes, simulation, parallel computing and so on. It includes calculations, visualization and programming in a user-friendly environment. Problems and solutions are

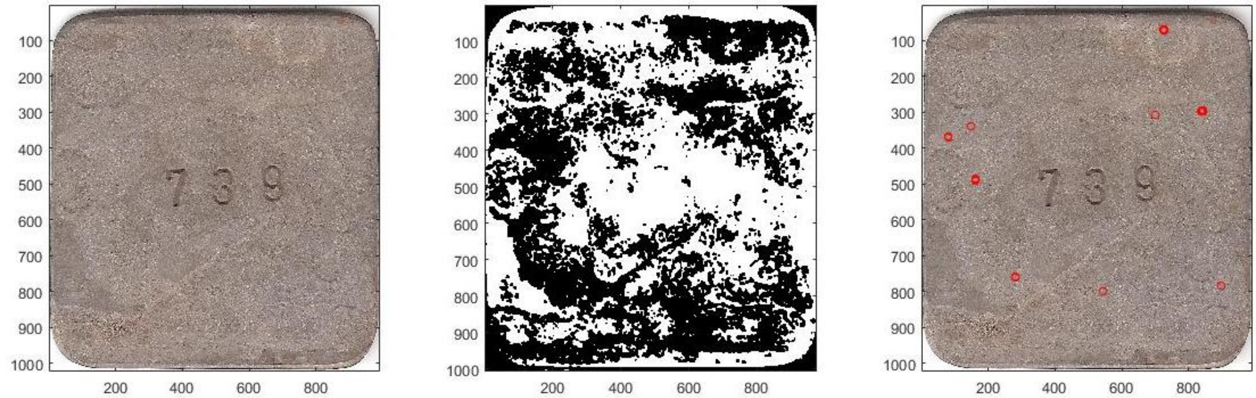

Figure 8. Graphic evaluation of the corrosion coupon using the Matlab software – coupon 739a. Areas evaluated as pitting corrosion are marked with a red colour

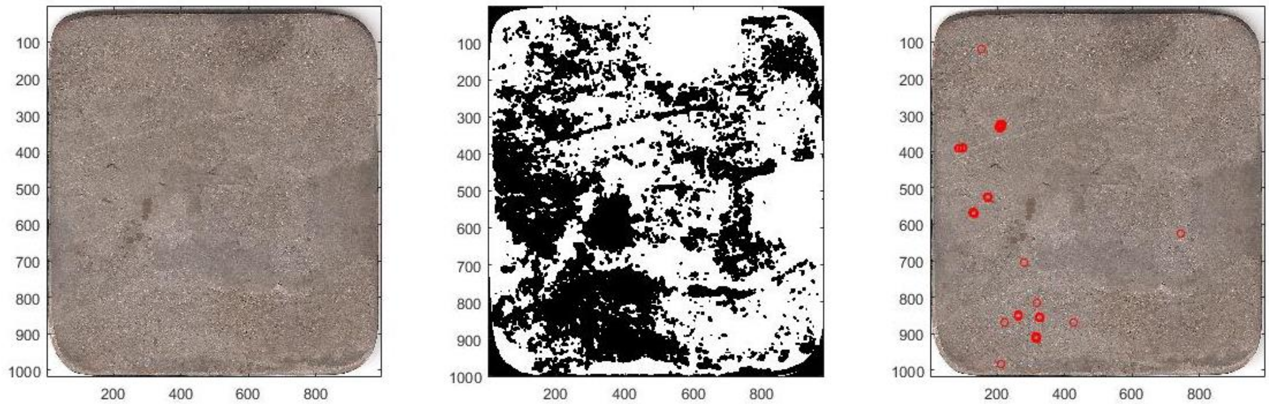

Figure 9. Graphical evaluation of the corrosion coupon using the Matlab — coupon 739b

most often expressed by known mathematical relationships. All the objects in Matlab are field elements (matrix). These elements can be not only numbers or variables but also more complicated structures such as Pictures [12].

4.2. Procedure and principal of transfer

To determine the impact of the general corrosion and pitting corrosion on the steel plate using Matlab, it is first necessary to convert coupons into an electronic form. We choose a scan transfer. For this purpose, we used a multifunctional printer with a scanner HP PSC 1410 All-in-One. The scanning parameters were set to 600 dpi resolution and saved as JPG.

The steel plates were scanned from both sides. We determined the side with stamped number as a front and assigned it an index a, the backside was assigned with index b. At the end, there is the designation for example 34a (which corresponds to the coupon with a stamped number 34 at the front side).

4.3. Compiling the algorithm

To designate corroded parts in the image, a method of image segmentation using the threshold value was used. Because the corrosion in the image achieves significantly darker values, segmentation is determined based on the luminance value.

To remove noise from the image, a 15 pixel Gauss's filter was used (with a standard deviation of 3 pixels). Then, the boarder was selected as the average of all the brightness values in the whole image.

Pixels that had lower value than the calculated threshold correspond to corrosion and are assigned with number 0. Pixels with higher brightness values were assigned with number 1 and correspond to a non-corroded area.

General corrosion is then calculated as a percentage of pixels affected by corrosion out of the total number of pixels. Pitting corrosion is considered as an area that is larger than a circle with a radius of 3 pixels and smaller than a circle with a radius of 19 pixels. To find this area, two binary masks of a size of 40×40 pixels were compiled with the two circles placed in the centre of the circle. Using the convolution of the image with a mask, the areas with the pitting corrosion are identified.

4.4. Weight evaluation

An example is given in Table 1 — the evaluation of corrosion loss, amount of the corrosion products captured on plates, calculated corrosion rate and incrustation

Date		Jun 27	Aug 01			Sep 17		
Interval [days]			35			82		
T_{H_2O} [°C]			15			13		
pH		7.5	7.5			7.5		
	No.	**Weights, weight differences** [g], **corrosion losses**						
	739	13.2988				12.7664	0.5324	144
	740	13.4841				13.0259	0.4582	124
	741	13.5287				13.0262	0.5025	136
	742	13.5184				12.9885	0.5299	143.4
	743	13.3014	13.0469	0.2545	68.9			
	744	13.3917	13.1378	0.2539	68.7			
	745	13.4382	13.2013	0.2369	64.1			
	746	13.2975	13.0505	0.2470	66.8			
Corrosion loss of individual plates k [$\mathrm{g\,m^{-2}}$]					67.1			136.8
Corrosion loss U_t[µm]					8.5			17.4
Corrosion loss v_u[$\mathrm{\mu m\,year^{-1}}$]					89.1			77.5
	755		13.3152			12.9208	0.3944	106.7
	756		13.3355			12.9370	0.3985	107.8
	757		13.4061			13.0211	0.3850	104.2
	758		13.4430			13.0973	0.3457	93.5
Corrosion loss of individual plates k [$\mathrm{g\,m^{-2}}$]								103.1
Corrosion loss U_t[µm]								13.1
Corrosion loss v_u[$\mathrm{\mu m\,year^{-1}}$]								101.8

TABLE 1. Evaluation of the Corrosion Test in the VJD Hodusin, June 27th – Sept 17th, 2013

Designation no.	**Weight before exposed** [g]	**Weight after exposed** [g]		**Weight of the incrustation captured on the plates** [g]	
		with incrustation	**without incrustation**		
739	13.2988	13.7466	12.7664	0.9802	0.9039
740	13.4841	13.7709	13.0259	0.7450	
741	13.5287	13.9429	13.0262	0.9167	
742	13.5184	13.9621	12.9885	0.9736	

TABLE 2. Evaluation of the incrustation weight captured on the test plates

weight on plates mounted in the tank Hodusin in period June 27th–September 17th, 2013.

The first interval lasted 35 days, the second 47 days and the whole cycle of influencing plates was 82 days.

Within the first period, plates number 739 to 746 were inserted into the pipelines and after 35 days plates number 743 to 746 were removed and replaced by plates number 755 to 758.

The corrosion rate was in range of 77.5 to 101.8 $\mathrm{\mu m\,year^{-1}}$, therefore, according to The Standard TN 75 7121 Requirements for quality of water transported by pipeline this is Aggressive Level II — Medium Aggressiveness.

In this case, The Standard recommends an individual anticorrosion approach with respect to the required pipeline life based on the results of the technical and economic analysis.

Interesting is also the comparison of the weights of the test plates after exposure with incrustation and after incrustation removal from which we can observe the behaviour of the environment in the pipeline when compared with the weight before exposure. The weight is, in some cases, greater before the exposure and in other cases vice versa.

An example of the evaluation of the incrustation captured on the test plates is visible in Table 2.

4.5. CORROSION EVALUATION

Using the Matlab, an impact of a general corrosion and pitting corrosion was evaluated. Each of the coupons was evaluated from both sides. The percentage of the area corrosion impact is marked with a letter P and the percentage of the pitting corrosion is marked B. Sample results of the percentage impact of the plates marked 739 to 742 are in Table 3. The first column shows the exposure time in days.

Time [days]	**Designation no.**	**Front side (a)**		**Back side (b)**		**Weight loss** [g]
		P [%]	**B** [%]	**P** [%]	**B** [%]	
82	739	57.26	0.26	64.38	0.22	0.5324
	740	72.18	0.17	52.13	0.16	0.4582
	741	67.85	0.17	79.45	0.16	0.5025
	742	58.14	0.24	64.56	0.28	0.5299

Table 3. Percentage evaluation of area and pitting corrosion on mounted coupons number 739 to 742 on water reservoirs Milevsko and Hodušín. Time: 82 days.

5. Discussion

Corrosion rate evaluation was assessed by Galik in 2014. The aim of his work was to observe the occurrence and effect of corrosive processes and to experimentally determine the influence of seasonality on the effect of corrosion on the water pipeline [13]. When comparing the results of the STN standard (Slovakian Technical standard) and ASTM standard (American Society for Testing and Materials), he detected that short-term measurements differ from one another, but long-term (annual) measurements show almost identical corrosion rates. The aggressiveness of water has changed over the measuring period according to the measured corrosion rates. Results of an annual monitoring of water aggressivity indicate a decrease of corrosion rate during long-term tests over short-term tests. According to Galik, [13] there is no need for long-term actions to reduce the corrosion formation on the water pipeline. These results are the same as those measured during my research. The research also confirmed the conclusions of the short-term and long-term impact of the environment on the corrosion rate evaluation. Coupons fitted throughout the cycle had a lower average corrosion affection than coupons exposed to the environment for a half-time of the cycle.

6. Conclusions

The whole research was carried out in South Bohemia in Water Reservoir Hodusin and Milevsko in a period between June 27th and December 2nd, 2013. Each time the plates were mounted, the samples were taken and subsequently all the data were evaluated in the labs of Faculty of Civil Engineering of the Technical Faculty in Prague.

At a first glance, the corrosion rate of plates differs at the water reservoir Milevsko between the 1st and 35th day of measurement, which may be caused by an error in the measurement or by an unexpected interference on the grid. All the collected data were compared to the degree number 252/2004 Coll. The value of pH changed in the fifth measurement on December 2nd, 2013. The greatest difference between the two water reservoirs occurred during the conductivity determination when the difference averaged 5 mS m^{-1} and the values from Hodusin reservoir were more balanced then the values from Milevsko reservoir. The amounts of free and total chlorine fluctuated between recommended values. The temperature drop was caused by the selected measurement period — starting in summer and finishing in the beginning of December. The temperature influenced also the evaluation of the oxygen; its solubility increases with a decreasing temperature.

An increase of water age in the pipeline system corresponds to the increase of the corrosion rate evaluated along whole route of the pipeline system. The corrosion rate of the treated water was about 3 µm year^{-1} on average at ÚV Plav. In the same period and under corresponding conditions, the corrosion rate was over 80 µm year^{-1} at the outermost reservoir in Milevsko.

The corrosion rates measured in the first cycle (approx. 80–100 µm year^{-1}) varied according to the standard in the middle (II. degree) of the water aggression assessment scale but increased during the second cycle (approx. 100–135 µm year^{-1}) to the boundary of III. degree of aggression, that means medium to severely aggressive water.

Research has also confirmed the impact of short and long-term environmental influences on corrosion rates. Coupons fitted throughout the cycle had a lower average corrosion affection than coupons exposed to the environment for a half-time of the cycle.

There is an apparent balance of the data measured during both cycles from the evaluation of the coupons affection by the general corrosion and pitting corrosion on the Milevsko reservoir. The general corrosion in Hodušín reservoir ranged from 27 to 63 %, while the general corrosion at the outflow was much more balanced and ranged by about 12 %. The pitting corrosion damage is minimal in all cases, the lowest values were measured at the Milevsko reservoir, where the pitting corrosion did not exceed 0.2 %, while the data measured in the Hodušín water reservoir climbed over 1 % at least twice (from 4 determinations).

The research of the pitting corrosion and general corrosion has showed that if the general corrosion is higher, the pitting corrosion is lower and conversely. The weight of incrustations corresponds to the affection of the coupons by the general corrosion, it means the greater is the general corrosion, the greater is the number of incrustations.

There is a large difference in the measured values after comparing the results of the corrosion rates from water treatment plant Plav and the results on the outermost water reservoirs (Hodušín and Milevsko) of the northern branch. This result is indicative of the poor state of this entire distribution branch.

Although, the research has been carried out mainly on the western branch of the drinking water distribution system in southern Bohemia, there most probably are similar problems existing in other parts of the system. This statement was confirmed by the modelling and evaluation of the results of the northern branch.

These conclusions are valuable documents for the water management infrastructure owners within the whole system. Now, it has to perform a technical and economic analysis of the current state and its possibilities on how to proceed the pipeline reconstruction and what are the possible corrosion measures.

We suggest a replacement of the most affected sections, eventually at least a remediation of the inner surface of the pipeline by cement or plastics. From the long term perspective, it is the best and the most effective way to solve problems connected with the long-distance water transport.

The realization itself should be preceded by a detailed evaluation of the number of failures on the pipeline outside the valve itself and subsequently a selection of the suitable technology for feasibility as well as prevention from possible negative influences on the quality of the transported water.

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