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Effect of Cathodic Protection on Corrosion of Water-pipe Network in Kraków - Case Study

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Abstract

The paper is a summary of a project aimed at identifying and eliminating or minimizing the causes of frequent failures of the Krakow water supply network related to corrosion damage. The paper presents the method of searching for factors responsible for frequent corrosion damage. There were taken into account several factors that may destroy the pipes associated with corrosion processes, such as the composition of the water, aggressiveness of ground, or stray currents. The monitoring method of the corrosion processes applied to observe the condition of the water supply network was discussed. The study showed that the main problem appeared to be stray currents related to the electrical infrastructure widely present in a large city, such as a tram or railway network. To eliminate this threat, a cathodic protection system has been implemented to prevent further failures. There were also demonstrated results of research proving that the applied solutions are effective.

Keywords: Materials, Water pipelines, Corrosion, Cathodic protection

1. Introduction

The drinking water supply of residents of large cities is one of the fundamental issues. The failure rate of the water supply system translates into a deterioration in the quality of life, and sometimes into an increase in epidemiological risk, which is of great importance these days.

In the Krakow agglomeration, the total network of pipelines is approx. 2300 km, of which 29.6% is made of structural steel and 26% of cast iron. Only 26% of pipes were installed less than 30 years ago, 35% are circa 70 years old and 9% are even older [1] (the waterworks in Kraków started operating in 1901). About 20% of pipeline failures are due to material corrosion [1]. Annual losses on this account were estimated at the amount of almost 1 million USD (2013). The situation is similar in other urban agglomerations.

In 2013 were lunched the project concerning an analysis of the main causes of corrosion of pipelines [2-4], implementation of a corrosion monitoring system [5] and development of methods of protection of the water supply network to reduce the number of damages and related repair costs.

Proper evaluation of the causes of corrosion of the underground construction has a significant impact on the selection of appropriate forms of corrosion prevention, therefore the number of parameters that could be a cause of corrosion of pipes in the drinking water system should be taken into account.

First of the tested parameters affecting the corrosion of the pipe network was water aggressiveness [2, 3, 6]. Kraków is supplied with drinking water from three main intakes: Bielany (Sanka river), Dłubnia, and Raba (the river fed mainly by mountain streams). Particular parts of the city are supplied with water from mentioned sources mixed in 3 reservoirs located nearby Kościuszko Mound (60% water from the Raba river, 40% Sanka), at Hallera St., (Raba) and in Nowa Huta district (75% of water from the Raba i and 25% of Dłubnia). There is also a main water supply bus in Wodna St., supplied by water from Raba river redirecting water streams to the particular districts of the city. Corrosivity of water in the water supply systems strictly depends on the type of source water. Figure 1 presents areas of the city supplied by water from the above-mentioned intakes.

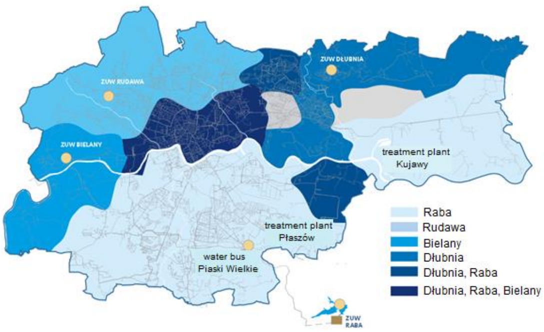


Fig. 1. Map of Krakow indicating areas fed by water from particular intakes

Table 1 presents the most important parameters determining the corrosive aggressiveness of water measured at the temp. of 20°C [2].

Table 1.
Parameters determining the corrosive aggressiveness of water (tested in the Central Laboratory of the municipal water company in Krakow) .

tested parameter	units	Bielany	Dłubnia	Rudawa	Raba
pH	-	7.3	7.7	7.2	7.8
Hardness	mg/dm^3 $CaCO_3$	70	56	56	52
Total alkalinity	mg/dm^3 $CaCO_3$	188	233	183	103
Condu-ctivity	mS/cm	0.64	0.58	0.55	0.31
Ca^{2+}	mg/ dm^3	86	56	57.2	38
Mg^{2+}	mg/ dm^3	6.4	4.8	6	5.7
NO_3^-	mg/ dm^3	1.3	2.6	1.8	3.52
K^+	mg/ dm^3	5.3	2.4	3.9	3.1
Cl^-	mg/ dm^3	46	45	42	32
SO_4^{2-}	mg/ dm^3	83	27	57	22
PO_4^{3-}	mg/ dm^3	14	11	16	16
Fe^{2+}	mg/ dm^3	0.03	0.01	0	0
Langelier Index	25°C	0.39	0.82	0.14	0.4
Ryznar Index	25°C	6.52	6.03	6.95	7.08
Aggressi-veness	-	mode-rate	mode-rate	mode-rate	high

Fig. 2. Collecting the soil samples

Table 2.
Parameters determining the corrosive aggressiveness of soil

Tested parameter	Units	Kościuszko Mound	Hallera St.	Nowa Huta
pH		7.02	6.97	4.58
humidity	[%]	18.6	13.86	24.4
conductivity	[mS/m]	38.69	17.64	39.3
resistance	Ωm	26.26	96.43	53.96
SO_4^{2-} overall	mg/kg	84.5	57.71	30
SO_4^{2-} eluted	mg/kg	16.6	6.86	7.2
Fe^{2+} overall	mg/kg	14620.9	8167.71	13174.2
Fe^{2+} eluted	mg/kg	80.2	146.14	95
Cl^-	mg/kg	30.3	41.57	25
H_2S		absent	absent	present
corrosiveness		moderate	moderate	high

The aggressiveness of water and the soil wasn't both enough explanation for plenty of corrosion failures noticed in the Krakow water supply system. There was also examined occurrence of stray currents to check their impact on the corrosion processes of the water supply network [8-12]. Due to this purpose was developed and built a network of monitoring stations. Main monitoring stations were located near to the water reservoirs - Kościuszko Mound, Hallera St., Nowa Huta district and nearby to the water bus supply in Wodna St. (Fig.3) [3]. Monitoring the pipeline's potential relative to the portable reference electrode along the pipeline allowed to detect places where there was a change in the pipeline potential value towards electropositive values compared to non-impact conditions. In these places, the harmful effects of static fields of stray currents was expected. A method of investigating the impact of dynamic stray currents was adopted, consisting of a combined time-frequency analysis of the signals recorded in the areas of interference. This method makes it possible to locate and identify sources of stray currents (e.g. electric traction) and to record their time-frequency characteristics [5, 13-15]. The corrosion rate was measured based on linear polarization resistance (LPR) measurements which allowed for the determination of the corrosion rate [16-18].

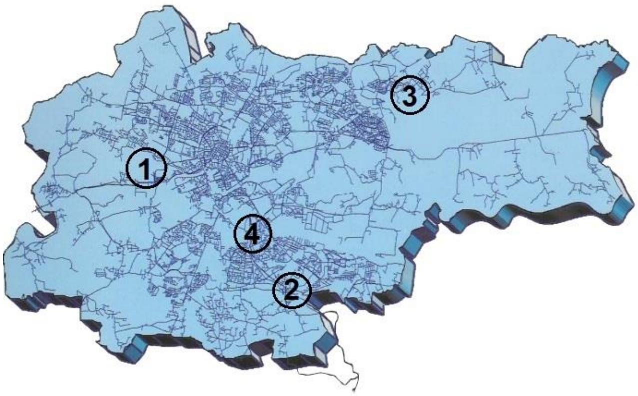


Fig. 3. Location of monitoring stations nearby drinking water tanks in Krakow: 1 - vicinity of Kościuszko Mound, 2 - Hallera St., 3 - Nowa Huta district, 4 - water supply bus at Wodna St

Monitoring the pipeline's potential relative to the portable reference electrode along the pipeline makes it possible to detect places where there is a change in the pipeline potential value towards electropositive values compared to non-impact conditions. In these places, the harmful effects of static fields of stray currents are expected. A method of investigating the impact of dynamic stray currents was adopted, consisting of a combined time-frequency analysis of the signals recorded in the areas of interference. This method makes it possible to locate and identify sources of stray currents (e.g. electric traction) and to obtain their time-frequency characteristics [5, 13-15]. The corrosion rate was measured based on linear polarization resistance (LPR) measurements which allowed for the determination of the corrosion rate [16-18].

Most failures occurred at a site distant from the sources of stray currents sources namely the tramway and railway traction systems. For the Kościuszko Reservoir, despite the distance of about 1 km from the tram line, the impact of stray currents on the water supply system was visible. For the measurement point in Nowa Huta district, it was found that the water supply system was not endangered by the harmful effects of stray currents associated with the presence of tram traction or high voltage lines. For water supply bus at Wodna St. both the railway and tram lines occurred to be the source of the cathodic polarization of the pipe network in this area. Despite the significant distance from the tram and railway lines, the influence of stray currents was observed in the area of Hallera St. Figure 4 presents the effects of stray currents on water pipe corrosion.

Fig. 4. Corrosion damage of water pipe as a result of stray currents

2. Experimental

Samples of carbon steel with working area of 3.46 cm^2 were placed in soil for 4 years (June 2015 - May 2019) in the vicinity of the water reservoirs:

- Kosciuszko Mound - 1 sample connected to the water pipe, no CP station in the area,
- Nowa Huta district - 1 sample connected to the water pipe, no CP station in the area,
- Wodna St. water bus supply - 1 sample connected with the water pipe, CP station at the distance of 10 meters,
- Hallera St. - 2 samples: 1st not connected to the pipe, no CP, 2nd connected to the pipe, CP station at the distance of 800 meters.

The samples after four years of exposure were cleaned according to the ASTM-G1 standard, etched in Clarke's solution and weighed. The corrosion rate was calculated based on the formula [19]:

$$v_{corr} \quad \left[\frac{\text{mm}}{\text{year}}\right] = \frac{\text{K} \cdot w}{A \cdot t \cdot d}$$

where:
K = constant (3.45 x 10^6), w = mass loss in grams, A = area in cm^2, t = time of exposure in hours, d = 7.84 density in g/cm^3,

Figure 5 presents samples taken out of the foil protecting non-corroding surface.

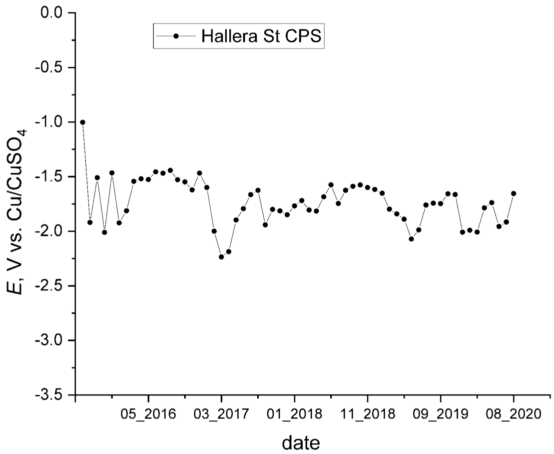
Fig. 5. Carbon steel samples after 4 years of exposure in the soil nearby to the main water tanks of Krakow water supply network

3. Results and discussion

To eliminate the influence of stray currents on the pipes transporting drinking water in the area of Krakow and to prevent metal corrosion as a result of electrochemical reactions with aggressive components of water and soil, the cathodic protection system was modernized and significantly expanded. In many places, interactions with other parts of the city infrastructure, such as gas lines, etc., which caused a short circuit with water pipes and initiated corrosion processes, were eliminated. The cathodic electrolytic protection system with an external DC electrical power source was used. By the end of 2020 in Krakow was installed 18 cathodic protection stations and 86 measuring points allowing control of potential in the pipeline.

The current applied by the stations of the cathodic protection was set to maintain the value of the potential -850 mV vs. $Cu/CuSO_4$ electrode [13, 20-24]. Figures 6 a and b present the potential change of the water pipeline registered during 4 years period in CP stations at Hallera St. and water supply bus in Wodna St.

a)



b)

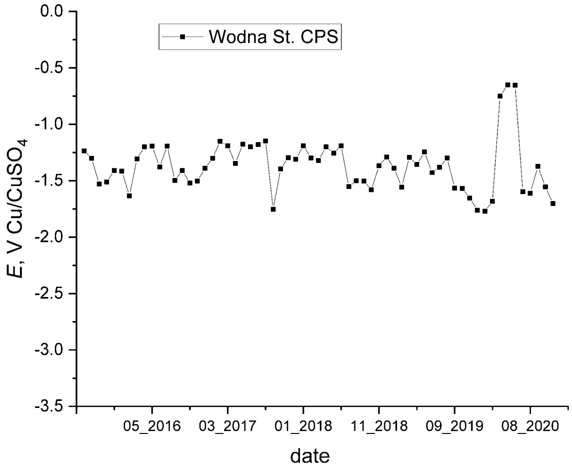


Fig. 6. Change in potential values of water pipes registered in cathodic protection station: (a) at the area of water tank in Hallera St., (b) in the vicinity of water supply bus at Wodna St.

The measured potential of the water pipe in the vicinity of the cathodic station in both cases indicates that the applied current density was sufficient to keep the pipeline potential at the desired level below -850 mV vs. $Cu/CuSO_4$.

Table 3 presents the results of the weight loss of samples with their location and the distance to the nearest cathodic control station.

Table 3.
Weight loss results

	Δm	v_{kor} [mm/year]	connection with water pipe	place	CPS distance
1	0.6309	2.394744	yes	Nowa Huta district	no CP
2	0.0164	0.06229	yes	Wodna St.	CP 10m
3	0.4120	1.564845	no	Hallera St	no CP
4	0.1578	0.599351	yes	Hallera St	CP 800 m
5	0.2483	0.943085	yes	Kościuszko Mound	no CP

The lowest corrosion rate was recorded for the sample located in the immediate vicinity of the cathodic protection station. The highest corrosion rate was observed for the sample exposed in the Nowa Huta district, in highly corrosive soil (see Table 2) in the absence of cathodic protection. A very significant difference in the rate of corrosion was observed for two samples located at Hallera St. The value for the sample without any current protection is three times higher than that of a twin sample connected with a pipeline protected by a cathodic station almost one kilometer distant.

4. Conclusions

1. Several main causes of corrosion damage to Krakow's water supply systems have been identified, including aggressive components of water supplying the waterworks system, corrosive properties of soil, and stray currents associated with urban infrastructure, which turned out to have the greatest impact on the corrosive failures of the pipes.
2. The corrosion monitoring system was implemented, which allowed to locate the most critical places in terms of corrosion risk and allowed to monitor the condition of the water supply system after the introduction of corrosion protection
3. The DC-powered cathodic protection system used for corrosion protection effectively protects the water supply network, as demonstrated by a long-term analysis of the pipe potential and the corrosion rate tests of carbon steel samples exposed in selected places of the water supply network.

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