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EXPERIMENTAL RESEARCH ON THE IMPACT OF DIFFERENT HARDNESS WATERS ON THEIR CONTAMINATION BY PROTECTIVE CEMENT MORTAR LININGS AFTER PIPE RENOVATION

BADANIA EKSPERYMENTALNE WPŁYWU WÓD O ODMIENNEJ TWARDOŚCI NA ICH ZANIECZYSZCZANIE PRZEZ OCHRONNE WYKŁADZINY CEMENTOWE PO RENOWACJI PRZEWODÓW

Abstract

The paper presents laboratory experiments on the influence of different hardness water samples collected from the municipal water supply system on the intensification of leaching pollutants from the internal cement mortar pipe lining to drinking water. The paper presents the analysis of water quality indices, such as pH, aluminum and selected heavy metals concentrations after contacting with cement coatings.

Keywords: water hardness, renovation, cement mortar lining, water pipes

Streszczenie

W artykule przestawiono wyniki badań laboratoryjnych opisujących wpływ wód pobranych z miejskiej sieci wodociągowej, charakteryzujących się odmiennymi twardościami, na stopień przenikania do nich zanieczyszczeń z wewnętrznych powłok cementowych. Niniejsze opracowanie obejmuje analizę wskaźników jakości wody, takich jak pH, stężenie glinu oraz stężenie wybranych metali ciężkich na skutek jej kontaktu z powłokami cementowymi.

Słowa kluczowe: twardość wody, renowacja, wykładzina cementowa, przewody wodociągowe

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1. Introduction

Corrosion of old iron or steel pipes in distribution systems contributes to many different problems. Corrosion products accumulated on the inner surface of water pipelines cause the reduction of the hydraulic capacity, increase of water flow resistance and thus, increase of water supply system operation costs. Additionally, corrosion products have a negative impact on the potable water quality. Deterioration of the water quality is mainly related to leaching of iron compounds from corroded metal pipes to the water. As a consequence, the color of the water becomes red and brown and the water turbidity increases. The corroded pipes influence the consumption of dissolved disinfectants, dissolved oxygen and intensive microbiological growth [1–4].

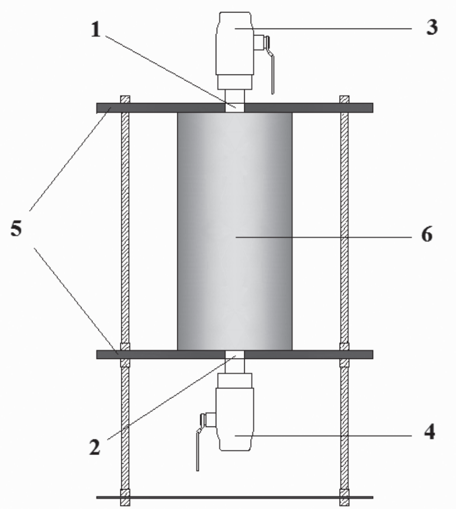
In order to protect the inner surface of water pipes against corrosion, many different methods are used, among which are trenchless technologies. The most commonly used trenchless method is cement coating by spraying, which was invented in 1930 [5, 6]. In opposite to other techniques, cement mortar lining protects pipes against corrosion not only by a mechanical separation of metal pipe from the water, but also by chemical protection. Cement mortar creates a high-alkaline environment, which strongly reduces corrosion process [7].

Considering the fact that the natural cements consist of many different components, mainly calcium, silicon, aluminum, iron, magnesium, sulfur, sodium, potassium compounds and also particularly dangerous trace chemical elements, such as arsenic, cadmium, chromium, lead, copper, nickel or zinc [8, 9], it is very important to analyze the impact of cement mortar lining on the water quality. Numerous performed studies show that, in a short period after applying cement coatings, the deterioration of some water quality parameters can be observed, especially an increase in water pH values and alkalinity [10–13] and also the growth of some chemical elements concentrations, mainly aluminum, calcium and chromium [10, 13, 14]. The level of water contamination by cement coating soon after renovation depends on the type of used cement [14, 15] and also on the quality of transported water. The hardness of water contacting with cement coating seems to be an important parameter for leaching of pollutants from the cement mortar. In comparison to the hard waters, soft waters are characterized by a low carbonate and bicarbonate content, and thus, soft waters are aggressive to calcium hydroxide, the main cement mortar component, which is visibly leached out from fresh cement mortar lining. Aggressive soft waters can also attack calcium silicate, which leads to the formation of silica gels and thus, to the reduction of the mechanical strength of cement coating. As a result of leaching out calcium from cement mortar lining, the value of pH cement coating decreases, water pH increases and the danger of leaching out the toxic metals from protective cement coating to water is greater [16, 17].

Given the above, it seemed to be important to analyze the influence of water hardness on polluting the water transported in distribution system by fresh protective inner cement coating. Two kinds of water samples, characterized by relatively high and relatively low hardness, were collected from outflows of two different Cracow water treatment plants for laboratory tests. The experiments were conducted under static conditions, using two test stands constructed for the purpose of this research. Numerous water quality parameters were tested during the experiments. However, only some of them, such as pH, aluminum, chromium, lead and cadmium concentrations, are analyzed in this paper. The results indicate which types of water are more exposed to contamination by leaching out the pollutants from cement mortar coating and show importance of water hardness parameter for process intensification.

2. Material and methods

Two identical test stands presented in Figure 1 were used in the experiments. The main element of both test stands was a steel pipe with internal cement mortar coating (Fig. 2).



1 - hole for filling
2 - hole for emptying
3 - valve for filling
4 - valve for emptying
5 - stainless steel plates
6 - steel pipe with internal cement mortar coating

Fig. 1. The scheme of test stand for static research (Source: own elaboration)

Fig. 2. Steel pipes with internal cement coating (Source: author's photo)

The length of water pipes with the nominal diameter of 80 mm was 25.0 cm. The thickness of cement mortar coating was 0.7 cm and was made by mixing Portland Cement 42.5R manufactured by CEMEX with quartz sand in a ratio of 1 to 1 and with water, maintaining 0.35 water-cement ratio. Cement mortar lining process was made manually with 24 hours cure time. After this time, pipes interiors were filled with water samples collected from outflow of two different Cracow water treatment plants. The first one was filled with hard water (293.0 mg $CaCO_3/dm^3$) and the second one was filled with soft water (130.0 mg $CaCO_3/dm^3$). Both water samples remained in contact with cement coatings for the same periods of time, which were determined based on the Dutch Standard (EA NEN 7375:2004) [18] and Polish Standard (PN-EN 14944-3:2008) [19]. Water samples contacting with cement mortar were replaced by raw water after the following periods: 0.25, 1, 2.25, 5, 6, 9, 13, 16, 33, 36, 52 and 56 days. All replaced water samples were collected and tested. Water quality indices like pH, alkalinity, aluminum, chromium, calcium, cadmium and lead concentrations were tested for samples collected during experiments. According to the Dutch Standard EA NEN 7375:2004 [18] and based on experimental measurements, the cumulative leaching aluminum and chromium from cement mortar lining to water was counted and presented in this paper.

3. Results

Figure 3 presents pH changes of both collected raw water samples contacting with cement mortar linings. The pH of both (soft and hard) raw water samples before contacting with cement mortar linings has reached 7.7. Soon after the contact of both water samples with cement mortar linings, the significant increase of pH was observed. The pH has reached 11.7 in both cases, exceeding maximum allowable value for drinking water, determined by the Polish Ministry of Health Regulation (pH = 6.5-9.5) [20] and also by U.S. EPA Secondary Drinking Water Standards (pH = 6.5-8.5) [21]. It was probably caused by intensive leaching of calcium alkali from cement mortar to water. For the first 13 days of contacting time, pH of both kinds of water samples was slightly rising up, reaching similar values, but not exceeding 12. After this time, a rapid decrease of hard water pH was observed, whereas pH of soft water was still kept at around 12. The decrease of hard water was still continued and reached 8.3 value after about 60 days of contact time, whereas decrees of pH of soft water was noticed after 36 days, finally reaching 10.3 after about 60 days of contact time. This research clearly shows that soft waters are more exposed to the maintaining a high level of pH values for a longer period of time than hard waters.

Figure 4 shows the increase of cumulative leaching aluminum for hard and soft waters contacting with cement mortar lining. The amounts of leached aluminum to both: hard and soft waters were initially almost the same. However, over time, the amount of leached aluminum for soft water was larger than for hard water. After the third day of the experiment, the difference between leaching of aluminum to soft and hard waters started to increase. After 52 days of contact time, leaching of aluminum to both types of tested waters almost stopped. Summarizing the above, for very short period after renovation it is expected to observe a similar leaching of aluminum independently on water hardness. However, leaching of aluminum from the cement mortar contacting with hard water decreases much quicker over time than contacting with a soft water.

In turn, as it was expected, the analysis of chromium concentration for tested waters shows that the amounts of leached chromium from cement mortar lining to both: hard and soft waters were much smaller than amounts of leached aluminum (Fig. 5). Initially, soon

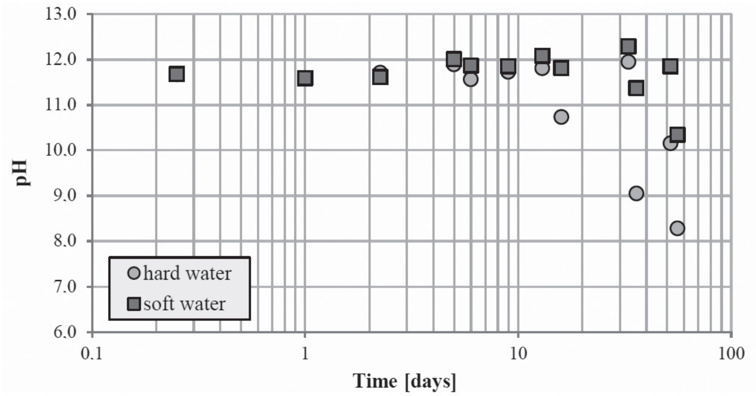


Fig. 3. Noted pH values of hard water and soft water in contact with cement mortar lining (Source: own elaboration)

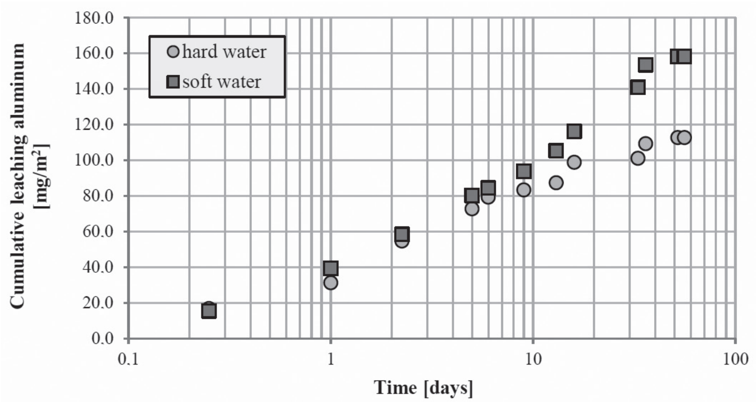


Fig. 4. Cumulative leaching aluminum from cement mortar lining to hard water and soft water (Source: own elaboration)

after lining, leaching of chromium from cement mortar to soft water was a few times higher than to hard water. However, over time, intensification of chromium leaching to soft water became quite similar to the leaching intensification of chromium to hard water. After 33 days of the study, it was noted that leaching of chromium to the hard water almost stopped. In the case of soft water, leaching process after 52 days was ceased.

Based on the obtained results concerning to the leaching aluminum and chromium from cement mortar lining to the water, it can be concluded that generally soft water in comparison to hard water is more exposed to the pollution by these chemical elements.

In the conducted experimental research, the measurements of the concentration of heavy metals, which are particularly harmful for drinking water quality, such as lead and cadmium, were also performed. The obtained research results indicate that there is no risk of water contamination caused by the leaching these toxic metals from cement mortar lining to both

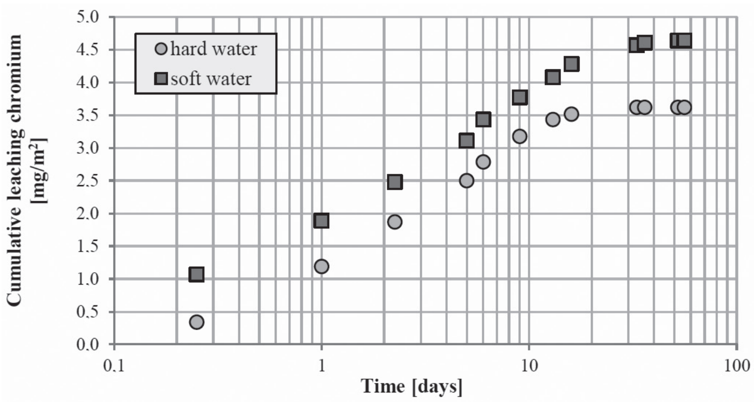


Fig. 5. Cumulative leaching chromium from cement mortar lining to hard water and soft water (Source: own elaboration)

tested waters. In all collected water samples, noted concentration of lead and cadmium was below detection. Lead concentration in all water samples was less than 0.002 mg/dm^3 (limitation value in drinking water regulated by [20] and [21] is 0.010 mg/dm^3) and cadmium concentration in all water samples was less than 0.00045 mg/dm^3 (limitation value for drinking water regulated by [20] and [21] is 0.005 mg/dm^3).

4. Conclusions

Cement mortar lining belongs to the widely used trenchless pipe rehabilitation technologies. This technique provides highly effective protection against corrosion, improves a technical conditions of the pipelines and their hydraulic parameters and also prevents against the secondary pollutants. Since cement includes many different compounds, controlling potential leaching of pollutants from fresh cement mortar to drinking water in short period after cementing is important.

The obtained research results indicate the influence of different hardness waters on pollutant leaching from fresh cement coatings. For both soft and hard waters, a significant increase of pH was observed. pH raised up to about 11.7. However, high pH values were maintained longer in the case of soft water than in the case of hard water.

Intensification of aluminum leaching from cement mortar contacting with both kinds of waters initially, soon after coating was very similar. However, in the case of soft water, a fairly high intensification was maintained much longer than in the case of hard water.

Intensification of chromium leaching was initially, soon after lining, a few times higher for soft water than for hard water. However, during the rest of the experiment, the intensification of chromium leaching was almost the same for both kinds of waters and decreased over time.

The conducted experimental research also showed that the risk of water contamination by lead or cadmium leached from cement mortar is negligible.

The experimental research confirmed that the water quality transported through water pipes within a short period after renovation by cement coating influences the degree of water contamination. It can be supposed that generally water pipelines transported soft water are more exposed to the contamination by leaching cement mortar compounds than hard water, especially aluminum and calcium ions. Thus, the probability of deterioration water quality delivered to the consumers and also the reduction of mechanical strength of protective coating as a consequence of leaching of its compounds is greater.

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