Prediction of corrosion rates of water distribution pipelines according to aggressive corrosive water in Korea

W.S. Chung*, M.J. Yu and H.D. Lee***

* Construction Environment Research Department, Korea Institute of Construction Technology, 2311, Daehwa-dong, Ilsan-ku, Koyang, Kyonggi-do, 411-712, Republic of Korea (E-mail: *wsjeong@kict.re.kr*)

** Department of Environmental Engineering, The University of Seoul, 90 Cheonnong-dong, Dongdaemun-ku Seoul, 130-743 Republic of Korea (E-mail: *myong@uos.ac.kr*)

Abstract The drinking water network serving Korea has been used for almost 100 years. Therefore, pipelines have suffered various degrees of deterioration due to aggressive environments. The pipe breaks were caused by in-external corrosion, water hammer, surface loading, etc. In this paper, we focused on describing corrosion status in water distribution pipes in Korea and reviewing some methods to predict corrosion rates. Results indicate that corrosive water of lakes was more aggressive than river water and the winter was more aggressive compared to other seasons. The roughness growth rates of Dongbok lake showed 0.23 mm/year. The high variation of corrosion rates is controlled by the aging pipes and smaller diameter. Also the phenolphthalein test on a cementitious core of cement mortar lined ductile cast iron pipe indicated the pipes over 15 years old had lost 50~100% of their lime active cross sectional area.

Keywords Aggressive water; corrosion rates; distribution pipelines; drinking water

Water Science and Technology **Vol 49 No 2 pp 19–26** © IWA Publishing 2004

Introduction

The drinking water network serving Korea is almost 100 years old. Although the older parts of these networks had been built under proper standards, they are losing their integrity. Additionally, as water supply pipelines were constructed underground they have been influenced by overlying soil, surface traffic, and internal corrosion by aggressive water.

Internal corrosion of water distribution systems gives rise to many problems for water utilities. The first is the failure of the distribution system pipes. This failure results in water leakage and loss of hydraulic capacity caused by buildup of corrosion products. The second problem is an unwanted change in water quality as the water is being transported through the distribution system (AWWARF, 1996) due to corrosion products entering the water (Voyles, 1984).

In cast iron and steel pipe, the major corrosion problems are associated with the buildup of corrosion products on the pipe walls and the release of corrosion products into the water (Sharp and Walski, 1988; Lamont, 1981). Contact of cement materials with the transported water produces changes in the cement matrix (Leroy *et al.*, 1996). The interactions between the cement material and the water result from the great surface contact between these two phases, especially in the pores. The first and primary type of interaction with water concerns the calcium carbonate saturation state and carbonate species of the water, which can lead to the rapid degradation of the cement material. This is generally called carbonic aggressivity (corrosivity). Another type of interaction concerns the chemical equilibrium with the various calcium aluminates or calcium silicate phases (AWWARF, 1996). The primary interaction between water and cement materials leads to lime leaching, which induces a substantial pH increase (AWWARF, 1996). Such leaching can have important consequences for water quality. The amount of impact on the increase of the pH of a water depends on the total alkalinity and buffer capacity of the transported water, the type of cement used, the contact time between the water and the cement material, and the pipe diameter (AWWARF, 1996). Corrosion of cement materials in a domestic water system is governed principally by solubility considerations. The dissolution reactions have been proposed for the cement matrix of A/C pipe (Schock and Buelow, 1981) and should be applicable to other cement-containing pipe materials.

When Langelier proposed his theory about protective layers in the 1930s, pH became the parameter to adjust the carbonate ion concentration to levels above the precipitation of calcium carbonate for the current calcium ion contents. When these theories were developed and this precipitation reaction became less important, a stable pH was considered favorable in order to achieve good precipitation conditions for the corrosion products at the pipe wall. Instead of pH, the buffer capacity came into focus. The buffer capacity is related to the alkalinity of the water and this is why an increased alkalinity is regarded as favorable (AWWARF, 1996).

Recent results show the free carbon dioxide content (or bicarbonate) is a parameter of great importance. The corrosion rate decreases with increasing free carbon dioxide content. Thus, a low pH and a high alkalinity are favorable in order to reduce iron corrosion, while the calcium contents are of less importance, at least when alkalinity is high (AWWARF, 1996).

Application of corrosive indices to scaling and corrosivity evaluation of the waters indicated mixed results. One index would predict a given water as corrosive while the other would suggest the water is either scaling (noncorrosive) or stable (at equilibrium). In some instances, the corrosivity predictions by the indices are contrary to the results of the laboratory loop studies and corrosion monitoring results in the field investigations (Pisigan, 1992; Lauer and Lohman, 1993, 1994). However, water corrosive indices are being utilized as the indicator to predict tubercle growth rate on cast iron pipe and to estimate cement mortar lining deterioration.

In Korea, studies on corrosion control are scarce and limited in scope. Lee *et al.* (1990) studied the overall corrosion control technologies in Korea and reported the water quality adjustment for corrosion control using various chemicals. Nam (1993) investigated the water quality variation in the distribution system and Kwak (1997) studied the corrosivity of water using corrosion index, and found that the water is corrosive with respect to calcium carbonate precipitation. Seo *et al.* (1998), Kwak *et al.* (2001) reported the water quality in Korea is very corrosive and was caused by unwanted water quality change. Lee *et al.* (1997, 1998, 1999) studied on evaluation of corrosion effects on water quality, showing that control of DO, pH and alkalinity adjustment was an effective method for corrosion control. Chung (2001) recently evaluated the characteristics of pipe deterioration for both internal and external corrosion and presented the pipe deterioration assessment model.

It is necessary to establish suitable guidelines or standards for pH, alkalinity, and other parameters in order to predict corrosion rate, but unfortunately there is no guideline or standard for corrosion control in Korea. In this paper, we focussed on the evaluation of treated water quality corrosivity using corrosion indices, corrosion related status in water distribution pipes, and some technical methods.

Methods

Data collection and processing

Status of drinking water supply pipeline in Korea. The total length of pipelines in Korea is 115,740 km. The length of pipelines that transported from water resources to water treatment plant is 1.319 km (1.1%), and the length of pipelines that transported from water treatment plant to service area is 4.952 km (4.3%). The length of pipelines that transported from reservoir or pump to service pipe device is 48,404 km (41.8%), and the length of the service pipe is 61,065 km (52.8%). The length of pipe that has been laid in over 21 years, in 15–20 years, in 10–14 years, in 5–9 years, and in under 4 years is 10,963 km (9.5%), 16,022 km (13.8%), 28,284 km (24.4%), 33,650 km (29.1%), and 26,821 km (23.2%), respectively.

Data collection and sampling periods. In the current study, we collected 56 pipe specimen samples from the cast iron pipe (CIP) and 35 samples from the cement mortar lined ductile cast iron pipe (CML-DCIP) and sampling periods took from 1997 to 1999. Seasonal treated water quality data were collected from three water treatment plants every month during the whole year in 1999. Also pipe specimens are analyzed for physical components such as hardness, tensile strength, pipe thickness, corrosion depths, and chemical composition.

Effect of corrosive water quality on pipe inner status

Analysis of corrosive water. The major water resources in Korea are mainly composed of Han river, Nakdong river, Youngsan river and some lakes. To evaluate the corrosive water quality, some corrosive indices such as LI (Langelier Index), CCPP (Calcium Carbonate Precipitation Potential) and LR (Larson Ratio) are analyzed. And target water resources are chosen as Han river, Nakdong river, and Dongbok lake, which are the main water resources in Korea.

Phenolphthalein test of CML-DCIP. The optical analysis data on pipe and onsite water quality data, which is being serviced by the water treatment plant, was used to investigate the water quality factors affecting cement mortar lining neutralization (CML-N) of CML-DCIP. CML-N analysis is determined by 10% phenolphthalein solution. When the CML was neutralized, the color of CML was not changed. Figure 1 shows the photograph of the phenolphthalein test of CML-DCIP.

Hydraulic capacity reduction analysis of CIP. The hydraulic capacity reduction of CIP is analyzed and determined by measuring the difference between calculated volume of pipe and the water filled in the tested pipe. Figure 2 shows the photograph of the CIP sample. And statistical analysis (correlation and multiple regression) was conducted for degrees of internal corrosion and water quality characteristics.

Statistic analysis. Table 1 shows the pipe and water quality analysis items used in statistical analysis. The correlation and multiple regression using SPSS 10 is performed to estimate correlation between internal corrosion and water quality characteristics. Table 2 indicates the classification of CIP and CML-DCIP for statistical data processing. It is considered as the sum of optical analysis points based on degrees of internal corrosion or pipe deterioration.

Figure 1 Photograph of phenolphthalein test of DCIP

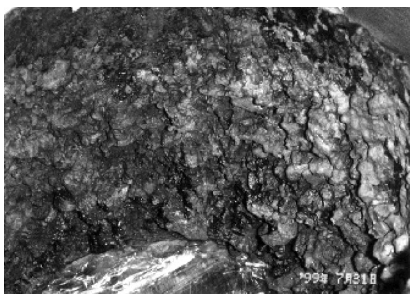

Figure 2 Photograph of CIP sample

Corrosion rate

Prediction of roughness growth rates using corrosive indices. The prediction of roughness growth rates used the equations suggested by Lamont (1981) and Sharp and Walski (1988) on $a = 0.0248e^{0.8795LI}$. It is compared with the analysis data of corrosive water quality collected from 3 water resources.

Calculation of corrosion rates. The calculation of corrosion rates is related to installation year and reduced thickness of pipe.

Results and discussion

Corrosive water quality in Korea

Table 3 shows the results of corrosive indices for major water resources. The results of corrosivity evaluation with respect to different water resources revealed more corrosive compared to corrosion indices such as LI, CCPP and LR. The LI and CCPP indicate that the waters were nonscaling and unsaturation with $CaCO_3$. And the water taken from Dongbok lake contained low alkalinity and calcium hardness, and was relatively more corrosive than waters taken from Han and Nakdong river with respect to the LI, CCPP. But the water taken from Nakdong river indicated relatively high sulfate and chloride concentration, and was more corrosive than those of Han river and Dongbok lake with respect to the LR. Especially, results showed that the corrosivity of water, which was taken from Han and Nakdong river resources, was less than that of water taken from Dongbok lake resources with respect to LI and CCPP. The significant seasonal variations of corrosivity indices are not shown for different water resources.

The apparent water quality differences between Han and Nakdong river, and Dongbok lake are due to sulfate, chloride alkalinity and hardness. These water quality parameters in the lake are less than those of Han and Nakdong river. The concentration of major ions in the water taken from river and lake water resources and the predominant inorganic minerals in raw waters are calcium, magnesium, sodium, potassium, bicarbonate/carbonate, sulfate, and chloride.

Table 1 Pipe and water quality analysis items used in statistical analysis

Contents		Analysis items
Treated water quality	Corrosion inhibition	pH, Alkalinity (mg/L as $CaCO_3$), Hardness (mg/L as $CaCO_3$), Calcium (mg/L as $CaCO_3$)
	Corrosion acceleration	Conductivity (μ ohm^{-1} m^{-1}), Chlorine residual (mg/L), Chloride (mg/L), Sulfate (mg/L)
Pipe	Inner status of cast iron pipe	Corrosion product accumulation area (%), Corrosion product height as tubercle (mm) Hydraulic capacity reduction ratio (%)
	Inner status of ductile cast iron pipe	Cement mortar lining phenolphthalein test – not pink part(%) Cement mortar lining damage area (%) Seal coat damage area (%)

Table 2 Classification of CIP and DCIP for statistical analysis

Type of pipe	Items	Classified level for statistical analysis			
		1	2	3	4
Cast iron pipe	Corrosion product area in pipe (%)	0–10	10–50	50–80	Above 80
	Tubercle size as height (mm)	0–0.5	0.5–20	20–40	Above 50
	Hydraulic capacity reduction ratio (%)	0–5	5–10	10–20	Above 30
Cement mortar lined ductile cast iron pipe	Phenolphthalein test (%)	0–25	25–50	50–75	Above 75
	Lining damage area (%)	0–5	5–10	10–50	Above 50
	Seal coat damage area (%)	0	0–10	10–50	Above 50

Table 3 Corrosive indices of treated water for major 3rd water resources with seasons

		Han River	Nakdong River	Dongbok Lake
Winter	LI	−2.1– −1.1	−1.13– −1.61	−2.8– −2.2
	LR	0.9–1.0	2.0–2.4	0.5–0.8
	CCPP	−3.9– −3.42	−3.33– −2.85	−5.83– −4.90
Spring	LI	−1.7– −1.4	−1.35– −1.77	−2.3– −2.9
Autumn	LR	0.8–0.9	0.97–1.9	0.6–1.1
	CCPP	−3.25– −2.94	−2.56– −2.50	−5.36– −3.60
Summer	LI	−1.7– −1.4	−1.44– −1.77	−2.5– −2.8
	LR	0.7–0.9	0.93–1.58	0.6–0.9
	CCPP	−3.30– −2.76	−3.63– −2.29	−4.70– −4.01

* LI < 0, CCPP < 0, LR > 0.7: corrosive

The ratio of cations (calcium and magnesium) and anions (bicarbonate, sulfate, and chloride) ranges from 0.39 to 0.58. Commonly the ratio of cations and anions in water resources is almost 1.

Phenolphthalein test

Figure 3 shows the results of the phenolphthalein test on a cementitious core using CML-DCIP. The pipes of installation year over 15 years were not plotted pink areas of 50–100%. This may stem from damage of the seal coat that protects CML surface. In general, the seal coat in Korea is exchanged every 5 years.

Hydraulic capacity reduction (HCR) analysis

Figure 4 plots the results of hydraulic capacity reduction analysis using CIP. The pipe samples used were installed before 1985 in Korea, and there is no clear tendency between HCR and installation year. Because it probably is the site-specific characteristics on the distribution pipelines.

Correlation of corrosive water quality and inner status in pipe

Table 4 shows the correlation of inner status in pipe and corrosive water quality. Results reveal that pH is correlated with CML-N negatively, indicating that CML-N showed a downward trend on pH. Also, the correlation between HCR and water quality shows that none of water quality factors is correlated with HCR. However, pipe diameter is correlated with HCR negatively, indicating that HCR displayed a downward trend on pipe diameter. Consequently, according to the results of multiple regression the main water quality factor affecting HCR and CML-N is pH.

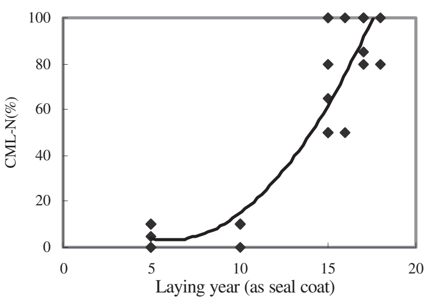

Figure 3 Phenolphthalein test using CML-DCIP

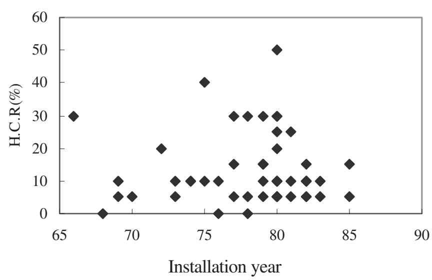

Figure 4 Hydraulic capacity reduction analysis using CIP

Table 4 Correlation of inner status in pipe and water quality

Type	Items	pH	Alkalinity	Hardness	Calcium	Conductivity	Chlorine residual	Chloride	Sulfate
CIP	H.C.R.	0.236	0.153	0.147	0.154	0.227	0.028	0.096	0.203
	Pipe dia.	–0.255	–0.175	–0.175	–0.176	–0.238	0.006	–0.096	–0.234
DCIP	CML-N	–0.363*	–0.049	–0.033	–0.050	–0.138	0.011	–0.033	–0.077

* Correlation is significant at the 0.05 level (2-tailed)

Figure 5 and Figure 6 show the photographs of SEM scanning for DCIP of 1993 and CIP of 1970, respectively. The CIP was rehabilitated by epoxy resin lining in 1987 and had quantitatively and qualitatively more corrosion product compared to DCIP.

Prediction of roughness growth rates (RGR)

Figure 7 displays the results of RGR prediction with respect to different water resources. Especially, the RGR result of Dongbok lakes reveals higher aggressive water characteristics compared to Han and Nakdong river, predicting 0.23 mm/year.

Corrosion rates

Figure 8 and Figure 9 plot the relationship between corrosion rates and installation year and pipe diameter. The results reveal that the corrosion rates are mainly controlled by the aging pipes and smaller diameter.

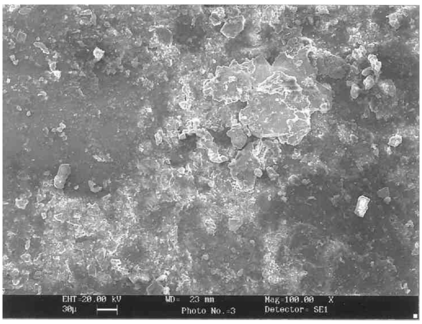

Figure 5 Photograph of SEM scanning of DCIP ('93)

Figure 6 Photograph of SEM scanning of CIP (70)

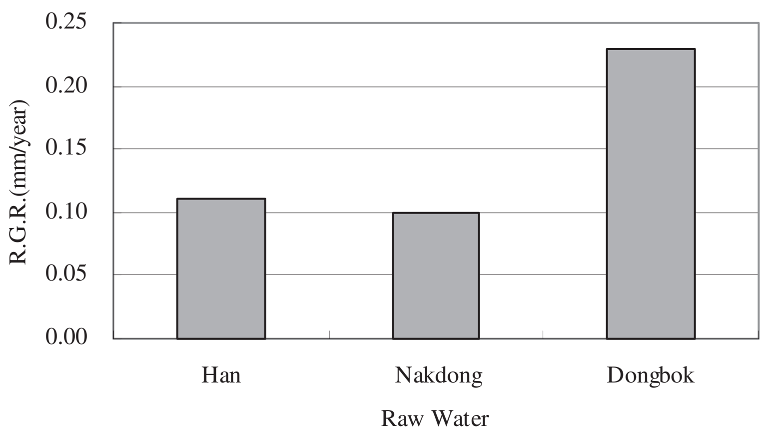

Figure 7 Prediction of roughness growth rate with respect to Han and Nakdong river, and Dongbok Lake

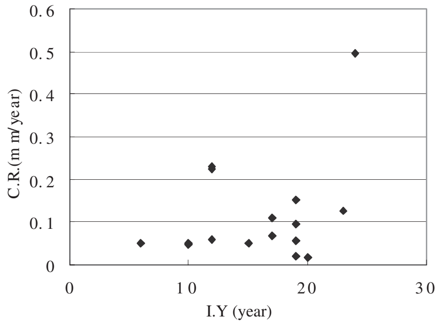

Figure 8 Relationship between corrosion rate and installation year

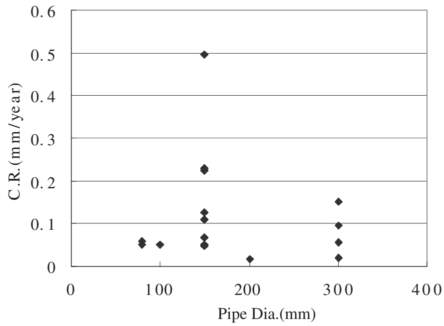

Figure 9 Relationship between corrosion rate and pipe diameter

Conclusions

As the internal corrosion problem is becoming one of the important issues in Korea, the current study was conducted for three different water resources in order to identify and predict their characteristics. Particularly, the water taken from the lakes as raw water may be more aggressive compared to rivers with respect to LI and CCPP. However, LR is not showing an apparent difference between river and lake water resources. The significant seasonal variations of corrosivity indices are not displayed for different water resources. The optical analysis data on pipe and onsite water quality data, which is serviced by water treatment plants was used to investigate the water quality factors affecting cement mortar lining neutralization (CML-N) for CML-DCIP and hydraulic capacity reduction for CIP. Results show that pH is correlated with CML-N negatively, indicating that CML-N shows a downward trend on pH. However, it requires further study to fully understand internal corrosion complexes and aggressive corrosive water characteristics.

Acknowledgement

This research was supported by a grant (code 4-2-1) from Sustainable Water Resources Research Center of 21st Century Frontier Research Program.

References

AWWA Research Foundation (1996). "Internal Corrosion of Water Distribution Systems, Second Edition".

Chung, W.S. (2001). Evaluation Model of Pipe Deterioration and Determination Model of Optimal Rehabilitation Time for Water Distribution systems, Dissertation of the Requirements for the Degree of Doctor of Philosophy, University of Seoul.

Kwak, P.J., Lee, H.D. and Nam, S.H. (1997). Evaluation on the Aggressivity of Drinking Water for Corrosion Control in Water Distribution System, *Jour. of the Korean Society of Water and Wastewater*, **11**(1), 53–63.

Kwak, P.J., Lee, H.D. and Nam, S.H. (2001). The Characteristic Properties of Corrosivity and Metal Release on Water Quality with Water Resources, *Jour. of Korean Society of Environmental Engineers,* **23**(7), 1195–1203.

Lamont, P.A. (1981). Common Pipe Flow Formulas Compared with the Theory of Roughness, *Jour. of American Water Works Association*, **73**(5), 274–280.

Langelier, W.F. (1936). The Analytical Controled Anti-Corrosion Water Treatment, *Jour. of American Water Works Association*, **28**(10), pp. 1500.

Langelier, W.F. (1946). Chemical Equilibria in Water Treatment, *Jour. of American Water Works Association*, **38**(2), pp. 169.

Lee, H.D., Bae, C.H., Park, J.H., Chung, W.S. and Kwak, P.J. (2001). Evaluation of Water Quality Characteristics Effects on the Internal Corrosion of Galvanized Steel Service Pipe in the Building, *Jour. of Korean Society on Water Quality*, **17**(5), 627–625.

Lee, H.D., Jung, H.R., Kwak, P.J. and Chung, W.S. (2000). The Effect of pH and Alkalinity Adjustment on

Internal Corrosion Control and Water Quality in Drinking Water Pipelines, *Jour. of Korean Society of Environmental Engineers*, **22**(4), 661–669.

Leroy, P., Schock, M.R., Wagner, I. and Holtschulte, H. (1996). Cement-Based Materials, Internal Corrosion of Water Distribution Systems, 2nd Ed. Edited by AWWARF, and DVGW-TZW.

Rossum, J.R. and Merrill, D.T. (1983). An evaluation of the calcium carbonate saturation index, *Joural of American Water Works Association*, **75**(2), 95–100.

Seo, G.H., Lee, H.D., Chung, W.S. and Gee, C.S. (1998). Characteristics of Water Quality Parameters on Enhancing and Inhibiting Corrosion in Water Distribution System, *Jour. of Korean Society of Environmental Engineers*, **20**(8), 1151–1160.

Sharp, W.W. and Walski, T.M. (1988). Predicting Internal Roughness in Water Mains, *Journal of the American Water Works Association*, **80**(11), 34–40.

Voyles, C.F. (1984). Determining Internal Corrosion Potential in Water Supply Systems, *Jour. AWWA*, **67**(8), 83–88.