United States
Environmental Protection
Agency

Municipal Environmental
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-84-065 Apr. 1984

EPA

Project Summary

Seattle Distribution System Corrosion Control Study: Volume II. Tolt River Water Pilot Plant Study

Carlos E. Herrera and Brian P. Hoyt

The Seattle, Washington, Water Department conducted a 6-month pilot plant study of corrosion control of Tolt River water through treatment with (1) lime and sodium carbonate, (2) lime and sodium bicarbonate, and (3) lime, sodium bicarbonate, and silicate. Continuous-flow pipe coupon tests were conducted to determine corrosion rates, penetration rates, and corrosion types for copper, galvanized steel, and black steel pipes. Metal leaching tests were conducted using small-diameter pipes.

Results showed that using lime and sodium carbonate, lime and sodium bicarbonate, or lime, sodium bicarbonate, and silicate will significantly reduce corrosion in home plumbing systems. Copper and galvanized steel showed the following respective corrosion rate reductions: 85% and 24% with lime and sodium carbonate, 85% and 43% with lime and sodium bicarbonate, and 83% and 49% with lime, sodium bicarbonate, and silicate. Metal-leaching tests showed that all the treatments significantly reduced lead, zinc, and copper levels in water. As a result of this pilot study, lime and sodium carbonate treatment is recommended for both the Tolt and Cedar River water supplies at an average dosage of 1.7 mg/L CaO. This dose should achieve an average distribution system pH of 7.45 and 7.9 and an alkalinity of 14 and 18 mg/L $CaCO_3$, respectively.

The Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Corrosion-related problems have plagued water supply customers in the Seattle, Washington, area for many years. Customer complaints of rusty water, fixtures stained red and blue, and metallic tastes are common. Furthermore, hot water galvanized and copper pipes have an expected life of only 25 years in this system. Levels of lead, copper, and iron in overnight-standing tap water are also a concern, since they frequently exceed limits defined by the National Interim Primary Drinking Water Regulations and the National Secondary Drinking Water Regulations. High levels of cadmium and zinc are also found after overnight standing in home plumbing, but they rarely exceed Federal limits. Though the health impact of such high metal levels poses no acute problem, exposure should be reduced whenever possible.

This corrosion of plumbing and the associated degradation in water quality has been a major concern of the Seattle Water Department (SWD) for many years. This project is the result of a 1975 study commissioned by the SWD to analyze the corrosion problem and to recommend possible solutions. The earlier study confirmed the existence, causes, and impacts of corrosive water, and it identified alternative measures for reducing the corrosiveness. The purpose of this project was to determine which of three suggested treatments was most effective in controlling plumbing corrosion caused by water from the Tolt River water supply system.

Description of the Tolt Supply System

Basic Characteristics

The SWD serves an averageof 161 million gallons per day (MGD) of high quality water to nearly 1 million people in the greater Seattle area. The water originates in the Cascade Mountains from two sources — the Cedar and Tolt Rivers. The watersheds are well protected, and the water requires only disinfection with gaseous chlorine to meet Federal standards.

The Tolt River water supply system was developed in 1964 and serves about one-third of the greater Seattle area. The remaining two-thirds is supplied by the Cedar River system. Because these mountain waters are composed predominantly of rainfall and snowmelt runoff, they are very soft and tend to be highly corrosive to the unlined, metallic pipes in home plumbing systems.

Causes of Corrosion

The corrosiveness of Tolt water results from several related factors, including:

- *Acidity,* as indicated by low pH. (The raw Tolt water pH is approximately 6.7; after chlorination and fluoridation, pH is reduced to 5.8 to 6.2).
- *Dissolved oxygen* concentration at saturated conditions.
- *Insufficient calcium and bicarbonate alkalinity* in the water to form protective calcium carbonate films on pipe surfaces.
- *A relatively high (halogen + sulfate)/alkalinity ratio;* (halogen + $SO_4^{=}$)/alk of 2.5 that results in conditions favorable to pitting corrosion.

In 1970, three factors combined to intensify the corrosiveness of this water supply. First, the chlorine dosage at the open distribution reservoir outlets was increased to decrease the occurrence of positive bacteriological samples within the distribution system. Second, at the request of the U.S. Public Health Service, ammoniation of the water supply was stopped to enable a free chlorine residual to be maintained throughout the distribution system. This change from combined chlorination to free chlorination was implemented to provide quicker, more effective disinfection of the unfiltered water supply. The third factor was fluoridation with hydrofluorosilicic acid, which began in 1970 based on a vote of the Seattle citizens in 1968.

Internal Corrosion Study

In December 1975, the City of Seattle retained a consulting engineering firm to perform a detailed analysis of the corrosion problem and to recommend possible solutions. The Internal Corrosion Study, which included a 9-month pilot plant investigation, confirmed the corrosiveness of Seattle water, the causes of corrosion, and the impacts associated with the corrosive water; it also evaluated alternative measures to reduce the corrosiveness of the water supply. Alternative methods to reduce corrosion included changing the methods of disinfection and fluoridation, blending the water supply with ground water supplies, and adding corrosion-inhibiting chemicals.

Based on the findings of this study, an Internal Corrosion Control Management Plan was developed. Because the very low levels of mineral solids, pH, and alkalinity constitute the major causes of corrosiveness, this plan was designed to correct the natural deficiency of minerals in Seattle's water through chemical addition.

The consultant recommended water quality goals using various chemical combinations that included the addition of lime and sodium bicarbonate. The actual selection of chemical combinations and optimum dosages became the task of the Seattle Water Department.

Scope of Work

This research was performed to determine which treatment best controls plumbing corrosion caused by Tolt water — lime and sodium carbonate, lime and sodium bicarbonate, or lime and sodium bicarbonate and silicate. The scope of work included the following:

1. Determining the corrosion rates, penetration rates, and corrosion types of copper, galvanized steel, and iron pipe exposed to untreated water and to water treated with lime and sodium carbonate, lime and sodium bicarbonate, and lime, sodium bicarbonate, and silicate;
2. Predicting increases or reductions in the life of residential pipe;
3. Determining metal leaching levels from galvanized pipe, copper pipe, lead/tin and tin/antimony solder associated with each treatment; and
4. Establishing the optimal full-scale chemical dosages required for both treatments.

From May 1980 to December 1980, four continuous-flow corrosion test apparatus were operated at Seattle's Tolt Pump Station. Water used for the tests was either untreated (control) or treated with lime and sodium carbonate, lime and sodium bicarbonate, or lime, sodium bicarbonate, and silicate. This test site was chosen because it has the same water quality that is delivered to the SWD customers. The targeted water quality characteristics for the tests are presented in Table 1.

Corrosion coupon tests were used to document average corrosion rates based on weight loss, penetration rates based on pit depths, and corrosion types based on visual observations.

To evaluate the effects of treatment on the quality of overnight-standing water, SWD developed a new test method: Small-diameter pipe sections attached to the main test apparatus were used to determine copper, lead, cadmium, and zinc leaching levels from galvanized pipe, copper pipe, lead/tin solder, and tin/antimony solder.

Procedures

The pilot test apparatus consisted of a continuous-flow test unit and a metal pick-up test unit (Figure 1). The continuous-flow test unit contained four pipe segment coupons (10.2 cm long and 2.54 cm in diameter) of copper, galvanized iron, and black steel pipe. A velocity of 0.30 m/s through the pipe coupons was held stable by the use of a constant head reservoir. The coupons were removed from the test loop periodically to be cleaned and weighed. Weight loss for each coupon was calculated and plotted over time for each metal and treatment (Figure 2). Average corrosion rates were then calculated from these curves.

Results and Discussion

Treated water showed substantially lower corrosion rates than the untreated control (Table 2). Copper corrosion rates were approximately equal for the three treatments and were measured in mils per year (mpy). Treatment with lime, sodium bicarbonate, and silicate produced the lowest zinc and iron corrosion rates.

Penetration rates were determined for the black steel coupons. The coupons were split into quarters, and the pit depths were measured using either a pointed tip micrometer or a binocular microscope with a graduated fine focus adjustment. Penetration rates were then calculated in mpy based on the average of the 10 deepest pits on each specimen.

The penetration rate results were not as promising as those for corrosion rates. Average iron penetration rates for the control and for water treated with lime and sodium carbonate, lime and sodium bicarbonate, and lime, sodium bicarbonate, and silicate were 44.6, 49.1, 43.7, and 53.7 mpy,

Table 1. Targeted Water Quality for Pilot Tests

Characteristic*	Loop #1 (Control, Tolt Distribution)	Loop #2 (Lime + Soda Ash)	Loop #3 (Lime + Bicarbonate)	Loop #4 (Lime + Bicarbonate + Silicate)
pH	5.8-6.2	7.85	7.95	7.95
Alkalinity (mg/L $CaCO_3$	2.0	14.5	21	21
Chlorine Residual	0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.4
Lime dosage, CaO	0	1.5	4.5	3.5
Na_2CO_3 dosage	0	10.0	0	0
$NaHCO_3$ dosage	0	0	20.0	20.0
NaO/SiO_2 dosage (as SiO_2)	0	0	0	4

* *All characteristic measurements, except ph, are in mg/L.*

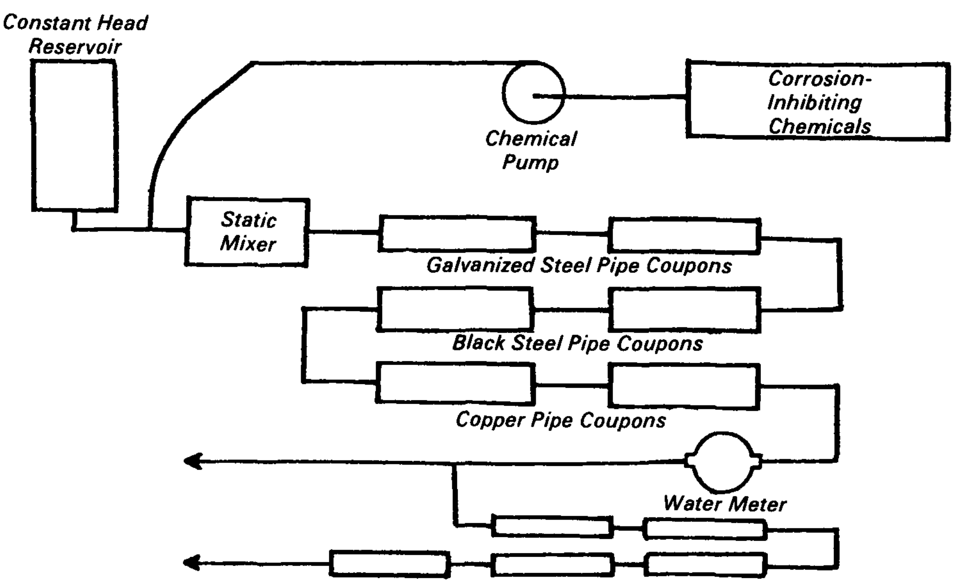

Figure 1. *Pilot plant flow schematic.*

respectively. These results demonstrated that treatment produced increases or only small reductions in penetration rates.

The metal leaching test unit consisted of 25- and 51-cm lengths of 0.635-cm-diameter pipes attached to the continuous flow test unit. The leaching pipe sections were made of copper, copper plus 50/50 lead-tin (Pb-Sn) solder, copper plus 95/5 tin-antimony (Sn-Sb) solder, galvanized steel (new), and black iron pipe. These sections were analyzed for copper, lead, zinc, cadmium, and iron leaching. Two velocities were used (0.12 m/s and 0.18 m/s) in establishing corrosion films in the metal leaching sections. The pipe sections were then periodically removed, and dissolved metals were measured in the laboratory after approximately 24-hour contract with test water.

The treatments resulted in substantial reductions of lead and copper leaching from copper pipe plus 50/50 lead-tin solder and from copper pipe plus 95/5 tin-antimony solder. Substantial reductions of zinc leaching from galvanized pipe were also realized.

Conclusions

The following conclusions have been reached for each chemical treatment alternative, based on the data in Table 3.

Lime and Sodium Carbonate Treatment

Based on a matrix analysis of alternatives, the lime and sodium carbonate treatment produced the most cost effective protection against corrosion and metal leaching. This treatment produced better reductions of zinc leaching from galvanized pipe and lead leaching from lead/tin solder than did treatment with lime and sodium bicarbonate or with lime, sodium bicarbonate, and silicate. Approximately equal reductions in copper corrosion were achieved with all three treatments (Figure 3).

Lime and sodium carbonate treatment is by far the least expensive treatment; and because both lime and sodium carbonate can be used alone for pH control, a lime and sodium carbonate system can maintain a more consistent water quality during periods of equipment breakdown.

Lime and Sodium Bicarbonate Treatment

The lime and sodium bicarbonate treatment did not produce the best results in any category; but it did produce better reductions than the lime and sodium carbonate treatment in three areas: galvanized steel corrosion rates, copper leaching from copper pipe, and lead leaching from tin/antimony solder.

Lime, Sodium Bicarbonate, and Silicate Treatment

The lime, sodium bicarbonate, and silicate treatment demonstrated the best reductions in four areas: copper leaching from copper pipe, lead leaching from tin/antimony solder, and galvanized steel and black iron corrosion rates. Although the addition of silicate produced larger reductions in the corrosion of these items, the added expense of feeding silicate is not justified.

No Treatment

Untreated (control) water samples demonstrated greater corrosion rates and metal leachate levels than did treated water except in three areas: black steel corrosion rates, and lead and cadmium leaching from galvanized pipe.

Recommendations

Results of the pilot plant test program demonstrate that lime and sodium carbonate

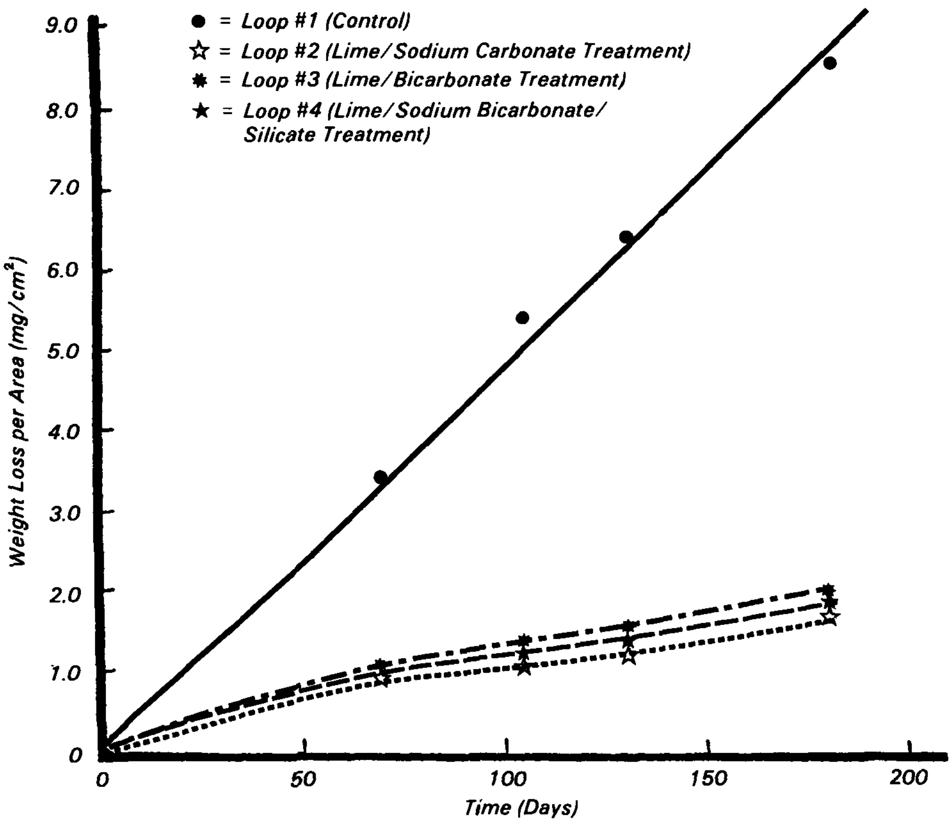

Figure 2. *Weight loss for copper coupons during the Tolt pilot plant test.*

treatment is the most appropriate chemical treatment for the Tolt water supply. This treatment is recommended for both the Tolt and Cedar River water supplies at an average dosage of 1.7 mg/L CaO. This dose should achieve an average distribution system pH of 7.45 and 7.9 and an alkalinity of 14 and 18 mg/L $CaCO_3$, respectively. Recommended chemical dosages, target water quality, and chemical costs are detailed in Table 4 for the Tolt water supply.

The full report was submitted in fulfillment of Grant No. 806686 010 by the Seattle Water Department under the sponsorship of the U.S. Environmental Protection Agency.

Table 2. *Corrosion Rates in Treated and Untreated Tolt Water*

Type of Treatment	Copper Corrosion Rate (mpy*)	Iron Corrosion Rate (mpy)	Galvanized Pipe Corrosion Rate (mpy)
Control	0.74	6.29	4.61
Lime/sodium carbonate	0.11	8.34	3.51
Lime/sodium bicarbonate	0.11	7.54	2.61
Lime/sodium bicarbonate/ silicate	0.12	5.78	2.36

* Mils per year.

Table 3. *Percent of Corrosion Reduction Produced by Treatment*

	Copper Corrosion		Copper and Solder Corrosion		Galvanized Steel Corrosion				Black Steel Corrosion	
Treatment*	Corrosion Rate by Weight Loss	Copper Leaching	Lead Leaching from Lead/Tin Solder	Lead Leaching from Tin/Antimony Solder	Corrosion Rate by Weight Loss	Zinc Leaching	Lead Leaching	Cadmium Leaching	Corrosion Rate by Weight Loss	Pitting
A	0	0	0	0	0	0	0	0	0	0
B	85	67	80	48	24	61	-105	-35	-33	-10
C	85	72	55	89	43	51	-128	-35	-20	2
D	83	78	69	99	49	38	-112	-47	8	-20

*Identification: A = Control
B = Lime/sodium carbonate
C = Lime/sodium bicarbonate
D = Lime/bicarbonate/silicate

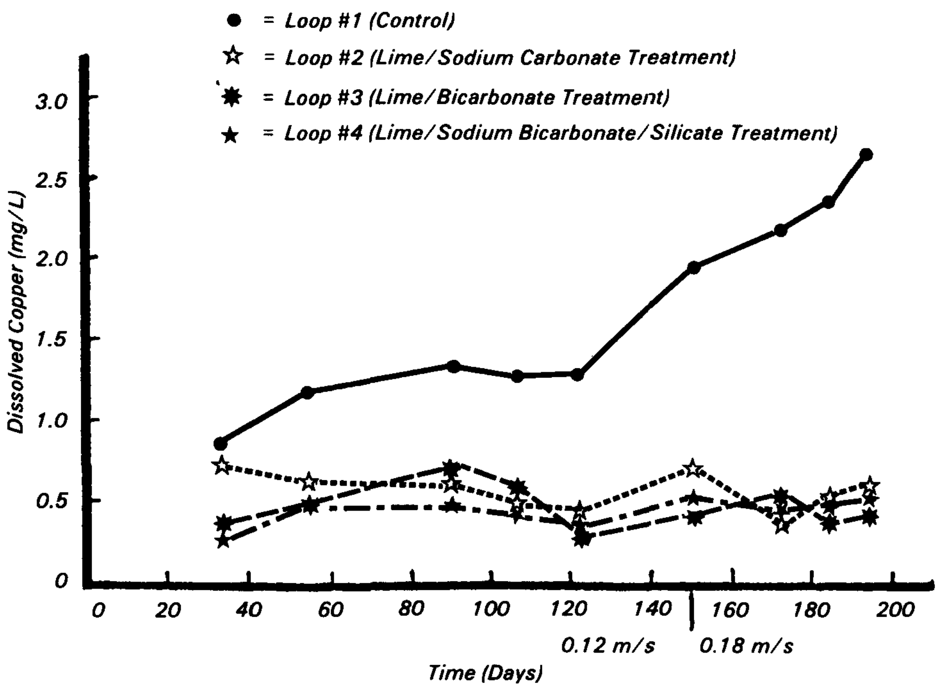

Figure 3. *Copper leaching from copper piping & 50/50 lead/tin solder during the Tolt pilot plant test.*

Table 4. *Recommended Chemical Dosages, Target Water Quality, and Chemical Costs for the Tolt Water Supply*

Item	*Present Conditions*	*With Lime Plus Sodium Carbonate Treatment*
Treatment plant CO_2	*6.0**	*0.0*
Treatment plant pH	*6.0**	*8.3*
Average total alkalinity ($CaCO_3$)	*2.5**	*14.0*
Atmospheric equilibrium pH @ 15°C	*6.95*	*7.75*
Minimum distribution pH	*5.6**	*7.45†*
Estimated average distribution pH	*5.9**	*7.85*
Average distribution conductivity	*27.0**	*42.0*
(Halogen + $SO_4^=$)/alk ratio	*2.5-5.9†*	*0.45-1.1†*
Average lime dosage (mg/L CaO)	—	*1.7*
Average sodium carbonate dosage (Na_2CO_3)	—	*9.0*
Chemical cost per year ($)	—	*147,000‡*

* *Based on SWD water quality monitoring data.*
† *By calculation.*
‡ *Based ɔn cost of chemicals delivered to the Tolt regulating basin in June 1981.*

Carlos E. Herrera and Brian P. Hoyt are with Seattle Water Department, Seattle, WA 98144.
***Marvin C. Gardels** is the EPA Project Officer (see below).*
The complete report, entitled "Seattle Distribution System Corrosion Control Study: Volume II. Tolt River Water Pilot Plant Study," (Order No. PB 84-170 810; Cost: $7.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

Official Business
Penalty for Private Use $300

MERL0063240
LOU W TILLEY
REGION V EPA
LIBRARIAN
230 S DEARBORN ST
CHICAGO IL 60604

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984-759-102/930