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Project Summary

Seattle Distribution System Corrosion Control Study: Volume IV. On-Site Evaluation of Corrosion Treatment

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The Seattle, Washington, Water Department conducted an 8-month pilot-plant study on the treatment of Tolt River water with lime and sodium carbonate to prevent pipe corrosion. Pipe loop tests were conducted with the following objectives: (1) to determine the appropriate chemical startup procedures for two full-scale corrosion treatment facilities, (2) to document the effectiveness of the corrosion treatment program in suppressing corrosion, metal leaching, and tuberculation in older, galvanized-steel premise plumbing systems, (3) to document the effects of the corrosion treatment program on bacteria in water, and (4) to anticipate any possible customer problems caused by implementing the corrosion treatment program.

The study monitored the effects of simulated corrosion treatment startup on chemical and microbiological water quality from an old galvanized plumbing system. Standing water samples collected after treatment startup displayed increased iron deposits, organic debris, and bacterial populations compared with untreated standing-water samples. Zinc leaching was reduced during treatment at pH 6 to 7 and increased at pH 7 to 8. Iron leaching increased by approximately 38% during treatment startup, whereas copper and lead leaching were reduced by 53% and 57% respectively. Corrosion treatment also reduced the tuberculation rate by about 32%.

Based on this pilot study, a full-scale corrosion treatment schedule is recommended that minimizes possible water quality problems caused by implementation. The recommended approach includes the gradual addition of lime and sodium carbonate to a final treatment pH of 8.3.

This 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

The Seattle Water Department serves an average of 161 MGD of high-quality water to nearly 1 million persons in the greater Seattle area. The water originates in the Cascades from two mountain 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 Cedar River system, developed in 1901, serves about two-thirds of the area; the remaining third is served by the newer Tolt supply. These mountain waters, which are predominantly rainfall and snowmelt runoff, are very soft and tend to be highly corrosive to the unlined metallic pipes in home plumbing systems. Corrosion of the plumbing systems and the associated water quality degradation has been a major concern of the Seattle Water Department for many years. Corrosion has caused aesthetic, economic, and health problems. This summary discusses these problems and an

Customer complaints of aesthetically undesirable rusty water, red- and blue-stained fixtures, and metallic tastes are frequently received from within the Cedar water distributrion system. These problems have been documented by accurate complaint records and by a questionnaire survey conducted by the Seattle Water Department in 1973. The survey, which was distributed to 10% of all service units within the direct service area, showed that 16.7% of customers in the Cedar water distribution system experienced corrosion-related problems.

Piping corrosion in the premise plumbing systems served by the Cedar supply also places a significant economic burden on the homeowner. The average estimated life span of hot water galvanized and copper pipes is approximately 35 years. The average annual cost forecast in 1978 for maintaining serviceability in these pipes is estimated to be approximately $4 million.

Studies performed from 1972 to 1976 demonstrate that the levels of lead, copper, and iron in overnight-standing Cedar tap water often exceed the levels defined by the National Interim Primary Drinking Water Regulations and the National Secondary Drinking Water Regulations. Cadmium and zinc also increased after standing overnight in home plumbing, but they rarely exceeded permissible levels. These metals originate from the copper and galvanized pipes and the solders used in home plumbing systems. Though the health impact of metal contaminants in overnight-standing water is not an acute problem, it is certainly desirable to reduce exposure where possible.

Causes of Corrosion

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

- *Acidity*, as indicated by low pH (the raw Cedar water pH is approximately 7.6; after chlorination and fluoridation, pH is reduced to 6.8 to 7.2);
- *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* of 0.5 to 0.8 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 systems. Second, ammoniation of the water supply was stopped at the request of the U.S. Public Health Service to enable a free chlorine residual to be maintained throughout the distribution system. This change from combined to free chlorination was implemented to provide quicker, more effective disinfection of the unfiltered water supply. The third factor to intensify the corrosiveness of the water supply was the implementation of fluoridation with hydrofluosilicic acid in 1970 after 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, and evaluated alternative measures to reduce the corrosiveness of the water supply. The latter included changing the methods of disinfection and fluoridation, blending the water supply with groundwater 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 the water's 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.

Tolt and Cedar Pilot-Plant Studies

The Tolt and Cedar pilot-plant studies were conducted in 1979-80 to define precisely the chemical treatment and dosages needed for corrosion control in both water supplies, and to document further the effects of such treatment.

These studies recommend the addition of lime only to the Cedar supply and lime plus sodium carbonate to the Tolt supply for internal corrosion control. The treatments were designed to achieve the water quality characteristics listed in Table 1.

Study Objectives and Scope of Work

The objectives of this research were as follows:

1. To determine appropriate chemical startup procedures for the Tolt and Cedar full-scale corrosion treatment facilities,
2. To document the effectiveness of the corrosion treatment program in suppressing corrosion, metal leaching, and tuberculation in older galvanized-steel premise plumbing systems,
3. To document the effects of the corrosion treatment program on bacteria in water, and
4. To anticipate any possible customer problems caused by implementing the corrosion treatment program.

From January 1981 to August 1981, tests designed to simulate corrosion treatment startup were conducted at the City of Seattle Fire Station No. 35. This test site was chosen because it contains older galvanized plumbing that experiences severe corrosion-related water quality problems. Also, the test site was located in the Tolt distribution system because the changes in water quality caused by corrosion treatment will be greater there than in the Cedar distribution system.

The corrosion tests documented the effects of corrosion treatment startup based on metal leaching, bacteriological water quality, aesthetic water quality, and pipe tuberculation. Running-water samples and 24-hr-standing samples were collected from an 8.5-m pipe loop system. The samples were collected before treatment (to establish baseline data) and during the simulated treatment startup.

Operation, Results, and Evaluation

The pilot test apparatus consisted of a chemical feeding and mixing system and a 1.9-cm-diameter old galvanized pipe test loop (Figure 1).

The pipe loop system was made from 10-year-old galvanized hot-water pipe collected from the University of Washington. When the pipe loop was installed, it was highly tuberculated. The pipe loop was 8.5 m long and contained five elbows. Pressure test gauges were located at the beginning and end of the loop to determine headloss in the loop. A flow of 10.5 L/min was maintained through the loop using a throttling valve at its end. Also at the end of the loop was a flowmeter. The throttling valve was periodically shut off to collect 24-hr-standing samples.

Table 1. Present and Proposed Water Quality Characteristics

Parameter	Present Quality of Chlorinated and Fluoridated Water: Cedar	Tolt	Proposed Water Quality After Corrosion Treatment: Cedar	Tolt
pH	6.8-7.4	5.8-6.2	7.8-8.3	7.8-8.3
Alkalinity (mg/L($CaCO_3$)/(Halogen + Sulfate))	15-18	2	20	14
Alkalinity Ratio	0.5-0.8	2.5-4.5	0.5	0.5

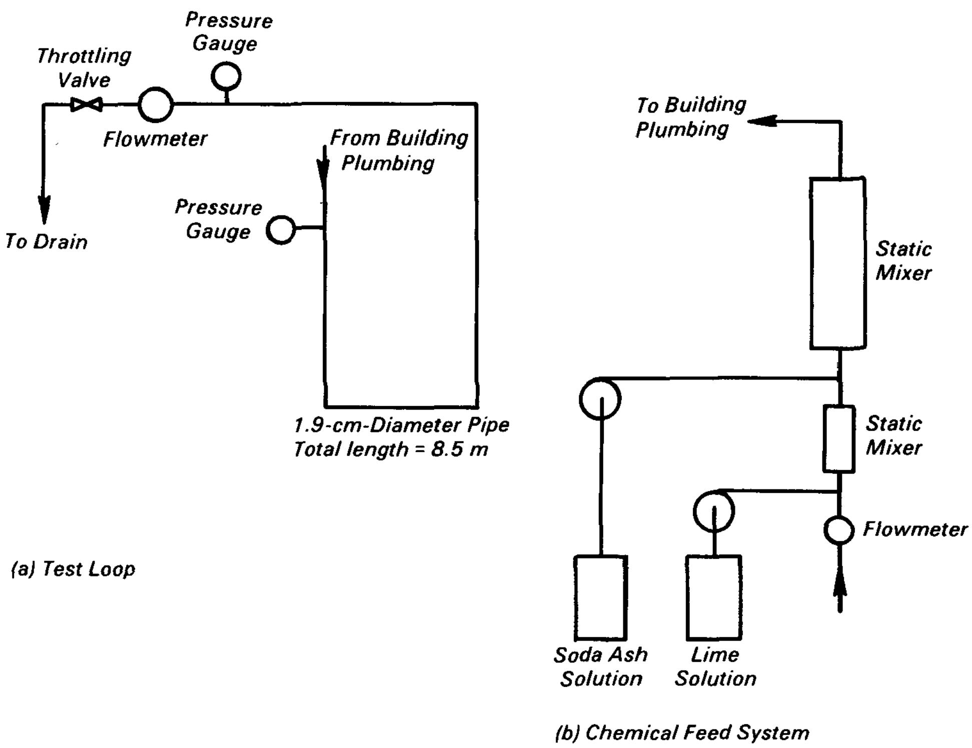

Figure 1. Pilot plant flow schematic.

The test treatment conditions were chosen to simulate average distribution system levels of pH and alkalinity during full-scale treatment startup. Target water quality for the test conditions appears in Table 2.

The effects of treatment startup were determined from standing and running samples and headloss determinations collected from the test pipe loop system. Standing water samples represented 24-hr stagnant water conditions in the pipe loop system. Running water samples were collected after a 2-min flushing of the pipe loop system at 10.5 L/min following the collection of the 24-hr standing sample. The samples were analyzed for metal concentrations, physical parameters, and microbiological quality before and after corrosion treatment. The microbiological quality of the water and pipe incrustations were examined with selective enrichment culture media and scanning electron microscopy. The chemical composition of the tubercles and suspended particulate matter in the water were determined by x-ray, energy-dispersive microanalysis. Headloss in the test pipe loop system was used as an indication of pipe blockage.

The more frequently observed water quality changes occurring in the pipe loop before and after treatment were higher bacterial plate counts in 24-hr standing water than in running water (by two to three orders of magnitude), increased levels of iron concentrations, turbidity, and apparent color in the standing water as opposed to running water.

Standing-water samples collected after treatment startup displayed increased iron deposits, organic debris, and bacterial populations compared with untreated standing-water samples. Iron-oxidizing and sulfate-reducing organisms were shown to exist within the pipe loop system in both the standing water and tubercular incrustations. Opportunistic pathogens and coliform antagonists (including *Pseudomonas* and *Flavobacterium*) were detected in standing-water samples and increased in number with treatment startup. The public health significance of sissile microbial communities in drinking water was also considered.

In standing water, zinc leaching decreased during treatment at pH 6 to 7 and increased at pH 7 to 8. Iron leaching increased by approximately 38% during treatment startup, whereas copper and lead leaching decreased by 53% and 57% respectively.

In running water, reductions occurred in zinc and iron leaching during treatment startup, and significant change was noted in lead or cadmium leaching.

Corrosion treatment reduced the tuberculation rate and subsequent pipe blockage by about 32%.

Conclusions

A full-scale corrosion treatment schedule (Table 3) based on the test results was recommended to minimize possible water quality problems caused by the implementation of corrosion treatment. The recommended approach was first to add lime and sodium carbonate gradually to the Tolt supply until the pH equals that of the Cedar supply and then simultaneously to add lime to the Cedar supply and sodium carbonate to the Tolt supply to a final treatment pH of 8.3.

The full report was submitted in fulfillment of Grant No. R806686 010 by the Seattle Water Department under the sponsorship of the U.S. Environmental Protection Agency.

Table 2. *On-Site Test Treatment Conditions*

Item	Phase I	Phase II	Phase III	Phase IV
pH	6.00	7.00	7.60	8.00
Alkalinity (mg/L $CaCO_3$)	2.0	9.0	8.0	14.0
Lime Dosage, CaO (mg/L)	0	0	2.00	1.70
Na_2CO_3 Dosage (mg/L)	0	7.42	6.40	9.00

Table 3. *Corrosion Treatment Plant Startup Procedure for Tolt and Cedar Supplies*

	Total				Cedar		
Day	Lime Dosage (mg/L CaO)	Sodium Carbonate Dosage (mg/L Na_2CO_3)	pH	Alkalinity (mg/L $CaCO_3$)	Lime Dosage (mg/L CaO)	pH	Alkalinity (mg/L $CaCO_3$)
1	0.8	0	6.3	3.4	0	7.2	16
8	1.7	0	6.6	5.0	0	7.2	16
15	1.7	4.0	7.1	8.8	0	7.2	16
29	1.7	6.0	7.5	10.7	1.0	7.5	17.8
42	1.7	9.0	8.3	13.5	1.7	8.3	19.0

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The complete report, entitled "Seattle Distribution System Corrosion Control Study: Volume IV. On-Site Evaluation of Corrosion Treatment," (Order No. PB 83-241 729; Cost: $11.50 subject to change) will be available only from:
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