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Project Summary

Seattle Distribution System Corrosion Control Study: Volume V. Counteractive Effects of Disinfection and Corrosion Control

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This study is the fifth in a series of corrosion control studies in the Seattle, Washington, water distribution system. The present project consisted of three research phases designed to evaluate the counteractive effects of corrosion treatment (pH adjustment) and disinfection. These phases consisted of (chlorination)/electrochemical tests, onsite treatment tests, and bacteriological tests. In the electrochemical tests, copper corrosion rates were measured under varying pH, free chlorine residuals, and chloride concentrations using a rotating disc electrode and linear potential sweep technique with solution resistance compensation. The onsite treatment tests monitored the effects of simulated corrosion treatment startup on chemical and microbial water quality from an old galvanized plumbing system. The bacteriological tests determined the survival of *Pseudomonas aeruginosa, Escherichia coli,* and *Enterobacter aerogenes* under varying pH and free chlorine residuals.

The results of the electrochemical tests showed that copper corrosion rates increased about 70% when free chlorine residuals were increased from 0 to 1.0 mg/L. These results indicate that increases in chlorine dosages may offset the corrosion reduction benefits realized with pH adjustment.

In the onsite treatment tests, standing water samples collected after treatment startup had larger bacterial populations than the untreated standing water samples. Iron-oxidizing and sulfate-reducing organisms were found in both 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 results of the bacteriological tests showed a slower death rate at pH 8 for all three bacteria than at pH 7 or 6. But 100% mortality was achieved at all pH values tested for all three species with a free chlorine residual of 0.2 mg/L or less and 1 min of contact time. The Seattle Water Department's present chlorination practices should therefore be sufficient to provide adequate disinfection at increased pH.

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 people 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 comes from 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 three types of problems — aesthetic, economic, and health. This summary discussed these problems and the approach to reducing corrosion in the distribution area.

Customer complaints of aesthetically undesirable rusty water, red and blue stained fixtures, and metallic tastes are frequently received from within the Cedar water distribution system. This problem has 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 services 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 and Tolt supplies 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 in the Cedar system and 25 years in the Tolt system The average annual cost in 1978 for maintaining serviceability in these pipes was about $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 were also found to increase after overnight standing in home plumbing, but they rarely exceeded their limits. These metals originate from the copper and galvanized pipes and the solders used in home plumbing systems. Although the health impact of metal levels from overnight standing water is not an acute problem, it is certainly desirable to reduce exposure wherever 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 only 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; and
- *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, to decrease the occurrence of positive bacteriological samples within the distribution system, the chlorine dosage at the open distribution reservoir outlets was increased. 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. And third, as the result of a 1968 vote of the Seattle citizens, fluoridation of the water supply with hydrofluorosilicic acid began in 1970.

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 it 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 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 waters' 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. He also suggested that because of the addition of these chemicals, chlorine dosages might need to be increased to provide adequate disinfection. 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 and 1980 to define a precise chemical treatment and dosages needed for corrosion control in both water supplies, and to document further the effects of such treatment.

These studies recommended 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 to:

1. Document the effects of the free chlorine residual on corrosion rates.
2. Determine whether chlorine dosages should be increased to provide adequate disinfection when pH adjustment is implemented.
3. Document the effects of the corrosion treatment program on bacteria in the water.

The study was divided into the following research phases:

Electrochemical Tests

Corrosion rates were determined electrochemically for copper in Cedar River water under various pH, free chlorine residuals, and chloride concentrations to determine the effects of chlorination on corrosion rates. Corrosion rates were determined with (1) a standard linear potential sweep method modified to include positive feedback compensation for

Table 1. Present and Proposed Water Quality Characteristics

Parameter	Present Quality of Chlorinated and Fluoridated Water		Proposed Water Quality After Corrosion Treatment	
	Cedar	Tolt	Cedar	Tolt
pH	6.8-7.4	5.8-6 2	7.8-8 3	7.8-8.3
Alkalinity (as mg/L $CaCO_3$)	15-18	2	20	14
(Halogen + sulfate)/ alkalinity ratio	0.5-0.8	2.5-4.5	0.5	0.5

potential drop resulting from solution resistance, and (2) a rotating disc electrode to eliminate mass transport limitations.

Onsite Corrosion Treatment Tests

During the period January 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 contained older galvanized plumbing that experiences severe corrosion-related water quality problems. Also, the test site was located in the Tolt distribution system, where the changes in water quality caused by corrosion treatment would be greater than in the Cedar distribution system.

Microbiological Laboratory Tests

Microbiological laboratory tests were conducted to determine whether chlorine dosages should be increased upon implementation of corrosion treatment. The tests measured the effects of various pH and free chlorine residuals on the survival of *Pseudomonas aeruginosa, Escherichia coli,* and *Enterobacter aerogenes.* The tests were conducted at three free chlorine residuals and three pH values.

Results and Conclusions

Electrochemical Tests

The electrochemical tests demonstrated that chlorination (using either NaOCl or Cl_2) substantially increases copper corrosion rates. A 1.0-mg/L free chlorine residual increased corrosion rates by approximately 20%. Also, for free chlorine concentrations greater than 0.2 mg/L, the corrosion rate at pH 8 was about equal to the corrosion rate at pH 7. Although previous studies have shown that substantial corrosion reduction can be achieved by treatment to pH 8.0, the electrochemical test results indicate that increases in chlorine dosages would diminish the benefits received by pH adjustment.

Onsite Corrosion Treatment Tests

The changes that occur in overnight standing and running water quality at the customer's tap with corrosion treatment vary depending on the parameter under consideration.

Assessment of the effects of corrosion treatment on bacteriological water quality showed the standard plate counts from treated, 24-hour standing water were two to three orders of magnitude higher than those from the untreated standing water samples. Standing water samples collected after treatment began also displayed increased iron deposits and organic debris, compared with untreated standing water samples. Iron-oxidizing organisms (e.g., *Gallionella*) and sulfate-reducing organisms (e.g., *Desulfovibrio*) existed within the pipe loop system in both the standing water and tubercular incrustations. Both of these organisms increased with corrosion treatment. Stalk- or bud-producing microorganisms (e.g., *Caulobacter* spp., or iron-precipitating bacteria) were observed in the water samples and attached to the surface of (or embedded in) the tubercles. *Pseudomonas aeruginosa* counts increased 47% in standing water samples during corrosion treatment. Opportunistic pathogens and coliform antagonists (including *Pseudomonas* spp. and *Flavobacterium* spp.) were detected in standing water samples, and they increased in number with treatment startup. Opportunistic pathogens accounted for approximately 77% of the total standard plate count isolates in 24-hour standing water samples, and coliform antagonists accounted for approximately 71%.

In running water, reductions occurred in zinc and iron leaching during treatment startup. No appreciable change occurred in lead or cadmium leaching, apparent color, and turbidity concentrations in running water.

In standing water, zinc leaching decreased during treatment at pH 6 to 7 and increased at pH 7 to 8. Iron leaching increased by about 35% during treatment startup, and copper and lead leaching were decreased 53% and 57%, respectively. Also, apparent color and turbidity increased in standing water during treatment startup.

Microbiological Laboratory Tests

The results of the microbiological laboratory tests indicate that the Seattle Water Department will not need to increase chlorine dosages to provide adequate disinfection when corrosion treatment is implemented. At pH 8 and 0.2 mg/L free chlorine residual, 100% kill was achieved for *P. aeruginosa* and *E. coli* with contact times of less than 2 min. The Seattle Water Department chlorination program, which maintains a free chlorine residual of 0.6 mg/L for a minimum contact time of 10 min will therefore provide a safety factor sufficient to ensure adequate disinfection at pH 8.0.

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The complete report, entitled "Seattle Distribution System Corrosion Control Study: Volume V. Counteractive Effects of Disinfection and Corrosion Control," (Order No. PB 84-169 747; Cost: $17.50, subject to change) will be available only from:
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