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Project Summary

Biologically Mediated Corrosion and Water Quality Deterioration in Distribution Systems

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Research was conducted to evaluate biologically mediated corrosion and deterioration of water quality in municipal water distribution systems. The investigation included (1) a national questionnaire survey of water utilities, (2) an in-depth evaluation of five Missouri water supply systems, (3) a 1-year study of nine water distribution systems across the country, (4) fabrication of a pipe manifold system to monitor and study water quality changes and microbiological growths in the laboratory, (5) construction of a laboratory-scale pipe loop study to simulate a water distribution system and study water quality changes and corrosion, (6) studies of biologically mediated corrosion in a batch reactor system, and (7) an evaluation of cast iron corrosion control using polyphosphate formulations.

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 quality of water leaving water treatment plants in most municipalities meets the federal standards set for drinking waters. Often substantial degradation occurs in the water quality while water is being transported through the distribution system to the consumer. This deterioration in water quality results in common nuisances such as iron staining of laundry and porcelain fixtures, unpleasant tastes and odors, and the presence of sediments in drinking water. Many of these quality changes can be brought about by the activity of microorganisms. The present study investigated the biologically mediated water quality changes in actual and simulated water distribution systems.

Scope

The research program had the following specific objectives: (1) to determine the extent and nature of water quality problems originating in water distribution systems in the United States, (2) to conduct laboratory studies to assess the potential for a treated water to promote sediment deposition and microbiological growth in the simulated distribution systems, (3) to determine the role of microorganisms in mediating chemical changes observed in distribution systems, (4) to determine remedial measures for controlling sediment deposition, organism growth, and quality deterioration, and (5) to prepare a guideline document for use by water utilities for assessing and controlling water quality problems in distribution systems.

Results and Conclusions

1. A survey conducted to determine the extent and nature of water quality problems in distribution systems in the United States indi-

cated that 60% of the responding utilities reported taste and odor to be their most common water quality problems. So-called red water ranked second, with 47.7% of the utilities reporting this problem. Complaints of cloudy and black water were, respectively, the next two most frequently cited water quality problems. These responses indicated that regardless of water source, utility size, or geographical location, virtually every utility periodically experiences some water quality problem that originates in its distribution system.

2. Evaluations of distribution system water quality in five Missouri communities indicated that the most frequently observed water quality changes included the loss of chlorine residuals, decreases in dissolved oxygen concentrations, increases in iron concentration, and increase in hydrogen sulfide concentrations without significant changes in sulfate ion concentrations. Higher bacterial plate counts were generally observed at locations where consumers reported water quality problems. Higher standard plate counts (SPC) were also associated with low chlorine residuals. With the use of selective enrichment culture media, a variety of microorganisms were isolated from these distribution systems. They included sulfate-reducing, sulfate-oxidizing, iron-precipitating, nitrogen-fixing, nitrifying, denitrifying and stalk-producing microorganisms. These microorganisms belong to groups that can transform carbon, nitrogen, sulfur, and iron as part of their microbiotic cycles. Water quality changes can thus be influenced and mediated by organisms indigenous to these water distribution systems.

3. An additional 1-year study of water quality data from nine water distribution systems throughout the United States confirmed some of the observations made from the Missouri water distribution system studies. The systems studied were Tacoma, WA; Chicago, IL; Springfield, IL; Champaign, IL; Durham, NC; Columbia, MO; Tampa, FL; Minneapolis, MN; and Sioux Falls, SD.

4. The analysis of hydrant flushing samples from 12 utilities throughout the United States indicated that samples that had low turbidity and low total and volatile solids had few organisms as measured by SPC and on R-2A plates. Samples that were turbid and brown showed positive results for most of the microbiological enrichment culture tests They also exhibited high concentrations of total solids and total iron. Many of the samples showed the presence of sulfate-reducing bacteria. In most samples analyzed, the diluted SPC media developed more colony growth compared with R-2A media.

5. The results of studies using a pipe manifold system to simulate a water distribution system showed that the microbial growth on pipes are related to TOC levels in the water. TOC levels of 5.0 mg/L and less limit the amount of microbial growth in pipe manifold systems. The addition of chlorine reduced the accumulation of microbial growth. Free chlorine residuals of 1.0 mg/L and higher suppressed microbial growth significantly. Chloramine doses in the range of 1 to 2 mg/L were not as effective.

The presence of methane in source water stimulates microbial growth. Methane concentrations of about 9 to 13 mg/L in the influent water increased the amount of microbial growth in the system markedly. Studies of the effect of pipe materials on sediment accumulation and biological growth on the pipe surfaces showed that steel pipes developed the largest amount of attached sediment compared with PVC or copper pipes. The major portion of the accumulation on steel pipes was nonfilterable, inert residue. Despite less accumulation on PVC and copper pipes, bacterial plate count data indicated that a comparable number of microoganisms existed in the sediments of all pipe materials. Thus the potential for microbiologically mediated reactions may be equal in all three pipe materials. Bacterial plate counts of materials accumulated on pipe surfaces indicated that neither chlorine nor chloramine residuals prevented microorganisms from accumulating within the sediments attached to the pipe surface. This result may be especially important to understanding how microbial processes can proceed in water mains, even where low bacterial counts and sufficient disinfectant residuals are observed in samples of the bulk water.

6. Laboratory-scale PVC and steel pipe loop systems were used to simulate piping in water distribution systems. The oxidation of iron metal in the pipe loops was primarily responsible for contributing iron to the water. The oxidation of the iron in turn contributed to the depletion in dissolved oxygen.

The TOC concentration in water was important in estimating the potential capacity for organism growth in the pipe loop system. Since the influent test water contained exceptionally small amounts of TOC (0.5 mg/L), relatively little microbial activity was observed. Bacterial plate counts of water were generally low when they were enumerated according to standard methods. Higher plate counts were obtained when the organisms were incubated at a lower temperature (25°C) or for an extended incubation period (7 days). As with earlier field survey experiments, a wide variety of physiologically different populations of microorganisms were observed in the pipe loop systems. An evaluation of the effect of microbial growth on the corrosion rate of cast iron and steel pipe in the loop system was inconclusive.

7. Batch culture corrosion studies of cast iron test specimens exposed to pipe loop water indicated that dissolved oxygen was the most important controlling parameter in iron oxidation. The relative effect of oxygen on the corrosion rate of cast iron exposed to tap water was much greater than any other influence, including that of microbial activity. The corrosion intensity of cast iron after 26 days of exposure to an aqueous system with more than 7 mg/L dissolved oxygen was found to be about 2000 mg per square decimeter (dm^2), whereas in a system with less than 2 mg/L dissolved oxygen, the cast iron corrosion intensity was only 200 mg/dm^2. In the presence of microorganisms, the corrosion intensity of cast iron test specimens increased to about

500 mg/dm[2] for specimens exposed to pipe loop water for 26 days. Visual evidence of localized corrosion on cast iron specimens in the presence of microorganisms was clearly evident in this study. A major influence of microorganisms in water distribution systems appears to be that of promoting localized pits on pipe surfaces. Decreases in alkalinity were observed in all cast iron corrosion tests, possibly as a result of the formation of ferrous carbonate from oxidized iron and bicarbonate ions present in the system.

8. The results of batch tests to determine the effectiveness of hosphate compound (sodium metaphosphate, sodium hexameta phosphate, and zinc polyphosphate) additions to water supplies for corrosion control showed that these compounds did not effectively decrease the corrosion rate of cast iron in a galvanic test system (both under unsaturated and super-saturated conditions with respect to calcium carbonate) until a sufficient amount of phosphate (greater than 20 mg/L as P_2O_5) had been added. In nongalvanic test systems, zinc polyphosphate did not decrease cast iron corrosion rates until the phosphate dosage was greater than 10 mg/L as P_2O_5. The corrosion rate of cast iron at a polyphosphate dosage of 20 mg/L as P_2O_5 can be reduced by increasing the total alkalinity, pH, and calcium concentration, as well as by decreasing the concentration of dissolved oxygen. In continuous test flow systems, a polyphosphate dosage of 20 mg/L decreased the cast iron corrosion by about 56%, whereas a dosage of 10 mg/L as P_2O_5 produced no corrosion inhibition after an exposure period of 28 days. Conventional corrosion indices such as Langelier's saturation index and Ryznar's stability index were unable to indicate the $CaCO_3$ deposition or dissolution tendencies of phosphate-enriched waters, since the equilibrium chemistry of the phosphate-enriched water is different from that of the natural bicarbonate-buffered water. Addition of zinc polyphosphate at a concentration of 10 and 20 mg/L as P_2O_5 increased biological growths (as indicated by standard plate counts) up to 80 times as much as the untreated control. In both cases, a slight dissolved oxygen reduction was observed in the phosphate-enriched systems. In actual distribution system management, additional chlorine residuals may be needed to control microbiological growth caused by phosphate additions to water distribution systems.

Reports Based on This Research

The following publications were based on research conducted under this grant:

Banerji, S. K., Knocke, W. R., Lee, S. H., and O'Connor, J. T., "Biologically Mediated Water Quality Changes in Water." Proceedings, American Water Works Assoc. Annual Conference, Part 1, 1977.

Lee, S. H., O'Connor, J. T., and Banerji, S. K., "Biologically Mediated Deterioration of Water Quality in Distribution Systems." Proceedings, American Water Works Assoc. 5th Annual Water Quality Technology Conference, Kansas City, MO, December 1977.

Banerji, S. K., "Water Quality Deterioration in Mains." Journal of the Missouri Water & Sewage Conference, pp 46-56, 1978.

Lee, S. H., O'Connor, J. T., and Banerji, S. K., "Biologically Mediated Corrosion and Water Quality Distribution Systems." Proceedings, American Water Works Assoc. 7th Annual Water Quality Technology Conference, Philadelphia, PA, pp 137-166, 1979.

Lee, S. H., O'Connor, J. T., and Banerji, S. K., "Biologically Mediated Corrosion and Its Effects on Water Quality in Distribution Systems." Journal of the American Water Works Assoc., Vol. 72, pp 636-644, 1980.

Prahash, T. M., Banerji, S. K., and O'Connor, J. T., "Development of a Pipe Manifold System for Monitoring Water Quality in Water Distribution Systems." Proceedings, American Water Works Assoc. Annual Conference, Part 1, 1982.

Banerji, S. K., O'Connor, J. T., and Huang, D. J. S., "Polyphosphate Additions for Corrosion Control in Water Distribution Systems." Proceedings, ASCE National Conference on Environmental Engineering, Boulder, CO, pp 97-109, 1983.

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***Eugene W. Rice** and **Raymond H. Taylor** are the EPA Project Officers (see below).*

The complete report, entitled "Biologically Mediated Corrosion and Water Quality Deterioration in Distribution Systems," (Order No. PB 84-157 494; Cost: $32.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

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