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Project Summary

Seattle Distribution System Corrosion Control Study: Volume III. Potential for Drinking Water Contamination from Tin/Antimony Solder

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This study was conducted to evaluate the potential leaching of metals into drinking water from tin/antimony solder. The study consisted of five research steps: (1) An investigation of the theory of corrosion products that formed from the solder was conducted using pe-pH diagrams and galvanic coupling relationships, (2) static laboratory metal leaching tests were performed to determine the extent of antimony leaching from the solder, (3) field water samples were taken from buildings that contained tin/antimony soldered plumbing, (4) continuous-flow metal leaching tests were used to compare metal leaching from tin/antimony solder with lead/tin solder under three water treatments (lime plus sodium carbonate, lime plus sodium bicarbonate, and lime plus sodium bicarbonate plus silicate), and (5) corrosion films that formed on both tin/antimony and lead/tin solder were analyzed by scanning electron microscopy and X-ray diffraction.

The results indicate that increases in metal concentrations resulting from the corrosion of tin/antimony solder are minimal. Metal leaching from the solder is inhibited by the sacrificial corrosion of tin and the formation of a stable, double-layer tin passivation film (SnO and SnO_2). Side-by-side tests comparing metal leaching from tin/antimony with that from lead/tin solders show substantial reductions in standing water lead concentrations when tin/antimony solder is used.

The use of tin/antimony solder in place of lead-based solders should result in reduced human exposure to lead from drinking water with only minimal increases in antimony exposure.

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 (SWD) serves an average of 161 mgd of high quality water to a population of more than 1 million 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 state requirements 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.

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

- *Acidity*, as indicated by low pH (after chlorination and fluoridation, pH is reduced to a range of 6.8 to 7.2 for the Cedar supply and 5.8 to 6.2 for the Tolt supply);
- *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* that indicates conditions favorable to pitting corrosion.

In 1970, three factors combined to intensify the corrosiveness of the water supplies. 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, 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 chlorination to free chlorination was implemented to provide quicker, more effective disinfection of the unfiltered water supply. The third factor that increased corrosiveness was the initiation of flouridation with hydrofluorosilicic acid in 1970.

Corrosion of the plumbing systems and the associated water quality degradation has been a major concern of the SWD for many years. Studies performed from 1972 to 1976 demonstrate that the levels of lead, copper, and iron in overnight standing tap water often exceed the maximum contaminant levels defined by the National Interim Primary and Secondary Drinking Water Regulations. Cadmium and zinc were also found to increase after overnight standing in home plumbing, but they rarely exceeded their maximum levels. 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 accute problem, it is certainly desirable to reduce exposure where possible.

The use of lead-based solders to join copper pipe can create a problem with regard to lead leaching. To reduce the potential for lead contributions from this source, the maximum allowable lead in solder was limited to 0.20% by amendment of the Seattle plumbing code. The effect of this amendment was to require contractors to use 95/5 tin/antimony solder

Purpose and Scope of Work

This study was undertaken to evaluate the potential leaching of metals into drinking water from the tin/antimony solder now being used in Seattle plumbing. The study consisted of five research steps: (1) An investigation of the theory of corrosion products that formed from the solder was conducted using pe-pH diagrams and galvanic coupling relationships, (2) static laboratory metal leaching tests were performed to determine the extent of antimony leaching from the solder, (3) field water samples were taken from the buildings that contained tin/antimony soldered plumbing, (4) continuous flow metal leaching tests were used to compare metal leaching from tin/antimony solder with that from lead/tin solder under three water treatments (lime plus sodium carbonate, lime plus sodium bicarbonate, and lime plus sodium bicarbonate plus silicate), and (5) corrosion films that formed on both tin/antimony and lead/tin solder were analyzed by scanning electron microscopy and X-ray diffraction.

Procedures, Results and Discussion

Theoretical Analysis

An investigation of the theory of corrosion products formed from the solder was conducted using pe-pH diagrams and galvanic coupling relationships. Results indicated that the leaching of antimony from the solder may be inhibited by two mechanisms:

1. *Sacrificial Corrosion.* Though antimony alone is quite soluble, the galvanic coupling relationships among the three metals that make up a soldered joint (tin, antimony, and copper) indicate that the corrosion of tin is theoretically more favorable than the corrosion of antimony. Tin, therefore, may act as a sacrificial anode.
2. *Passivation.* Since tin can be passivated by tin oxide, a passivation film may cover the entire surface of the solder and therby inhibit metal leaching from the solder.

Laboratory Experiments

Laboratory experiments were conducted to verify the theoretical phase of the study Twenty test specimens constructed from tin/antimony solder and copper sheet were immersed in Cedar water in a sealed 50-ml glass container. The samples were held under static conditions at 20°C for periods of 0.5 to 98 hr. In addition, two samples of antimony metal equalling the weight of antimony in the solder specimens were tested as described above for a 70-hr period.

The laboratory static coupon tests demonstrated that antimony dissolution from tin/antimony solder is substantially less than the theoretical or observed dissolution from pure antimony metal. The highest antimony concentration observed in the tin/antimony solder coupon test was 3.7 μg/L, whereas 18,000 μg/L and 22,000 μg/L of dissolved antimony were observed in the pure antimony metal corrosion tests.

These results support the theoretical conclusions already put forward. In the short term, the inhibition of antimony leaching from tin/antimony solder is a result of the galvanic coupling relationship, namely the sacrificial corrosion of tin.

Field Sampling

The University of Washington has been using 95/5 tin/antimony solder on building plumbing systems since about 1968. The field study consisted of taking 0.95-L samples of overnight tap water that had stood overnight in eight buildings on the University campus. The plumbing systems of the buildings tested ranged from 1 to 10 years in age and supposedly consisted of copper piping bonded with 95/5 tin/antimony solder.

Samples of running water (0.95 L) were taken at the mechanical room (where the building plumbing connects with the distribution system) of each building to obtain the characteristics of the inflow water The 0.95-L water sample that had stood overnight was then taken from the potable water tap furthest from the mechanical room of the building.

The samples were then analyzed for temperature, conductivity, alkalinity, total and dissolved antimony, and total lead, copper, and zinc.

The field sampling showed that, in the long term, antimony corrosion is inhibited by the passivation of tin in the solder. Of all the samples tested, a detectable antimony concentration was found in only one building water sample. In addition, scanning electron microscopy showed that two distinct passivation films were present on the tin/antimony-soldered joints removed from the buildings at the University of Washington.

Metal Leaching Tests

Short pipe sections of copper, copper plus 50/50 lead/tin solder, and copper plus 95/5 tin/antimony solder were attached to continuous flow test units for comparison of copper, lead, tin, and antimony leaching under three alternative treatments. Two velocities were used in establishing corrosion films in the metal leaching sections. The pipe sections were periodically removed from the continuous flow test unit and dissolved metals were determined after periodic 22- to 24-hr contact with test water in the laboratory.

The side-by-side metal leaching tests indicated that lead leaching is substantially less from tin/antimony solder than from lead/tin solder. Some lead initially leaches from the tin/antimony solder; but after approximately 6 weeks of testing, lead leaching was reduced to below the detection limit. Antimony leaching from the 95/5 tin/antimony solder was also consistently below the detection limit of 1.4 μg/L.

Conclusions

Lead leaching is substantially reduced and the subsequent increase in the antimony concentration of the drinking water is minimal if tin/antimony solder is used in plumbing systems in place of lead-based solder. The low metal leaching levels from 95/5 tin/antimony solder are mainly because of the sacrificial corrosion of tin and the formation of a tin oxide passivation film that protects the surface of the solder from corrosion.

The theoretical and experimental results obtained in this study therefore indicate that 95/5 tin/antimony solder would be an excellent replacement for lead-based solders in private and commercial plumbing systems where lead leaching is a problem.

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The complete report, entitled "Seattle Distribution System Corrosion Control Study: Volume III. Potential for Drinking Water Contamination from Tin/Antimony Solder," (Order No. PB 82-231 242; Cost: $10.50, subject to change) will be available only from:
National Technical Information Service
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Telephone: 703-487-4650
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