Investigations of Copper Corrosion at Willmar, Minnesota

Part 2: Nitrification, Bacteria and Copper Corrosion in Household Plumbing

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Sequential Sampling Studies at Household Taps: Profiling Water Quality Changes, including Copper Corrosion, During Water Storage in Household Plumbing

In the present study, the progress of copper corrosion in a household plumbing system was profiled using a sequential sampling procedure. The procedure involves the sequential collection of each 250 ml aliquot from a household or building tap. While intermixing of water occurs progressively, this procedure provides insight into:

- the quantity (usually, 2-5 liters) and quality of water within the (heated) household plumbing system,
- the quantity and quality of water in the service connection to the home and
- the quality of water in the distribution mains prior to entering the home.

A representative number of the sequential samples are normally analyzed for:

- *temperature* (Generally, warm in the home; cool in the service connection and main.)
- *total bacteria* (Cell counts may be exceptionally high in the household plumbing and, progressively, lower in the service connection and main.)
- *disinfectant residual* (While frequently low or absent in the household plumbing, residuals generally persist in the service connection and main.)
- *dissolved oxygen* (While generally present in the main, oxygen may be progressively depleted in the household plumbing in proportion to the period of storage and the activity of nitrifying bacteria.)
- *ammonium ion* (Ammonium ion may be depleted in household plumbing in proportion to the oxygen depletion caused by bacterial nitrification.)

The unique feature of the present sequential sampling program is the measurement of *copper*. The data shown in Figure 1, for the Bart Murphy residence near the Southwest treatment plant, is likely the first such complete representation of the water quality in a household plumbing system.

Figure 1 indicates a dramatic reduction in the amount of oxygen in household plumbing as the water progresses from the tap, where oxygen was depleted to 4.5 mg O/l, to the main (with 11.5 mg O/l). The reduction of ammonium ion from 2.2 (main) to 0.5 mg N/l (tap) is consistent with the stoichiometry for microbial nitrification.

One of the principal reasons microbial activity is facilitated in household plumbing systems relates to the surface area provided by small diameter piping. A high ratio of surface area to stored water volume increases the potential for the accumulation of sediments, organic matter and microbial growths (biological films or slimes). In contact with the chloraminated water, these attached reducing agents rapidly consume disinfectant residuals which retard bacterial growths. Figure 1 illustrates this phenomena. Whereas chloramine exceeds 2 mg Cl/l in the main, it is virtually absent at the tap and in the first three liters withdrawn from the household plumbing during the sequential sampling.

Similarly, the concentration of copper is approximately 1.5 mg Cu/l, marginally exceeding the 'copper action level', in the first three liters of the Bart Murphy household plumbing system.
Based on this profile, it is evident that both microbially-mediated nitrification and copper corrosion are occurring simultaneously within this residential plumbing system.

The results of a similar study are given on Figure 2 for a *newly constructed house*. Although ammonium ion concentrations at this site are low, there is little evidence of nitrification within the plumbing system itself. Ammonium ion remains near-constant at 0.25 to 0.3 mg N/l in both the plumbing and the flushings from the distribution main.

Copper concentrations in the household plumbing, while variable, are *low*, averaging 0.25 mg Cu/l. Chloramine and dissolved oxygen were absent throughout the sampling. From these results, it appears that extensive copper corrosion did not occur immediately in the new copper pipe, but may develop over a period of time. In addition, the limited availability of the oxidizing agents, chloramine and oxygen, likely retarded the rate of copper corrosion.

Although more limited in scope, the results of an early study of the plumbing system at the South (Electrical) Sub-Station, presented in Figure 3, show the significant depletion of oxygen which occurs even before water enters the Sub-Station. Oxygen in finished water leaving the Southwest Water Treatment Plant was averaging 11 mg O/l, while approximately 3 mg O/l arrived at the Sub-Station. This result indicates that significant oxygen depletion due to nitrification takes place in the distribution system mains even at low water temperatures.

Within the Sub-Station plumbing, pH was found to have declined from 8.1 at the Southwest Plant to 7.0. This effect, a result of microbial nitrification, can contribute significantly to the observed rate of copper corrosion.

Total Bacterial Cell Counts and Heterotrophic Plate Count Bacteria in Well Waters, Treatment Plant Finished Waters, Distribution System Samples and a Household Plumbing System

Removal of Bacteria by Treatment

Throughout this study, samples were taken for microscopic analysis for total bacterial cell count. This is an analytical technique which provides data which is new to most water utilities. Without pretreatment, water samples are directly filtered through a 0.2 μm membrane filter to retain all bacteria and larger particles. The membrane is then stained with a fluorochrome, acridine orange, and examined under a microscope. This rapid procedure allows for immediate particle identification and the enumeration of total bacteria by direct microscopic count.

In the Willmar well water sources, there are few particles other than small, thin bacteria. As shown on the accompanying Figure 4, the number of bacteria in the well waters (raw) ranged from 56,200 to 142,000 cells/ml, averaging about 100,000 cells/ml. This cell count is typical of many Midwestern ground waters which are not sterile as many have assumed. Since most of the organisms are not culturable on plate count media, these waters typically exhibit low heterotrophic plate counts (HPC). This is especially true of Willmar's system which was found to contain almost no culturable (HPC) organisms either in the well water sources or the distribution system.

Total bacterial populations, as shown in Figure 4, rather than being reduced by filtration, generally increased during treatment. An exception was observed on March 23, 1996 when a significant reduction in cell count was observed at the Southwest Plant.

From these initial observations, it appears that the cells entering the treatment plant with the source water were increasing in number during treatment and entering the distribution system.

Bacteria in Household Plumbing

In conjunction with the study of nitrification and copper corrosion in the household plumbing system of Bart Murphy's home, samples were also collected for total bacterial cell count. The results, shown in Figure 5, indicate that the water in the main (flushed) contained 68,000 cells/ml, probably reflecting the population discharged into the system from the treatment plant.

With the depletion of chloramine in the household plumbing, bacteriostatic restraints on bacterial cell recovery and growth were lost. As a result, bacterial populations in the first tap water samples were found to have more than doubled to cell counts as high as 175,000 cells/ml. Some of these cells may have been recruited (sheared) from the household plumbing system pipe walls. Clumps and sheets of cells were observed microscopically. Moreover, many cells were observed to be dividing, an indication of active cell growth. Cell growth as indicated by cell division is not observed in the presence of bacteriostatic disinfectant residuals.

While its role in copper corrosion has not been defined, at least, the simultaneous progress of bacterial activity has been observed in a Willmar household plumbing system.

Effectiveness of Chloramine Residual

The presence of a chloramine residual is expected to be essential in preventing the regrowth of bacteria during distribution. Accordingly, samples were taken from the distribution system on two dates. The results of total bacterial cell counts are plotted as a function of chloramine residual at these locations in Figures 6 and 7.

The results show a wide range of chloramine residuals in the distribution system, indicating the rapid consumption of chloramines in the mains. Whereas the March 19 sampling shows no significant response of bacterial population to chloramine residual, the March 21 data indicates that higher bacterial populations were present when chloramine residuals declined to 0.5 mg Cl/l or less.

The management of the concentration of chloramine in the Willmar distribution system poses a troublesome dilemma. Low disinfectant residuals facilitate the development and activity of the *nitrifying organisms* which are creating nitrite ion and lowering pH. At the same time, chloramine is a strong oxidizing agent, relative to oxygen, and is likely involved in the direct oxidation of copper metal to cuprous and cupric ion.

Ongoing studies by the City at the Southwest Water Treatment Plant are revealing that higher chloramine dosages are resulting in increased copper concentrations in copper piping. To minimize *chemically-induced* copper corrosion in household plumbing, minimization of the chloramine dosage is indicated.

Heterotrophic Bacteria

Preliminary results indicate that, despite the degree of nitrification taking place throughout the distribution system, there is virtually no heterotrophic bacterial activity. This result is surprising and warrants further investigation. In some instances, the absence of competitors enhances the activity of an ecologically-advantaged microbial population.

Part 3, *"Results of Pilot Plant Column and Copper Pipe Test Loop Studies"*, of this series will describe the results of in-plant studies conducted using pilot plant columns containing cation exchange resin, granular activated carbon and plastic contact media. In addition, it will present the results of copper corrosion studies utilizing specially-constructed copper pipe test loops to simulate corrosion in full-scale household plumbing systems.

Figure 1. Sequential Household Tap Sampling at Bart Murphy Residence

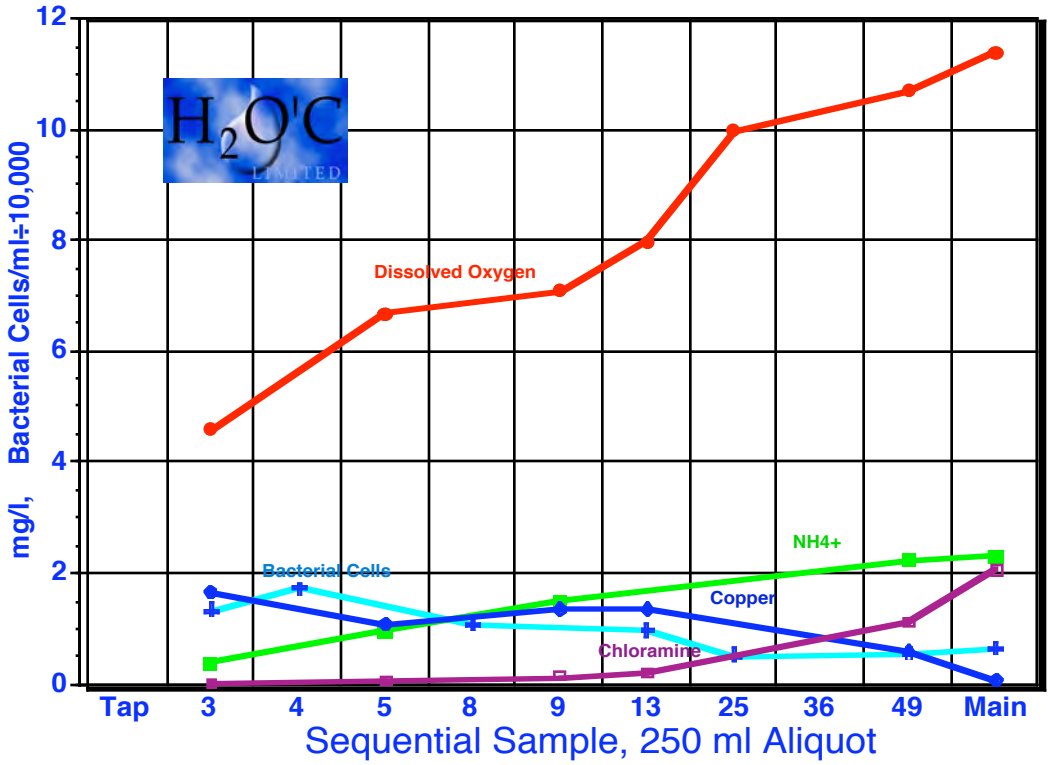
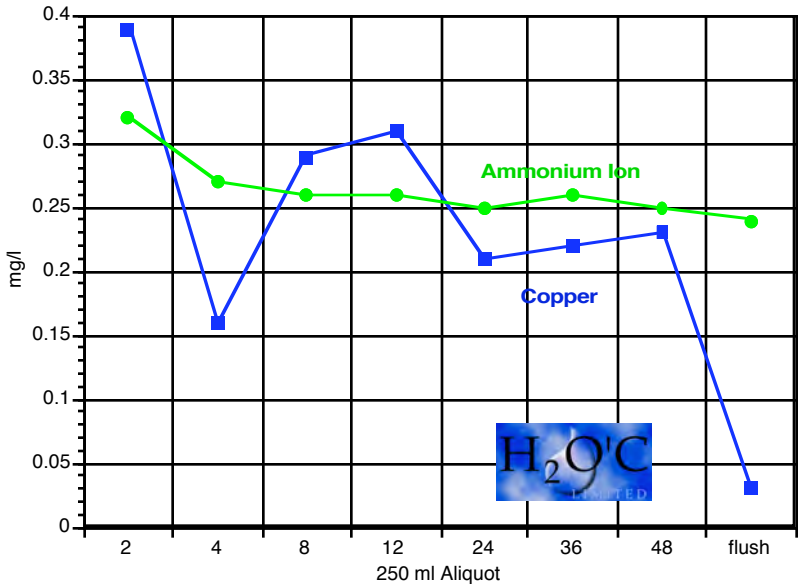


Figure 2. Sequential Sampling at New House



NOTES:
Chloramine and Dissolved Oxygen remained at or near 0 mg/l throughout the sampling.
Water temperature was approximately 13 °C in the household plumbing; 5 °C in the flushed sample (main).

Figure 3. Sequential Sampling at South Sub-Station: 6 hours retention, 13 March 1996

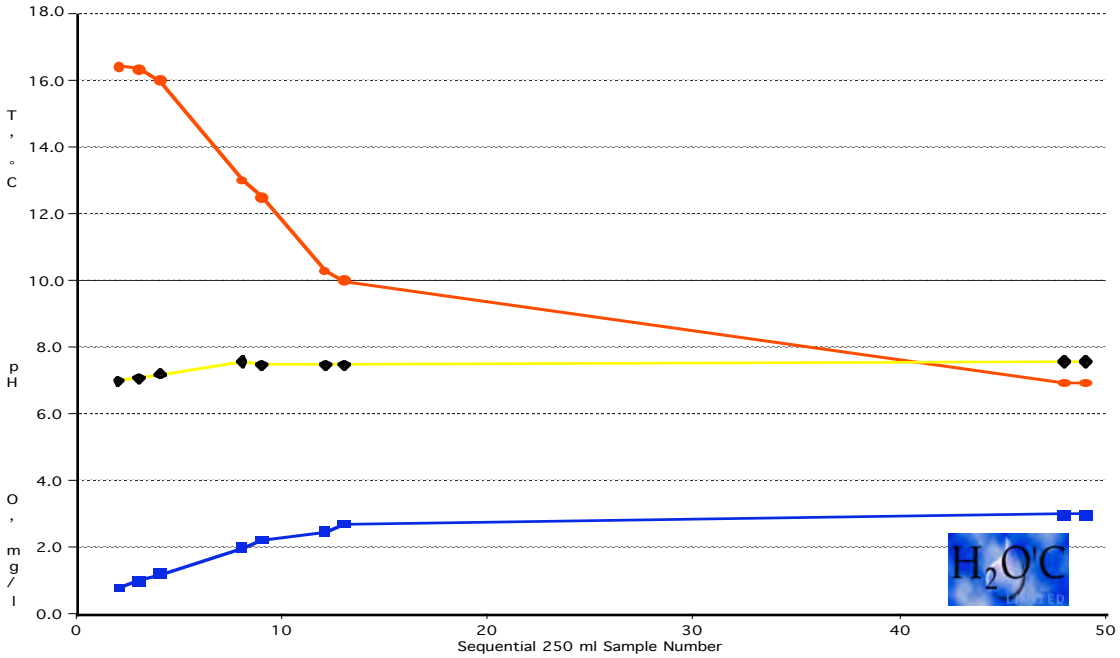


Figure 4. Bacteria in SW and NE Plant Raw and Finished Water

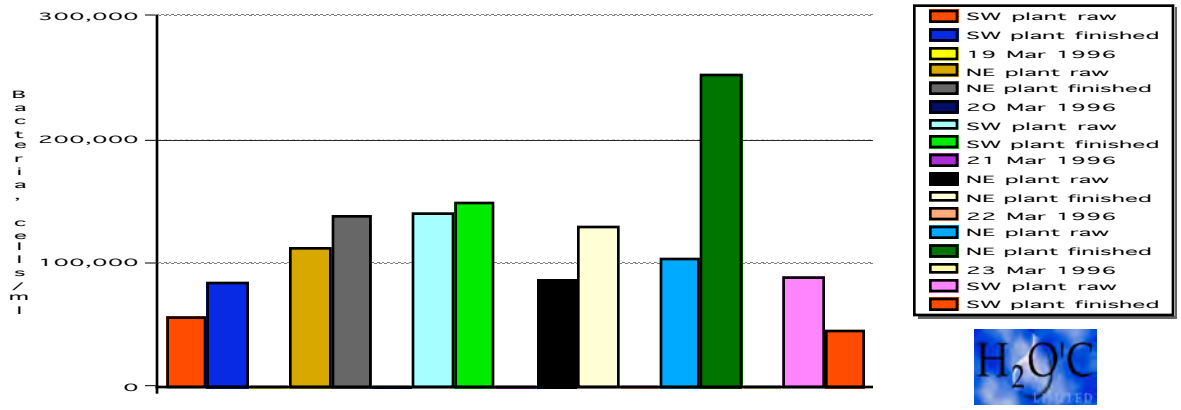


Figure 5. Bacteria In Sequential 250 ml Samples - Bart Murphy's Household Plumbing System

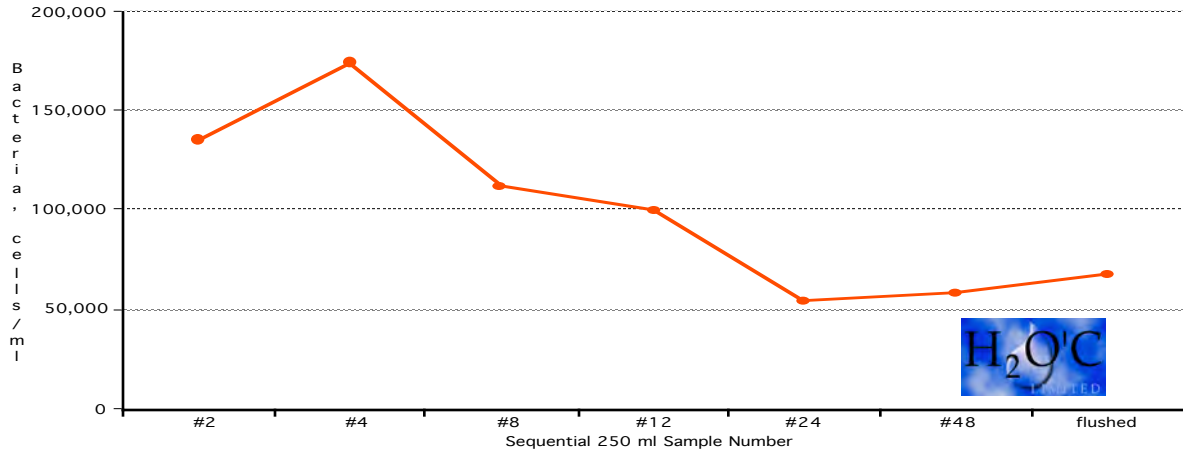


Figure 6. Bacteria in Distribution System versus Chlorine Residual - 19 March 1996

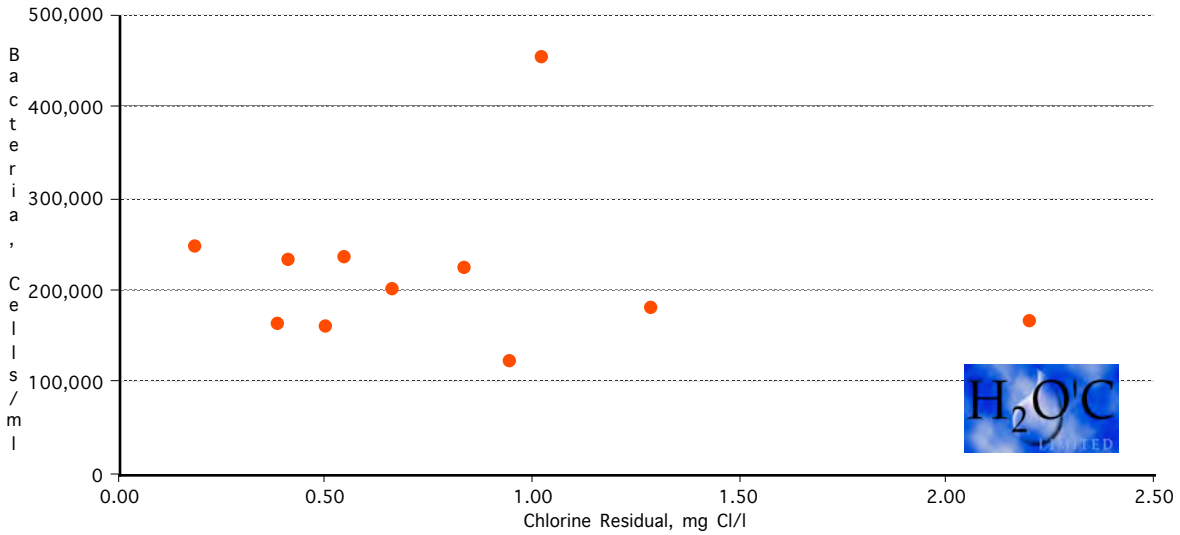


Figure 7. Bacteria in Willmar, MN Distribution System versus Chlorine Residual - 21 March 1996