Contamination and Decontamination of Building Plumbing Systems

Stephen Treado, Mark Kedzierski, Stephanie Watson, Kenneth Cole
National Institute of Standards and Technology
Gaithersburg, MD 20899

Prepared for 2006 AIChE Annual Conference

Introduction

The quality of drinking water has always been a subject of interest. In fact, a stable and secure supply of clean drinking water is a hallmark of modern society. Recently, new concerns have arisen regarding the potential occurrence of intentional or accidental contamination of water supply systems by the addition of undesirable and/or harmful substances after the water treatment facility. There have been occasional documented incidents of this type in the past, which have raised substantial public health concerns and remediation challenges. There is a growing effort to protect our nation's infrastructure, including water distribution systems, from compromise or damage. As part of this general effort, the EPA has established a research program to help determine the vulnerability of water distribution systems to contamination events, to identify important issues related to their occurrence, and to develop methods and guidelines for responding to any contamination events.

As part of this research program, the National Institute of Standards and Technology (NIST) has commenced an interdisciplinary project to evaluate contamination and decontamination issues associated with building plumbing systems. The goal of this NIST project is to develop the technical basis for guidelines, methodologies and procedures for responding to water contamination events involving building plumbing systems. This research project includes a detailed analysis of the interactions between various potential contaminants and the materials encountered in building plumbing systems, measurements of the accumulation of contaminants under different operating scenarios, evaluation of different decontamination procedures, and the development of analytical and computer models of contaminant accumulation and removal (Treado, 2005).

Background

The basic questions that this research is trying to answer are:

1. Do various potential water-borne contaminants accumulate in building plumbing systems, and if so, why, where, and how much?
2. How can contaminants that have accumulated in the plumbing system be safely and effectively removed?

These relatively simple questions are actually very formidable challenges, requiring a deep and broad understanding of chemical and biological reactions, fluid mechanics and surface phenomena, as they relate to the design and operation of building water supply systems. We can further subdivide the above questions into the following components:

1. What are the contaminants of interest?
    a. Organic chemicals: Pesticides, Herbicides, Solvents, Fuels

    b. Inorganic chemicals: Poisons, Toxic metals, Preservatives, Industrial chemicals, Warfare agents
    c. Biologicals: Bacteria, Spores, Toxins, Viruses
2. What are the plumbing system materials of interest? Copper pipe, PVC pipe, Steel pipe, Rubber and polymer gaskets, Aluminum , Stainless steel, Brass, Alloys
3. What other surface conditions must be considered?
    a. Chemical deposits: Calcium carbonate, Scale
    b. Corrosion
    c. Biofilms
4. How do the contaminants mix or react with water?
5. What is the effect of water characteristics on contaminant mixing, reaction and delivery? PH, Residual chlorine, Temperature, Dissolved minerals, Oxygen content
6. How can the presence of contaminants be detected?
    a. Water borne
    b. Surface accumulation
7. How can any accumulated contaminants be safely removed?
    a. Flushing mixtures
    b. Decontamination methods
8. How can the safety of the water supply system be verified after decontamination?

The general approach being taken for the project involves measurement and analysis at several levels, ranging from static measurements of small test coupons exposed to water contaminant mixtures, to well-controlled dynamic flow measurements, to typical building plumbing systems under intermittent flow conditions. Supporting this focus on measurement is a parallel effort to characterize and model contaminant transport, dispersal, and accumulation. Finally, and probably most importantly, methods for removing accumulated contaminants and restoring a building water supply system to safe conditions are being investigated.

Measurement Results

A number of measurement efforts are underway at NIST to evaluate the accumulation and removal characteristics of various contaminants on materials used in building plumbing systems, and within plumbing system components (Treado et al., 2006). Tests have been conducted using copper and PVC pipes with various biological and chemical contaminants, with and without the presence of biofilms and chemical deposits. Both laboratory conditioned pipes and used pipes obtained in the field have been tested. The following provides an overview of some of the measurement results to date.

Figure 1 shows *Bacillus thuringiensis* spores that have become attached to a biofilm on the inner surface of a copper pipe. The biofilm was grown on the pipe surface in the laboratory using indigenous bacteria and synthetic tap water (Reipa et al., 2005). This figure illustrates how spores can accumulate on pipe surfaces, and be protected from disinfecting agents by the biofilm. In addition, the biofilm can exhaust the disinfecting capability of the cleaning material, leaving less of the substance to combat the spores.

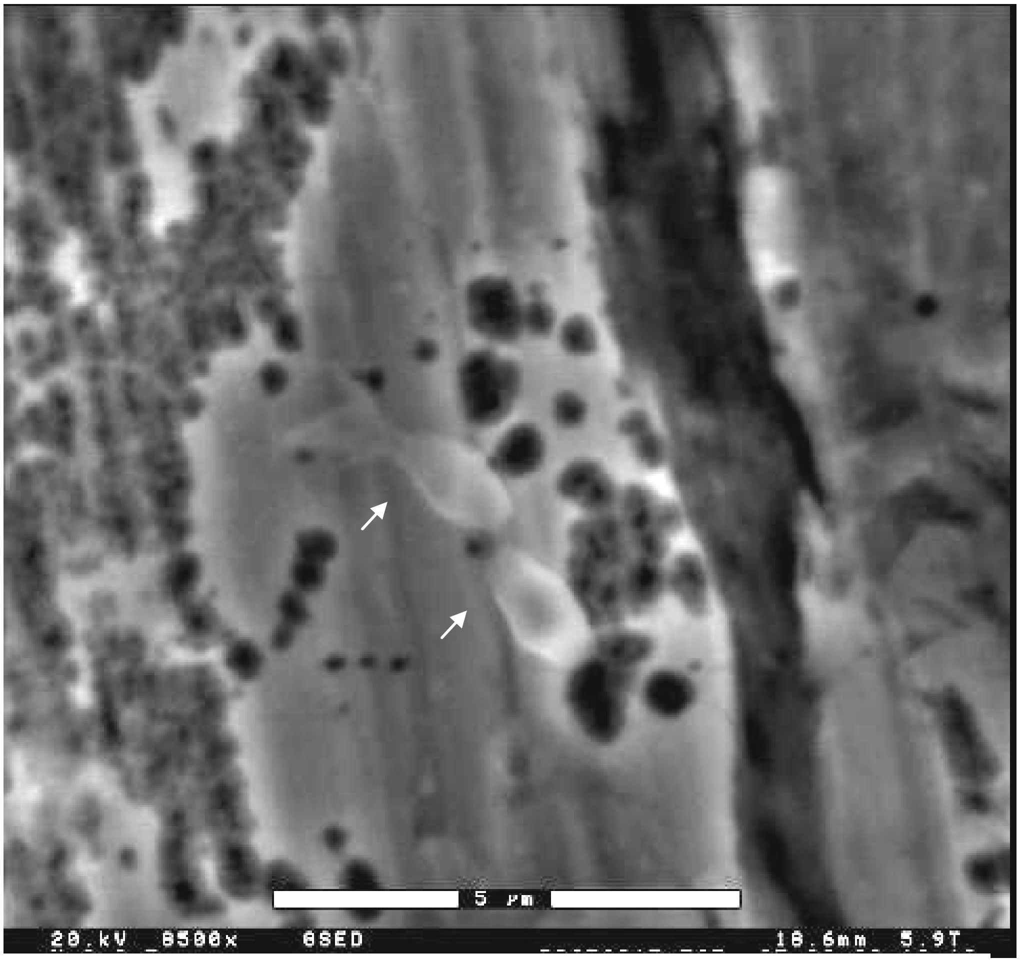


Figure 1. *Bacillus thuringiensis* spores associated with biofilm polysaccharide on a copper pipe surface. Environmental Scanning Electron Microscopy (ESEM) images were collected at nearly 100% relative humidity, arrows indicate spores, bar = 5 µm.

Figure 2 shows biofilm accumulation and retention of two biological contaminants (*E. coli* O157:H7 and BT spores) on two pipe substrates (copper and PVC), for two different fluid shear values. The left side shows accumulation before dosing with chlorine, and the right side shows the amount remaining after chlorine. Substantial accumulations are seen, and the chlorine is more effective at disinfecting the E. coli than the BT spores, particularly on the copper pipe.

Figure 3 presents the effectiveness of chlorine at disinfecting BT spores that have accumulated on copper and PVC pipe surfaces as a function of time and the presence of a biofilm. This figure clearly indicates the shielding impact of the biofilm on the BT spores.

Figures 4 and 5 present adsorption isotherm data for to concentrations of the chemical contaminant NaCN and copper pipe. The cyanide was substantially depleted from the water within about two hours of the insertion of the copper pipe sample, with an exponential behavior.

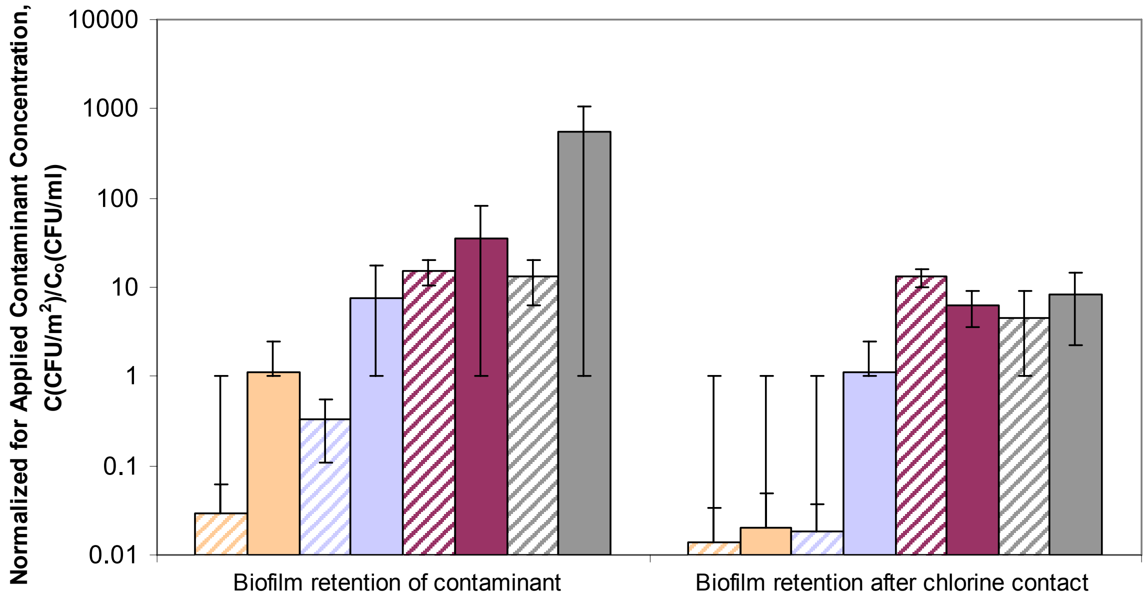
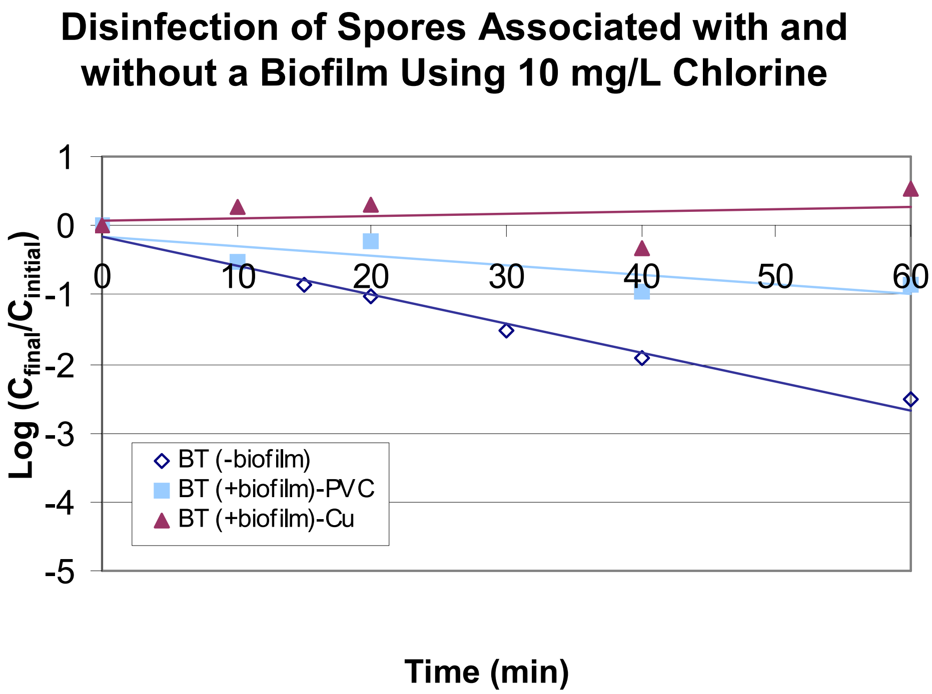


Figure 2. CDC reactor biofilm retention of biological contaminant before and after chlorine contact as a function of fluid shear. Contaminant retention under low shear conditions (60 rpm), hatched bars, and high shear (180 rpm), solid bars, are shown for two contaminants and two pipe types. *E. coli* O157:H7 on copper pipe coupons, ■, *E. coli* O157:H7 on PVC pipe coupons, ■, BT spores on copper pipe coupons, ■, and BT spores on PVC pipe coupons, ■, error bars indicate ± one standard deviation for n = 6. Chlorine doses were 10.3 ± 0.2 mg/L and 102 mg/L of free chlorine for the *E. coli* cells and BT spores, respectively.

Figure 6 shows the accumulation of diesel fuel on a copper substrate measured using a novel fluorescence technique, for various flow rates (Kedzierski, 2006). This figure also shows the effectiveness of flushing with clean water. The accumulation of diesel on the copper was greatest at intermediate flow rates, and flushing with water was effective at removing the diesel layer.

Figure 7 displays the accumulation of the contaminant phorate on copper pipe sections as a function of time for various water flow rates and phorate concentrations. No discernable effect of water flow rate was observed, and phorate accumulation appeared to level off. Phorate has a low solubility in water, so although it does accumulate on pipe surfaces, it does so in a non-homogeneous manner, as can be seen in figure 8.



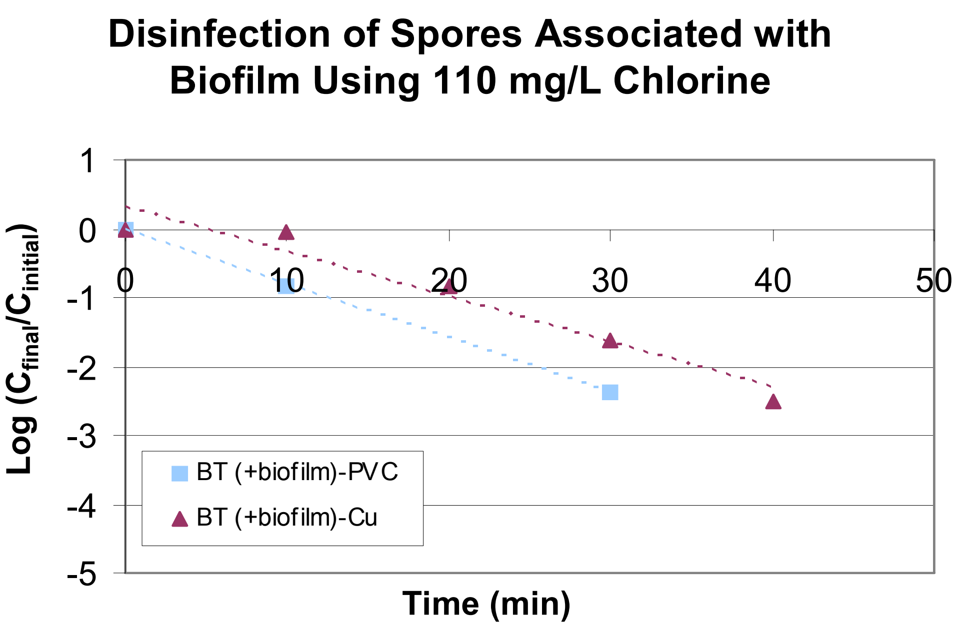


Figure 3. Disinfection of BT Spores Associated with biofilms on PVC and Copper Coupons and in solution with by Chlorine Solutions of 10 mg/L (top) and 110 mg/L (bottom).

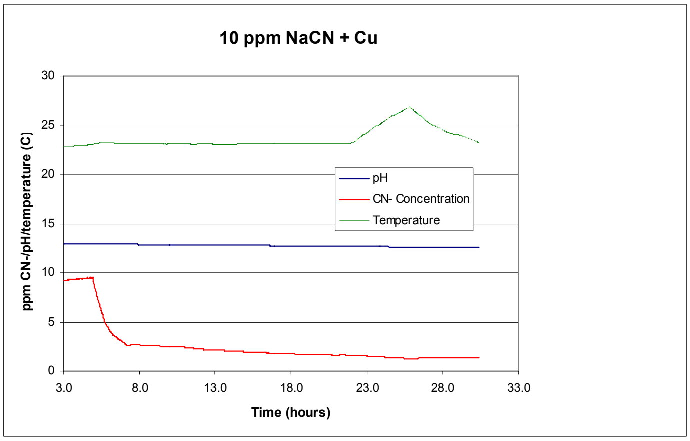


Figure 4. Adsorption isotherm for 10 ppm NaCN and copper pipe.

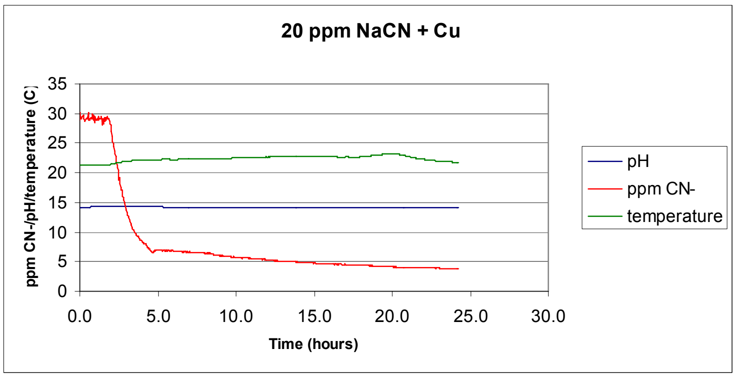


Figure 5. Adsorption isotherm for 20 ppm NaCN and copper pipe.

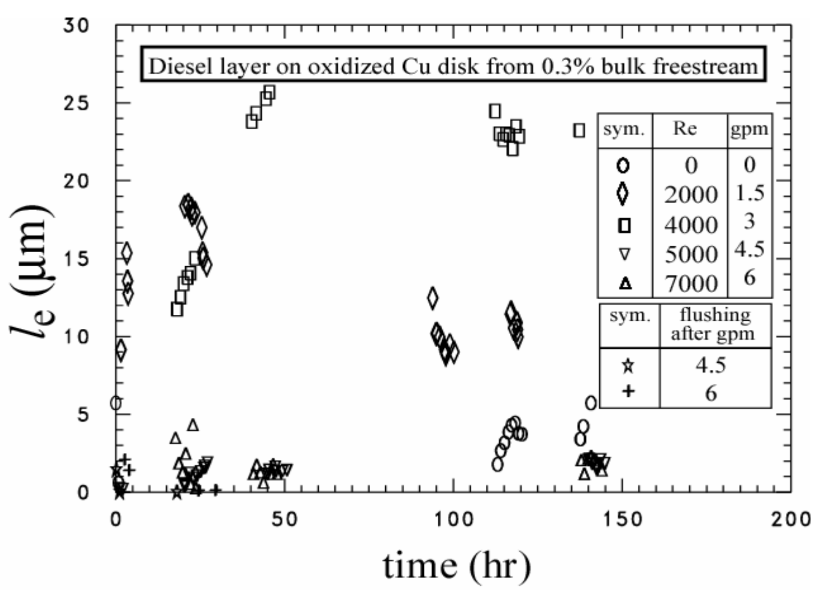


Figure 6. Diesel layer versus exposure time for various flow rates

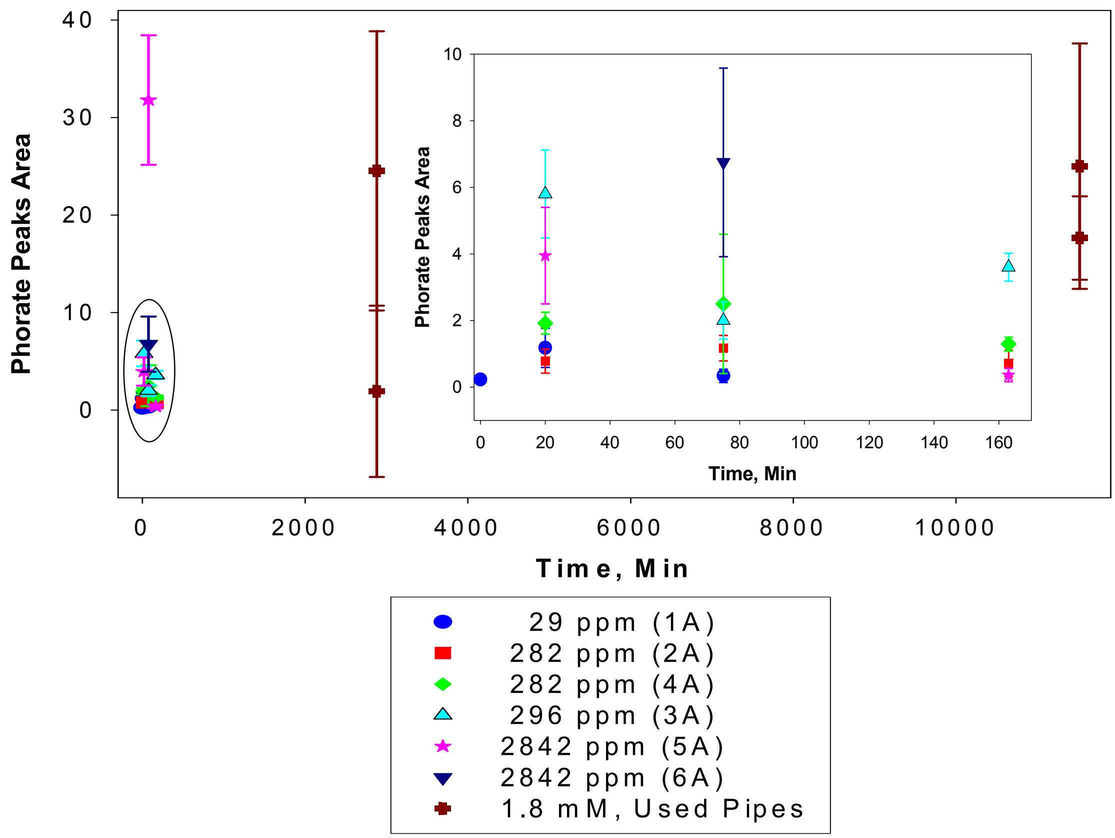


Figure 7. Phorate accumulation on copper pipe sections for different water flow rates and phorate concentrations

Summary

Measurements of various chemical and biological contaminants added to water supply systems indicate that there is a potential for contaminant accumulation on pipe materials and in building plumbing systems. Some contaminant accumulations may be eliminated by flushing with clean water, while others may require more aggressive applications of cleaners and/or disinfectants. Further research is underway to determine the most effective methods for decontaminating building plumbing systems while avoiding damage to the plumbing system components. The presence of naturally occurring biofilms and chemical deposits magnifies the decontamination challenges, due to their interactions with the contaminants and cleaning substances.

Pipe Analysis

FTIR microspectroscopy maps of Cu pipes with Phorate

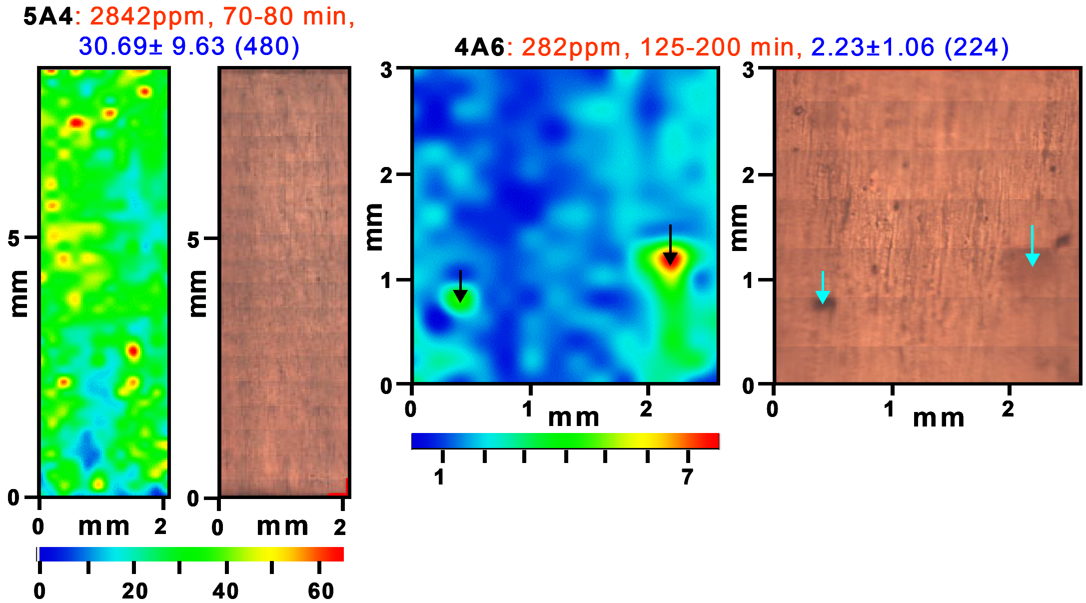


Figure 8. Phorate accumulation maps for copper pipes

References

Kedzierski, M., Development of a Fluorescence Based Measurement Technique to Quantify Water Contaminants at Pipe Surfaces During Flow, NISTIR (in review), National Institute of Standards and Technology, Gaithersburg, MD, 20899, 9/2006

Reipa, V., Almeida, J., Cole, K., Long-term monitoring of biofilm growth and disinfection using a quartz crystal microbalance and reflectance measurements, National Institute of Standards and Technology, Gaithersburg, MD, 20899, 10/2005

Treado, S., Technical Issues Related to the Measurement and Modeling of Contaminant Transport and Accumulation in Building Plumbing Systems, NISTIR 7253, National Institute of Standards and Technology, Gaithersburg, MD, 20899, 8/2005

Treado, S., Kedzierski, M., Watson, S., Bentz, D., Martys, N., Cole, K., Report of Phase One Measurement and Analysis of Building Water System Contamination and Decontamination, NISTIR (in review), National Institute of Standards and Technology, Gaithersburg, MD, 20899, 9/2006