PILOT-SCALE EVALUATION OF VARIOUS APPROACHES FOR THE DECONTAMINATION OF DRINKING WATER DISTRIBUTION SYSTEMS

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The safety and security of water supplies have come under reassessment in the United States in recent years. Issues ranging from public safety and health, ecological, and national security are under consideration. The terrorist attacks on the United States on September 11, 2001 and the subsequent delivery of Anthrax-contaminated letters through the mail raised concerns about protecting U.S. citizens and the nation's critical infrastructure. Presidential Decision Directive 63 (PDD 63) designates the Environmental Protection Agency (EPA) as the lead for securing the national water infrastructure. Therefore, the Agency is working to be proactive in anticipation, detection, and identification of the threat of deliberate or accidental contamination of our water supplies. One of the more important roles of EPA in dealing with a contamination threat is how to treat, contain, and dispose of contaminated water. Depending on where the contaminant is introduced, this may involve actions within source waters, drinking water treatment plants, distribution systems, or points downstream. Any material (including the water) may need to be disposed of properly. Furthermore, the physical infrastructure of water distribution systems will require decontamination before it is reused. To evaluate the efficacy of various decontamination methods, a series of tests were conducted using a unique pilot-scale drinking water distribution system simulator (DSS) located at the EPA Test and Evaluation (T&E) Facility, Cincinnati, Ohio. These studies were aimed to provide information on the efficiencies of various techniques for the proper containment, treatment and decontamination of any material that might result in the deliberate or accidental contamination of U.S. water supplies or water supply systems.

The primary objectives of this decontamination research were to quantitatively determine the potential of target contaminants for persistence in a dynamic drinking water distribution system and to perform quantitative determination of the efficacy of various decontamination methods for removing contaminants from a drinking water distribution system.

A complete decontamination test included an evaluation of the contaminant adherence to pipe surface followed by an evaluation of a specific decontamination procedure. During the adherence test, contaminants were injected into the pilot-scale pipe-loop system at the EPA T&E Facility to assess the potential for persistence of target contaminants to drinking water distribution system pipe surface. The specific contaminants that have significant potential to stick to the pipe surface and to present serious decontamination were identified. For these contaminants, appropriate decontamination technologies were selected for testing and their effectiveness was determined during the decontamination test.

The primary experimental design parameters for the decontamination studies included pipe-loop material, biofilm, target contaminants, concentration of contaminants, DSS operating parameters (e.g. flow rate, contact time between contaminant and pipe surface), and decontamination approaches.

A pilot-scale DSS constructed from clear polyvinyl chloride (PVC) was used for the study. The main components of the DSS are a large reservoir used to supply water to the PVC pipe loop, approximately 75 feet of PVC pipe (primarily 6-inch diameter except for a 4-inch-diameter section that is ~5 feet long), a recirculation tank (in line with the main pipe) with 100 gallon capacity, water pumps, and the associated valves and electronic control devices necessary to operate the system. The total volume in the DSS, including the 85 gallons in the recirculation tank, is approximately 220 gallons.

In order to quantify the extent of adherence of the contaminants to the surface of real-world pipe materials, ten small rings (coupons) from real-world pipe sections were integrated into the PVC DSS. The real-world pipe coupons used for the study were made of used cement-lined ductile iron pipe sections, which were scavenged from an old drinking water distribution simulator within the T&E Facility that had been in service for 5 years. A set of PVC coupons was included to serve as "control" coupons. Each coupon measures 6-inch inside diameter and 1 inch in width. At the end of each run, the coupons were removed from the system and analyzed for specific contaminants using appropriate procedures for coupon treatment. All ten coupons were sacrificed after each run, and a "new" set of coupons were reintegrated in the following test run.

To effectively study the adsorption of contaminants on pipe walls, it is essential to ensure that there is a viable biofilm on the pipe wall surfaces. The PVC DSS at the T&E Facility was newly fabricated in 2003 and the pipes in the loop have been in limited service, and there is little biofilm or tubercle buildup on the inside surfaces. Therefore, an accelerated biofilm cultivation protocol was implemented and biofilm was cultivated in the DSS for 2-3 weeks prior to the injection of contaminants. A bacterial cell count of $10^4/cm^2$ or higher was considered to adequately represent a viable biofilm population in the pipe- loop system. The biofilm cultivation was conducted prior to each test.

Target contaminants selected for this study included arsenic, mercury, and *Bacillus subtilis*. The target initial concentration of arsenic/mercury and *Bacillus subtilis* in the pipe loop was 10 mg/L and 10^3 cells/mL, respectively.

Laminar and turbulent flow regimes were evaluated at three flow rates – 1, 15, and 60 gpm, corresponding to Reynolds Number of 520, 7,800, and 31,200, respectively – to examine the effect of flow rate on contaminant adherence to pipe surfaces. A contact time of 2 days following the contaminant injection has been selected for each test to establish equilibrium conditions.

Various decontamination techniques were evaluated in this research, including simple flushing, low pH flushing, phosphate buffer flushing, acidified potassium permanganate flushing, and shock chlorination.

Each test run was initiated with integration of "real-world" pipe coupons into the DSS. Upon confirmation of biofilm growth in the pipe loop, a contaminant was injected into the DSS at the target initial concentration in the pipe loop system. The DSS was operated in a recirculation mode under the designated flow rate condition. After a 2-day contact period, the coupons (real-world pipe materials) were sampled to determine the adherence of contaminant to the pipe loop materials. Upon completion of the adherence study, a selected decontamination approach was evaluated. After decontamination, the coupon walls were analyzed for residual, adsorbed contaminant.

The contaminant adherence test results indicated that all contaminants tested, i.e. arsenic, mercury, and *Bacillus subtilis*, showed strong adherence to cement-lined ductile iron pipe surfaces. Arsenic and mercury showed stronger adherence to cement-lined ductile iron pipe surfaces as compared to the clear PVC pipe surfaces, though *Bacillus subtilis* showed similar strong adherence to both the cement-lined ductile iron and clear PVC pipe surfaces. Under the same test conditions, mercury has stronger adherence to cement-lined ductile iron pipe surfaces compared to arsenic.

The flow evaluation tests conducted for arsenic and mercury indicated that the extent of adherence of arsenic and mercury to the cement-lined ductile iron pipe surfaces varies at different flow regimes, and that the adherence of arsenic and mercury to pipe surfaces is higher under turbulent flow conditions.

The decontamination test results indicated that simple flushing is effective in partial decontamination of cement-lined ductile iron pipe surfaces for arsenic and mercury.
Simple flushing at 2.5 fps could remove up to 51% and 57% of adsorbed arsenic and mercury, respectively, from the cement-lined ductile iron pipe surfaces. However, simple flushing resulted in no removal of *Bacillus subtilis* from the pipe-loop system.

Further evaluations on more rigorous decontamination techniques were performed to evaluate decontamination efficiencies for three contaminants tested. These included low pH flushing, phosphate buffer flushing, and acidified potassium permanganate flushing for arsenic; low pH flushing and acidified potassium permanganate flushing for mercury; and shock chlorination for *Bacillus subtilis*. These decontamination test results indicated that the decontamination efficiency for arsenic and mercury from cement-lined ductile iron pipe surfaces was not improved by low pH flushing as compared to simple flushing. Also, it was found that phosphate buffer flushing resulted in no removal of arsenic. Acidified potassium permanganate flushing was effective in partial decontamination of arsenic with up to 61% removal of arsenic from the pipe surfaces. However, this decontamination approach proved to be a very effective technique for removal of mercury contaminant from the pipe-loop system, removing up to 96% of adsorbed mercury from the cement-lined ductile iron pipe surfaces. The decontamination efficiency for removal of mercury from cement-lined ductile iron pipe surfaces was significantly improved by using acidified potassium permanganate flushing as compared to simple flushing and low pH flushing. Shock chlorination, using a CT (Product of Free Chlorine Residual and Time Required) value of 30,000 mg/L-min, was found to be a very effective decontamination technique for removing *Bacillus subtilis* from the cement-lined ductile iron pipe surfaces. The decontamination efficiency of shock chlorination for *Bacillus subtilis* averaged 95% for cement-lined ductile iron pipe material.

The tests conducted to date show that arsenic, mercury, and *Bacillus subtilis* all strongly adhere to cement-lined ductile iron pipe surfaces. Of the decontamination techniques tested to date, acidified potassium permanganate and shock chlorination appear to be the most effective decontamination methods for arsenic/mercury and *Bacillus subtilis,* respectively, from cement-lined ductile iron pipe surfaces.

Future tests will involve an organic contaminant (e.g. diesel fuel, chlordane), and evaluation of alternative real-world pipe materials.