Excerpt From:

Final Report on the Validation of Mixed-Oxidants For the Disinfection and Removal of Biofilms From Distribution Systems

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ABSTRACT

Problem Statement:

As drinking water regulations are applied to smaller utilities, an area of emerging concern for the water industry is the installation of disinfection systems to meet the newly imposed standards. Since traditional disinfection technologies are usually beyond the safety, economic, and/or site restraint considerations for small systems, an alternative is required. The mixed-oxidants (MIOX) disinfection system appears to provide a reasonable alternative for small distribution systems as a safe, reliable, and cost effective technology that is easy to operate and is readily compatible with other treatment systems.

The goal of this five-phase study was to evaluate the potential of the MIOX disinfectant (produced on-site using feedstocks of ordinary salt, water, and twelve volt electricity) against free chlorine for biocidal efficacy, biofilm/biofouling removal, biofilm regrowth potential, relative corrosion potential, and cost effectiveness. Although mixed-oxidants have been proven effective in potable water disinfection, biofilm removal is a new application for this alternative disinfection technology.

Procedures and Results:

Phases one and two tested mixed-oxidants against free chlorine on laboratory-grown biofilms in new PVC pipe and field-grown biofilms in pipes removed from a small distribution system in rural Montana that was in repeated violation of the total coliform rule due to regrowth events in the distribution system. Results indicate that the mixed-oxidants solution was at least as effective at the removal, destruction, and regrowth prevention of biofilms as chlorine at comparable residual levels.

Phase three was a full-scale demonstration of the effectiveness of the MIOX system installed at the same small rural water distribution system in phase two. The system effectively improved water quality as demonstrated by increased water pressure, cleaner filters, less observed build-up in pies, and no infractions of total coliform regulations.

Phase four involved experiments to determine the relative potential for corrosion of ferrous metal pipes by MIOX vs. free chlorine. Results from annular reactors indicate that MIOX corrosion levels (as measured by amounts of dissolved ferrous iron) are no greater than those of free chlorine, and are less than those of untreated water.

Phase five was an informal cost analysis of the actual operating expenses of the mixed-oxidants process which indicated that the higher capital costs could be easily recovered through the lower operational costs.

Conclusions:

The mixed-oxidants technology appears to be an economically viable disinfection technology for small water distribution systems since it is safe to operate; requires a minimum of operator training, maintenance, and process monitoring; provides biofouling removal and improved drinking water quality; exceeds EPA drinking water standards for disinfection by-products; and provides chlorine residual without imparting a chlorinous taste or odor to the treated water.

Coliform Compliance. The KOA system has not had a single non-compliance since the mixed-oxidants generation unit was put on line. Previously, even with free chlorine slug dosage levels (from powdered sodium hypochlorite) as high as 1000 parts per million, positive coliform samples were repeatedly obtained.

Advantages of Mixed-Oxidants Over Chlorine Disinfection. The mixed-oxidants disinfection process is far less labor intensive than dosing with powdered sodium hypochlorite. The MIOX disinfectant solution is safer, cleaner, less expensive, and easier to use. There is no detectable off-gassing which can be highly corrosive to electrical equipment in the disinfection area. The mixed-oxidants solution contains no granules of undissolved disinfectant which can lead to clogging of the injectors. The mixed-oxidants process can be sited at any convenient location and does not require special containment conditions. The mixed-oxidants generator is easily integrated into existing chlorine injection systems.

Effects on Distribution System. Mixed-oxidants led to the sloughing off of previously accumulated biofilm/biofouling in the KOA's water distribution system. This resulted in an obvious increase in the water pressure and water quality at the manger's residence. Prevention of biofilm formation was observed through absence of "black slime", a common biofilm (27), in the showers.

After the initial sloughing of corrosion products and biofilm, the filters throughout the distribution system required far less maintenance than before the installation of the mixed-oxidants system: the filters are cleaned every three to four weeks now as compared to every two to three days previously.

Prior to the use of mixed-oxidants, loss of pressure in the water distribution system during periods of electrical problems (frequent power outages) caused the release of biofouling in the pipelines. These sloughing events always required flushing of the system when pressure was regained. In contrast, upon restart of the system after a loss of pressure this summer due to a well malfunction, no discoloration was present and no flushing was required.

Effects on Contact Water Distribution System. The water theme park is well into its second season of disinfection by mixed-oxidants. At a dosage of two to three parts per million of free chlorine from the mixed-oxidants solution, there have been no consumer complaints of chlorine taste/odor. The growth of algae on pool area surfaces is typically a problem for the majority of outdoor swimming pools. However, there has been no algal growth, even on the unpainted concrete areas, eliminating the need for algacide application.

The only disinfection process used for the pool area has been that of mixed-oxidants, since the opening of the water park coincided with the installation of the mixed-oxidants treatment process. Visual inspection of pool pipe, connections, and filters has revealed that all components remain in essentially new condition. There is no visual or tactile accumulation of biofilms or corrosion products. In contrast, when sodium hypochlorite was used for potable water disinfection, corrosion products and “slime” were developed in a very short time on all new (from repairs, replacements, or extensions) distribution system components.

The only problem with the treatment process was that on days of very high pool usage (typically eighty to ninety percent of campground chlorine demand), it was necessary to provide supplemental disinfection through the addition of sodium hypochlorite. This problem will be taken care of with the installation of a larger disinfectant solution storage reservoir.

Informal Cost Analysis (Phase V):

The actual operation costs of the mixed-oxidants disinfection system for the demonstration site were attributed almost totally to the salt requirements. During KOA water system peak usage (100,000 gallons per day), only one fifty pound bag of salt per day at a total cost of $2.79 was required, as compared to the $35.00 average daily cost of powdered sodium hypochlorite for dosing with free chlorine. Eighty to ninety percent of this biocide demand was attributed to the water park area. During the off-season, a fifty pound bag of salt was sufficient for up to two months of solution generation.
The generation of the mixed-oxidants solution required to meet chlorine demands in the peak season required a daily operational time of eighteen to twenty hours, dropping to less than one half hour per day during the off-season. Due to the large electrical requirements of the campground (average summer monthly electrical bill of $3000.00), there was no detectable increase in power costs associated with the use of the mixed-oxidants system.

Monitoring, maintenance, and operator training costs were negligible. During the limited down-time of the mixed-oxidants unit, the reversion to application of sodium hypochlorite was easily accomplished at no additional cost or modification to the existing system.

Alternate possibilities for disinfection processes at the campground are quite limited. The continuation of sodium hypochlorite is an option, but requires too much of the manager’s time for mixing and monitoring. He feels his time commitment for disinfection is substantially reduced by the use of mixed-oxidants Gaseous chlorine or ozone generation systems are completely unfeasible as options for disinfection treatment processes at the campground due to the high equipment costs, the rigorous operator training requirements, the highly variable (seasonal) disinfectant demands, and the operational site restrictions.

The only limiting factor in the campground manager’s consideration of future installations of mixed-oxidants disinfection systems is the high capital cost of the generation unit itself. The retail price, installation not included, for the unit in operation at the campground is $12,000. Although considerably more expensive than a sodium or calcium hypochlorite injection system, this capital cost is actually substantially less than that of gaseous chlorine systems. When total costs are amortized over ten years, the cost per thousand gallons of water treated is less than half that of gaseous chlorine (18).

Detailed comparative cost analyses of four sizes of mixed-oxidants systems versus gaseous chlorine, sodium hypochlorite, and calcium hypochlorite systems are presented in Appendix F (18).

Results of Related Research:

Additional supporting evidence for the success of mixed-oxidants as a viable alternative water treatment option is provided by related research. A 1996 study on a 0.5 MGD drinking water treatment facility demonstrated that mixed-oxidants could reduce manganese levels to below the secondary standard contaminant levels (SMCLs) with a smaller dose and a shorter reaction time than potassium permanganate at an operational cost of about $1.50 per day (3).

A 1.2 MGD drinking water treatment plant was able to reduce total THM content of finished water by 20% and realize a 50% savings in disinfectant generation costs using mixed-oxidants instead of gaseous chlorine (10).

Laboratory tests have indicated that the mixed-oxidants solution may produce from 10-40 percent of the total trihalomethanes (TTHMs) of hypochlorite on an equal chlorine basis (6, 11). The non-chlorine oxidant species present in the mixed-oxidants solution have consistently had the effect of reducing the free chlorine demand of both model and real waters when compared to equivalent amounts of sodium hypochlorite, without enhancing the formation of trihalomethanes (THMs) (13).

Mixed-oxidant generators have been used successfully at less than half the price of hydrogen peroxide (H_2O_2) to treat sewage odor problems by removing dissolved and atmospheric hydrogen sulfide (H_2S) without the formation of sulfites (SO_3^{2-}) or sulfates (SO_3^{2-}). Lower H_2S levels resulted in decreased corrosion of concrete pipes (24).

Data from evaluation on wastewater clearly show that the mixed-oxidants solution is an effective biocide with strong oxidizing power which produces finished water quality parameters typical of those expected for a well operated municipal wastewater treatment plant (28).

Mixed-oxidants have been shown to inactivate both *Cryptosporidium parvum* oocysts and *Clostridium perfringens* spores more effectively than free chlorine at the same dosage and exposure (30, 31). Effective removal has also been demonstrated against *E. coli, Serratia marcescens*, coliforms, total aerobes, and some viruses (4,5).

Industrial studies indicate that the use of mixed-oxidants consistently results in poultry processing chill water samples that are less contaminated by *E. coli* and coliforms than chill water samples treated with the same levels of free available chlorine from sodium hypochlorite (33).

Anecdotal evidence supports the removal of biofilm/biofouling by the application of mixed-oxidants disinfection. Following the replacement of a gaseous chlorine system with a mixed-oxidants system at the Sandia Ranger Station in Tijeras, New Mexico, operation staff observed the sloughing of “orange deposit” (presumed corrosion products and biomass). Another installation site in West Richland, Washington, reported sloughing of manganese build-up and removal of “green slime” from distribution pipes after a few weeks of operation (12).