Case Study: How Chloramines Improve Water Quality – 08/01/1999

When would a utility consider chloramine disinfection? What are its benefits and secondary impacts?

Drinking water utilities have used chlorine and chloramines in the U.S. since the early 1900s to disinfect microorganisms, to control tastes and odors, to oxidize inorganics and organics, and to suppress microbiological growth in distribution systems. Chloramines have historically been considered desirable because they provide a persistent disinfectant residual. In light of more stringent disinfection byproduct (DBP) regulations, more utilities are turning to chloramine disinfection to limit DBP production. Utilities considering chloramination must weigh the benefits and secondary impacts of chloramines for their systems and make an informed decision based on current research findings. Pertinent questions include:

- Under what circumstances should a utility consider chloramination?
- What benefits can be expected from chloramination?
- What secondary impacts may be associated with chloramination?

Role of Water Research Foundation Research

The Water Research Foundation has produced several reports that drinking water utilities have used to better understand how chloramination affects water quality and distribution systems:

- Kirmeyer, G.J., et al. 1993. *Optimizing Choramine Treatment.* Denver, Colo.: AwwaRF and AWWA (Order #90620).
- Kirmeyer, G.J., et al. 1995. *Nitrification Occurrence and Control in Chloraminated Water Systems*. Denver, Colo.: AwwaRF and AWWA (Available in limited quantities to subscribers, order #90669).
- Symons, J.M., et al. 1998*. Factors Affecting DBP Formation During Chloramination*. Denver, Colo.: AwwaRF and AWWA (Order #90728).
- Valentine, R.L., et al. 1998. *Chloramine Decomposition in Distribution System and Model Waters*. Denver, Colo.: AwwaRF and AWWA (Order #90721).

Research shows that chloramines play a major role in disinfecting pathogens, controlling tastes and odors, oxidizing inorganics and organics, and suppressing microbiological growth in distribution systems. For utilities with extensive distribution systems and long detention times, chloramines aid in maintaining disinfectant residuals. Chloramines also have been found to produce fewer total trihalomethanes (TTHMs) than free chlorine.

Chloramine chemistry. Chloramines are composed of three chemicals formed when chlorine and ammonia-nitrogen are combined in water: monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine, or nitrogen trichloride (NCl_3). Monochloramine is preferred because of its biocidal properties and minimal taste and odor.

Monochloramine is created by controlling the chlorine-to-ammonia ratio to a value generally less than 5:1 by weight or 1:1 on a molar basis.

Disinfection. Because they are more stable and less reactive than free chlorine, chloramines as secondary disinfectants help maintain a detectable residual throughout the distribution system. Although chloramines are weaker disinfectants and require greater contact times than chlorine, utilities that experience bacterial regrowth in their distribution systems and switch to chloramines find that chloramines apparently penetrate deeper into the biofilm layer to inactivate microorganisms and inhibit their growth.

Disinfection by-products. Because chloramines produce fewer TTHM disinfection by-products, the US Environmental Protection Agency has suggested the use of chloramines to replace free chlorine as a disinfectant. Case studies indicate common TTHM reductions of 40 to 80 percent when free chlorine is replaced by chloramines. Although haloacetic acids are present in lower concentrations with chloramination than with chlorination, research shows that, under certain circumstances, dihaloacetic acids and dissolved organic halogen are not well controlled by the use of chloramines. Research results imply that many unreported DBPs are created by chloramines. Generally, DBP formation decreases as pH increases and the chlorine-to-ammonia ratio decreases. Changing these two operating variables can significantly impact DBP formation.

Tastes and odors. Chloramines generally have less of a tendency than chlorine to impart a chlorinous taste or odor. As research shows, chloramines improve taste when phenols are present, but utilities should perform flavor profile analyses on their own sources of supply.

Special users. Secondary impacts of chloramination include potential adverse effects on special water users, i.e., kidney dialysis and aquaculture activities. Chloramines must be removed from water used in kidney dialysis, and medical authorities and patients should be informed of the presence of chloramines. Effective procedures are available to remove chloramines once these users are made aware of their presence.

Nitrification. Research has found that two-thirds of medium and large systems in the U.S. that chloraminate experience nitrification to some degree. With this two-step microbial process, ammonia is converted to nitrite and then to nitrate. The intermediate stage-nitrite--depletes the chloramine residual and increases heterotrophic bacteria. Two groups of factors influence nitrification and methods of control: water quality factors (pH, temperature, chloramine residual, ammonia concentration, chlorine-to-ammonia ratio, and concentrations of organic compounds) and distribution factors (detention time, reservoir design and operation, sediment, tuberculation in piping, biofilm, and absence of sunlight).

Corrosion. Increased chloramines also lead to accelerated corrosion and degradation of elastomers (i.e., gaskets) and some metals in distribution systems.

Utility Application of the Research

A number of utilities and consultants have applied Foundation research in developing, implementing, and optimizing their chloramination programs.

Massachusetts Water Resources Authority. MWRA was experiencing difficulty maintaining adequate disinfection residuals at remote points in the distribution system. After adjusting the chlorine-to-ammonia ratio downward to 5:1, MWRA was able to eliminate six chlorine booster stations-an estimated saving of more than $100,000 annually for the utility and its communities. The new ratio also reduces DBPs by not having to add chlorine to boost disinfection residual.

The greatest impact, though, is on the distribution system, which includes unlined cast-iron, 100-year-old pipes. Water takes from two hours to a week to reach the farthest points of MWRA's distribution system, and increased chlorine was ineffective in reaching bacteria tubercules. Decreasing the chlorine-to-ammonia ratio to 5:1 not only helped the utility with respect to residual decay, but also decreased iron corrosion in the system.

Gulf Coast Water Authority. Since November 1983, Gulf Coast, Tex., has modified its disinfection process seven times, arriving at the use of chlorine dioxide and chloramines to disinfect and to reduce total trihalomethanes.

Gulf Coast's system experiences all the characteristics favoring DBP formation-high influent total organic carbon ranging from 4 to 8 mg/L, bromide up to 0.3 mg/L, high influent temperatures, and long residence times in the distribution system. With the advent of the original TTHM regulation, the water supplier realized that DBP control would be a major issue.

The strong disinfection capability of chlorine dioxide, combined with good biofilm control provided by chloramines, has allowed plate counts to remain low. Total trihalomethane concentrations with chloramine have decreased from more than 300 µg/L to between 50 and 70 µg/L, a reduction of about 80 percent. Part of this reduction may be attributable to the addition of filter granular activated carbon caps and a change in reservoir operation that reduced source water algae. Although other utilities may not enjoy an 80 percent reduction in TTHM formation (the most common range is between 40 and 80 percent), a well-operated and high-purity chlorine dioxide feed system coupled with chloramines for secondary disinfection will substantially reduce chlorinated DBP formation.

City of Portland. The Portland Water Bureau has used chloramines successfully for nearly 50 years. In 1991, Portland, Ore., modified its chlorination process and began using a chlorine-to-ammonia ratio of about 5.5:1. In 1997, Portland raised its pH from 6.7 to 7.5 for corrosion control and decreased the chlorine-to-ammonia ratio to about 5:1. While providing improved chloramine persistence and decreased dichloramine formation, these measures also created more favorable conditions for nitrification in the distribution system.

Understanding the chemistry has been key to building a monitoring strategy and optimizing chloramination. During the first year of corrosion control treatment, Portland found that chloramine residuals decreased rapidly due to unseasonably warm water temperatures. The utility could limit further increases in influent water temperatures by withdrawing water from lower levels of a storage reservoir, but this strategy would be at the expense of decreased hydropower production. By providing information based, in part, on a recent Foundation research report, Portland was able to justify this action to the local electrical utility.

Portland has also used booster chlorination at some finished-water reservoirs to minimize the risk of nitrification. As water flows through the finished-water reservoir, chlorine decay and demand in the chloraminated water results in free ammonia in water leaving the reservoir. Portland implemented monitoring strategies to identify the appropriate dose of sodium hypochlorite to react with the free ammonia. This practice of using booster chlorination for chloraminated water has limited the supply of free ammonia that would otherwise serve as a food source for nitrifying organisms and has increased chloramine residuals in the distribution system.

City of Ann Arbor. The City of Ann Arbor (Mich.) Water Treatment Plant began experimenting with chloramine disinfection in 1980 to meet the lowered TTHM regulations. Switching from free chlorine to chloramine effectively reduced TTHMs, and distribution water quality remained stable for many years. In 1989, an unexpected and persistent decrease in disinfection residual occurred in several remote areas of the distribution system. Additional investigation combined with literature review pointed to nitrification as the cause.

Two questions confronted the utility: Why did nitrification occur at that point in time and not before? How could the utility reverse the degradation in water quality? Obvious approaches, such as hydrant flushing, only temporarily improved water quality.

Historical investigation pointed to two problems: 1) a low chlorine-to-ammonia ratio applied ahead of newly installed GAC filters and 2) finished water pH that had been lowered over the years. It was necessary to breakpoint chlorinate to 2.3 mg/L free chlorine residual leaving the plant to halt nitrification. After a chlorine residual returned to all stations, increasing the chlorine-to-ammonia ratio from 3:1 to 4.75:1 and raising the pH to 9.3 have largely prevented nitrification. A brief episode of nitrification appeared in one part of the distribution system in 1994. Staff concluded that the high pH and other control measures, such as chlorine-to-ammonia ratio, significantly reduced the occurrence of nitrification, but were not a complete cure. Ann Arbor recently switched from chloramine to ozone as primary disinfectant and retained chloramine as secondary disinfectant.

Conclusions

Managing disinfection by-products in light of DBP regulations has created new challenges for drinking water utilities, many of whom find themselves in an increasingly constricted box of limited options. Chloramine disinfection may provide more alternatives for those utilities facing confining DBP regulations, difficulties maintaining residuals throughout extensive distribution systems, and problems with tastes and odors.

Water Research Foundation General Resources on Chloramination

- LeChevallier, M.W., et al. 1996. *Factors Limiting Microbial Growth in Distribution Systems: Full-Scale Experiments*. Denver, Colo.: AwwaRF and AWWA (Order #90709).
- Reiber, Steven. 1993. *Chloramine Effects on Distribution System Materials*. Denver, Colo.: AwwaRF and AWWA (Order #90624).
- Singer, P.C., G.W. Harrington, G.A. Cowman, M.E. Smith, D.S. Schecter, and L.J. Harrington. 1999. *Impacts of Ozonation on the Formation of Chlorination and Chloramination By-Products*. Denver, Colo.: AwwaRF and AWWA (Order #90766).