CHLORAMINATION OF BUILDING WATER SYSTEMS AS AN ALTERNATIVE TO CHLORINATION

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SUMMARY

Monochloramine is increasingly promoted for direct on-site addition to premise plumbing for supplemental disinfection. Notwithstanding the claimed advantages, monochloramine compares unfavorably to the use of chlorine for supplemental disinfection.

Compared to supplemental chlorination of building water systems, the alternative use of chloramine is not preferred because:

1) Microbial control is inadequate
2) It results in higher proportions of *Mycobacterium*, *Pseudomonas*, *Acinetobacter* and nitrifying bacteria in biofilms
3) It induces the viable-but-nonculturable (VBNC) state in *Legionella*
4) Higher concentrations of nitrite and nitrate (regulated drinking water contaminants) can occur
5) It degrades to ammonium ion in premise plumbing treatments which can lead to nitrification
6) Corrosivity of elastomers and other construction materials is significant
7) Volatility is very high
8) The application is more complex due to instability of chloramines
9) The application is more expensive because the cost of chlorine is very low
10) N-Nitrosodimethylamine (NDMA), a potent carcinogen, in chloraminated drinking water is an emerging issue of great concern

Therefore, supplemental chlorination of building water systems is more effective, simpler, safer and less expensive compared to chloramination. Additionally, in cases where the water supply is chloraminated, supplemental chlorination of the building water is a very effective control strategy.

DETAILS

Since the first observations that *Legionella* bacteria in building plumbing systems are susceptible to monochloramine (Kool 1999, Flannery 2006), many on-site supplemental disinfection applications have been installed in building water systems, mostly outside the U.S. Much has been learned from this experience. Research has confirmed that short-term *Legionella* control can be achieved with chloramine treatments. However, also from this research, it is now known that numerous problems arise that in many cases make matters much worse (Edwards 2005, attached).

Chloramination of drinking water distribution systems is applied in about 30% of the municipalities in the U.S. Microbial control in these systems is often inadequate and therefore requires periodic chlorination (sometimes referred to as "burn out") to control nitrification and microbial fouling (Zhang 2009a, Regan 2002). Similar lack of microbial control has been observed in premise plumbing applications of chloramines (Wang 2012 and Edwards 2005, attached).

Perhaps the most significant aspect of inadequate microbial control with chloramine treatments is the selective enrichment of potentially pathogenic bacteria in biofilms. It is now confirmed that chloramine treatments result in higher proportions of *Mycobacterium*, *Pseudomonas*, *Acinetobacter* in premise plumbing biofilms, and these changes occur rapidly when chloramination is applied (Baron 2014, Revetta 2013, Hoefel 2005) and may also include enrichment of *Legionella* (Chiao 2014) or selection of more resistant, more virulent strains. These phenomena were not observed in the first applications previously referenced, but have since emerged as very serious problems. Enrichment of pathogens in the biofilms of premise plumbing systems and associated fixtures, such as showerheads, is an issue of increasing concern (Feazel 2009).

When oxidizing disinfectants in premise plumbing treatments degrade or are consumed, the result is chemical reduction: chlorine reduces to chloride; chloramine reduces to ammonium ion and chloride. Ammonium ion fertilizes microbial growth in the biofilms of premise plumbing systems. In buildings where water age is more than a few hours, such as is common in hot water loops and storage tanks, ammonium ion from degraded chloramine can fertilize microbial growth (Edwards 2005, attached).

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Nitrification is the microbial process of oxidizing ammonia for metabolic energy. Nitrification in chloraminated systems is now recognized as a significant issue (Zhang 2009a). Nitrite and nitrate are precursors to nitrosoamine carcinogens and are therefore strictly regulated in drinking water. Chloramination is associated with increasing nitrification from biofilms and deposits because excess ammonia provides nutrient for nitrifying bacteria in the premise plumbing of buildings. The association of this problem with chloramination has been observed and confirmed (Zhang 2009b, Nguyen 2012). After only six months, supplemental chloramination of a hospital water system increased nitrate concentration more than 10x and free ammonia concentration 85x (Stout 2012, see Table 2).

In carefully controlled laboratory simulations of premise plumbing systems, chloramination was shown to be less effective than chlorination because of poor biofilm control and almost no effect on amoeba in biofilm or in the bulk water compared to controls (Loret 2005).

Monochloramine treatments have been shown to induce the "viable but nonculturable" (VBNC) state in *Legionella* (Alleron 2006, Turetgen 2008, Alleron 2008, Alleron 2013). *Legionella* in the VBNC state are unable to grow on the media used for plate counts, but are nevertheless still alive and potentially virulent. Therefore, culture tests from chloraminated systems may return false-negative results relative to the actual viability and potential pathogenicity of *Legionella* in the system, which is emerging as a significant analytical problem.

Monochloramine is nearly 10x more volatile compared to chlorine in water (Blatchley 1992, McCoy 1991). Most building water systems are not entirely closed systems, such as those systems with storage tanks and partially filled pipes. Volatility due to the higher air-water partition co-efficient of chloramine can result in significant oxidant loss and also can result in what is known as "vapor-phase" corrosion.

Chloramines are not sufficiently stable to be shipped. Therefore, on-site production is required. Chloramination devices are complex and involve reacting chlorine with an ammonium-containing compound together to manufacture monochloramine

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on-site. This chemical manufacturing operation is potentially dangerous; it requires reacting an oxidizing agent with a reducing agent on-site and therefore must be carefully managed.

Because of the complexity of reaction and the equipment necessary to do it safely, chloramination is far more expensive compared to supplemental chlorination. Of course, pricing and costs vary, but it is important to note that because the volume of water in premise plumbing systems is relatively small, the chemical cost of chlorination is very low. For instance, hot water loops in buildings typically contain less than 1,000 gallons of water; thus, the cost in chemical to continuously chlorinate a system of this size is essentially negligible.

An emerging issue of great concern from the chloramination of drinking water is a disinfection by-product recently identified but not yet widely regulated: N-nitrosodimethylamine (NDMA). NDMA is a disinfection by-product of chloramination that occurs when monochloramine reacts with dimethylamine, a ubiquitous natural component of water. There is conclusive evidence that NDMA is a potent carcinogen in experimental animals by several routes of exposure, including through ingestion of drinking water. NDMA has been classified as probably carcinogenic to humans. The mechanism by which NDMA produces cancer is well-understood and suggests that humans may be especially sensitive to the carcinogenicity of NDMA. Where chloramination is used, distribution system samples can have much higher levels of NDMA than the finished water at a treatment plant; levels as high as 0.16 µg/l (ppb) have been measured in distribution systems. Potential methods for reducing the formation of NDMA during disinfection include avoiding the use of chloramination, using breakpoint chlorination and removing ammonia prior to chlorination (WHO 2011). California has established a public health goal of 3 ppb NDMA in drinking water. Massachusetts has established a regulatory limit of 10 ppb in drinking water. These low levels reflect the potent nature of this carcinogen. Further regulation of NDMA in drinking water is expected in the future.

CONCLUSION

Compared to supplemental chlorination for building water systems, chloramination is 1) not sufficiently effective, 2) potentially more corrosive, 3) more complex to apply, 4) more volatile, 5) more expensive and 6) more dangerous.

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