CHLORINATION OF BUILDING WATER SYSTEMS

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BIAS DISCLOSURE

Phigenics does not sell chemicals or disinfection devices. We have no commercial affiliation with suppliers or manufacturers of such products. We do not accept money from suppliers or manufacturers to evaluate their products.

Phigenics is paid to provide commercially independent expert guidance for development and implementation of water management programs. The purposes are to prevent building-associated injury and disease and to improve operational efficiency of facilities.

We provide independent validation and verification through real-time monitoring of control measures, on-line data management, setting intensity metrics, utilizing data analytics to enhance decision making, environmental testing for all waterborne pathogens and analytical services for water chemistry.

SUMMARY

Chlorine disinfection is the most sensible, simplest, safest, least hazardous and least expensive means to control microbial hazards in building water systems. Application issues are often overstated as objections by vendors selling more complex and expensive alternatives.

Table 1. Summary of application issues for chlorination.

Application Issue	***Potential Problems***	***Practical Consequences***
Effect of high pH	2-5x more chemical may be required at pH above 8.0 compared to lower pH water systems.	Minimal. The increased cost of chemical is negligible compared to use of far more expensive, more hazardous alternatives.
Disinfection by-products (DBPs)	Trihalomethane (THMs) and/or haloacetic acids (HAAs), especially in hot water recirculation loops.	Minimal. Short contact time results in minimal if any additional chlorine DBPs. The DBPs from ClO_2 and NH_2Cl are far more problematic.
Biofilm control	Biofilms provide safe harbor for microorganisms, consume chlorine and breed chlorine-tolerant bacteria.	Manageable. In well-controlled, scientifically defensible comparisons that simulate real-world conditions, biofilm control with chlorine is as good as or better than alternatives.
Protozoan control	Higher life forms are more tolerant to chlorine compared to bacteria.	Manageable. In well-controlled, scientifically defensible comparisons, protozoan control with chlorine is as good as or better than alternatives.
Volatility	Air-stripping “flashoff,” especially in hot water systems, can deplete chlorine residual.	Minimal. Chlorine in water is far less prone to flashoff compared to all other disinfectants except bromine, which is not acceptable for drinking water.
Reactivity with ammonia	Chlorine is consumed by ammonia in water and oxidizes ammonia to nitrogen gas, which is referred to as breakpoint chlorination.	Desirable. Ammonia in water is the result of inadequate microbial control. It fertilizes biofilms. Chlorination is a practical means to remove ammonia from water.
Corrosion	Over feed or poor control can cause corrosion of premise plumbing, including fixtures, pipes, seals and heat exchangers.	Manageable. Overfeed or inadequate control of <u>any</u> disinfectant, including chlorine, can cause corrosion. When used properly, chlorine is not more corrosive. Silicate inhibitors are highly effective for those building water systems in which corrosion is a problem.

DETAILS

Any discussion of building water system disinfection must be preceded by acknowledgement that effective, defensible control must be within the context of a site-specific Water Management Program (WMP). The WMP must be based on the principles of hazard analysis and control, including independent third-party verification and validation. Descriptions of effective WMPs are beyond the scope of this paper (for more information about WMPs, see ASHRAE 2015, McCoy 2015, McCoy 2014, WHO 2011, McCoy 2005).

Also preceding any discussion of disinfection alternatives, it must be acknowledged that product feed, monitoring and distribution are often at issue. Regardless of which water disinfectant is used, if product feed is not well controlled or if its distribution throughout the building water system is inadequate, then effective control cannot be achieved.

Lastly before discussing disinfectant alternatives, it should be understood that microorganisms are adaptive and the biofilms they develop are highly diverse. Therefore, it is necessary to combine several control measures, such as controlling water age, temperature and disinfectant residuals throughout the facility. It is unlikely that one single control measure is adequate to control microbial fouling in complex building water systems.

Scientifically well-controlled comparisons and experience from many decades of successful practical application of water treatment indicate that well-managed chlorination of building water systems effectively controls microbial hazards in the built environment. Therefore, none of the many alternatives to chlorine disinfection for water systems have successfully displaced chlorine as the predominant means of disinfecting water in buildings.

> *Chlorine is widely credited with virtually eliminating outbreaks of waterborne disease in the United States and other developed countries. The use of chlorine to control microbes has the lowest production and operating costs of any disinfectant, as well as the longest history for large continuous disinfection operations. Among Public Water Systems (PWSs) that disinfect, chlorine is the most commonly used disinfectant.*
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> *Quoted from Draft - Technologies for Legionella Control: Scientific Literature Review. Office of Water (4607M) EPA 815-D-15-001 October 2015*

In the 1980s, continuous supplemental chlorination (CSC) of building water systems was successfully implemented in several healthcare facilities (Snyder 1990). Many of those early CSC applications are still operating successfully today. Since then, numerous successful real-world applications have been in operation for many years. The disinfectant for both cold and hot water systems recommended by the Centers for Disease Control and Prevention (CDC) and by the Healthcare Infection Control Practices Advisory Committee (HICPAC) is chlorine; alternatives have been described but with no recommendations given (CDC 2003, HICPAC 2003, Sehulster 2004). Many examples of building water system chlorination applications are available for your inspection and reference. Please contact a Phigenics representative to discuss specific real-world applications that are relevant to your facility (info@phigenics.com).

Results from a Pilot-scale Study of a Potable Building Water System

A systematic study to compare the efficiency of different disinfectants applicable to *Legionella* control in domestic potable water systems was undertaken (Loret 2005). A unit that allowed simulation of real-world domestic water supply conditions was developed for this purpose. The system, consisting of seven identical rigs, was used to compare treatment efficiency under equivalent conditions of system design, materials, hydraulics, water quality, temperature and initial contamination. The water temperature during all experiments was 35 °C (95 °F) and the pH was 8.5. Other details of water chemistry and operating conditions were set to simulate building water system conditions and have been previously described (Loret 2005). During the study, each of six loops received continuous application of one of the following disinfectants: chlorine (as sodium hypochlorite), electrolytically generated chlorine, chlorine dioxide, monochloramine, ozone or copper-silver ionization. The seventh loop was used as the negative (untreated) control. Performance evaluation of these disinfectants was based on their ability to control *Legionella*, protozoa and biofilms. Figures 1 shows the rig.

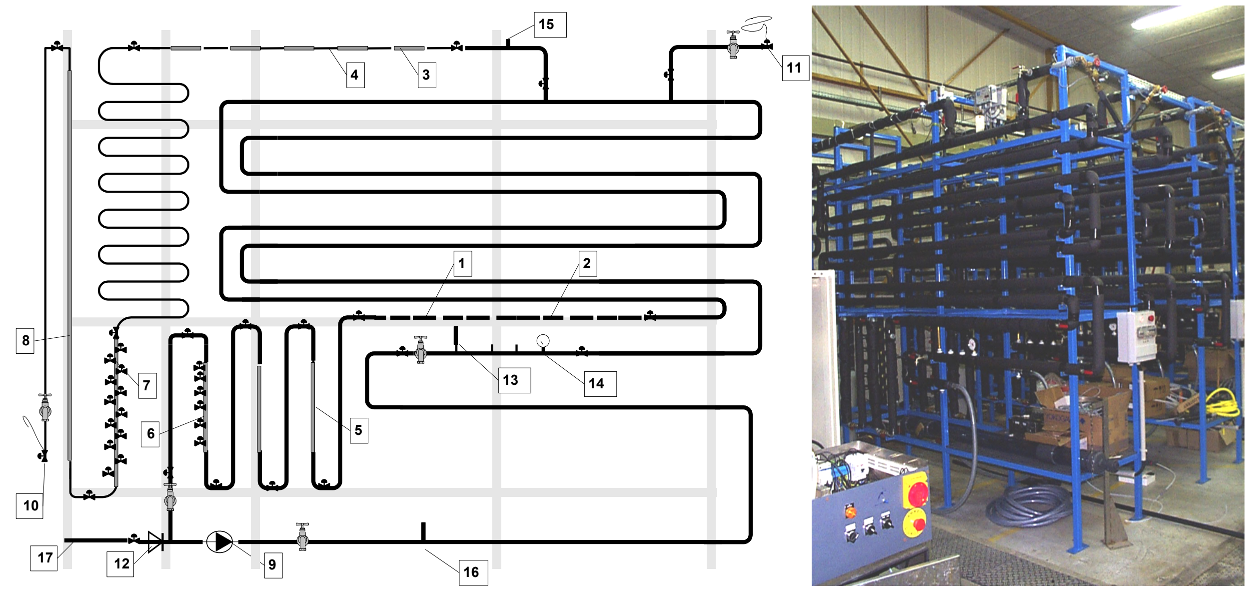

Figure 1. Domestic water supply simulation unit. 1: galvanized steel coupons, 2: mild steel coupons, 3: copper coupons, 4: brass coupons, 5 and 8: glass beads for biofilm monitoring, 6 and 7: PVC coupons for biofilm monitoring, 9: re-circulation pump, 10 and 11: solenoid valves, 12: non-return valve, 13: temperature probe, 14: pressure gauge, 15: air trap, 16: point of injection of disinfectants, 17: connection to the water heater. The water temperature during all experiments was 35 °C (95 °F) and the pH was 8.5. Note insulated pipes.

Against free-floating (planktonic) *Legionella*, all of the treatments except copper-silver (Cu/Ag) ionization were equally effective (Figure 2). These results indicate that Cu/Ag could not be recommended for control of *Legionella* in building water systems.

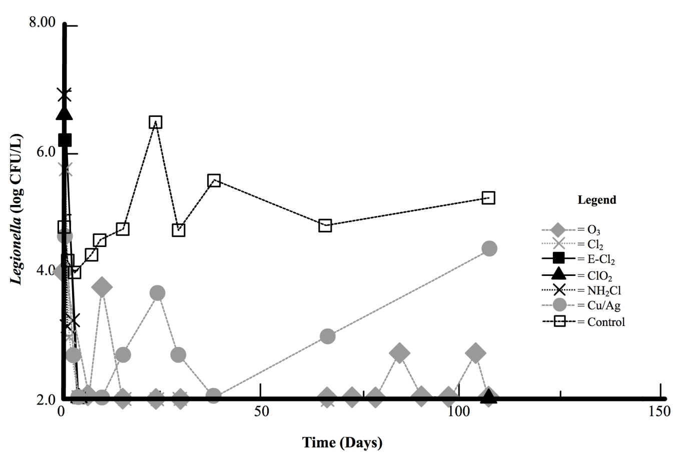

Figure 2. Control of planktonic (free-floating) Legionella in seven identical domestic water systems. All of the treatments were effective except copper-silver (Cu/Ag) ionization.

Legionella are parasitic to the amoebae in building water systems. They grow to vast numbers inside infected amoeba and are then released into the water distributed throughout the facility. The amoebae in test rigs were counted. Results of treatments were compared to the untreated control. All of the treatments reduced the amoeba by at least 99% except monochloramine and Cu/Ag treatments. Planktonic amoebae control was ineffective with monochloramine and Cu/Ag treatments compared to controls (Table 2).

Table 2. Changes in planktonic amoebae in re-circulation loops.

Amoebae (cysts/L)	***O_3***	***ClO_2***	***Cl_2[a]***	***Electro -Cl_2[a]***	***Monochloramine***	***Cu/Ag***	***Control***
log (initial population)	4.2	3.5	4.2	4.2	4.0	2.9	4.2
log (final population)	0.6	1.7	1.4	1.7	3.5	2.6	4.2
log (reduction)	3.6	1.8	2.8	2.5	0.5[b]	0.3[b]	0.0
% Reduction of amoebae	99.9+%	99%	99+%	99+%	0%[b]	0%[b]	0%

[a] Cl2 refers to sodium hypochlorite additions to the water; Electro-Cl2 refers to electrolytically generated sodium hypochlorite.

[b] Not significantly different than the no-treatment control, indicating that the treatments were not effective.

Biofilm Control

Chlorine (either as sodium hypochlorite or generated on-site electrolytically from sodium chloride), chlorine dioxide and ozone were the most effective biofilm control treatments. Of these, chlorine treatments were most effective; biofilm thickness was reduced to below detectable levels compared to controls. Monochloramine and Cu/Ag ionization treatments were not effective for biofilm control compared to controls (Figure 3).

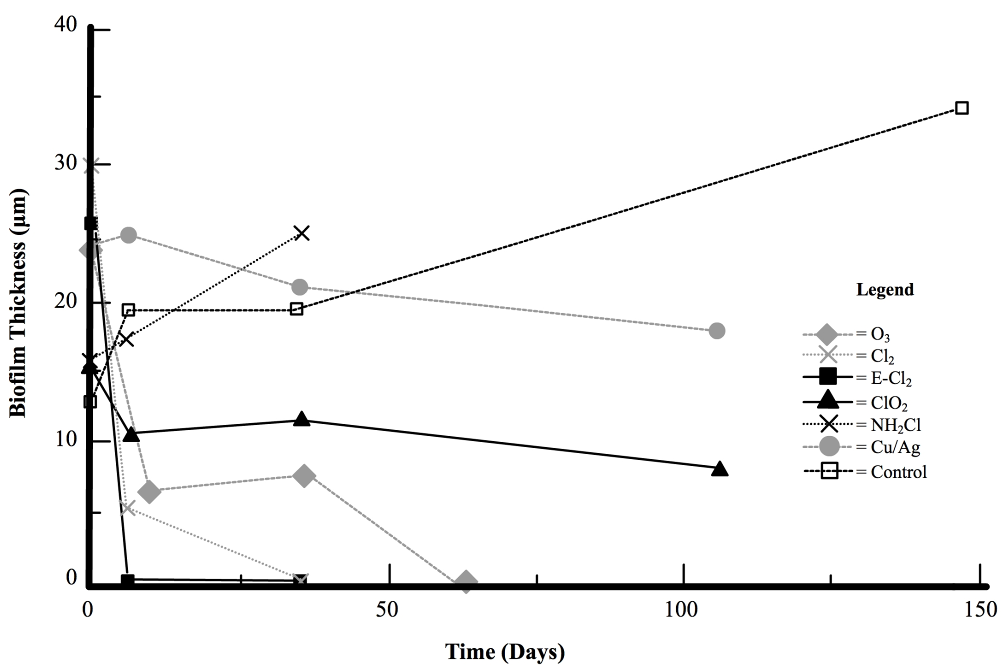

Figure 3. Biofilm control in seven identical domestic water systems. All of the treatments were effective except monochloramine and copper-silver (Cu/Ag) ionization. Chlorine (from sodium hypochlorite or electrolytically generated) were the most effective; biofilm thickness was reduced to below detectable levels by chlorine.

When considering safety, cost and simplicity (which includes regulatory and application issues), chlorine was the most preferred disinfectant for microbial control in potable building water systems, as summarized in Table 3.

Table 3. Ranking of performance, safety, cost and simplicity of application for six building water system disinfectants (adapted from Loret 2005). NaOCl = sodium hypochlorite; E-NaOCl = electrolytically generated sodium hypochlorite; ClO_2 = chlorine dioxide; Cu/Ag = copper and silver ionization; NH_2Cl = monochloramine; O_3 = ozone.

Rank	Performance	Safety	Cost	Simplicity[a]
Most Preferred	NaOCl	NaOCl	NaOCl	NaOCl
↑	E-NaOCl	Cu/Ag	E-NaOCl	E-NaOCl
	ClO_2	E-NaOCl	O_3	O_3
	NH_2Cl	NH_2Cl	NH_2Cl	NH_2Cl
	O_3	O_3	Cu/Ag	Cu/Ag
Least Preferred	Cu/Ag	ClO_2	ClO_2	ClO_2

[a] "Simplicity" includes implementation of the chemical treatment and regulatory issues.

Three doubts are often raised about the use of chlorine for building water system disinfection: 1) doubts about performance above pH 8, 2) doubts about performance against biofilms and 3) doubts about corrosion. However, as was shown in this study and in many others, microbial control in building water systems using chlorine is effective and inexpensive compared to all other alternatives, even above pH 8 and in high alkalinity water. Corrosion of premise plumbing is negligible at use concentrations of chlorine when the application is properly controlled (Loret 2005, Cantor 2003 and 2006). In systems where higher chlorine concentrations are necessary or where control of chemical feed is difficult, corrosion inhibition with silicate has been successful and can be recommended (Siwicki 1989, Thompson 1997).

Microbial Control in Utility Water Systems of Buildings

Proper application of cooling tower biocides and effective use of inhibitors to control scaling and corrosion have been shown to control all microbial hazards, including *Legionella*, in the non-potable water systems of buildings.

Properly applied sodium hypochlorite programs work well at a fraction of the cost compared to alternatives. In many situations, the more expensive products are overfed or otherwise misused. Another commonly observed problem is the over-dosing of phosphate and phosphonate inhibitors. This situation is problematic because the limiting nutrient for microorganisms in water systems is almost always phosphate; overfeed of phosphate and/or phosphonate products aggravates microbial fouling by fertilizing it (McCoy 2005).

Pilot-scale Cooling Towers (PCTs)

Pilot cooling towers (PCTs; see Figure 4) have been used to simulate all the processes in open recirculating cooling tower systems (McCoy 2014). PCTs provide a means for well-controlled, scientifically defensible comparisons of microbial control programs. Any situation encountered in the real world of HVAC cooling for building water systems can be simulated and studied with these pilot-scale cooling towers.

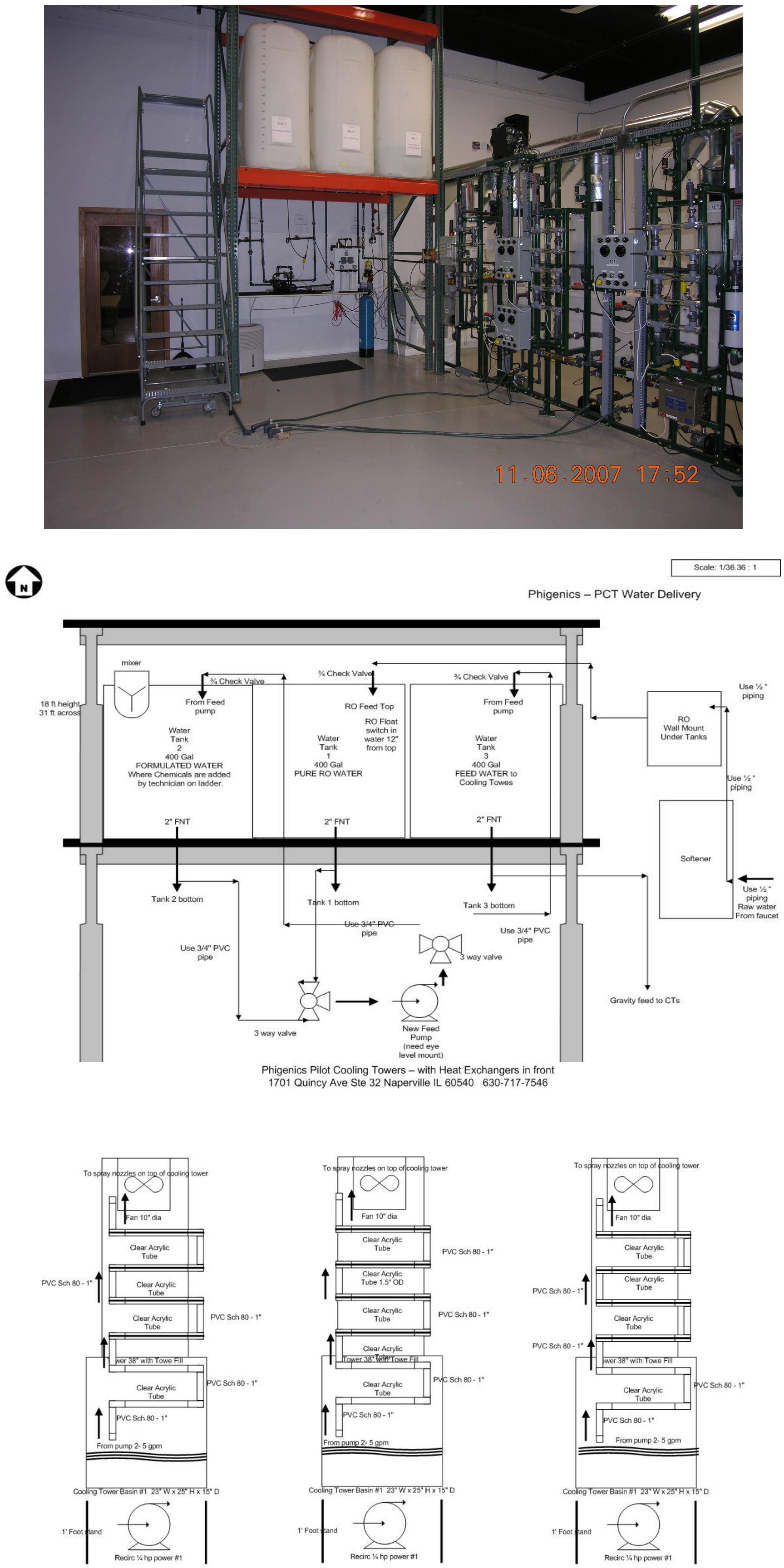

Figure 4. Photographs and schematic diagrams of the pilot cooling tower simulation system.

Biofilm Control and Removal

A common misconception is that sodium hypochlorite treatments are somehow not effective for removing biofilm from surfaces in building water systems. However, when applied properly, chlorine treatments are effective for both control and removal of preexisting biofilms. In conditions that simulated extremely heavy fouling conditions at pH 8.5 with high alkalinity, microbial control with sodium hypochlorite treatments were effective and practical (Figure 5).

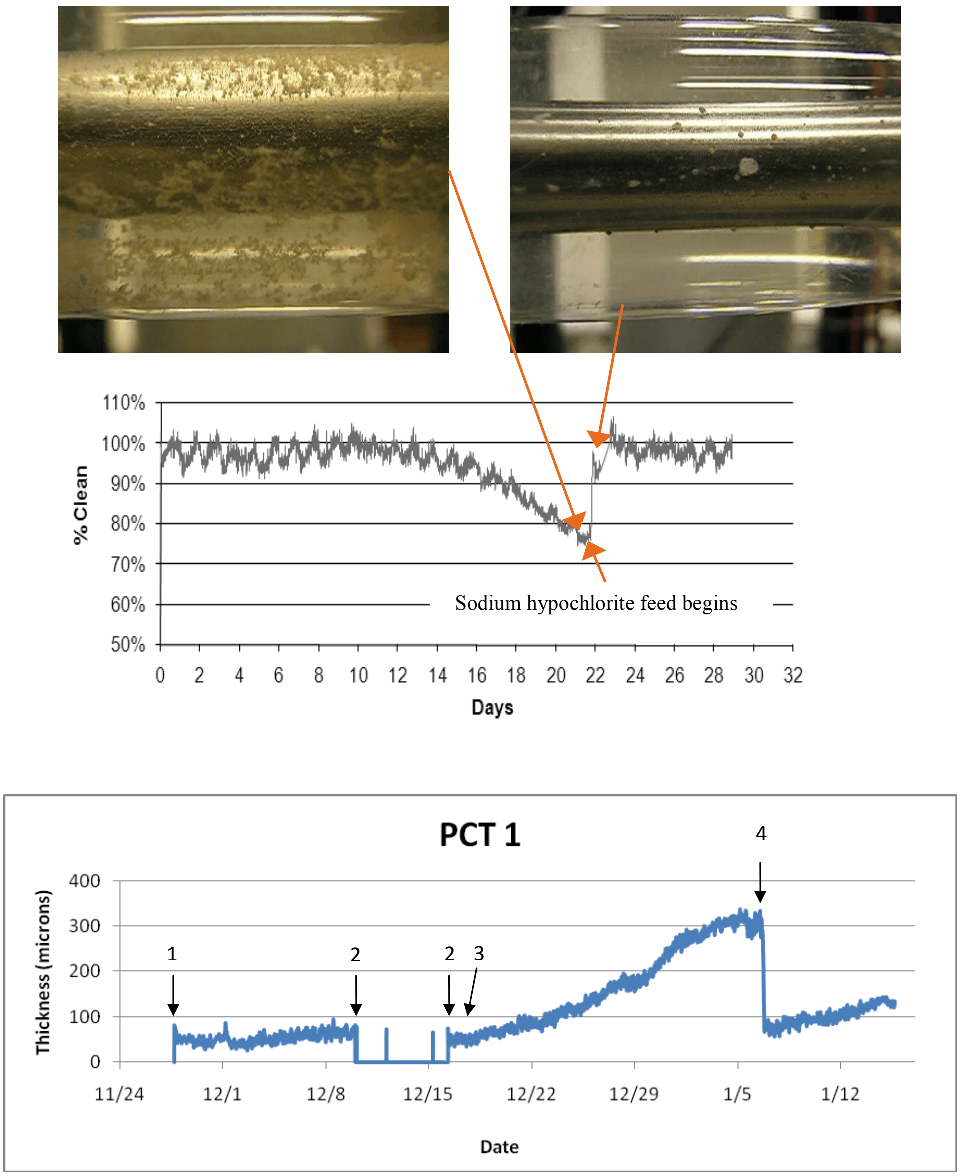

Figure 5. Microbial control in pilot cooling towers (PCTs). Conditions were conducive to heavy fouling and scaling with pH 8.5 and Langelier Saturation Index (LSI) always much greater than 1. Top panel photographs correlate with heat transfer resistance measurements (% Clean). Very heavy microbial fouling (photograph, left, correlated to 30% heat transfer loss) was quickly controlled with chlorine at typical concentrations used in the field.

Bottom panel: Event indicators: At 1 – Continuous 10 ppm glucose nutrient feed; 5 ppm phosphate concentration from scale inhibitor and water conditions previously shown to result in heavy fouling without microbial control, pH 8.5. Biocide applied was sodium hypochlorite at 2 ppm FRO (free residual oxidant) continuously. At 1-2 – Control of biofilm was maintained during chlorine feed. At 2 – Software error; data lost; new updated software installed. At 3 – Chlorine treatment stopped; thickness of biofilm on heat exchanger surfaces increased from about 50 µm to over 300 µm because there was no chlorine applied during Period 3-4. At 4 – Begin 5-10 ppm FRO from sodium hypochlorite continuously for 8hrs; biofilm removal began almost immediately and microbial control was restored within the first day of treatment.

Studies Funded by the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE).

A series of cross-flow cooling tower cells was used to evaluate several treatment practices for microbial control in cooling towers (Thomas 1999). The tower cells were operated to maintain a heterotrophic bacterial population >10^6 CFU/mL after 48 hrs of operation. The chlorine treatment protocol (0.5-1.5 ppm as free residual oxidant) reduced planktonic heterotrophic bacteria by at least 3 orders of magnitude (99.9%) and reduced heterotrophic bacteria in biofilms by 3-4 orders of magnitude (99.9+%) compared to controls. Sodium hypochlorite treatments were more effective on biofilm control than any other biocides tested. For overall performance, sodium hypochlorite treatments were as effective or more compared to all other biocides tested.

Another HVAC cooling tower simulation rig was used to study the performance of several devices marketed and sold as "non-chemical devices" (Vidic 2010). None of the devices were effective for microbial control compared to sodium hypochlorite treatment controls. The chlorine treatments provided "positive controls" essential to providing scientifically defensible evidence that industry-tested disinfection methods were effective for the control of microbial growth in the cooling tower simulation. The selection of free chlorine as a positive control was based on common practice in cooling water treatment. Results of the study indicated that sodium hypochlorite treatments were highly effective for cooling water microbial control. Chlorine treatments typically reduced viable planktonic (free-floating) bacteria by 3 orders of magnitude (99.9%) and viable biofilm bacteria by 3-4 orders of magnitude (99.9+%).

The most significant value of these studies is that they provide documented proof that chlorine fed as sodium hypochlorite is highly effective for microbial control of cooling water systems in scientifically defensible, well-controlled experiments.

CONTRADICTORY DATA IN PEER-REVIEWED PUBLICATIONS

A great deal of confusion ensues from studies published in the scientific literature presenting contradictory or conflicting data about the comparative effectiveness of disinfectants. Perspective, insight and caution are necessary to make sense of all the data.

Many studies have shown that typical chlorine treatments of building water systems are highly effective against bacteria, including *Legionella*, and for biofilm control. However, other peer-reviewed scientific publications show data indicating that typical chlorine treatments are essentially not effective at all or only marginally so. Care must be taken to look at the study details. For example, we are aware of laboratory studies that lack defensible controls to confirm the actual free residual concentrations applied in the treatments. If the controls are not well constructed, carefully performed and documented, then the results from the study may not be reliable.

Another common practice in the literature is to cite field applications for which there were essentially no controls at all. For example, studies often involve inadequately managed building water systems that were converted from chlorinated water to one of the more expensive and complex chlorine alternatives; results are then presented to indicate improved microbial control. Take care to look at the study details. Often, in addition to the new disinfectant, many other changes occurred during the study, including heightened awareness, more monitoring, better distribution of residuals throughout the facility and decreased water age in the building water system. Thus, such studies do not disprove that optimizing the management of the chlorinated water entering the facility and/or a simple supplemental chlorine treatment within a defensible Water Management Program would have done just as well at a fraction of the cost.

Finally, care must be taken with regard to bias and commercial conflict of interest. Just because a scientific paper does not fully disclose the bias and commercial interests of the authors does not mean there is no conflict of interest. We are aware of very strong bias among prominent researchers who have published many times with intent to show that chlorine just doesn't work well enough and therefore, an alternative (which is more complex and expensive) is necessary.

COST COMPARISONS

The chemical cost of chlorine is and always will be far lower compared to any alternative. Typically the cost of chemical for chlorine alternatives is more than 100x greater compared to the cost of EPA-registered sodium hypochlorite.

The cost of on-site chemical production of chlorine dioxide and monochloramine can exceed $100,000 per year for each on-site generator. This cost is entirely unnecessary for chlorination of building water systems.

The cost to monitor disinfection by-products from chlorine dioxide (chlorite and chlorate) is substantially greater than chlorine or other alternatives because on-site analyses of grab samples are required daily. Depending on the number of chlorine dioxide application points, this requirement may require significant investment.

The cost to feed and control disinfectant is about the same for chlorine and all the chlorine alternatives. However, monitoring, product feed, control and data management services vary greatly. If chlorine is not properly fed, controlled and monitored, then building water systems may become more hazardous and less safe. For further information, please inquire with a Phigenics representative (info@phigenics.com).

To comparatively evaluate the cost of disinfection alternatives, calculate the disinfection cost per gallon of water used. Sum the projected annual CAPEX and OPEX for the disinfection program and divide it by the total annual gallons the facility uses. Then, compare this metric across the proposed disinfection options.

CONCLUSION

Successful disinfection of a building water system with chlorine must always begin with the development of a facility-specific Water Management Program based on hazard analysis and control principles.

From the development of the WMP, a facility water management team can defensibly decide whether or not additional, supplemental disinfection is even necessary. Often, improved monitoring, better control of water age, temperature, distribution of disinfection residual and better management of cooling water treatment chemicals result in safe building water and improved operational efficiency without any additional disinfectant at all.

If the water management team determines that additional, supplemental disinfection is required for their facility, then the WMP process must be used to make defensible decisions about which hazard control option to use, where to use it, how much to use, how to feed and control it and any regulatory requirements that may apply. The Safe Drinking Water Act specifies federal requirements for treating drinking water in buildings. Cooling tower biocides are also regulated by the federal government. Discussions of these regulatory requirements are beyond the scope of this paper. For information, please contact a Phigenics representative (info@phigenics.com).

Facility managers should always begin with the simplest, safest, least hazardous and least expensive option: supplemental chlorination. It is by far the most sensible approach to hazard control for building water systems when properly applied within the context of a well-designed and fully implemented Water Management Program.

Independent third-party verification and validation should always be employed to ensure defensible application of any disinfectant or biocide to building water systems, including drinking water and cooling tower water.

After these actions have been fully implemented, if validation evidence shows that microbial control with chlorination is inadequate and after all effort has been made to optimize the treatment, only then should the facility water management team consider more complex, expensive alternatives.

REFERENCES

American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2015. ANSI/ASHRAE Standard 188-2015 Legionellosis: Risk management for building water systems. www.ashrae.org

Cantor, A.F., Park, J.K. and Vaiyavatjamai, P. 2003. Effect of chlorine on corrosion in drinking water systems. Journal of the American Water Works Association 95: 112-123.

Cantor, A.F., *et al*. 2006. Copper pipe failure by microbiologically influenced corrosion. Materials Performance. 38-41.

Centers for Disease Control and Prevention (CDC). 2003. Guidelines for Preventing Health-Care-Associated Pneumonia: Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee. Morbidity and Mortality Weekly Report. 53(RR03): 1-36. http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5303a1.htm

Environmental Protection Agency. October 2015. Draft - Technologies for Legionella Control: Scientific Literature Review. Office of Water (4607M). EPA 815-D-15-001.

Healthcare Infection Control Practices Advisory Committee (HICPAC). 2003. Guidelines for Preventing Health-Care-Associated Pneumonia: Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee. Pg. 29. http://www.cdc.gov/hicpac/pdf/guidelines/HApneu2003guidelines.pdf

Loret, J.F., Robert, S., Thomas, V., Cooper, A.J., McCoy, W.F. and Lévi, Y. 2005. Comparison of disinfectants for biofilm, protozoa and Legionella control. Journal of Water and Health 3(4): 423-433.

McCoy, W.F. and Rosenblatt, A.A. 2015. HACCP-Based programs for preventing disease and injury from premise plumbing: A building consensus. *Pathogens* 4: 513-528. doi:10.3390/pathogens4030513

McCoy, W.F. 2014. HACCP-based building water management programs. In: *Legionella* na Visão de Especialistas, Ed., Marcos Bensoussan. Chpt 8. ISBN: 978-85-388-0484-0

McCoy, W.F. 2005. Preventing legionellosis with hazard analysis and control systems. *Legionella*: State of the art 30 years after its recognition. In: Proceedings of the 6th International Conference on *Legionella*. Eds., Cianciotto, N. *et al*. ASM Publishing. ISBN-10: 1555813909

McCoy, W.F. 2005. *Preventing Legionellosis*. Intl. Water Association Publishing. London, UK. ISBN: 1 84339 094 9

Sehulster, L., *et al*. 2004. Guidelines for environmental infection control in health-care facilities. Recommendations from CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC). Chicago IL; American Society for Healthcare Engineering/American Hospital Association; 2004. Pg. 54. http://www.cdc.gov/hicpac/pdf/guidelines/eic_in_HCF_03.pdf

Siwicki, M. 1989. Controlling Legionnaires' disease in water systems. *Healthcare Facilities Management*. May 1989. 30-35.

Snyder, M.B., Siwicki, M., Wireman, J., Pohlod D., Grimes, M., Bowman-Riney, S. and Saravolatz, L.D. 1990. Reduction in *Legionella pneumophila* through heat flushing followed by continuous supplemental chlorination of hospital hot water. *Inf. Diseases* 162: 127-132.

Thomas, W.M., Eccles, J. and Fricker, C. 1999. Laboratory observations of biocide efficiency against *Legionella* in model cooling tower systems. ASHRAE Transactions 105(2): 1-14.

Thompson, J., Scheetz, B. Schock, M., Lytle, D. and Delaney, P. 1997. Sodium silicate corrosion inhibitors: Issues of effectiveness and mechanism. Proceedings of the 1997 AWWA Water Quality Technology Conference, November 9-12, 1997. Denver, CO.

Vidic, R.D., Duda, S. and Stout, J.E. 2010. Biological control in cooling water systems using non-chemical treatment devices. ASHRAE RP-1361. *www.ashrae.org*

World Health Organization (WHO). 2011. Guidelines for drinking-water quality, 4th Ed. 20, Avenue Appia, CH-1211 Geneva, Switzerland.