A Low-cost, Safe, Effective Halogen Disinfectant for Cooling Towers

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Abstract

On-site, on-demand generation of MIOX mixed oxidant disinfecting solution provides several advantages for the cooling tower industry. These include excellent control of microbial populations even at the elevated pH typical of cooling tower waters, no negative impact on traditional scale and corrosion inhibitors, and environmentally friendly operating conditions. As an inherently safe technology, it only uses common sodium chloride salt as a feed stock. The solution can be fed directly to the cooling tower and controlled via Oxidation Reduction Potential (ORP). Case studies demonstrate significant reductions in operational costs when compared to conventional biocide chemicals, not only on a commodity cost basis, but also for elimination of safety related costs. This paper uses case studies and laboratory data to demonstrate mixed oxidant advantages for cooling tower disinfection.

Introduction

The cooling industry must address five major challenges for cooling tower maintenance. They include traditional issues such as 1) controlling inorganic scale deposition on cooling surfaces (Ca Co_3, $CaSo_4$ and silica deposits), 2) providing corrosion protection for steel, copper, copper/nickel tubing, and cooper alloys (admiralty), 3) controlling microbiologic growth, including biofilms on cooling surfaces and bacterial counts in the cooling tower basin water, 4) preventing fouling in heat exchangers and condensers and 5) controlling airborne impurities and contaminants that enter external to the water source.[1] More recently, disease outbreaks caused by the aerosolization of waterborne bacteria from inadequately managed cooling towers have caused concern and, in some cases, legal action.[2,3]

The cooling industry addresses many of these traditional challenges through chemical addition programs using various combinations of antiscalants, corrosion inhibitors, dispersants, biocides, and the use of disinfectant(s) to provide a free halogen residual. Chemical disinfection of the water is the primary means for controlling biological growths and biofouling, in conjunction with other physical process such as settling and filtration. Bulk hypochlorite (chlorine), bromine and/or combinations of bromine and chlorine are often used to control bacterial growth and provide the disinfection residual, in addition to use of costly specialty organic biocides and algecides.

However, regulatory trends at both the state and federal level concerning the safe and secure transport, storage and use of biocides, are pushing the industry to consider safer, less costly technologies. Regulatory drivers include chemical security regulations[4], registration of chemicals and mil taxes in some states, and biocide discharge residues of cooling tower blowdown.[5] Meeting new regulations can be costly and time-consuming.

Further, while most of these biocides achieve control, provided they are dosed appropriately and monitored by competent personnel, they constitute 30 to 70% of the chemical spend for a cooling tower system. As a result, chronic underdosing to reduce costs is common. The biocides are highly corrosive and typically fed under pressurized lines that may burst or leak during use.

This paper introduces a reliable disinfection technology that performs just as well as bromine disinfectants at high pH, provides enhanced cooling water disinfection, removes biofilm and algae, maintains compatibility with most deposition and corrosion control programs, provides payback on capital equipment cost within 2 years, eliminates the need for hazardous chemicals and is considered environmentally friendly, i.e. a green technology.

The Technology

MIOX systems use the basic electrolytic process used at chlor-alkali plants to make chlorine-based oxidizing compounds for over 100 years. These forms of chlorine include chlorine gas and 12-15% bulk hypochlorite. However, rather than requiring transport of the disinfectant to the site, the MIOX equipment generates the disinfectant on site using only salt, water, and power. The concentration of the solution is <1% as Free Available Chlorine (FAC), below any safety thresholds.

The MIOX Corporation began manufacturing and marketing systems in 1994 following a period of intense development and testing. While MIOX Mixed Oxidant Solution (MOS) systems were originally designed primarily for potable and waste water treatment, several laboratory and field tests have shown that the technology provides measurable benefits in swimming pool and industrial cooling applications above and beyond traditional disinfection technologies.

On-site, on-demand generation of MOS from sodium chloride (salt) provides an attractive solution to concentrated biocides. Mixed oxidants are generated at the site by passing a 3 to 4% brine solution through an electrolytic cell. The brine solution is converted to a powerful oxidant consisting primarily of sodium hypochlorite (bleach) and minor components of other oxidants. The oxidants may be fed directly into the system and monitored using existing equipment, such as ORP or on-line chlorine residual monitors.

A major difference between MOS and hypochlorite is that MOS performs at the elevated pH values typically found in cooling towers. Often, pH adjustment is not needed and MOS performance meets or exceeds that of bromine. This is most likely due to the small quantities of other oxidants produced in addition to hypochlorite during electrolysis.

The mixed-oxidant solution consists primarily of chlorine (as HOCl and OCl^- depending on pH), as well as other chlor-oxygen species which are short-lived when presented with an oxidant-demanding substance, such as total organic carbon or microorganisms. This feature of the other-oxidant component of MOS was demonstrated first by Dowd[6] and continues to manifest in virtually all MIOX system installations. The relative disinfecting capabilities of the mixed-oxidant solution, which are significantly greater than those of chlorine alone, are most likely caused by the synergism of the oxidants working together. Synergy between oxidants has been demonstrated by others in the water treatment research community.[7] Numerous studies show that MOS provides the disinfection needed to meet or exceed all bacteria/residual standards in potable water. These same studies also show that MOS exceeds all other current chlorine-based technologies in kill effectiveness of viruses and cysts while also reducing disinfection by-product concentrations compared to chlorine. For example, MOS can inactivate *Giardia lamblia* cysts and *Cryptosporidium parvum* oocysts by more than 99.9% at practical doses (as FAC) of 5 mg/L[8]; in the case of *C. parvum* oocysts, no inactivation occurs by equal doses of chlorine alone.

Safety

Most biocides have U.S. National Fire Protection Association[9] safety ratings of 2 or 3. Salt, the starting material for on-site generated MOS, has a safety rating of 0. Many of these biocides also have reportable quantities for spills. Because MOS is approximately 0.4%, it does not exceed any federal or state safety thresholds.

Several of the biocides require pressurized lines for adequate delivery, putting personnel at risk in the case of a line break or leak. MOS is directly fed into the system, or stored in an oxidant tank depending upon customer requirements.

No handling of chlorine is required, personnel do not have to wear protective gear, and there are no storage compatibility issues. An environmentally “Green” feed-stock of sodium chloride is all that is needed. The potential to form chlorine gas by accidentally combining high pH bulk hypochlorite and acid is eliminated. Corrosion damage to the facility is also reduced providing savings on building repair.

The only potential safety concern with on-site generation is the production of small amounts of hydrogen gas, a byproduct of all electrolytic processes. Proper system design vents the hydrogen gas to the atmosphere. MIOX Corporation sought the assistance of Hydrogen Safety LLC to evaluate its venting designs, documentation and labeling information. In a letter dated March 16, 2007, Donald M. Rode P.E., Principal and Managing Director, stated that “MIOX Corporation is the safety leader for hydrogen mitigation for on-site generation technologies”.

Compliance

Cooling Technological Institute, OSHA, ASHRAE and others recommend maintaining a continual free halogen residual within the cooling tower system as a Best Practice to minimize the risks associated with *Legionellae.* MOS is very effective against *Legionella pneumophila*, especially when compared to sodium hypochlorite. Compelling field evidence and case studies also demonstrate that MOS removes biofilm, a medium that harbors *Legionella* and other pathogens, from several different types of surfaces, including cooling tower surfaces. This benefit decreases the risk of waterborne diseases, outbreaks, and illnesses. Slime, bacteria, and algae are eliminated from cooling tower surfaces, re-growth is prevented, and water is clear.

The Need for Microbiological Control in Cooling Towers

Favorable temperatures (70 to 110°F) and the availability of nutrients make cooling tower systems ideal places for microbial growth. These microorganisms include algae, bacteria, cysts, and viruses. Another issue for cooling towers is the accumulation of biofilm. Biofilms impede proper heat transfer and secrete metabolic products that contribute to microbiologically influenced corrosion (MIC) and poor heat transfer. The films also propagate and release disease-causing bacteria. For example, it has been shown that Legionellae, Pseudomonas, and Bacillus genus members form or associate with biofilms.[10,11] Biofilm cells may be dispersed by sheering due to flow effects, by shedding of daughter cells from actively growing cells or by detachment as a result of environmental conditions.[12]

If Legionellae, Pseudomonas, or Bacillus bacteria become aerosolized, they may become health risks. Cooling towers, showers, spa pools, faucets, and residential water systems that circulate contaminated water are capable of producing a potentially lethal aerosol. For example, *Legionella pneumophila* is an ubiquitous aquatic organism that thrives in warm environments and causes over 90% of deaths associated with Legionellae in the U.S. An estimated 10 to 15 thousand persons contract Legionnaires disease in the U.S. each year and 10 to 15% of these cases are fatal.[13] A number of these cases were linked to cooling towers where Legionnaires disease was found in biofilm throughout the entire water distribution system. Several high profile Legionnaires Disease cases have resulted in multimillion dollar class action suits, including a recent example in Toronto, Canada causing 21 deaths at a nursing home, and ultimately resulting in a $600-million lawsuit. In 2002, a *Legionella* outbreak caused seven deaths in the UK and a manslaughter charge to one local official.[3] Other recent examples include a Florida hotel, a Pennsylvania nursing home, a N.Y. correctional facility, and a South Dakota restaurant. In Murcia, Spain, 449 cases of LD were confirmed and 6 of those people died when a cooling tower released *L. pneumophila* into the environment.[2]

In addition to the human health and legal aspects caused by inadequate microbiological control in water systems, biofilms affect cooling tower efficiency. Biofilm consists of microbial cells, the polysaccharide biopolymer they produce, and debris extracted from the recirculating cooling water. These components can form a gelatinous layer on heat transfer surfaces, fill material, and basins. The problems caused by biofilm include 1) physical plugging of cooling tower fill, tubes, and water passages, 2) accelerated corrosion, 3) reduced heat exchanger efficiency and 4) increased risk of Legionnaires disease, and other infectious diseases caused by water – aerosol bacterial transmission. Physical Plugging caused by biofilm is eliminated - The gelatinous mass of biofilm can obstruct water flow through the cooling tower fill and tubing. Build-up of biofilm reduces the normal ΔT heat rejection efficiency of the fill. There have even been reported incidences of fill collapsing due to the weight of biofilm build-up.

- **Accelerated Corrosion caused by biofilm is prevented** - Areas underneath biofilm deposits are more prone to corrosion due to biofilm excretion products. This phenomenon is known as MIC.
- **Reduction in Efficiency is minimized -** Biofilms significantly reduce the efficiency of heat transfer in chillers, or cooling towers and other water cooled

systems. If heat is not transferred properly, the system must work harder to accomplish the same amount of cooling. Compared to other scaling constituents, biofilms are one of the worst types of interference in a cooling system. Because the thermal conductivity of biofilm is low (0.6), heat does not get transferred well when biofilms colonize on heat transfer elements. This is in contrast to calcium carbonate which is over 4 times as resistant to heat transfer than biofilms (thermal conductivity = 2.6). Calculations show that a biofilm only 0.045 inches thick on the condenser tubes of a centrifugal chiller results in a 35% reduction in heat transfer (See Figure 1). For a 200-ton chiller operating at 50% annual average load, at $0.05/kWh, this would increase annual power costs of $26,280 by an additional $9,198.[14] In this case, removing the biofilm with MOS would result in approximately 184,000 kWh of savings each year.

Insert Figure 1 here

- **Biofilm removal provides significant health advantages –** These include removal of Legionella, Pseudomonas and Bacillus species and the subsequent risk of introducing a harmful pathogen into the surrounding air. Microorganisms can develop resistance to biocides in recirculating cooling water systems, especially if the treatment train is incorrect due to improper identification of the resistant pathogen.[15] Further, it has been shown that chlorine is ineffective at preventing attachment of surviving viable cells and subsequent biofilm accumulation. In contrast, MIOX mixed oxidant solution effectively removes biofilms at reasonable FAC value.

Microbiological and Biofilm Control Using MOS

Inactivation of Free-floating bacteria by MOS

Two studies with direct relevance to water quality in cooling towers are highlighted in this paper. In 1996, Barton, evaluated the disinfection effectiveness of MOS against three bacterial species commonly found in cooling systems, *Bacillus stearothermophilus*, *Pseudomonas aeruginosa* and *L. pneumophila*.[16] These measurements were performed in direct comparison with hypochlorite. Results showed that after 10 minutes of exposure at a pH of 8.0, MOS achieved total kill against *L. pneumophila* and *P. pseudomonas* while chlorine alone did not (Table 1). Further, mixed oxidants were significantly more effective than chlorine at achieving inactivation of *B. stearothermophilus*, a spore-forming bacteria with lineage to *B. anthracis*, even at doses as low as 2 mg/L (as FAC).

Insert Table 1 here

The second study was performed by Bradford et al.[17] In this study, the researchers demonstrated that in simulated cooling tower waters, MOS maintains superior FAC and a Total Chlorine (TC) residuals compared to sodium hypochlorite (NaOCl). The results of those tests over a period of 60 minutes after dosing the test solutions at phosphate-buffered pH 6.5 are shown in Table 2, and at phosphate-buffered pH 9.0 are shown in Table 3. The implication of these results is that smaller (compared to chlorine) doses of FAC as mixed-oxidant solution are required to maintain a target FAC or TC residual in the cooling water.

Insert Tables 2 and 3 here

Removal of Biofilm by MOS

MIOX Corporation has several field studies demonstrating that MOS removes biofilm in both small and large distribution systems.

Field example 1: A Hot Springs in Japan had been using sodium hypochlorite for treatment of their pool water and was experiencing positive *Legionella* and coliform counts. In December of 2002, the Hot Springs installed a MIOX SAL-80 mixed-oxidant system for treatment of their spring water. After only 5-1/2 hours of MIOX MOS system operation, operators began removing biofilm sloughing that appeared in the pool. The pH of the water was 8. The dose rate with sodium hypochlorite was 1.5 mg/L with a residual of less than 0.2 mg/L. After 22 days and removal of biofilm, the dose rate was reduced by 60% with mixed oxidants to 0.6 mg/L while the residual doubled to 0.4 mg/L. Figure 2 shows these data graphically. A boroscope camera was used to document the piping system. Figure 2 shows the pipe prior to application on mixed oxidants (on the left). The photo on the right shows the pipe after 22 days of MOS treatment. The pipe is virtually clean of deposits and the Legionellae and coliform counts were reduced to nothing.

Insert Figure 2 here

Field example 2: A city in Texas was using two different disinfection strategies to service its community. Gas chlorine was the prior routine practice in the five well systems. A brown biofilm slime on pipes in the distribution system was commonly noticed (see pipe on left in Figure 3). One well, and distribution branch, was converted to a MIOX MOS system. One year following the conversion, an astute water plant operator was servicing pipe breaks in each of the distribution lines. He noted the pipe treated with MOS was clean (shown on right). He further observed that the pipe on the left was only a few hundred feet from the water plant while the MOS treated pipe was several miles from the plant.

Insert Figure 3 here

Additional studies by the Orange County Water District in California[18] and the Center of Excellence for Biofilm Engineering at Montana State University[19] show that MOS is even more effective than conventional chlorine at destroying biofilms and preventing regrowth.

Case Histories

Case Study 1: Evaluations Performed by Trident Chemicals, Inc.

In 1999, the first 6 month pilot study was conducted by Trident Technologies, Inc. to assess the effectiveness of MOS as a replacement for oxidizing and non-oxidizing biocides on a cooling tower.[20] Trident Technologies provides chemical water treatment programs for cooling and boiler water systems, and was very interested in evaluating MOS as a new approach to providing improved program performance.

The pilot study replaced a dual biocide program of hydantoin and gluteraldehyde. The pH was controlled in the range of 8.4-8.6 using H_2SO_4 and an all organic corrosion/scale inhibitor program was used. In Jan 1997, biocides were taken off-line and the MIOX system was substituted for microbiological control. All other maintenance operations initially remained unchanged. Midway through the 6-month test, the pH control was removed.

Insert Table 4 here

Case Study 2: Evaluations performed by Fehr Solutions, LLC.

A cooling tower system for a large district in downtown Chicago was chosen for an initial two year pilot study. The biocide/disinfection strategy was a combination of slug fed sodium hypochlorite and isothiazolin (Kathon). The sodium hypochlorite was fed two times per week (8 gallons per slug) and the isothiazolin was fed twice per week (6 gallons per slug). The cooling tower pH was uncontrolled, but remained around 8.9 – 9.1.

A MIOX Corporation SAL-80 MOS on-site generator was installed and pilot tested for performance. To determine the effectiveness of MOS on microbial growth, MOS dosage rates were ramped up to continuous feed of 16 lbs/day of MOS as FAC. Within two weeks of achieving 16 lbs/day feed, the basin was cleared of algae and biofilm was substantially reduced. Within four weeks all remaining biofilm was removed. The oxidant concentration was routinely measured at 0.6 to 0.8 ppm as FAC. Even at the highest concentrations of mixed oxidant, no degradation of phosphonates, polymer, or azole was measured. Further, no corrosion occurred, as determined by comparison to baseline measurements.[21]

Insert Table 5 here

A second pilot study replaced 480 gallons of bleach and 360 gallons of Kathon with salt, the starting material for MOS on-site, on-demand generation. Similar results were realized. Further, it was easier to maintain a residual within the tower. When compared to bleach, the MOS solution is dilute, preventing chlorine spikes versus high chlorine spikes when a high concentration (12-15%) of hypochlorite is added.[22] The data from these case studies provides guidelines for MOS dosage needs (Table 6).

Insert Table 6 here

Economics

Payback for the units described in the second case study has averaged between 11 and 18 months. The small systems use 1 to 2 bags of water softener salt per day depending on water usage within the system. Properly designed systems can result in no storage of any chemical as MOS can be fed directly to the cooling tower and controlled via ORP. These units have eliminated the handling of two hazardous chemicals (28,500 total pounds per year) and the subsequent disposal of 51 chemical drums.

Mixed oxidant technology is cost effective, often giving a return on investment (ROI) of less than 2 years. The ROI is manifested in the elimination of safety related costs of maintaining hazardous biocides, in the reduction of biocides needed to achieve the same level of performance with MOS. Further, MOS can typically be produced at a significant cost savings over bulk hypochlorite and other frequently used biocides. The shelf-life of salt is indefinite, whereas other chemicals, especially bulk hypochlorite, can degrade over time. Energy savings resulting from improved heat transfer are expected, but must be quantified site by site. While the initial capital cost may constitute a resistance to implementation, numerous financing options exist to amortize these costs over the short ROI period while still maintaining positive cash flow for the operation.

How MOS Meets or Exceeds CTI Recommendations

Several institutes and organizations, including CTI, have published guidelines for control of *Legionella* in water systems.[23] MIOX MOS can be a solution provider for these applications. *L. pneumophila* survives typical chlorine disinfection. The Cooling Technology Institute recommends hyperhalogenation at 5 mg/L for at least 6 hours if the bacterial condition of the cooling tower system is unmanageable. If biofilm exists, the reports recommend eliminating biofilm as well as amoeba and other protozoa that serve as hosts for *Legionella*. Not only does MIOX MOS inactivate these microorganisms at practical water treatment doses as FAC, it also eliminates biofilm and prevents scale formation associated with biofilms. The CTI report recommends dipslide counts of <10,000/mL. Systems using MIOX MOS for routine disinfection maintenance report dip slide counts of <1,000/mL. Finally MOS may be run continuously through the system or a residual may be held at 0.2-0.3 mg/L for one hour each day. This is in contrast to "halogen residuals" which according to these reports must be held at 1.0mg/L for at least one hour each day.

Insert Table 7 here

Conclusions

Laboratory, field studies, and case studies show that the MOS solution controls microbial populations, even at the elevated pH typical of cooling tower waters. No negative impact on traditional scale and corrosion inhibitors was observed. The units are easy to operate and require minimal maintenance. MOS technology is inherently safer than the use of biocides, chlorine gas, or

bulk bleach. MOS technology is economical and cost-efficient and is more effective at removing biofilm than other biocide programs. For these reasons, MIOX mixed oxidant technology is emerging as the leading technology for cooling tower maintenance.

[1] Metcalf & Eddy, Inc., 1991 "Wastewater Engineering: Treatment, Disposal, and Reuse, third Edition, Revised by G. Tchobanoglouw and F.L. Burton, McGraw-Hill, Inc., New York, NY, 1334 pp.

[2] Garcia-Fulgueiras, A., et al., 2003 "Legionnaires' Disease Outbreak in Murcia, Spain" *Emerg. Infect. Dis*. 9, 915-921.
[3] McCoy, W. 2005 "Preventing Legionellosis" IWA Publishing, Seattle pp.8-10
[4] Code of Federal Regulations, Title 6 Part 27. "Chemical Facility Anti-Terrorism Standards."
[5] www.epa.gov
[6] Dowd, M.T., 1994, "Assessment of THM Formation with MIOX", Master's Thesis, University of North Carolina, Department of Environmental Sciences and Engineering, School of Public Health, Chapel Hill, NC.
[7] Kouame, Y. and C.N. Haas, 1991, "Inactivation of *E. coli* by Combined Action of Free Chlorine and Monochloramine", Wat. Res., 25(9):1027-1032.
[8] Venczel, L.V., M. Arrowood, M. Hurd, and M.D. Sobsey, 1997, "Inactivation of *Cryptosporidium parvum* Oocysts and *Clostridium perfringens* Spores by a Mixed-Oxidant Disinfectant and by Free Chlorine", *Appl. Environ. Microbiol*., 63(4):1598-1601.
Casteel, M.J. M.D. Sobsey, and M.J. Arrowood, 1999, "Inactivation of *Cryptosporidium parvum* Oocysts in Water and Wastewater by Electrochemically Generated Mixed Oxidants", presented at the International Conference on Minimizing the Risk from *Cryptosporidium* and Other Waterbourne Particles, Paris, France, April 19-23, 1999, International Association on Water Quality, International Water Services Association, and the International Ozone Association.
[9] NFPA 704 is a standard defining the colloquial "fire diamond" used by emergency personnel to quickly and easily identify the risks posed by nearby hazardous materials.
[10] Costerton, J.W., Stewart, P.S. and Greenberg, E.P. 1999 "Bacterial Biofilms: A Common Cause of Persistent Infections" Science, 284; 1318-1322.
[11] Szabo, J.G., Rice, E. W., Bishop, P.L. 2007 "Persistence and Decontamination of *Bacillus atrophaeus* subsp. *globigii* Spores on Corroded Iron in a Model Drinking Water System." *Appl. Envir. Microbiol*. 73, 2451-2457.
[12] Donlan, R.M. 2002 "Biofilms: Microbial Life of Surfaces*" Emerg. Infect. Dis*. Volume 8, Number 9, Sept. Available from: URL: http://www.cdc.gov/ncidod/EID/vol8no9/02-0063.htm
[13] www.cdc.gov Accessed on Aug 30, 2006.
[14] Downloaded from http://www.prochemtech.com/Literature/literature.html
[15] Wiatr, C. L., "Bacterial Resistance to Biocides in Recalculating Cooling Water Systems." 2006 CTI Journal: 27, 1, 46-58.
[16] Barton, L., 1996, "Disinfection of Simulated Cooling Tower Water," University of New Mexico, Albuquerque, NM, March, 1996.
[17] Bradford, W.L., F.A. Baker, and R.I. Cisneros, 1997, "Results of Tests Comparing the Disinfection Effectiveness of Mixed-Oxidant Solution and Sodium Hypochlorite on Simulated Cooling Water", LATA/MX-97/0027, Los Alamos Technical Associates, Los Alamos, NM, and MIOX Corporation, Albuquerque, NM, January, 1997.
[18] Phipps, D and Rodriguez, G., Water Resources and Technology Department, Orange County Water District, California. *Comparison of the Efficiency of Bacterial Removal and Reduction of Bacterial Viability by Mixed-Oxidant Solution (MOS) and Chlorine (as NaOCl) on a Reverse Osmosis Membrane.* June, 2001.
[19] Crayton, C., et al. Montana Water Resources Center, Montana State University. *Final Report on the Validation of Mixed Oxidants for the Disinfection and Removal of Biofilms from Distribution Systems.* October 1997.
[20] Petersen, P., and Bradford, W.L., "Mixed Oxidant Application in Cooling Tower Maintenance" January, 2000.
[21] Fehr, M. "An Alternative Cooling Tower Disinfectant: On-site Generated Mixed Oxidants" *Industrial WaterWorld*, September, 2006.
[22] Michael Fehr, Ph.D., Technical Manager of Fehr Solutions, LLC. Personal communication, 2005.
[23] Cooling Technology Institute. Legionellosis Guideline: Best Practices for Control of Legionella, July, 2006.

Figure 1. Ranking of Common Foulants

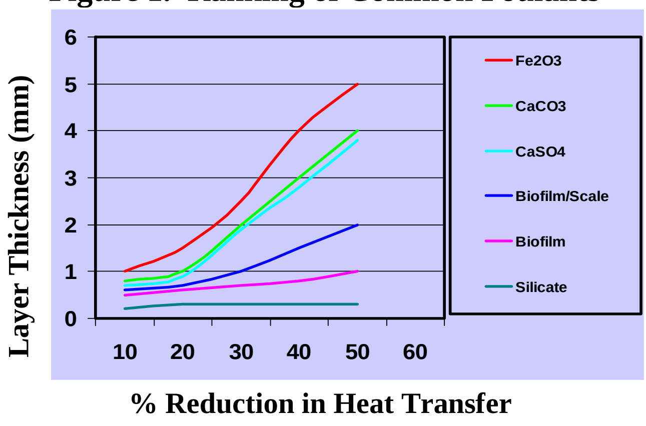
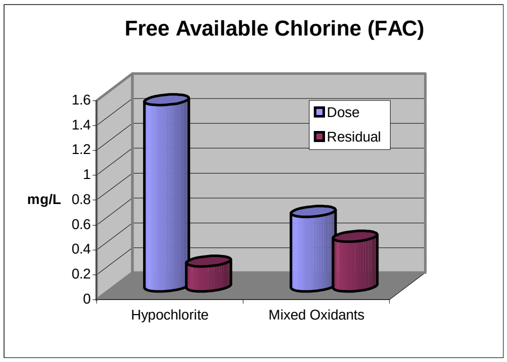


Figure 2.



With delivered hypo

With mixed oxidants

Figure 3.

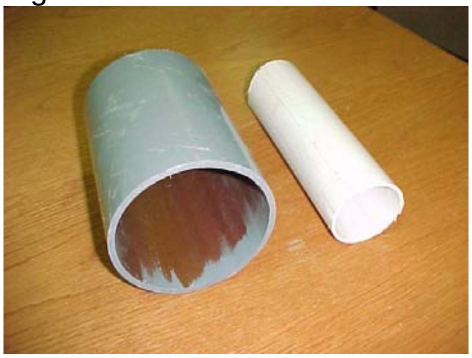


Table 1: Bacteria present (CFU/ml): pH = 8; Exposure = 10 minutes

Type of Microorganism:	Initial Microorganism Concentration:	Chlorine Equivalent Concentrations (mg/L):			
		2 mg/L Dose		4 mg/L Dose	
		Mixed Oxidants	NaOCl	Mixed Oxidants	NaOCl
Bacillus stearothermophilus	2×10^5	35 CFU/ml	1400 CFU/ml	0 CFU/ml	12 CFU/ml
Pseudomonas aeruginosa	1×10^5	0 CFU/ml	1200 CFU/ml	0 CFU/ml	110 CFU/ml
Legionella pneumophila	1×10^5	0 CFU/ml	> 2 CFU/ml	*0 CFU/ml*	> 2 CFU/ml

Table 2: FAC and TC in Test Solution:pH = 6.5; 2 mg/L NH_3; Temperature = 50^{o}C

FAC Dose	5 minutes		10 minutes		15 minutes		30 minutes		60 minutes	
	FAC	TC	FAC	TC	FAC	TC	FAC	TC	FAC	TC
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
FAC Dose as Mixed-Oxidant Solution										
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.60	1.2	0.55	1.0	0.32	0.75	0.21	0.65	0.15	0.40
4	0.60	2.3	0.90	2.0	0.75	1.9	0.70	1.6	0.60	0.95
6	1.5	3.6	1.3	3.5	2.2	3.5	1.8	2.6	1.3	1.8
8	2.2	5.4	2.2	4.4	4.3	5.3	1.9	4.2	2.3	3.2
FAC Dose as NaOCl										
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.18	0.60	0.40	0.55	0.30	0.50	0.25	0.40	0.15	0.30
4	0.48	1.5	0.90	1.4	0.80	1.3	0.55	1.0	0.30	0.85
6	0.50	1.8	1.4	1.9	1.3	2.0	1.3	1.7	1.0	1.5
8	0.90	2.8	1.6	2.3	1.4	2.1	0.80	1.9	0.80	1.5

Table 3: FAC and TC in Test Solution:pH = 9.0; 2 mg/L NH_3; Temperature = 50^oC

FAC Dose	5 minutes		10 minutes		15 minutes		30 minutes		60 minutes	
	FAC	TC	FAC	TC	FAC	TC	FAC	TC	FAC	TC
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
FAC Dose as Mixed-Oxidant Solution										
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.35	1.1	0.70	0.90	0.60	0.40	0.35	0.55	0.21	0.30
4	2.2	3.5	1.3	2.1	1.6	1.8	0.95	1.3	0.65	0.90
6	3.6	4.6	3.6	4.4	2.8	4.0	2.2	3.2	1.6	2.0
8	5.8	5.2	5.2	5.5	4.6	5.6	3.8	5.1	2.7	3.6
FAC Dose as NaOCl										
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.12	0.65	0.28	0.60	0.38	0.50	0.05	0.40	0.15	0.30
4	0.15	1.6	0.38	1.3	0.42	1.2	0.08	0.90	0.38	0.60
6	0.15	2.0	0.85	1.8	0.68	1.8	0.10	1.3	0.60	1.0
8	0.20	4.4	1.8	3.6	1.0	3.9	0.25	3.0	0.38	1.7

Table 4 summarizes the results of case study 1.

	Before ***(Dual Biocide Program)***	**After** ***(MIOX Mixed Oxidants)***
Aerobic Bacteria Count†	Occasional excursions to > 1000 CFU/mL	Complete sterility (< 1000 CFU/mL) consistently
Algae Growth	Some algae growth in the cooling water basin	Algae removed and controlled, no terbutylazine shocking was needed
Biofouling	Accumulation of biofilms on cooling surfaces	Removed existing biofilm and scaling associated with biofilm
Residual	0.2-0.3 free halogen	0.5 FAC
Scaling	Managed using all-organic polymer program	No scale deposition despite rise in pH after pH control was removed
Water Clarity	Somewhat cloudy water due to surfactant nature of biocides	Crystal clear water in the basin
Corrosion*	Corrosion levels within industry norms (<2 mils/yr. on steel surfaces; <1 mil/yr. on copper surfaces) Copper heat exchange surfaces in good condition – azole program	Corrosion rates maintained within industry norms No effect on azoles used for copper; no effect on copper heat exchange surfaces

† Counts were determined using an Easicult TTC dipslide test
*When pH control was removed after 3 mo.'s, pitting-type corrosion began to appear on steel surfaces. Based on the hypothesis that MOS was degrading the all-organic corrosion inhibitors due to its stronger oxidizing properties, inorganic phosphates were substituted for the all-organic program and pH control was reestablished in the 7.4-7.5 range. The inorganic corrosion inhibitors and pH control eliminated pitting-type corrosion.

Table 5 summarized the results.

	Before *(Dual Biocide Program)*	**After** *(MIOX Mixed Oxidants)*
Aerobic Bacteria Count†	Consistent problems with biofilm in the basin of the cooling towers • Bacterial counts in the bulk water averaged 10,000 CFU/mL • Surface bacterial (sessile) counts averaged 100,000 - 500,000 CFU/mL.	Complete sterility (< 100 CFU/mL) consistently
Biofouling	Accumulation of biofilms on cooling surfaces	Removed existing biofilm when and where the film was in contact with water
Algae Growth	Algae growth in the cooling water basin	Algae removed and controlled, no terbutylazine shocking was needed
Residual	low	0.6-0.7 FAC
Scaling	Managed using phosphonate/polymer program	No effect on scaling
Water Clarity	Somewhat cloudy water due to surfactant nature of biocides	Crystal clear water in the basin
Corrosion*	Corrosion levels within industry norms (<2 mil/yr. on steel surfaces; <0.1 mil/yr. on copper surfaces) Copper heat exchange surfaces in good condition – azole program	Corrosion rates maintained within industry norms No effect on azoles used for copper; no effect on copper heat exchange surfaces

Table 6: Dosing Guidelines for MOS Systems.

Recirculation Rate (gpm)	500.0	1000.0	2500.0	5000.0	10000.0	15000.0
Gallons of water used/day	10800.0	21600.0	54000.0	108000.0	216000.0	324000.0
HVAC Tonnage	166.7	333.3	833.3	1666.7	3333.3	5000.0
#'s of FAC/operating day necessary	0.7	1.3	3.3	6.7	13.3	20.0
MIOX Unit necessary	SAL-1	SAL-30	SAL-40	SAL-80	Super-SAL 80	Super-SAL 80

* Table compiled by Michael Fehr, Ph.D.

Table 7: A comparison of CTI guidelines with MOS Performance.

Sect.	¶	CTI RECOMMENDATIONS/COMMENTS	MIOX PERFORMANCE
III	3	*Legionella pneumophila* survives typical chlorine disinfection	The MIOX mixed-oxidant solution has been shown to inactivate *L. pneumophila* at practical water treatment doses as Free Available Chlorine (FAC).
V	2	Cooling tower drift as aerosols can be inhaled; showers, wash stands, sinks, air scrubbers etc. can be good growth media.	Using MIOX mixed-oxidant solution for routine disinfection maintenance, the waters of cooling towers tested had nil aerobic bacteria on standard dip slide tests for over 2 years.
VI	1	Sediment, sludge, scale and organic materials can harbor the bacterium and promote growth. The formation of a biofilm within a water system is thought to play an important role in harboring and providing favorable condition in which *Legionella pneumophila* can grow.	Biofilm, which had been deposited on cooling tower surfaces during prior treatment regimes using oxidizing biocides, was removed by MIOX mixed-oxidant solution. MOS also prevented recolonization of biofilms. Similar results are observed in potable water systems.
VII	1	Recommended to maintain clean heat transfer surfaces and a healthy work environment around open recirculating cooling systems.	Using the MIOX mixed-oxidant solution for routine disinfection, cooling surfaces and entry areas on cooling towers under test appear completely clean of any biofilms or scale deposits.
VII	3	Recommended elimination of biofilms and amoeba and other protozoa that feed on biofilms and which serve as *Legionella* hosts.	In addition to the remarks above on biofilm control, the MIOX mixed-oxidant solution has been shown to inactivate the protozoans *Giardia lamblia* cyst and *Cryptosporidium parvum* oocyst at practical water treatment doses of as low as 3 mg/L as FAC.
VII	T	Recommended dipslide counts <10,000/mL and sessile (biofilm) counts <100,000/cm^2.	In cooling towers under test, weekly dipslide tests have shown counts routinely <1,000/mL. Others MOS case studies show <100/mL. No biofilms have been observed on cooling surfaces.
VII		Recommended establishing a "free halogen" residual of 1.0 mg/L and hold this residual for no less than 1 hour each day.	The results noted above have been achieved at FAC residual concentrations of 0.2-0.3 mg/L using the MIOX mixed-oxidant solution.
VII		Recommended "hyperhalogenation" at 5 mg/L for at least 6 hours if the bacterial condition of the cooling tower system is out of control for any one of several possible causes.	Hyperhalogenation, or shocking the cooling towers under test with chlorine or other oxidizing biocides, or with gluteraldehyde for algae control, has not been necessary for the entire period of the testing (over 2 years).