Use of Chlorine Dioxide for Legionella Control in Potable Water Systems

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ABSTRACT

Water systems in most buildings are colonized with microbes that can be sources of deadly infection. This can be a liability for the building owners and managers. Legionnaires' disease (LD), a preventable bacterial pneumonia, is the subject of strict legislation in western Europe and various focus groups in the United States forecast similar legislative action. Mechanical, physical, and chemical treatments exist to try to eliminate or destroy the Legionella pneumophila bacteria. The most effective of these is chlorine dioxide, but the major problem until now has been the fact that it must be generated on site. A new aqueous chlorine dioxide product eliminates the need for onsite generation, and can be dosed into the water with a simple pump. A site specific program for the application, management, and web-based regulatory reporting obviates the need for customer involvement in what can be a labor intensive and costly regulatory compliance program.

KEYWORDS: Chlorine dioxide, Legionella pneumophila, potable water, secondary disinfection, hospitals, Legionellosis

INTRODUCTION

Waterborne pathogens are a threat to public health. Water systems in most buildings are colonized with microbes that can be sources of deadly infection. This can be a liability for the building owners and managers. Increased attention is being focused on water distribution and water hygiene systems. Legionnaires' disease (LD), a preventable bacterial pneumonia, is the subject of strict legislation in Western Europe. Current activities by various focus groups in the United States forecast similar legislative action.

Since the first recognized outbreak of LD in the United States at the 1976 American Legion Convention in Philadelphia, professional organizations and health officials have been prompted to implement guidelines for diagnosing and reporting the disease and monitoring the organism in water systems. The Legionella bacterium can be found in all waters, groundwater as well as fresh and marine surface waters. Water distribution systems can provide optimal conditions for the bacterium to thrive and multiply. All that is required is warmth and nutrients. Sediment and biofilm found in water distribution systems provide the nutrients, and hot water systems provide warmth. Optimal growth conditions are $20^{o} – 45^{o}$ C ($68^{o} – 113^{o}$ F), well within the range of most distribution systems. The bigger and more complex a system is, the greater the risk for the growth of the bacterium due to the stagnant nature of vast parts of the system.

Mist from a cooling tower, whirlpool bath, nebulizers, showerheads, and faucets can release the bacterium into the air. When inhaled, legionellosis can occur. Aspiration of contaminated water can also cause the disease.

Serious liability can be associated with a "do nothing" approach to Legionella control. Litigation in one case in San Antonio, TX had plaintiffs seeking over $70 million. After three cases had been confirmed at a hotel in Orlando, FL they voluntarily closed their doors for more than two weeks while remediation was done. OSHA has classified Legionella as a preventable workplace hazard. The United Kingdom and Australia have set standards for acceptable and unacceptable levels of Legionella and have set severe penalties for non-compliance. Organizations such as The Cooling Technology Institute and ASHRAE have published standards for "best practices" in dealing with Legionella. The Center for Disease Control and Prevention has established a Healthcare Infection Control Practices Advisory Committee. In a recent study, CDC estimated the cost of Legionnaires' disease at $100-320 million annually. Starting in 2001, The Joint Commission has required hospitals to develop a program for managing pathogens in cooling towers, domestic hot water, and other aerosolizing water systems. In June 2003, the Association of Water Technologies (AWT) published *Legionella 2003: An Update and Statement by the Association of Water Technologies.* This is a comprehensive update of collective information and data available from numerous research, investigative, and authoritative sources on *Legionella* and legionellosis

Legionella is a parasite. It lives in biofilm and masses of dead organisms. The key to controlling it is a good microbiological control program.

THE NEXT STEP

The goals of any program to control Legionella in water should be;

- Reduce counts in domestic water systems, both cold and hot.
- Minimize the risk of an outbreak among patients and staff.
- Deliver and maintain a continuous, low residual dose of biocide.
- Conform to all regulatory requirements

An excellent article on the subject of establishing an evidence-based approach to Legionella control was published in the ASHRAE Journal of October 2007 entitled *Preventing Legionellosis.* The use of evidence-based criteria for evaluating recommendations is becoming the norm. Identifying the sources of possible infection, and then formulating a plan to disinfect the sources is the first step. A program of sampling done by a reputable laboratory certified for Legionella testing will identify these sources.

Once identified, a systematic approach to controlling the bacteria must be established. Many methods exist to accomplish this. Mechanical, physical, and chemical means of control can be evaluated.

MECHANICAL CONTROL TECHNIQUES

Mechanical means to control the spread of bacteria can be classified into two groups; aerosol control and elimination, and distribution system control. Things like drift eliminators, cooling tower design, materials of construction, and improved HVAC maintenance attempt to confine bacteria laden water vapor and mist to areas where they will not be inhaled by patients or staff. They do nothing to remove bacteria or disinfect the water itself. Controlling air exchange rates and static pressure between indoors and outdoors attempts to block the infiltration of bacteria from outdoor sources, but again does nothing to eliminate it. Elimination of dead legs in water distribution systems will help control the re-growth of bacteria colonies, but does not eliminate them. Air and water filtration can remove the bacteria, but constant and expensive maintenance is required or filters can exacerbate the problem.

PHYSICAL CONTROL TECHNIQUES

Superheating Water

Raising the temperature of hot water systems above 140^{o}F has proven effective in controlling Legionella bacteria. Yet at around 120^{o}F conditions are ideal for rapid growth. Many states have regulations banning the distribution of hot water at 140°F to avoid the risk of scalding. There is no residual downstream of the water heaters so re-growth is rapid. Higher temperatures result in higher cost for utilities. With nothing done to the cold water, new colonies always enter the system. So superheating is at best a temporary remedy.

Ultraviolet Light
Ultraviolet light is an excellent biocide when used at the proper wavelength to destroy bacteria. It is effective for high velocity recirculating loops. By its nature, UV is localized disinfection and ensures that no new bacteria enter the distribution system. It cannot do anything to control or eliminate colonies already in the system as no residual effects are seen. Energy costs can be high, depending on the size and recirculation rate of the system. Maintenance of the protective sleeves for the lamps is high due to the need to keep them clean so as not to interfere with light intensity reaching the bacteria. Lamps are also expensive and must be changed regularly to maintain light intensity.

CHEMICAL CONTROL TECHNIQUES

Copper-Silver Ionization
Copper-silver ionization exhibits good microbial control, but systems are high in initial capital cost. To affectively kill pathogenic microorganisms, copper and silver ions should be present in the entire water system. When the system is used little and the water flow is quite slow, or when there are dead-end points in the system, this can causes problems for disinfection. Maintenance costs associated with the electrodes and high voltage system can be excessive. Microbial control is sensitive to pH level and hardness in the water. When pH values are high, copper ions are less effective. When the pH value exceeds 6, insoluble copper complexes will precipitate. Copper-silver ionization affectivity is determined by the presence of chlorine. Chlorine causes silver-chlorine complex formation. When this occurs, silver ions are no longer available for disinfection. This makes control of the desired residual level difficult. Legionella bacteria can develop resistance to copper-silver ionization. Control and elimination of the biofilm where bacteria thrive is questionable. Sophisticated analytical techniques are required to measure residuals. The maximum contaminant level proposed by EPA for silver is less than 0.1 PPM. The question is then raised, is it advisable to use possibly toxic metals for microbial control?

Chloramines
Chloramines also exhibit good microbial control, but are more biostatic than biocidal. Long contact times are required for maximum effectiveness, thus making use in smaller systems somewhat difficult. They are ineffective against spores and cysts.

Chlorination
Hyper-chlorination at levels up to 6 ppm is effective against Legionella. Capital costs and safety issues associated with the storage and feeding of either gaseous chlorine or hypochlorite can be intensive. Even at elevated dosage levels, Legionella bacteria can be resistive, and re-growth occurs. Chlorine and hypochlorite can produce high corrosion rates in copper, steel, and cast iron pipes. Low level hypochlorite does not control biofilm. Chlorination’s effectiveness is pH sensitive, and depending on the water chemistry, can produce trihalomethanes (THM’s) and haloacetic acids (HAA’s), both of which are undesirable by-products of chlorination and controlled by EPA regulations. Taste and odor issues can also arise from hyper-chlorination.

Ozone
Ozone is an effective disinfectant against planktonic and sessile bacteria. Ozone is a more effective disinfectant than chlorine or chloramines. It is sparingly soluble in water and very difficult to control residuals. As ozone rapidly decomposes when in water, its residual may last less than one hour. High energy use and high maintenance costs are associated with ozone. It is toxic if released to the atmosphere and so can present health and safety issues of its own.

Chlorine Dioxide
Chlorine dioxide is a powerful biocide that can kill bacteria quickly and at low residual levels. It eliminates planktonic and sessile bacteria very rapidly at concentrations as low as 0.1 ppm. It is EPA approved as a drinking water additive. When treating potable water, it is effective over a wide range of water chemistry and pH. It exists as a dissolved gas in water and is effective by way of oxidation rather than chlorination. Thus, no THM's or HAA's are formed. Chlorine dioxide penetrates biofilm and destroys it, eliminating food for bacteria growth, thus providing superior microbiologic control. Microbes cannot build up a tolerance to chlorine dioxide. At the maximum allowable residual level of 0.8 ppm, it is safe for all types of piping systems. Also, at this low level, no taste or odor issues arise. Residual can be traced throughout a facility easily.

Chlorine dioxide has been identified by BSRIA (owned by The Building Services Research and Information Association) as Best Available Technology for control of Legionella pneumophila. In the May 2009 issue of the Journal of the AWWA, an article entitled *Legionella Control by Chlorine Dioxide in Hospital Water Systems* described results from two hospital studies and concluded that Legionella can be successfully controlled by chlorine dioxide.

CHLORINE DIOXIDE GENERATION METHODS

Liquid Generators
Several systems are marketed for the generation of chlorine dioxide on-site by mixing either two or three precursor liquid chemicals to form chlorine dioxide in a liquid stream. Each precursor chemical is drawn from a storage tank by a pump, and injected into a reaction chamber where they react to form chlorine dioxide. The reacted liquid is then either pumped or educed into the treated stream. Control of the precursor pumps to ensure proper mixing ratios can be cumbersome.

The main precursor chemical is sodium chlorite solution, made from solid sodium chlorite and water. Typically, a 25% solution is used in generators. The reaction process generates chlorine dioxide, but can also leave unreacted sodium chlorite in the product liquid. EPA regulates both chlorine dioxide and the disinfectant by-product chlorite. Thus, unreacted chlorite can add to the maximum allowable residual of 1.0 ppm, and reduce the amount of chlorine dioxide that can be fed without exceeding the limit. Other unwanted by-products of the generation process can carry over into the treated potable stream.

Sodium chlorate can be used as a precursor with an acid to produce chlorine dioxide, but chlorine is then a by-product and may be undesirable.

Solid-Liquid Generators
Sachets and two-part solid chemical systems exist for generating an aqueous solution of chlorine dioxide. Typically one of the components is sodium chlorite which provides the ion necessary for gas production. The other can be sodium bi-sulfate which when added to water will produce an acid for the reaction with the chlorite to produce chlorine dioxide. The reaction or activation time required can be as long as four hours. The process is highly dependent on the quality of water used to dissolve the solid chemicals, and use of water containing oxidizable solids will reduce the available gas. Also, the shelf life of the product solution can be somewhat short, and is dependent on the quality of water used. Concentration of the product solution tends to spike to a high level and then degrade over time. Batches are typically small, thus necessitating constant renewal and backup storage.

Electrochemical Generator

A relatively recent design in chlorine dioxide generators is the electrochemical cell. This system uses 25% sodium chlorite solution and electricity to generate chlorine dioxide in an electrochemical cell. Chlorine dioxide is produced as an analyte and passed through a dissolver column with water to make an aqueous solution. At the cathode, hydrogen is generated which becomes a waste stream. Also, the co-product of the reaction is sodium hydroxide, which also becomes a waste stream. Although the process produces 99.5% pure chlorine dioxide, the power required and maintenance of the electrochemical cell and various reaction columns required can be extensive.

All of these methods generate chlorine dioxide on site and thus require constant attention to keep them running optimally. A new method with off-site generation and dissolution has produced a ready-to-use product.

***Gas:Solid* Generator and 0.3% Aqueous Solution**

CDG Environmental, LLC has developed *CDG Solution 3000™* based on the patented *Gas:Solid*™ technology. The *Gas:Solid* method reacts dilute chlorine gas with specially processed, thermally stable solid sodium chlorite contained in sealed reactor cartridges. It produces high-purity chlorine dioxide gas (<99.7%) inherently free of chlorite (ClO_2^-) and chlorate (ClO_3^-) ions, as these ions do not exist in the gas phase. Any unreacted sodium chlorite feedstock or impurities remain in the sealed reactor cartridge. This pure product can be easily analyzed and its concentration accurately measured because, unlike chlorine dioxide produced by other processes, it does not contain contaminants that interfere with analytical techniques.

By dissolving this pure gas in pure water, a shelf stable aqueous solution of 3000 PPM chlorine dioxide can be produced. Shelf life is currently set at 9 months.

Storage stable *CDG Solution 3000* affords advantages over on-site generation by traditional approaches:

- Storage stable solutions are of precisely known concentration, enabling precise dosing.
- *CDG Solution 3000* is pure. It contains no chlorine, chlorite ion, chlorate ion, chloride ion, or perchlorate ion.
- High purity enables enhanced control of disinfection by-products, and helps to minimize corrosion.
- Storage stable solutions eliminate on-site mixing of chemicals, evolution of chlorine dioxide fumes into the workplace and the start-up, maintenance, and calibration associated with on-site generators.

CDG Solution 3000 is DOT approved for transport by truck or rail and is NSF and OMRI certified.

AQUASURETY

By combining a shelf stable aqueous solution of chlorine dioxide with a comprehensive system for delivery and monitoring of chlorine dioxide residuals and disinfectant by-products, CDG Environmental offers customers a user friendly means to eliminate concerns over Legionella pneumophila in their potable water systems.

The program is initiated with a site visit and sampling of the various water streams for Legionella analysis by a certified laboratory. A site-specific risk model is developed, and a comprehensive plan is custom tailored to the site and the needs of facility management. The plan is presented to the facility and required regulatory agencies.

Once the plan is approved, a remedial high-concentration system flush is done to sanitize the system as much as possible. The required equipment is installed and a Hazard and Operability Study (HAZOP) is performed. Once all concerns are satisfied, continuous application of *CDG Solution 3000* is begun and monitoring commences. The level of facility involvement in monitoring can be tailored from full involvement to hands-off.

Web-based monitoring of all process variables can be seen by both CDG and the facility. Four pathogen microbial testing is done twice per year. EPA required monthly chlorite and chlorine dioxide verification testing is done.

RESULTS

Pre-startup

A hospital in New York State had installed a copper-silver ionization system on their two hot water loops to control Legionella. Although it appeared that this system was functioning, positive counts for Legionella were over the industry standard of 30%, necessitating more frequent sample testing. The installation of 0.2 micron filters on all patient room shower heads and hot water taps was also mandated. Table 1 indicates that for the period of February through May of 2008, positive samples were at 37%. According to the Facility Director, the copper-silver ionization system was not effective in controlling Legionella due to the higher pH levels of their potable water supply. The hospital considered chlorine dioxide but was in no position to install a complex chlorine dioxide generation system. However, they needed a new biocide to protect their patients and staff from infection with Legionella and other serious health complications.

CDG Environmental was recommended to the hospital by consulting firms and laboratories. After meeting with the Facility Director and Project Manager, the *Aquasurety* program was initiated. Samples were taken from both hot water loops and the cold water feed from the municipality. These were sent to a certified laboratory for Legionella testing. Indications were that the bacterium was not only in the hot water loops, but also in the cold water, particularly in an emergency storage tank.

Based on this information, it was decided to do a high concentration flush of both hot water loops and a 10,000 gallon cold water storage tank of the top floor that serviced patient rooms, operating rooms, and the emergency room. All water service was shut down in the hospital and bottled water was provided for patients and staff. The flush was initiated after all critical services were ended for the day, and ran overnight.

Both hot water loops were dosed with *CDG Solution 3000* until the concentration was at 50-60 PPM. The water was allowed to circulate in the loop for four hours. Shower heads were removed and soaked in 50 PPM solution while the flush was being done. Samples were taken during the four hour sanitation period to ensure that chlorine dioxide levels remained at about 50 PPM. More *CDG Solution 3000* was added as necessary. At the end of four hours, taps were opened on all floors and the loops were rinsed with fresh water until the level of chlorine dioxide was below 0.8 PPM (EPA MCL for chlorine dioxide in drinking water). The cold water storage tank was partially drained and enough *CDG Solution 3000* was added to make at least a 50 PPM mixture in the tank. The tank was then filled entirely and allowed to sit for four hours. The entire content was drained and the tank was flushed with fresh water until the chlorine dioxide level was safe.

During the site evaluation, engineering, and construction phases Legionella levels remained lower than before the flush. Table 1 indicates that from May 2008 to May 2009 percent positive results dropped to 11%. The point of use filters were kept in place as a precaution. Figure 1 shows that at the end of this period the counts rose again to 30%, indicating re-growth was increasing.

Table 1: Comparison of Positive Results for Legionella Before and After Implementation of Chlorine Dioxide Feed

Time Period	Number of Samples Taken	Number of Positives	Percent Positive	Comments
Feb 08 -- May 08	32	12	37	Cu/Ag System Operating
May 08 -- May 09	120	13	11	After sanitizing flush. No continuous feed.
May 09 -- Jun 10	220	8	3.6	Continuous feed at 0.5 PPM chlorine dioxide

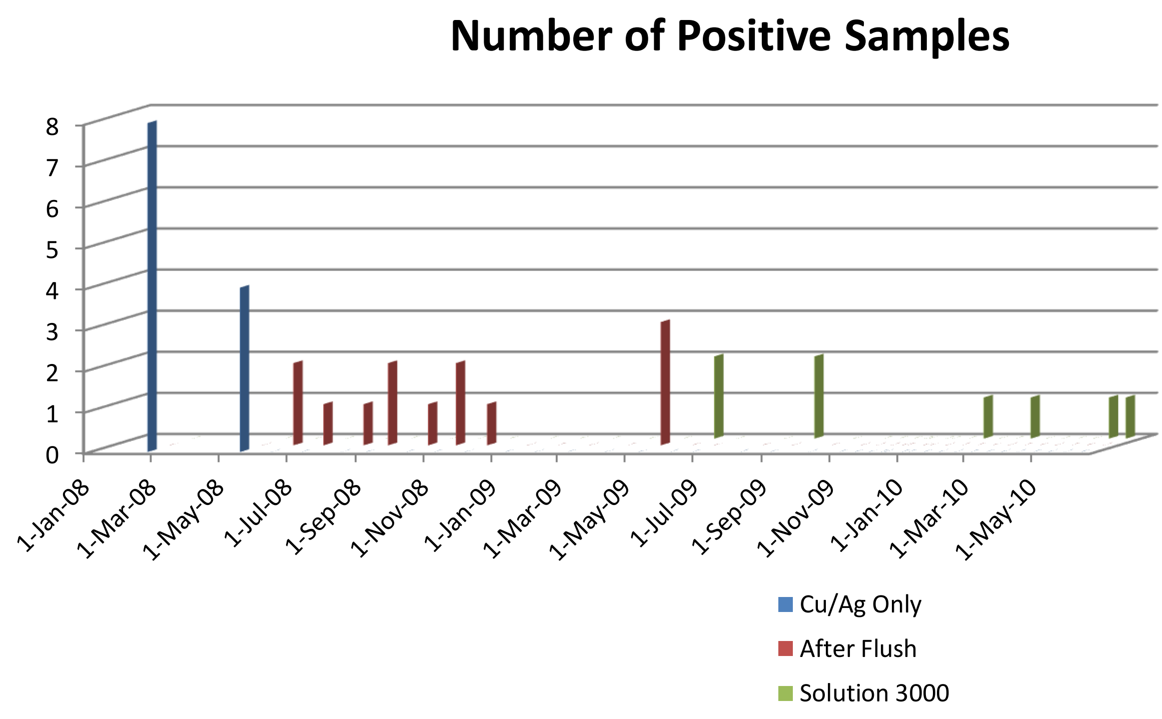

Figure 1: Comparison of Positive Samples for Legionella

Working with the Project Manager, the hospital was evaluated for optimal injection points, required sample points, and a location for the on-site storage and control room area. Injection points were chosen for the main cold water feed pipe and both hot water loops. The cold water injection point was selected as just before the main booster pumps for the complex. This provided excellent mixing of *CDG Solution 3000* in the water. Hot water injection points were chosen in the loop return line just prior to the recirculation pumps and heater tanks. All injections of *CDG Solution 3000* were based on flow rate of water, with the hot water based on cold water makeup to the system. This was done to control build up of chlorite in the hot water loops. EPA requirements for sampling of chlorine dioxide and chlorite dictate that sampling points must be located after the injection point, far enough away to allow mixing, and prior to the water entering the distribution system. Such sites were chosen and designed into the system. Heat exchangers were installed on both hot water samples lines to temper the sample prior to analysis.

After evaluating several possible sites, an area in the sub-basement of the main wing of the hospital was chosen for the on-site storage and control room area. It afforded access to two outside walls, the loading dock area, and sufficient space for 1500 gallons of storage, the sample analysis system, and the control package. The room was air conditioned, containment walls were installed around the storage tanks, and a two-speed fan was installed. The fan provides constant air circulation during normal operation, and emergency outside air purge in the event of a leak in the room. The exhaust from this fan goes up and over the roof of the building.

Chlorine dioxide gas monitors were located at each injection point and in the control room. In the event of a leak and detection of gas above 0.1 PPM, the control system will turn all injection pumps off. They remain off until the area is clear of gas.

A fill station was installed outside the control room. Shipments of fresh *CDG Solution 3000* are delivered here and unloaded into the storage tanks through double-walled containment piping. Level indictors show tank levels during fill operations, and will shut down filling if tank level exceeds 90% full. Tubing carrying *CDG Solution 3000* was run from individual dosing pumps in the control room to each injection point through 4" PVC containment pipe. The interior space within the pipe is monitored for leaks also.

Chlorine dioxide level in each water stream is continuously monitored by amperometric probes, and these are verified using Standard Method 4500-ClO2-D. Daily chlorite readings are taken for each stream using Ion Chromatography per EPA Method 300.1. Monthly verification samples are taken and sent to a certified laboratory. Results can be viewed online by CDG Environmental engineers and the hospital staff.

Once installation was completed, state and local regulatory officials were notified and approvals were secured.

Startup

The *Aquasurety* system was commissioned in May 2009. Average hospital water demand has been 75,000 GPD and average usage of *CDG Solution 3000* has been less than 15 GPD. Concentration level has been set at 0.5 PPM. Table 1 indicates that from May 2009 to June 2010 the rate of positive sample results has dropped to 3.6%, a tenfold decrease from pre-flush conditions. Figure 1 indicates that during this 13 month period two results were 20% positives and four were 10% positives, all below the industry standard of 30%.

The hospital has seen not adverse effects on piping within the facility. It has been able to remove the copper-silver ionization system completely, and also has removed the 0.2 micron filters from all sinks and shower heads with the exception of the Critical Care Unit and the Oncology Unit. The hospital wanted "hands off" system configuration for the *Aquasurety* program, and CDG Environmental provided this through automated sampling techniques and partnering with local laboratory personnel for emergency response and routine maintenance. The differential cost between ionization system maintenance plus filter replacement and the cost of the *Aquasurety* system provides the hospital an annual payback period of less than 6 months.

SUMMARY

Waterborne pathogens are a threat to public health. Increased attention is being focused on prevention and control in public water distribution systems. Legionella is a bacterium subject to strict legislation in western Europe, and current activities by groups in the United States forecast similar action. Control schemes are being recommended by groups such as CDC, ASHRAE, AWT, the Cooling Technology Institute, JCAHO, and various state agencies. Doing nothing is no longer an option, and ignoring the problem can bring severe and costly consequences.

Of all the methods available to control the Legionella bacterium, chlorine dioxide has been dubbed "Best Available Technology". *CDG Solution 3000* is the best chlorine dioxide option because it provides a pure product free of co-products, by-products, and contaminants. It is user friendly and requires only a minimum of readily available, easy to use equipment.

Coupled with the CDG Environmental *Aquasurety* Program, healthcare, commercial, and marine customers are provided with a proven system that meets regulatory requirements. In the cited hospital, costs for controlling Legionella in the hospital water systems were cut by more than half while providing a tenfold decrease in positive sample results.

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