Chlorine Dioxide: A Point of Entry Treatment Technology for the Control of *Legionella* in Sensitive Secondary Distribution Systems.

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Background

Numerous facilities operating secondary water distribution systems serving sensitive populations are searching for the appropriate point of entry (POE) disinfection technology to reduce the occurrence of *Legionella* at distal outlets. Chlorine dioxide has been successfully used in Europe and is beginning to appear in the United States as a POE disinfection technology. Chlorine dioxide has been used as a potable water treatment chemical in the United States since the 1940's when it was first utilized to remove phenol related compounds from drinking water. (Gates 98) Other uses for chlorine dioxide treatment of drinking water have been identified, including removal of iron and manganese and disinfection. Chlorine dioxide has proven to be a good disinfectant, with theoretical disinfection capability in excess of free chlorine. The selective organic oxidation of chlorine dioxide and its larger oxidation capacity enable chlorine dioxide to kill numerous pathogens in drinking water with a small CT value. (Gates 98; EPA 99; Simpson 00) However, the reaction rate of chlorine dioxide does not allow for a long lasting disinfection residual in large distribution systems. (Olivieri 86) It has therefore been used as a primary disinfectant in U.S. treatment systems, but seldom for long-term residual maintenance in primary distribution systems. Small-scale chlorine dioxide generators allow chlorine dioxide to be used in secondary distribution systems or buildings as a POE disinfectant.

Cchlorine dioxide is an effective disinfectant capable of killing numerous waterborne pathogens including *Legionella*, *E. coli*, *Cryptosporidium*, *Giardia*, and others. (Harakeh 88; Sobsey 89; Makin 98; Cowley 00; Gao 00; Hood 00; Taylor 00; Chauret 01; Li 01) The ability of chlorine dioxide to kill *Legionella* in drinking water is of great interest to hospitals, where susceptible patients can be at risk of contracting hospital acquired Legionnaires' disease. POE disinfection technologies have been deployed in an effort to control pathogens (particularly *Legionella)* within secondary distribution systems. Such technologies are relatively new and few data exists to demonstrate effectiveness in full-scale applications.

The Study

The study was implemented at a 437-bed acute care hospital in Central Pennsylvania (Hospital). The Hospital operates a secondary distribution system that includes a 520,000 gallon covered reservoir and 10,000 feet of distribution piping serving 23 buildings over 14 acres. Municipally supplied water accounts for ~80% of the daily demand, while the remaining supply is from an on-site chlorinated well. Identification of cases of hospital-acquired Legionnaires' disease prompted the Hospital to implement an environmental monitoring program and disinfection to control *Legionella* in the water distribution system. Control of *Legionella* was first attempted by maintaining a free chlorine residual between 0.3-0.5 mg/L and using a thermal eradication method from April 1998 – May 2000, but was ineffective for long-term control, logistically difficult, and costly. Copper-silver ionization was considered, but rejected because of the cost to install the ionization units in the many buildings. Chlorine dioxide was selected because it could be installed centrally at the reservoir to disinfect the water in all buildings, required minimal maintenance, and had a positive review in the literature from European and laboratory studies. The chlorine dioxide system was brought on-line in June 2000. From June 2000 to January 2001, the Hospital continued environmental surveillance for *Legionella* in conjunction with daily chlorine dioxide residual measurement. In February 2001 a standardized sampling protocol was initialized that included monthly collection of 100 ml of water from at least two hot and cold distal outlets in eight buildings, the source water to each building, and the reservoir (~48 samples/month). Monthly monitoring included pH, temperature (°C), chlorine dioxide residual (DPD method; mg/L), and *Legionella* culture (CFU/ml). Periodic analysis at select locations include total organic carbon (Hach test'n tube; ppm) and total disinfection by-product formation (ion chromatograph; ppm).

Results

Prior to implementation of chlorine dioxide, *Legionella* positivity at hot distal outlets was 23% (43/186). During the study *Legionella* positivity at hot distal outlets was observed to have significantly decreased ($p=0.005$) to 12% (32/257). A significant reduction ($p= 0.045$) was similarly observed in the cold building source water; decreasing from 9% (2/22) to 0% (0/80) after implementation of chlorine dioxide. *Legionella* positivity at cold distal outlets was 1% (3/257), a number not significantly different than 0%. No historic data was available to compare the cold water sampling with. During the last 13 months of the study 0% (0/240) *Legionella* was observed at the cold distal outlets and during the last 3 months 0% (0/36) *Legionella* was also observed in the hot distal outlets.

Mean chlorine dioxide residuals significantly decreased as the water moved from the reservoir to distal outlets. The mean residuals observed were: 0.57 mg/L at the reservoir, 0.33 mg/L at cold distal outlets, and 0.12 mg/L at hot distal outlets.

No cases of hospital acquired Legionnaires disease have been detected since the implementation of chlorine dioxide disinfection, despite continuous surveillance.

Discussion

Maintenance of a chlorine dioxide residual in the secondary distribution system for an extended period of time may be necessary to control *Legionella* at distal outlets. Complete eradication at the Hospital was not realized until after 1.75 years of continued chlorine dioxide application. This is consistent with previous European field studies, which reported successful *Legionella* disinfection when study durations were greater than 6 months; those less than 6 months reported marginal to no success. (Hamilton 96, Makin 98, Harris 99, Hill 00, Hood 00, Smith 01)

The successful European field studies also indicated a chlorine dioxide residual of 0.3-0.5 mg/L was maintained for *Legionella* control. This study observed positivity at the hot distal outlets only when the mean monthly chlorine dioxide residual was less than 0.14 mg/L. However, even when 0% positivity was observed at hot distal outlets, chlorine dioxide residual remained less than 0.3 mg/L. This suggests that duration of application may be as important as maintenance of a high residual for *Legionella* disinfection.

The ability to achieve and maintain a chlorine dioxide residual is dependent on numerous factors including water temperature, residence time, and water quality parameters. Mean chlorine dioxide residuals significantly decreased in each water regime as temperature and residence time increased. Chlorine dioxide was lost through decay in the secondary distribution system. Generator placement within a building distribution system or hydraulically closer to distal outlets may increase chlorine dioxide concentrations observed at distal outlets.

No cases of hospital acquired Legionnaires' disease have been identified since the installation of the chlorine dioxide system, compared with 3 cases which met the Center for Disease Control's criteria during 1998-99. Additionally, follow up sampling by the Hospital since the conclusion of the study in May 2002 has found hot distal outlets remain negative for *Legionella*.

Continued long-term sampling at the Hospital and proper studies of chlorine dioxide use in other U.S. hospitals should be performed to provide greater evidence that this is an effective disinfection method. The results obtained during this study indicate chlorine dioxide is an effective point of entry disinfectant for *Legionella* in secondary distribution systems.

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