Emerging Waterborne Pathogens in Buildings' Premise Plumbing Systems

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Abstract

Awareness of Legionella and Legionaries' disease by the public and the media has been constantly increasing in the last few years. One of the reasons this is happening is that, as reported by the Center for Diseases Control (CDC), the number of reported Legionaries' diseases cases has increased by a 9x factor in the last twenty years. It is clear that the treatment processes implemented by Public Water Supplies (PWS) is not effective in preventing the colonization of waterborne pathogens in building water systems (BWS).

Multiple organizations (ASHRAE, CDC, ASSE, AIHA) developed standards and guidelines in order to help buildings' owners and managers in implementing water management plans to minimize the risk for buildings' occupants to contract Legionella from building water systems. As a part of water management practices, buildings often install supplemental disinfection systems that include regular chlorine (bleach), chlorine dioxide and monochloramine.

Even if monochloramine was implemented only starting from the past decade (its first use in building water system is from the late 2000s) it is well demonstrated that it is the best choice for Legionella remediation and prevention in building water systems. Despite the efficacy of monochloramine for Legionella control, few reports are available that have comprehensively examined the efficacy and practicality of applying disinfection approaches for controlling other pathogenic microorganisms in building drinking water systems.

The goal of this paper and presentation is to provide data about the efficacy of monochloramine against different waterborne pathogens in drinking water from case studies and peer reviewed literature.

Introduction

Legionellae, a gram-negative bacteria genus comprising over 60 known species (Euzeby J. P., 2018), are ubiquitous in natural and artificial water environments worldwide, and survive in a range of environmental conditions (Fliermans et Al., 1981). Among these species, a significant number are able to cause disease (generally known as Legionellosis), with a range of different implication: from acute, self-limiting, influenza-like illness without pneumonia (Pontiac Fever) to severe pneumonia that, if untreated, can be fatal (Castillo et Al., 2016). For these reasons is of great importance to monitor its presence and to contrast its proliferation in human-related water distribution systems. Known risk factors that contribute to determine individual infection susceptibility include increasing age, male gender, smoking habit, chronic lung diseases and, more in general, any condition associated with immunodeficiency.

The Public Water Supplies (PWS) usually carry out two disinfection steps in the treatment plants. The first step is with chlorine or chlorine dioxide, and the second is with either chlorine or monochloramine. The aim of disinfection is to kill harmful waterborne pathogens but sometimes bacteria, such as Legionella, can survive this two-steps disinfection process and enter the water distribution system. Generally, Legionella is below the detectable level in the source water supply. It does not colonize well in cold water and therefore does not constitute a health threat. However, the conditions that favor Legionella growth and the way the infection is transmitted, dramatically increase the risk to acquire Legionaries' disease from the buildings' water systems. The perfect environments for the proliferation of this opportunistic waterborne pathogen are stagnant water and warm temperatures. This is why Legionella becomes a health risk once the bacteria enter the buildings' complex plumbing system and start to colonize it. This is particularly true in domestic hot water systems where temperatures are ideal for colonization and the formation of complex biofilms. The infection is then transmitted when a person breaths water droplets that contain Legionella germs. This is why hundreds of thousands of buildings such as healthcare facilities, nursing homes, apartment complexes, hotels and casinos are at risk. Legionella's fatality rate is about 10% in the overall population, but the rate goes up to approximately 30% in healthcare reported cases (Cunha, B. et Al., 2016). In 2017 the Center for Medicare Medicaid Services (CMS) published a letter mandating that all healthcare facilities must implement a water management plan (WMP) in order to mitigate the risk of healthcare acquired Legionella. Just recently, in January 2022, the joint commission published a notice saying that they will start to audit healthcare facilities to verify if the WMPs are being implemented properly.

Even if efforts are being implemented in order to prevent the number of Legionella infections, the number of Legionella cased raised by almost 10x from 2000 to 2018. The increase in Legionella case is due to more testing and increased complexity of building water systems.

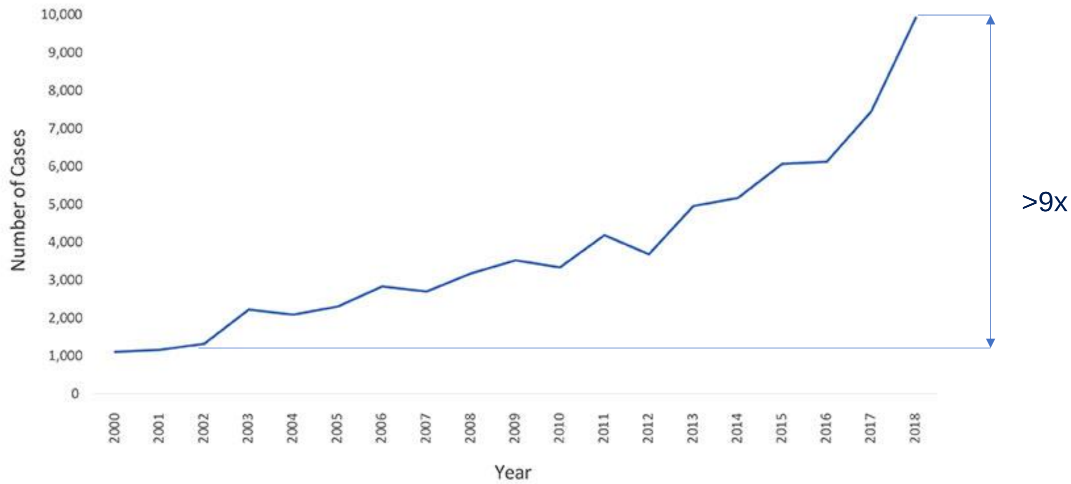

Figure 1: increase in Legionella cases from 2000 to 2018 (CDC).

Although most of the available literature, guidelines and standards (ASHRAE Std. 188, ASHRAE Guideline 12, ASHRAE Std. 514, CDC toolkit, CMS memo ASSE Std. 12080 and AIHA guideline) are mainly focused on Legionella, there are other pathogens and fungi that are naturally present in water that are a threat to public health. Some of these pathogens include Pseudomonas aeruginosa, Acinetobacter baumannii, Stenotrophomonas maltophilia, Fusarium spp., Aspergillus spp and non-tuberculosis mycobacteria (NTMs). The typical infections caused by these pathogens are reported in Table 1.

Pathogen	**Infection**
Pseudomonas aeruginosa	Blood (wounds) and lungs (pneumonia)
Acinetobacter baumannii	Blood (wounds), urinary tract, and lungs (pneumonia)
Stenotrophomonas maltophilia	Blood (wounds), urinary tract, and lungs (pneumonia)
Fusarium spp	Nails, eyes and bloodstream
Aspergillus spp	Allergic reactions, lung infections, and infections in other organs
Non-tuberculosis mycobacteria	Skin and soft tissue, bloodstream, lymph nodes and lungs (pneumonia).

Table 1: type of infections caused by different pathogens (CDC).

As a part of Legionella control strategies, the water management plan may suggest to feed a disinfectant to drinking water to establish a chemical residual in the building water system. The disinfectant that are fed onsite in buildings are also known as “supplemental” disinfectants and they include chlorine, monochloramine, chlorine dioxide and copper-silver ions. Chlorine, monochloramine and chlorine dioxide are listed as disinfectants under the EPA-Safe Drinking Water Act. The implementation of this type of technology is not always indicated in the water management plan but is the only category that ensures a long-term protection for the building occupants.

Chlorine is the disinfectant that has been used in building plumbing systems for the longest time whereas chlorine dioxide has been available in the marketplace since the mid-90s. Monochloramine has been used as a drinking water disinfectant from PWS since 1940 but its use as a supplemental disinfectant did not start until the late 2000s.

There is extensive peer-reviewed scientific literature available that addresses the efficacy of different drinking water disinfectants in preventing and remediating Legionella in buildings but not so much addressing the efficacy in inactivating different pathogens. Even if monochloramine was the latest chemicals to be used as a supplemental disinfectant among all the options, there is enough evidence published in the peer-reviewed literature to confirm that it the best option for Legionella control in building water systems (NAS report, 2019. EPA review, 2016). It is also documented that buildings whose water is supplied by PWS that use monochloramine as a secondary disinfectant experienced a reduction in Legionella contamination and in hospital-acquired Legionnaires' disease incidence, in comparison with buildings fed by chlorinated water (Kool, J.L et Al., 1999, Heffelfinger, J.D. et Al., 2003, Flannery, B. et Al., 2006). The main reason why monochloramine is more efficient than other alternatives to remediate and prevent Legionella in building water systems is its stability. Monochloramine is a weaker oxidizer that does not react with organics and does not decay as fast as other oxidants. Thanks to its stability monochloramine can achieve a consistent residual in the entre plumbing system resulting in a greater exposure between the disinfectant and the pathogens.

The goal of this paper is to review the data that is available about the efficacy of monochloramine against pathogens other than Legionella. The data presented in this paper comes from peer-reviewed literature, and five different case studies. All the data is from real scale drinking water applications in different environments, in particular:

Case study 1: monochloramine efficacy against Pseudomonas in a 400 beds hospital.

Case study 2: monochloramine efficacy against Pseudomonas in a dental clinic with 20 dental chairs.

Case study 3: monochloramine efficacy against Pseudomonas in a commercial building.

Case study 4: monochloramine efficacy against Pseudomonas in a municipal application.

Case study 5: monochloramine efficacy against different pathogens in a 997 beds hospital.

Peer reviewed paper: monochloramine efficacy against different pathogens and impact on water quality in a healthcare facility with 317 beds (Lytle D. A. et Al., 2021).

Monochloramine generator

Monochloramine was fed to drinking water (either cold or hot) using the same technology in all the studies. The monochloramine system that was used is a patented system named SANIKILL (Sanipur SPA, Brescia, Italy). The monochloramine generator produces monochloramine onsite combining ammonium ions, supplied as ammonium chloride with sodium hypochlorite. The generator feeds monochloramine based on water flow and the electronic controller maintains targeted residual in drinking water between 1.5 and 3 mg/L. The system monitors and limits the formation of free ammonia by measuring the redox (ORP) potential and adjusting the precursors feed rates.

The chemical precursors are certified to NSF/ANSI Std. 60 as drinking water additives and the monochloramine generator is certified to NSF/ANSI Std. 61 as drinking water component.

Case Study #1

A 400 beds hospital located in Northern Italy experienced Pseudomonas aeruginosa colonization in the domestic cold-water system at levels of 160 CFU/L.

In order to eradicate Pseudomonas from the building plumbing system the hospital water management team decided to implement an aggressive flushing protocol at all distal outlets. Even if the flushing protocol was being implemented and documented the levels of incoming disinfectant from the municipality were too low to reduce the microbial contamination. Average incoming free chlorine levels varied from non-detect to 0.2 mg/L. In general, regular flushing can help to control the microbial population in building water systems but it is proven that regular flushing is not effective over the long term.

Because of the low incoming free chlorine levels, flushing increased the Pseudomonas aeruginosa levels in drinking water. The levels went up to 4,000 CFU/L because more nutrients were possibly brought into the building water system by the flushing protocol or because the incoming water was already colonized.

The building water management team decided to implement monochloramine supplemental disinfection on the domestic cold-water systems. Monochloramine levels in drinking water were maintained between 2 mg/L and 3 mg/L. The water management team decided to test for Pseudomonas aeruginosa after one week from the beginning of the treatment and all the samples did not show any detectable level. The water management team decided to continue the treatment and all the samples that were collected periodically from the beginning of the treatment up to now (approximately one year) were always non detect.

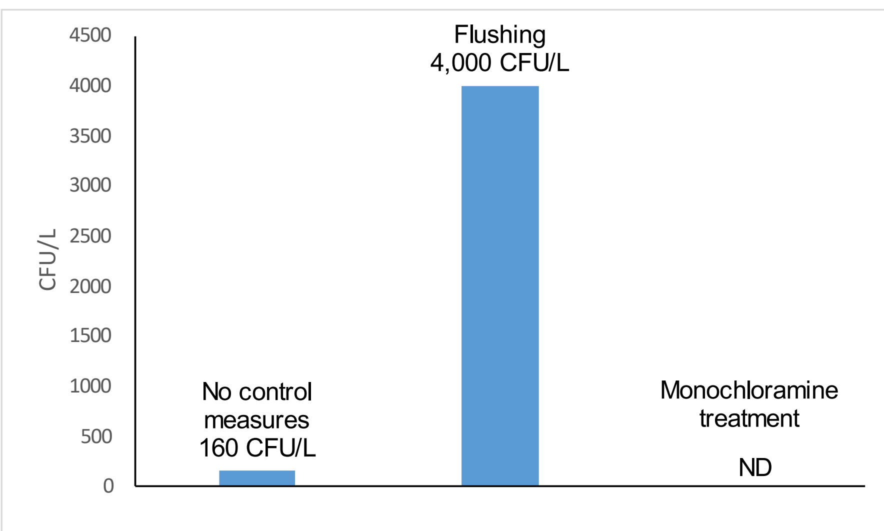

Figure 2: Case Study #1 results.

Case Study #2

A dental clinic located in Northern Italy with 20 dental chairs experienced Pseudomonas aeruginosa colonization. The facility performed periodic testing and Pseudomonas aeruginosa levels varied from 400 to 5,000 CFU/L. Heterotopic plate counts (HPC) were in the order of 10^2 - 10^3 CFU/mL. The facility occasionally tested for positive Legionella pneumophila as well but at always low levels (100 CFU/L).

The facility decided to implement shock hyperchlorination followed by regular flushing. Even if these control measures were successful in reducing the microbial colonization in the building, they didn't show to be effective over the long term and the Pseudomonas aeruginosa levels went back up to pre-treatment levels.

The facility decided to implement monochloramine supplemental disinfection on the domestic cold-water system. Monochloramine levels in drinking water were maintained between 2 mg/L and 3 mg/L.

The first round of water sampling was performed after two weeks, and all the samples showed no detectable levels of Pseudomonas aeruginosa and Legionella pneumophila. The facility continued to feed monochloramine to the building water system and periodical testing shower complete microbial control from the beginning of the treatment up to now (two years).

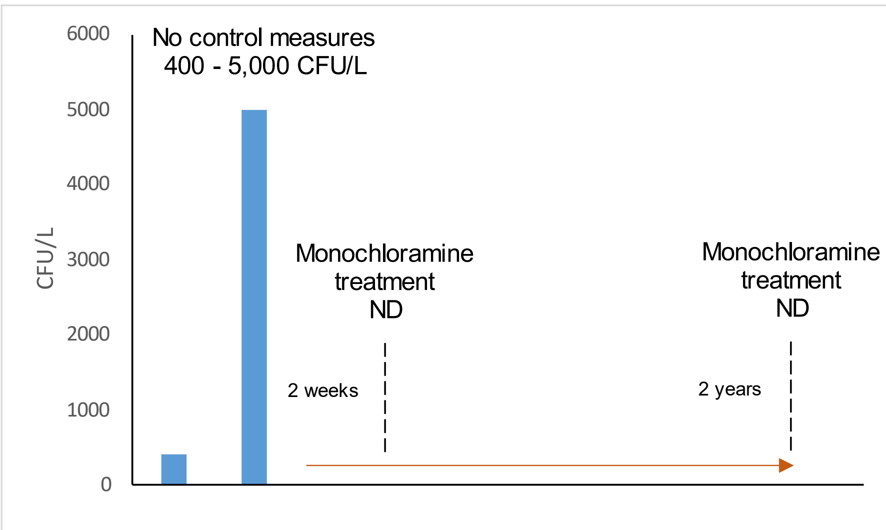

Figure 3: Case Study #2 results.

Case Study #3

The domestic plumbing system of a 5-story commercial facility located in central Italy was affected by Pseudomonas aeruginosa colonization. The drinking water in the facility feeds service areas, restrooms as well as a dietary and two coffee shops.

Periodical sampling showed Pseudomonas aeruginosa levels in the ≈ 500 CFU/L range. The facility implemented shock treatment with peracetic acid, but this control measure showed to be ineffective in lowering the microbial population.

The facility water management team decided to implement continuous supplemental disinfection of the domestic cold-water system with monochloramine. The monochloramine levels were maintained at 2 mg/L.

Water samples were pulled after one month from the beginning of the treatment and showed no detectable levels of Pseudomonas aeruginosa. More rounds of samples were pulled after three months and after six months showing the same results. Pseudomonas aeruginosa was never detected after the beginning of the treatment.

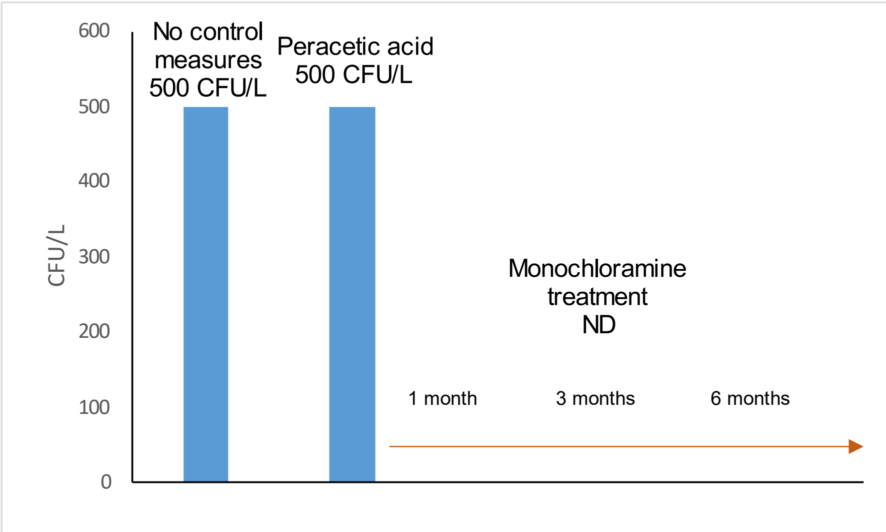

Figure 4: Case Study #3 results.

Case Study #4

A small public water utility located in Northern Italy delivering water to approximately 100 buildings which include residential, commercial and hospitals used regular free chlorine as a primary and secondary disinfectant. Average levels of free chlorine in the water that was being delivered to the distribution system were in the 0.15 – 0.20 mg/L.

Even though the free chlorine were maintained at the targeted levels, the public water utility showed Pseudomonas aeruginosa colonization in the entire distribution system at levels between 160 CFU/L and 200 CFU/L. Because of the nature of a PWS and the impossibility of disrupting the water supply to the buildings, remedial shock treatment was not a feasible option.

The public water utility decided to change the secondary disinfectant from regular free chlorine to monochloramine. the PWS obtained the permit from the local authority having jurisdiction to change the secondary disinfectant. Before monochloramine was being fed to the distribution system the public water utility performed an outreach plan to inform the population about the change in the water disinfectant.

Monochloramine was being fed at 2 mg/L for two weeks. After five days from the beginning of the application the monochloramine concentration was uniform in the entire distribution system. After two weeks the levels of Pseudomonas aeruginosa were all non-detectable and HPC levels were 10^2 CFU/mL. To decrease the HPC levels in drinking water, the public water utility increased the monochloramine residual to 3 mg/L for two additional weeks. After this time, the HPC counts showed all non-detects and the public water utility decreased the monochloramine levels to 2 mg/L. After more than one-year monochloramine shows a full control of the microbial population.

Case Study #5

In 2011 a new 997 beds healthcare facility was commissioned in Northern Italy and then opened to the public one year later, in 2012. The building consists of seven 5-stories towers and a 3-stories main building. The PWS uses regular chlorine as a secondary disinfectant but the levels of free chlorine in the incoming water were always below the necessary level for waterborne pathogens control.

Since the commissioning phase of the building the water management team decided to include proactive test for Legionella in the water management plan. The hospital has been collecting an average of 200 samples/year with monthly or by-monthly testing frequencies. According to the WMP, 70% of the samples were collected from representative points of the domestic hot water system (storage tank, DHW supply, distal outlets and DHW return). With little to no disinfectant coming from the PWS, in the first pre-opening round of samples, 18% of the samples were positive for Legionella whereas in the second round of pre-opening sampling 50% of the samples were positive to Legionella. Given the size of the domestic hot water system and the presence of thermostatic mixing valves at the point of use, the water management team decided that heat and flush would have been inadequate for controlling Legionella and decided to feed monochloramine to the domestic hot water system instead. Starting from 2016 the hospital started to sample for Pseudomonas aeruginosa, Acinetobacter baumannii, Stenotrophomonas maltophilia, Fusarium spp and Aspergillus spp.

Before the building was opened to the public, the water management team decided to perform a shock monochloramine treatment with concentrations at distal outlets of 7 – 10 mg/L. The maximum regulated disinfectant level (MRDL) for monochloramine in drinking water is 4 mg/L. The monochloramine shock treatment proved to be effective in controlling Legionella and all the samples pulled in the third pre-opening round showed non-detectable Legionella levels.

After the building opened to the public, monochloramine levels were maintained between 2.50 mg/L and 3.00 mg/L during the entire study (2013 – 2019, 7 years). The average monochloramine and free ammonia levels maintained in the domestic hot water system during the study are reported in Table 2.

Year	Monochloramine (mg/L)	Free ammonia (mg/L)
2013	2.57 ± 0.35	0.39 ± 0.13
2014	2.50 ± 0.43	0.43 ± 0.08
2015	2.58 ± 0.62	0.34 ± 0.11
2016	2.66 ± 0.21	0.35 ± 0.14
2017	2.56 ± 0.17	0.35 ± 0.11
2018	2.51 ± 0.27	0.37 ± 0.10
2019	2.51 ± 0.25	0.40 ± 0.06

Table 2: Average monochloramine and free ammonia concentrations.

The hospital continued to perform testing at regular intervals on both the domestic cold and domestic hot water samples for the entire duration of the study.

The Legionella sampling results are reported in Table 3.

Year	Number of samples		Positive samples (%)	Positive samples > 0.1 CFU/mL (%)
2013	148	HW = 138	0 (0.0 %)	0 (0.0 %)
		CW = 9	0 (0.0 %)	0 (0.0 %)
2014	183	HW = 161	0 (0.0 %)	0 (0.0 %)
		CW = 21	0 (0.0 %)	0 (0.0 %)
2015	191	HW = 171	0 (0.0 %)	0 (0.0 %)
		CW = 20	0 (0.0 %)	0 (0.0 %)
2016	191	HW = 169	2 (1.2 %)	1 (0.6 %)
		CW = 22	0 (0.0 %)	0 (0.0 %)
2017	259	HW = 232	4 (1.7 %)	1 (0.4 %)
		CW = 27	0 (0.0 %)	0 (0.0 %)
2018	300	HW = 264	5 (1.9 %)	3 (1.1 %)
		CW = 36	1 (2.8 %)	1 (2.8 %)
2019	255	HW = 210	3 (1.4 %)	0 (0.0 %)
		CW = 45	0 (0.0 %)	0 (0.0 %)

Table 3: Legionella samples results.

Monochloramine proved to be a great Legionella control strategy in the domestic hot water system during the duration of the entire study. Out of a total of 1,345 water samples collected from the domestic hot water system during the 7 years period, only 16 samples (1.2 %) were positive for Legionella and only 5 samples (0.4 %) had concentrations greater than 0.1 CFU/mL.

The sample results of other different microorganism are reported in Table 4.

Year	Number of samples		P. aeruginosa	A. baumannii	S. maltophilia	Fusarium spp	Aspergillus spp
2016	135	HW = 124	1 (0.8 %)	0 (0.0 %)	4 (3.2 %)	0 (0.0 %)	1 (0.8 %)
		CW = 11	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)
2017	223	HW = 196	4 (2 %)	0 (0.0 %)	10 (5.1 %)	2 (1.0 %)	4 (2.0 %)
		CW = 27	3 (11.1 %)	0 (0.0 %)	2 (7.4 %)	0 (0.0 %)	0 (0.0 %)
2018	268	HW = 236	5 (2.1 %)	1 (0.4 %)	1 (0.4 %)	2 (0.8 %)	3 (1.3 %)
		CW = 32	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)
2019	255	HW = 210	8 (3.8 %)	0 (0.0 %)	8 (3.8 %)	1 (0.5 %)	5 (2.4 %)
		CW = 45	4 (8.9 %)	0 (0.0 %)	2 (4.4 %)	0 (0.0 %)	3 (6.7 %)

Table 4: Other waterborne pathogen sampling results.

Based on the results reported in Table 4, it did not appear that the hospital had an active colonization of all the different microorganisms that were tested. The number of positive tests was always below 10% with the only exception for the cold-water sampling of Pseudomonas aeruginosa in 2017 (3/27, 11.1 %). Monochloramine demonstrated a complete microbial control of different waterborne pathogens as the overall rate of positivity remained low and showed little to no variations. Monochloramine did not promote the growth of certain pathogens.

Peer reviewed paper (Lytle D. A. et Al., 2021)

A medium sized (317 beds) healthcare facility located in Ohio performed sampling of hot and cold water for Legionella between 2006 and 2013. In 2013 the hospital observed positive Legionella pneumophila samples in the domestic hot water system even if the average incoming level of free chlorine was 0.80 mg/L with peaks at levels higher than 1.00 mg/L.

More culture results from 2014 confirmed that the hot water system was positive for L. pneumophila serogroup 1 at 71% of distal points. The hospital staff implemented a flushing program superheated water once every two weeks. While effective at first, analysis indicated that Legionella reappeared shortly after treatment. The hospital then decided to use monochloramine as a supplemental disinfectant and to feed it in the domestic hot water system.

The authors of this paper from the US-EPA and the Ohio-EPA performed microbiological and water chemistry monitoring for several months prior to the installation of the system and for almost one year after the installation of the monochloramine system. As reported by the authors, the three main goals of the study were:

- Better understand the effectiveness of monochloramine disinfection in reducing opportunistic pathogens (Legionella pneumophila, Pseudomonas spp., nontuberculous Mycobacteria [NTM]).
- Monitor for evidence of nitrification (e.g., nitrate, nitrite).
- Monitor for changes in other important drinking water quality parameters (e.g., total chlorine, monochloramine, pH, temperature, DBPs, lead, copper, and other metals).

The average monochloramine level in the domestic hot water system during the study was 2.01 ± 0.66 mg/L and they were reliably within the initial target dose range of 2 - 3.50 mg/L/ whereas the free ammonia remained in the 0.00 – 0.50 mg/L range.

The microbiological results of the study are reported in Table 5.

Pathogen	% Positivity pre-treatment	% Positivity post-treatment
Legionella pneumophila	68 %	6 %
Pseudomonas aeruginosa	42 %	1.1 %
Non-tuberculosis mycobacteria	61 %	14 %

Table 5: Waterborne pathogen sampling results (Lytle D. A. et Al., 2021).

The authors of the paper confirmed the efficacy of monochloramine in reducing the Legionella colonization in building water systems and proved that the disinfectant was also effective in reducing the % of positivity of Pseudomonas aeruginosa and non-tuberculosis mycobacteria.

The authors also reported that the monochloramine application did not have any noticeable impact on water quality and water chemistry. No nitrification was observed as the levels of nitrites and nitrates remained constant during the entire study. The corrosion rates of the plumbing system did not change from pre- to post-treatment and the levels of copper and lead in drinking water remained constant. The levels of disinfection by products (THMs and HAA5) did not vary between before and after monochloramine was applied to the domestic hot water system.

NDMA was also never detected during the entire duration of the study.

Conclusions

Because of the impact that Legionella has on the healthcare sector, there is data available in the literature addressing the efficacy of monochloramine against Legionella in building water system. Limited data is available in the literature addressing the efficacy of monochloramine and other disinfectants against different waterborne pathogens that pose a threat to public health. Most of the literature that is available addressing this issue come from municipal applications. The data from PWS does not necessarily give an understating of the behavior of disinfectants in building water system since public water utilities and buildings' domestic plumbing systems are completely different environments.

The results from this literature review from case studies to peer reviewed paper demonstrated that monochloramine is not only effective in remediating and controlling Legionella but it also reduces the colonization of other waterborne pathogens.

The data reported in the peer reviewed paper here presented also demonstrated that monochloramine does not have any impact on water quality with no unintended consequences after the application of the disinfectant.

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