The National Institutes of Health | Division of Technical Resources | Office of Research Facilities

Design Requirements Manual **News to Use**

August 2022

Vol. 02, No. 62

The formulae $\frac{\partial \rho \bar{U}_i}{\partial t}+\frac{\partial}{\partial x_j}(\rho \bar{U}_i \bar{U}_j)=-\frac{\partial \bar{P}}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu \frac{\partial \bar{U}_i}{\partial x_j}\right)+g_i(\rho-\rho_0)$ *for building* $\frac{\partial}{\partial x_j}(\rho \bar{U}_i \bar{U}_j)=-\frac{\partial \bar{P}}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu \frac{\partial \bar{U}_i}{\partial x_j}-\rho \overline{u_i' u_j'}\right)+g_i(\rho-\rho_0)$ *state of the art* $\frac{\partial}{\partial x_i}(\rho \bar{U}_i \bar{H})=\frac{\partial}{\partial x_i}\left(\lambda \frac{\partial \bar{T}}{\partial x_i}-\rho \overline{u_i' h'}\right)$ *biomedical research facilities.*

Combatting *Legionella* in Healthcare Facilities

Part I: Overview

Legionella is a genus of rod- or coccoid-shaped gram-negative bacteria that was discovered in 1976. Today, the genus consists of more than 65 different species. *Legionella* is generally found in freshwater environments as well as engineered water sources like cooling towers, showers, and plumbing networks. While all species of *Legionellae* can cause disease in humans, most of the infections are caused by the species known as *Legionella pneumophila*. Within this species, serogroup 1 strains are the most associated with infection. The *pneumophila* species can affect humans when inhaled via aerosol, causing a form of pneumonia called Legionnaires' disease (LD).

LD is on the rise in the United States. A combination of engineering, hygiene measures, and clinical strategies should be applied to make hospital water safe for vulnerable patients. There are a variety of different technologies currently available for controlling *Legionella* in healthcare facilities, such as supplemental disinfection systems (e.g., copper-silver ionization, chlorine dioxide, sodium hypochlorite, and monochloramine), temperature controls, or physical barriers.

The purpose of this series of articles is to provide the latest information on *Legionella*, an update on control and management practices at healthcare facilities, and an overview of engineering aspects in building water systems aimed at controlling and preventing *Legionella* growth.

Water Management Programs in Healthcare Facilities

Healthcare facilities can have complex water systems that could promote pathogen growth if not properly maintained. Water management programs should therefore be effective at limiting *Legionella* and other opportunistic pathogens and need to be continuously evaluated and monitored to maintain this effectiveness. The Centers for Disease Control and Prevention (CDC) prepared a Water Management Program (WMP) Toolkit that can help develop and implement a water management program to reduce a building's risk for the growth and spread of *Legionella*. An effective WMP should identify areas or devices in buildings where *Legionella* might be present so that appropriate risk-management actions can be taken. Water management programs should incorporate the industry standard requirements for medium to large buildings according to ASHRAE 188. There must be continuous coordination among members of the healthcare facility's water management program to identify problem areas, take corrective actions, and evaluate mitigation steps. Figure 1 illustrates the interactive relationship between healthcare facilities and water management programs at the chemical/microbiological inspection and plumbing improvement levels. A yearly audit on water management programs is also a valuable maintenance element.

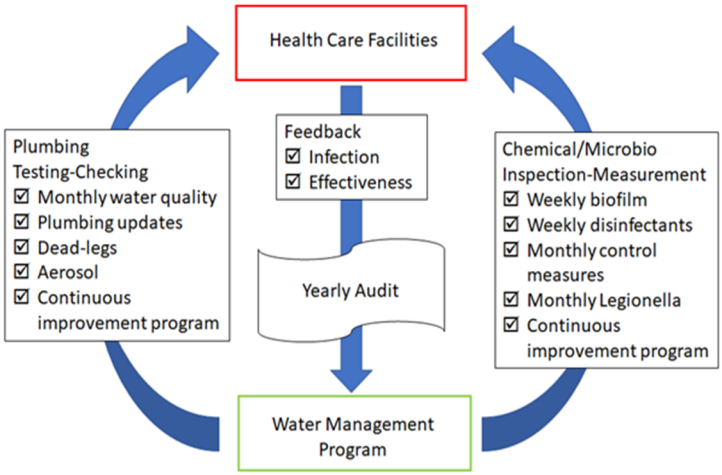

Figure 1: Interactive Relationship: Health Facilities and Water Management Program

Control Measures

There are several preventative measures and technologies available which are intended to limit bacterial growth in water supplies. Important considerations for *Legionella* control are provided in the CDC's WMP and *Legionella* Control Toolkits. Factors known to influence *Legionella* growth in water systems include temperature, disinfectant type and its active residual levels, hydraulic conditions (particularly those related to stagnation), presence of nutrients, pipe materials, presence of distal devices, and extent of aerosol formation. Most of these factors are considered during the initial building design and commissioning stages, while others can be more readily adjusted in existing buildings. Reactive measures, such as hyperchlorination, can be implemented if conditions that allow *Legionella* to grow and spread is detected when the facility is in use.

Legionella control measures include:

- Temperature control outside the organism's growth range of 25°C to 45°C (inhibits bacterial growth)
- Use of chemical disinfectants (inactivates planktonic/sessile bacteria and reduces biofilm formation)
- Ultraviolet irradiation (damages the bacteria's DNA and proteins)

- Copper-silver ionization (produces metal ions which disrupt bacterial membranes and enzymatic processes)
- Hydraulic system design and maintenance (maintains and delivers water at inhibitory temperatures, distributes disinfectants throughout the building, and limits water-age conditions)
- Limitation of organic and inorganic nutrients in water (helps control biofilm and prevent disinfectant depletion)
- Control of iron corrosion (limits the amount of iron, which is an essential nutrient for the growth of *Legionella,* in the water)
- Limitation of aerosol exposure via size-exclusion filters or laminar flow devices (prevents spread of bacteria)

The second part of this series will include more information on control measures to prevent *Legionella* growth.

Plumbing Material Selection

There are a variety of plumbing design choices that can help mitigate the risk of *Legionella*. Piping material selection is a particularly critical component of bacterial mitigation. Hot water is commonly used to control bacterial growth, so it is essential to use piping with adequate thermal ratings. Copper and stainless steel are traditionally chosen for higher-temperature applications; copper piping also has antimicrobial properties. Plastics such as chlorinated polyvinyl chloride are also an option and are additionally corrosion-resistant for chemical injections. Biostable materials can be used for any distal devices to minimize surface area available for biofilm growth where *Legionella* can proliferate.

Additional Plumbing Measures

There are multiple plumbing add-ons that can be used as additional preventative measures. Small diameter piping in the distal portion of premise plumbing helps to reduce stagnation. Additionally, if the premise plumbing is compromised by bacteria, point-of-use filtration barriers or flash disinfection devices can be installed to act as a final defense against bacterial transmission. A combination of improved design (e.g., limiting the number of outlets and removing of dead legs) and preventive flushing procedures help to maximize water circulation and thereby minimize the impact of disinfectant depletion. Thermostatic mixing valves (TMV) can be used to prevent against scalding (e.g., during showers), but they also provide surfaces for biofilm growth at temperatures optimal for *Legionella*, so designers should weigh the pros and cons of their application and prioritize TMV installation as near as possible to point-of-use filters to limit circulation of water at temperatures favorable for *Legionella* growth.

The third part of this series will contain more information on plumbing modification for *Legionella* control.

Conclusion

Proper water system maintenance is the key to preventing *Legionella* growth and LD. There are a variety of methods to reduce the risk of *Legionella* growth and spread; building owners, especially in healthcare facilities, should develop comprehensive water management programs with multiple control mechanisms for successful risk mitigation. If *Legionella* is found in a healthcare facility's water system, the facility should apply remedial measures to eliminate the bacteria by following or customizing standard guidelines.

Further Reading

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Further details on this month's topic are available on the DRM website: DRM Chapter 13, Aseptic Processing Facilities
https://www.orf.od.nih.gov/PoliciesAndGuidelines/BiomedicalandAnimalResearchFacilitiesDesignPoliciesandGuidelines/Pages/DesignRequirementsManual2016