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

Design Requirements Manual **News to Use**

September 2022

Vol. 02, No. 63

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

Combatting *Legionella* in Healthcare Facilities Part II: Controlling *Legionella*

Legionella bacteria can cause Legionnaires' disease, which is a particular risk for healthcare facilities. The key to mitigating this risk is developing a water management program that implements multiple technologies to control *Legionella* growth. Part I of this article series discussed the risks of *Legionella*, the importance of robust water management programs, and several measures and design choices to control *Legionella* growth and outbreaks in water systems. This article reviews the details of specific control technologies and emphasizes the importance of developing a multi-pronged approach for combatting *Legionella*.

Current Control Technologies and *Legionella* Identification

Controlling the spread of waterborne bacteria such as *Legionella* is a complex endeavor. There are a variety of resources that can be combined with different preventative methods to address *Legionella* outbreaks within a facility. These resources include the CDC Water Management Program Toolkit[1], the CDC Legionella Control Toolkit[2], ASHRAE Standard 188-2021[3], Addendum c to ASHRAE Guideline 12-2021[4], and the EPA Technologies for *Legionella* Control[5]. Depending on the size of the *Legionella* population, different treatment methods can be used. Table 1 shows some exemplary control technologies against *Legionella* growth and spread along with their mechanisms/characteristics and efficacies. For example, introducing disinfectants into the water system inactivates waterborne or planktonic bacteria and may help to destroy biofilms. Other methods include using flushing procedures to prevent stagnation and reduce water age (the time that water is in premise plumbing), as well as adding laminar flow devices to faucets that produce non-aerated water to reduce aerosol transmission. All technologies should be coordinated with existing water treatment programs.

If an outbreak occurs, the identification and quantification of *Legionella* is the first step to ensure the outbreak is effectively addressed. Once it is identified, public health guidance must be followed to confirm the correct steps are being taken to fully eradicate the bacteria. There are several methods for *Legionella* detection and enumeration: culture testing, polymerase chain reaction (PCR), quantitative PCR (qPCR), fluorescent in-situ hybridization, cytometry, lightmode spectroscopy, enzyme-amplified electrochemical detection, and resonance immunosensing. Culture testing is the most common practice to identify and enumerate these bacteria in colony forming units (CFUs)/mL. This information is crucial for identifying outbreak origins, performing risk assessment, and pursuing disease prevention. However, culture methods can take anywhere from one to two weeks to obtain analytical results. Quick identification methods, like qPCR and genome sequencing, can also be performed and take about a day to obtain results, though current qPCR technology is unable to differentiate between viable and deceased *Legionella* bacteria.

Considerations for Using Multiple Technologies

Most *Legionella* control technologies are relatively inexpensive and easy to install or incorporate into pre-existing water systems. It is best practice to use multiple technologies in parallel because *Legionella* protects itself with biofilms and applying multiple technologies at once will more effectively destroy the biofilm and prevent bacterial spread, which is especially important in healthcare facilities. However, some technologies may need regular maintenance to ensure they are working properly. Maintenance personnel need training and experience to work efficiently with certain technologies, such as the copper-silver ionization system. Technologies must also comply with any applicable regulations. Finally, it is important to consider that since *Legionella* is a bacterium, it may develop resistance to certain technologies, rendering them ineffective and risking the integrity of a facility's water system.

Conclusion

Using only a single technology to prevent or eradicate a *Legionella* outbreak has proven ineffective. To successfully combat *Legionella* in healthcare facilities, multiple technologies must be used in conjunction with proper building water system maintenance for optimal prevention. A combination of good management and prevention plans are critical to ensure the health and safety of patients.

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Table 1: Control Technologies against *Legionella* Growth and Spread, Mechanisms, and Efficacies

Technology	Mechanism/Characteristics	Efficiency
Temperature Control	Domestic water systems should keep cold water below 25°C, which may not be possible in warmer climate zones, and hot water above 45°C* to ensure the temperature is out of the organism's growth range. Hot water temperature control can be achieved using thermostatic mixing valves at the supply or point-of-use. *Note that higher temperatures can cause scalding in healthcare environments; to prevent this, state or local codes and regulations may specify a maximum temperature at a thermostatic mixing valve which can be within the *Legionella* growth range.	Efficient against both culturable and viable but nonculturable-like cells (live bacteria that do not grow nor divide) of *Legionella pneumophila*.[6, 7, 8, 9]
Disinfection	Adding chemical disinfectants, particularly oxidizing agents, (e.g., chlorine, chlorine dioxide, chloramine, and ozone), to water systems keeps the pipes clean by penetrating and inactivating microorganisms associated with biofilms.	Efficiency is dependent on the condition of *Legionella*, their host protozoa, and the physiochemical characteristics of the water.[7, 8, 10, 11, 12, 13]
Copper-Silver Ionization	Electrolysis introduces copper and silver ions into the water system. Copper ions penetrate the bacterial cell wall and silver ions bond to parts of the bacterium, immobilizing the cell and curtailing cell division. Neither ion will damage piping and the concentration levels necessary for efficacy are not toxic to humans.	Efficient for controlling *Legionella* in potable water systems, cooling towers, and other building plumbing systems. [7, 14, 15, 16, 17, 18, 19, 20]
Nutrient Limitation	Controlling the biofilm, iron corrosion, and inorganic nutrients; directly measuring assimilable organic carbon (AOC) and biodegradable dissolved organic carbon assays aid in preventing further growth of *Legionella*.	Lower AOC levels of 5 to 10 µg/L were associated with lower *Legionella pneumophila* levels in drinking water distribution systems.[21, 22, 23]
Distal Plumbing Design and Plumbing Materials	Use small diameter piping in the distal portion of premise plumbing and improve design to maximize water circulation and prevent water stagnation; use biostable materials to ensure proper piping material functionality; install point-of-use filters or flash disinfection devices as a final barrier; position thermostatic mixing valves as close as possible to points-of-use. Pipe material (copper, iron, plastics) influences the building-level water chemistry and shapes the biofilms that colonize premise plumbing in a unique manner.	A new extended-life faucet filter can ensure the removal of *Legionella* for several weeks. Maintaining awareness of the presence of iron pipes and practicing appropriate corrosion control are key to reducing risk factors for *Legionella*.[9, 14, 24, 25]
Aerosol Control	Replace faucet aerators with laminar flow devices; replace a showerhead with one that produces water streams (holes >1-mm diameter) and contains a micro-biofilter (*i.e.*, pore size <0.45-µm diameter). Keep laminar flow devices and showerheads clean to reduce bacterial contamination.	Changes in aeration technology (e.g., use of fine bubble diffusers) or covering the aeration basins can reduce aerosol formation and transport.[26]
Reducing Water Age and Stagnation	Introduce regular water flushing techniques to reduce water age and stagnation by increasing water flow for a set period, especially if the building has been unoccupied for a while; remove dead legs (sections of piping which are rarely or never used and have no regular flow).	Reducing water age and stagnation can aid in delivering other control measures like disinfectants. It also helps to prevent growth of *Legionella*. [27, 28]

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