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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* $\frac{\partial}{\partial x_j}(\rho\overline{U}_i\overline{U}_j)=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial\overline{U}_i}{\partial x_j}-\rho\overline{u_i'u_j'}\right)+g_i(\rho-\rho_0)$ *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 III: Plumbing Aspects for *Legionella* Control and Management

Opportunistic pathogens (OPs) are frequently found in premise plumbing systems, where they can exist either in suspended forms as aerosolized water droplets or within biofilms. In particular, the growth of *Legionella pneumophila* in these systems is an increasing threat to public health. The survival and growth of *Legionella* is influenced by a facility's mode of construction, which can create different complex environments due to chemical, microbiological, spatial, and temporal variations. Improperly managed premise plumbing systems can create ideal conditions for *Legionella* growth and spread, resulting in human exposure and harm. Parts I and II of this article series focused on the importance of robust water management programs, provided several measures and design choices to control *Legionella* growth in water systems, and emphasized the importance of developing a multi-pronged approach. This article will focus on how to use plumbing aspects to help prevent *Legionella*, specifically through plumbing-related contributing factors like material selection and design.

Contributing Factors to *Legionella* Growth

The mechanisms for *Legionella* growth are varied and complex. Both water chemistry and plumbing microbiome play a role in contributing to bacteria growth, such as through the delivery of growth-promoting nutrients, growth-inhibiting disinfectants, and influent microorganisms. Premise plumbing configurations, hydraulics, temperature, and water use patterns also contribute. There is strong variability between facilities, even those on the same premises, due to occupancy, building size, water heater design, water saving devices, storage, and other factors. This article will review material selection and facility design considerations in more detail, as they are critical for improving water management programs.

Material Selection

When selecting appropriate pipe material, the designer should evaluate various criteria (e.g., water temperature and pressure and water patterns like velocity, flow, or stagnation) that differ between building types and uses as well as building settings (e.g., healthcare vs. hospitality). Pipe material can affect *Legionella* growth in premise plumbing both directly (i.e., by enhancing or inhibiting growth) and indirectly (i.e., via secondary effects due to pipe material being released).

Copper piping is generally used for its antimicrobial properties. Currently, two hypotheses explain how copper inactivates bacteria. One hypothesized mechanism infers that positively charged copper ions obstruct the negatively charged cell membranes, thus creating holes in the bacteria, and rendering them inactive.[1] The other hypothesized mechanism states that copper ions disrupt the bacterium's replication and production of DNA, RNA, and proteins.[1] Copper piping can also withstand higher temperatures; however, this increase in temperature can lead to a higher rate of corrosion. If copper piping is not appropriate for a building, copper can also be supplemented into the water system through a water treatment process, such as copper-silver ionization. This complementary disinfection system uses electrolysis to introduce copper and silver ions into the water system. The copper ions will penetrate the bacterium and the silver ions will bond to parts within the bacterium and lyse it as well as curtail further cell division.

There is evidence for the inconsistent efficacy of copper piping for microbial control, mainly due to differences in water chemistry and the micronutrient properties of copper.[1,2] Water chemistry can reduce copper toxicity to OPs by reducing the solubility of copper ions, forming copper complexes, and increasing competition of other cations with copper for uptake of organism sites. Copper can also serve as a micronutrient for OPs; its aqueous concentration should therefore be maintained above OP tolerance limits.[3] Designers can manipulate plumbing design, configuration, and operation to control copper's interactions with water chemistry and resident microbes and maintain its efficacy.

Other common piping materials (e.g., plastic, polyvinylchloride (PVC), and iron) can be used, but they are not recommended in healthcare settings and would be better suited for residential settings. NIH's Design Requirements Manual (DRM) does specify that PVC and plastic piping be used for high purity water systems.[3] Plastic or PVC piping would prevent corrosion and may be useful in the long run; however, organic carbon from plastic and PVC pipes may leach into the water system and contribute to *Legionella* and biofilm growth. Similarly, adding iron into water systems can provide nutrients to *Legionella* which aids in bacterial growth, though leaching and biofilm colonization depend on various factors like water chemistry, stagnation, scale formation, and corrosion.

Design Considerations

To reduce possible *Legionella* growth, hot water in plumbing systems should be at temperatures that are outside the bacteria's growth range (around 25°C to 45°C). While this is suitable for inhibiting *Legionella* growth, it is not appropriate for human use (e.g., showers and sinks) as it can cause scalding. Installing thermostatic mixing valves (TMVs) will prevent scalding by mixing hot and cold water so that the water coming out of the faucet is at a comfortable temperature. There are two kinds of mixing valves: master mixing valves and point-of-use valves. Master mixing valves are centrally located after the water heater, which may result in inconsistent temperatures throughout the building water system that may be favorable for *Legionella* growth. Point-of-use mixing valves are located at the individual fixture level. It is recommended that TMVs be installed as close as possible to fixtures to inhibit Legionella growth and spread.[4]

It is important to note that some state or local codes may specify a maximum temperature that a TMV may reach. This maximum temperature may be within *Legionella*'s growth range, so additional technologies may also be necessary to lower the chances of bacteria growth. The DRM requires hot water in general potable water systems to be heated to 60-63°C and tempered to 52-54°C using an ASSE 1017 TMV device.[5] To further prevent conditions that encourage bacterial growth, the DRM also advises that emergency systems which use water loops and short runouts leading to emergency fixtures to minimize dead-legs and stagnation.[5]

Figure 1 shows an exemplary plumbing system using TMVs and copper piping in three environments of a healthcare facility, such as service, resident, and research. The main features delineate the need for an inhouse water treatment system, TMVs, appropriate piping material, and proper drainage with backflow prevention devices.

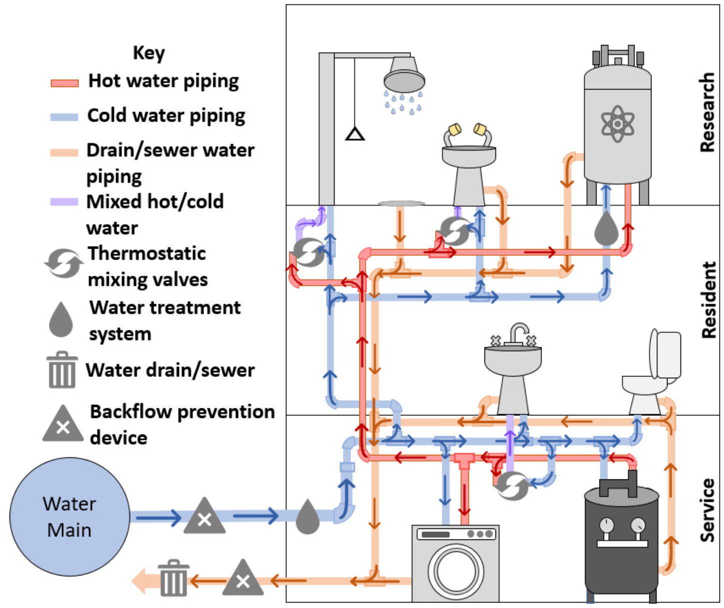

Figure 1: Exemplary plumbing considerations in a service, residential, and research environment.

Other technologies, such as point-of-use (POU) filters and flash disinfection devices, can be used as a final defense against possible *Legionella* exposure. POU filters are easily installed and effective, but the cost of installing them and maintaining them should be considered. These filters can also impact water age and disinfectant residuals. POU filters with a pore size of 0.2 microns or less that comply with the requirements of ASTM F838 can help to reduce the possibility of *Legionella* exposure via faucet.[6] Flash disinfection devices, such as ultraviolet (UV) light, reduce the proliferation of the bacterium, but they can also increase the decay of disinfectant residuals. Since UV light does not produce any disinfectant residual, a water system using only UV light may be susceptible to contamination at downstream points. It also requires routine maintenance to ensure that the UV dose remains adequate for inactivation of pathogens. Careful consideration of building water system design and operation is necessary before procuring filters and disinfection devices.

Conclusion

Material selection and plumbing design are critical components of a water management program. Designers should thoroughly consider the pros and cons of piping material to determine the best fit before proceeding to the design aspect of the plumbing system. They should also consider what add-ons would be necessary as additional preventative methods against *Legionella*. A combination of a robust water management program, installation and maintenance of facility-appropriate devices, and monitoring can decrease the potential for *Legionella* growth in building water systems.

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