Controlling Legionella in Domestic Hot Water Systems

a report by

Armstrong International, Inc.

More than a quarter of a century has passed since more than 200 people became sick from a mysterious disease at a fateful American Legion convention in Philadelphia. Ultimately, 34 people died from that exposure, which has since become known as Legionnaires' disease.

A year later, in 1977, a type of bacteria was discovered that subsequently was attributed to the cause of the disease. In honour and memory of the conventioneers, the bacterium was named *Legionella pneumophila*. Water is its primary medium for growth and, as the micro-organisms multiply by cell division, the result can run into millions of cells after a few hours or days. The legionella organism is found naturally in streams, ponds, lakes and soil.

Since the mid 1970s, much has been learned and written about the bacteria, how it grows, how it affects people, the likely symptoms and precautions that should be taken to prevent the disease. We have learned that the disease progresses through a series of steps.

Ideal Conditions

First, the legionella organism must find its way into an ideal place to live and colonise. When the water harbouring the bacteria in high concentrations is aerosolised into a mist and is subject to evaporation, the legionella organisms – now airborne – can be transmitted to a susceptible host (a human's lungs). The bacteria can be introduced into the airstream by showers, taps, whirlpool baths, respiratory therapy equipment, decorative fountains and even misters sometimes used in supermarket produce departments.

When the organisms are inhaled, they will likely migrate to the deepest part of the lungs where they will continue to multiply. It is also here that the infection will occur producing pneumonia-like symptoms.

It is estimated that between 10,000 and 100,000 cases of legionellosis occur annually in the US. The exact number of cases is unclear because the symptoms for legionellosis and pneumonia are similar. Many cases of legionellosis may be misdiagnosed as pneumonia without extensive testing. Furthermore, one known subgroup of the bacteria can cause Pontiac fever with flu-like symptoms.

The ideal way to eliminate the disease is to destroy the bacteria. However, because they are found naturally in the environment and because there are dozens of legionella species and many more subgroups, it is virtually impossible to eliminate the ubiquitous bacteria.

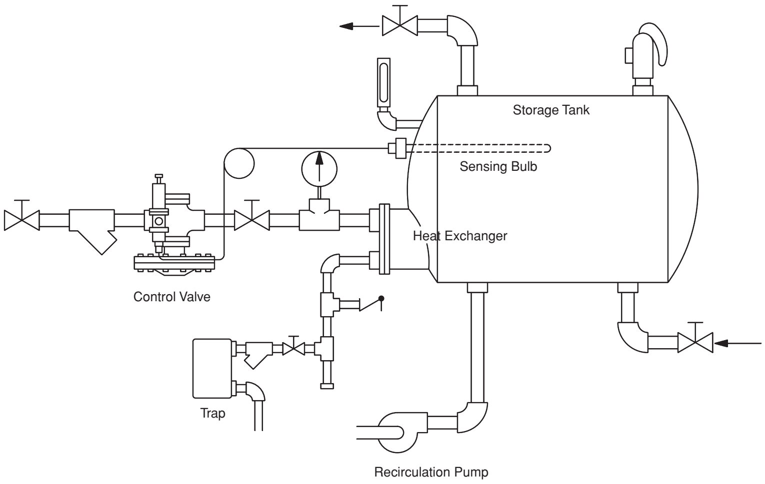
Focus on the Amplifiers

Plumbing engineers need to know that the next most logical place to take control of the problem is to eliminate places where the bacteria will amplify or multiply rapidly. These harbours for bacterial growth are often referred to as 'amplifiers'. It stands to reason that, if the amplifiers are removed, bacterial growth is minimised.

It is known that the bacteria require water, warm temperatures and a food source. While the bacteria will grow at temperatures of between 69°F (20.5°C) and 122°F (50°C), the optimal temperature range for the growth of legionella is between 95°F (35°C) and 115°F (46°C). The legionella bacteria cannot survive in water above 131°F (55°C) for more than five or six hours and its survival in temperatures above 131°F (55°C) is shorter, depending on the temperature. Instantaneous destruction of the bacteria occurs at a temperature of 158°F (70°C) and above.

With these parameters in mind, the number one man-made amplifying source for the bacteria in domestic hot water systems is storage-tank type water heaters. Cooling towers and evaporative condensers have tended to receive more attention due to many publicised outbreaks, which involve large numbers of people and is therefore newsworthy. The truth is that more confirmed cases of legionellosis have been traced back to domestic hot water systems then any other type of equipment or systems, making storage-tank type water heaters the largest amplifier of legionella bacteria.

Figure 1: Storage-tank Feedback System



Avoid Storage Tanks

One of the most comprehensive reports on legionellosis is a position paper approved by the Board of Directors for the American Society of Heating, Refrigeration and Air-conditioning engineers (ASHRAE), Inc. The paper states that, to minimise the growth of the bacteria, it is important to control domestic water temperatures to avoid the ranges in which legionella grow.

Water systems in hotels, hospitals, nursing homes and industrial plants have been linked to outbreaks of Legionnaires' disease. Typically, steam is used to heat water for these large institutional buildings and that heated water is then stored in large bulky storage tanks (see *Figure 1*). In these tanks, conditions are ideal for bacterial amplification. These include:

- areas of stagnant water;
- temperatures lowered from stratification due to stagnant conditions; and
- a food source of algae, amoeba or protozoa.

Studies of hot water storage tanks show that water stagnates at the bottom of the tank even with operational recirculation of the water through the tank. Temperatures monitored at the bottoms of tanks have been as low as the optimum growth range for legionella bacteria even when tank temperatures were kept at levels high enough to destroy the bacteria. Food sources of algae, amoeba and protozoa are always present in potable water system supply sources. Furthermore, scale, sediment and other build-up materials in the large storage tanks and piping furnish the bacteria with protection from high temperatures and/or chemical disinfection.

The recognition of these storage tanks as potential bacterial amplifiers by ASHRAE in their position paper is a result of studies such as this, as well as bacterial samplings done in storage tanks. If we are to be proactive at diminishing legionella disease in our domestic hot water systems, we must eliminate the bacterial amplifiers. This presents the issue of how conscientious utility managers can provide an ample supply of hot water within the desired temperature range, on a timely basis, without using hot water storage tanks, or creating other amplifying conditions for disease causing bacteria.

Instantaneous Hot Water Systems

Steam is a major source of efficient energy for heating water in commercial, industrial and institutional applications, which results in a hot water alternative to bacteria-amplifying storage tanks. That alternative is a tankless instantaneous hot water system. However, not all instantaneous hot water systems are designed the same.

Both of the two basic types of instantaneous hot water systems eliminate the tanks where bacteria may amplify. However, there are significant differences and the two systems are also differentiated by the nature of their responding principle. One is based on the feedback principle (reactive temperature control); the other is based on a feed-forward concept (proactive temperature control). As discussed later, there is a significant difference.

Like storage tank systems, feedback instantaneous hot water systems are reactive with respect to response time. That is to say, there is a slight delay between the time the system senses a need for more hot water and the time the system responds with more steam to heat the water.

How Hot?

As there is no storage tank with the instantaneous feedback system, the temperature-sensing bulb is inserted into the outlet water piping (see *Figure 2*). With a feedback system, a sensor transmits a temperature signal through a capillary tube to a temperature-regulating valve that modulates the steam pressure entering the heat exchanger in order to control the outlet water temperature. All feedback systems elevate ambient-temperature water up to the hot water set point only. This set point, in most cases, does not get hot enough to eliminate the bacteria instantly. This must be achieved at a minimum temperature of 158ºF (70ºC). The outlet water temperature is usually within the range of where the bacteria will survive.

Controlling the temperature of the output water is difficult with these type of heaters. Since feedback controls are essentially reactive, typical demands experienced in a domestic hot water system change frequently and usually before the controls can stabilise the temperature set point. Normally, this stabilising act was performed by the water storage tank acting as a temperature buffer for the inaccurate feedback controls, but this type of system does not use a tank. As a result, the instantaneous feedback system controls similar to the proverbial dog chasing its tail. This constant overshooting and undershooting of set-point temperature can create a dangerous situation.

Feed-forward instantaneous water heating systems are different. They essentially blend sterilised hot water with cold water to deliver water in the range of a typical domestic hot water system. As with the feedback instantaneous type system, the storage tank amplifier has been eliminated with a feed-forward type system.

With a feed-forward instantaneous hot water system (see *Figure 3*), the response time is proactive to demand and operates on the pressure differential created by this demand between the inlet and outlet water. The temperature regulator is replaced with a differential pressure diaphragm valve controlling the water side of the unit. In addition to this valve controlling the water flow, a constant steam pressure shell and tube heat exchanger completes the system.

Sterilising Temperatures

Feed-forward instantaneous hot water systems overheat and sterilise water above the 158ºF (70ºC) threshold within a shell and tube heat exchanger (see *Figure 4*). At this temperature, the legionella bacteria are killed instantly and the water sterilised.

The hot water is then proportionally blended with cold water as required, to achieve the preset outlet temperature. The cold inlet water is usually delivered at a temperature below the amplification point for the bacteria, which is 68ºF (20ºC) at the low end of the scale.

Feed-forward instantaneous systems satisfy the ASHRAE recommendations of avoiding bacteria amplifiers. There is no storage tank and no standing water pockets because the hot water is provided as needed, on demand. The amplifying sources are eliminated, and what water resides in the heater when there is no demand will be heated to well over 200ºF (93ºC) because of the constant steam pressure on the heat exchanger.

Proactive Control and Safety

With a feed-forward type system, a differential pressure diaphragm valve regulates the water flow through the heat exchanger and maintains accurate temperature control within a very narrow temperature band. As the hot water demand downstream of the valve increases, a pressure drop proportional to the volume of water demanded is created between the inlet water and the outlet water. This pressure drop is sensed by the differential pressure diaphragm, which causes it to reposition a series of three valves (see *Figure 5*). These control valves allow water to flow into the heat exchanger and, at the same time, proportionally bypass inlet water around the heat exchanger into a mixing chamber before it exits to the domestic hot water system.

Figure 2: Tankless Instantaneous Feedback System (note the location of the sensing bulb)

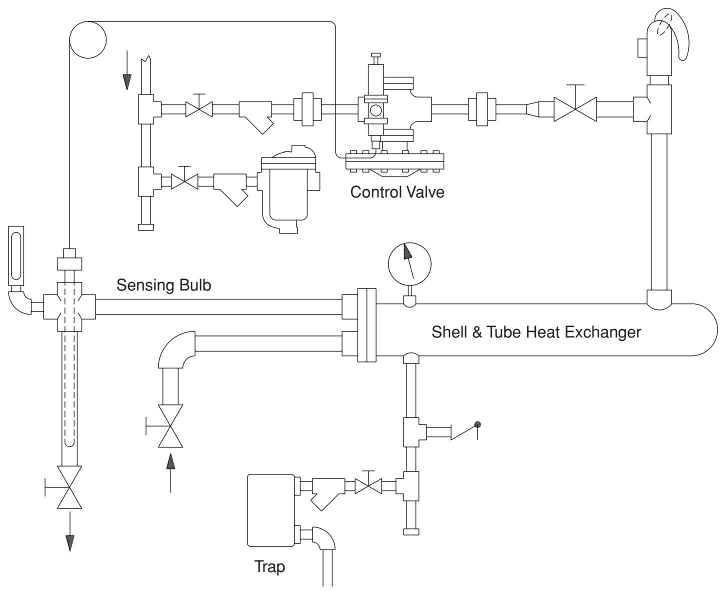


Figure 3: Installation Layout for a Feed-forward Instantaneous Hot Water System (note the thermal loops)

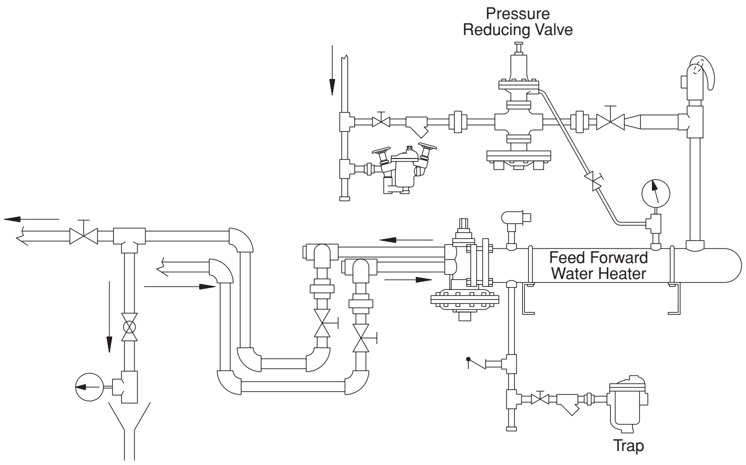
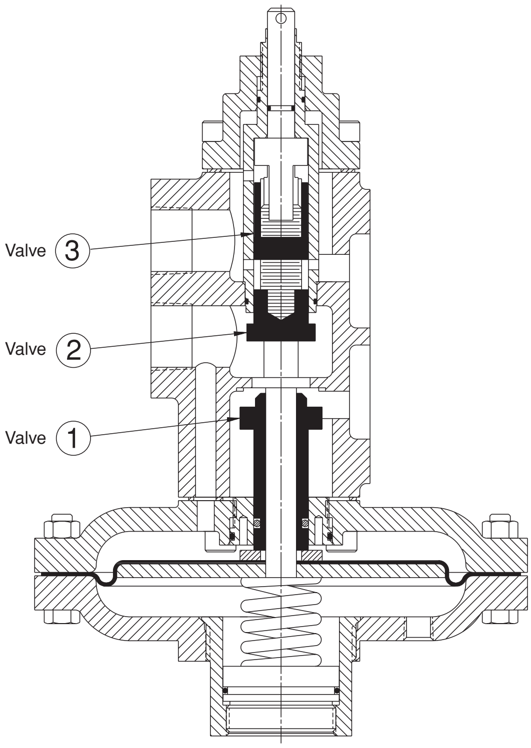


Figure 4 : Legionella Temperature Chart

Legionellae and Temperature
Below 68°F (20°C) legionellae can survive but are dormant
Legionellae growth range 68°F - 122°F (20°C - 50°C)
Ideal growth range 95 °F - 115 °F(35ºC - 46ºC)
Above 122 °F(50ºC) they can survive but do not multiply
At 131 °F(55ºC) legionellae die within 5 to 6 hours
At 140 °F(60ºC) legionellae die within 32 minutes
At 151 °F(66ºC) legionellae die within 2 minutes
Disinfection range 158 °F - 176 °F(70ºC - 80ºC)

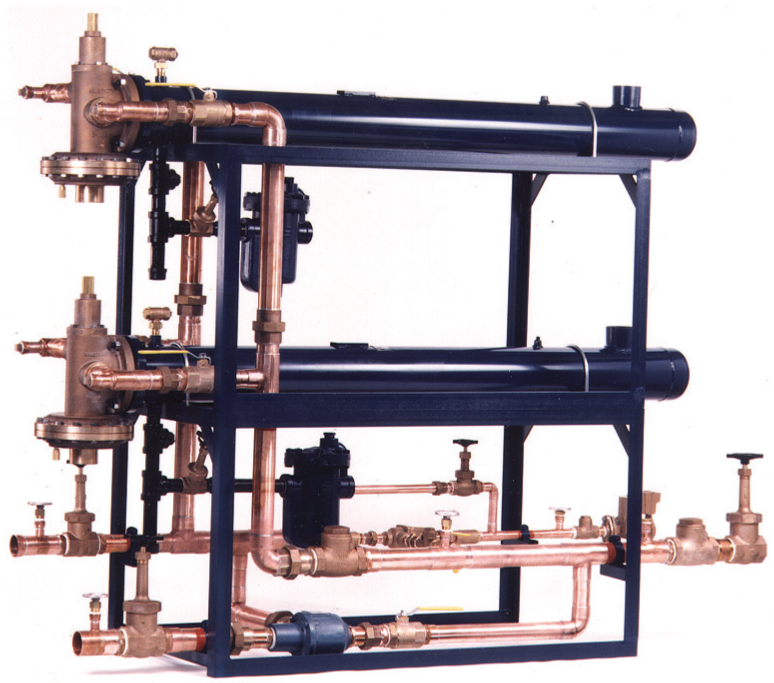
Aside from the legionella issue, there is another safety concern relating to accidental scalding. The inability of the regulator in feedback systems to reduce the steam pressure before overheating occurs can create a potentially scalding situation.

Figure 5: The Feed-forward Instantaneous Hot Water System



This system uses a unique valve that incorporates three valves operating in unison to provide a constant hot water temperature.

Figure 6: Parallel Feed-forward System – Offering increased capacity, this system requires minimal floor space (seven feet^{2})



The reactive controls of a feedback instantaneous system can cause inaccurate and dangerous temperature swings that may create a scalding hazard. The sensor location (in the outlet water piping) and the slow response time associated with self-contained temperature regulators, contribute to less-than-precise temperature control. For example, in its transition from low load to heavy load, there is a time lag for the temperature regulator to react, thus causing a noticeable drop in outlet water temperature. Conversely, when demand changes from heavy load to low load, this lag in response time will likely cause overheating of the outlet water (a scalding hazard).

The constant on/off cycling for a modulating steam system, which occurs at low demands, can prematurely wear out a thermostatic element. Plus, since the thermostatic element typically fails in the open (hot) position, it can flood the outlet with scalding hot water.

On the other hand, the constant steam pressure in the heat exchanger of the feed-forward system means that the outlet water temperature is predictable. This predictable temperature of the outlet water translates into eliminating the potentially hazardous temperature swings when modulating the steam pressure and, therefore, the temperature. With the feed-forward system, the steam temperature regulating valve is replaced with a water pressure sensing diaphragm valve that operates the three internal valves in unison to control the output water temperature strictly on demand. In the unlikely event of a valve failure, such as a ruptured diaphragm, only cold water will be dispensed, thus eliminating the concern for accidental scalding.

Conclusion

Feed-forward instantaneous hot water heating systems can be used to satisfy the demand for hot water generation without creating amplifying sources for legionella. They further control bacteria by heating water to a sterilising temperature first before blending it back down to the system set-point temperature.

Furthermore, there are energy savings when water is heated at the time it is demanded. Safety and compactness (requires only seven square feet of floor space) are additional positive features of the feed-forward instantaneous water heating system (see *Figure 6*).

Unique Valve Design Provides Immediate Response

A feed-forward instantaneous water heating system operates on a differential pressure principle. The sequence of operation is as follows: the cold water enters the valve body at line pressure, which is sensed through the cored body passage on the top of the valve diaphragm. The outlet pressure is sensed under the diaphragm and is transmitted to the bottom of the diaphragm through the hollow central main shaft that is ported to the outlet side of the valve (see *Figure 5*).

There are three valves operating in unison. Valve 1 controls the flow of the water going through the heat exchanger, which re-enters the control valve as overheated water in the top portion known as the mixing chamber. It has a spring return so that the valve stays closed in the event of a diaphragm failure. The valve begins to stroke at a pressure differential of one-quarter of a pound per square inch (psi) and is stroked completely open at six psi pressure differential.

At low flow, Valve 2 controls the amount of cold water that bypasses the heat exchanger and goes directly to the outlet mixing chamber. There it is blended with the overheated water from the heat exchanger.

Valve 3 works in series with Valve 2, remaining wide open at low demand and throttling proportionally at higher flows. When it comes into operation, it restricts the flow of cold water that mixes with overheated water coming from the heat exchanger. This takes into account the higher demand and flow rate through the heat exchanger and subsequently does not heat up as much as the low demand water flow. The water is not in the heat exchanger as long and, therefore, needs less cold water added to maintain a constant temperature output.

Both Valves 2 and 3 have external adjustments. The adjustment for Valve 2 is set during low demand flow conditions and controls during the low flow range of the unit. Adjustment of Valve 3 is made during high demand flow and controls throughout the unit's high flow ranges. Both adjustments are made in the field after installation. Once set, the valve should rarely need re-adjusting unless there is a need to increase or decrease the outlet water temperature.

All three valves are integral to the same hollow central shaft that is connected to the differential pressure diaphragm. When there is a hot water demand, the diaphragm strokes proportionally based on hot water demand. When it strokes, due to a change in outlet pressure, all three valves stroke downward at the same rate, positioning all three valves to perform their instantaneous mixing function without lag time. ■

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