WATER DISINFECTION IN COMMERCIAL BUILDINGS

If we are to stay healthy, it is essential that the water we drink and shower in is clean and one of the most widespread health hazards in any drinking water installation is Legionella pneumophila - an exceptionally resistant bacteria.
Legionella generally thrives in hot water systems with a low flow rate, areas of stagnation or badly serviced hot water tanks. A slimy layer of biofilm within pipes and tanks creates a protective habitat for legionella and other microorganisms. The bacteria breed and thrive in biofilm at temperatures between 25 and 46 °C, and they constitute a severe health risk.

Water disinfection is of utmost importance in all buildings with drinking water consumption and, most particularly, in buildings that supply shower and bathing facilities. Water disinfection is also essential in those applications where water mist is sprayed into the air, such as cooling towers and evaporative condensers.

By Jens Nørgaard, Application Manager for Grundfos Commercial Building Services

What are Legionella?

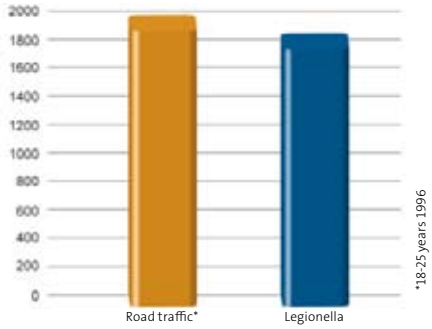
Legionella pneumophila – the bacterium associated with over 90% of all cases of Legionnaires' disease – is a bar-shaped bacterium of the Legionellaceae family. Water for domestic use in commercial buildings is very often infected with legionella pneumophila and therefore special measures have to be taken in order to combat it, since it is, for the most part, resistant to biocides.

Legionella pneumophila under microscopic analysis

What effects do Legionella have?

Legionella can be transferred to the human respiratory system in any water aerosol with a droplet size of between 3 and 5 µm and aerosols of this size are easily created in environments such as showers and cooling towers. Even a relatively low concentration of bacteria in the aerosols is sufficient to infect a healthy person. Following an incubation period of 2-10 days, the legionella pneumophila generate a special form of pneumonia (legionellosis) which can be accompanied by Pontiac fever. Estimates from the German Federal Statistical Office indicate that each year in Germany 25,000 to 30,000 people contract legionellosis. For people with weakened immune systems such as the elderly, sick and those who smoke, the illness can be fatal if not treated within the first four days.

- The legiollosis disease rate is up to 5 % of those inhaling infected aerosols.
- The death rate is up to 30 % of those who succumb to legiollosis.

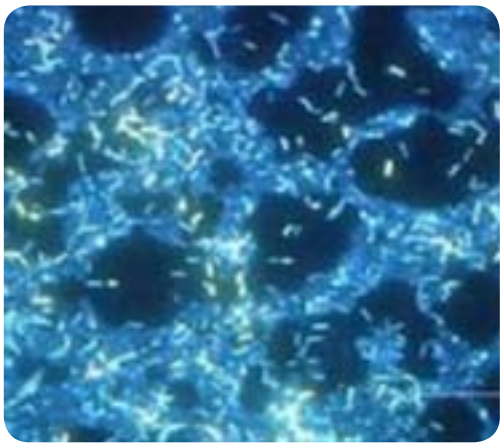


Number of traffic-related deaths and deaths caused by Legionella in Germany in 1996

Where are Legionella found?

Small quantities of Legionella are found naturally in the microflora of rivers, lakes and ground water. These low concentrations are not generally associated with disease, but when favourable growth conditions are created, the bacteria can reach hazardous concentrations.

Legionella travel into the water systems of buildings via intakes from both the surface and drinking water network.
Generally, conditions in hot water systems such as low flow rate, low temperatures, stagnant water and badly serviced water tanks offer optimum conditions for the growth of Legionella. Legionella reproduce abundantly in a temperature range between 25 and 46 °C and live in biofilms where they are shielded against most chemical disinfectants and most disinfection technologies.
Biofilm consists mainly of mixed colonies of microorganisms (bacteria, algae, fungi, protozoans) that are connected to one another and attached to a single substrate, and integrated fully or partially in a polymeric organic mass (slime) produced by the organisms. This gel-like film offers the ideal growth conditions and offers the ultimate protection for the bacteria.



Legionella in biofilm

Sources of legionella in commercial buildings
There are a number of applications in any commercial building from which the legionella bacteria can spread: Here are some potential sources of risk:

Hot water systems

All hot water systems are at risk of infection but there is an increased risk of growth in systems where:

- Warm water remains more or less stagnant owing to low consumption.
- Water temperature is between 25 °C and 46 °C which is "ideal" as legionella is a mesophile bacteria which breeds in exactly that temperature range.
- There are "dead ends" without flow.
- There is sediment, rust, scale and sludge, which provides food sources for the bacteria.
- The system is not properly maintained.

The temperature in hot water tanks should be 60 °C, whilst temperatures in the taps and circulation pipes should be no less than 55 °C. However, if the temperature exceeds 60 °C, unwanted scaling will occur in both tanks and pipes.

Cold water systems

In large and tall buildings, cold water frequently heats up to temperatures that create ideal growth conditions for several kinds of bacteria. At the water's main point of entrance into the building, the cold water usually has a temperature of 8-12°C. Beyond that point, the cold water temperature starts to increase owing to high surrounding temperatures. If the water ends its flow in an uninsulated rooftop tank, it is possible for a further increase in water temperature to occur. After some hours in a rooftop tank, the water re-enters the building for tapping. Not only will the consumer never experience what cold water is like; the cold water will also be likely to contain high levels of bacteria.

There is an increased risk of growth in systems where:

- Pipe- and tank insulation is missing or is in poor condition. Cold water pipes and tanks should always be insulated to avoid undesirable heating.
- Cold and hot water pipes are co-insulated. Heat will travel from the hot pipe to the cold pipe.
- Rooftop tanks and break tanks are used. If the use of tanks cannot be avoided, they should be located inside the building and should be sized with the lowest possible retention time.
- There are water tanks in organic material, as the tank itself will serve as a food source for bacteria.
- Pipes are oversized. Stagnant water increases the risk of bacteria growth.
- Pipe material is rustable. Rust is a good food source for bacteria.
- There are dead-legs where there is no water flow.

Rooftop cooling towers

Cooling towers and evaporative condensers are used to dissipate unwanted heat to the atmosphere through water evaporation. Water is sprayed into the cooling tower through spray nozzles and tiny airborne droplets are formed. While falling through the tower, some of the water evaporates but some droplets, known as drift, are carried out of the tower by the air stream produced by the fans. Legionella grows easily in the water and is easily dispersed together with the drift.

The spray from a cooling tower can easily travel 6 km.

Spa baths

Legionella are a particular problem in spa baths because:

- The water in spas is 32 to 35 °C which is an optimum temperature for the legionella bacteria to grow.
- Dirt and dead skin cells etc. from people using the bath provide food for the bacteria.
- The "hidden" air and water circulation pipes provide a large surface area for the bacteria to grow on.
  Bio film in these pipes can therefore not be removed.
- The agitated water forms aerosols and spray in which the bacteria can be dispersed and inhaled.

Water fountains

Water fountains in places such as shopping malls, airports, hotels and theme parks are subject to bacteria growth. Water is sprayed into the air, forming airborne droplets that are then easily inhaled into the lungs. Fountain water is the same temperature as the surrounding air and at that temperature, legionella and other bacteria grows readily in the water and biofilm.

What methods are used to combat Legionella?

Thermal treatment

One of the most commonly used methods to combat legionella is thermal pasteurisation.

Legionella begin to die at temperatures above 56 °C, which makes it possible to combat the bacteria by heating the infected water system.

A temperature of approximately 70 °C must be reached and maintained throughout the entire piping system over a period of around 10 minutes. However, this can seldom be achieved in typical installations because the water cools down as it reaches the water outlets.

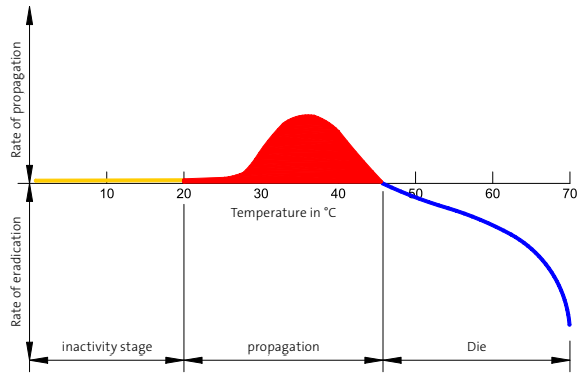
There are relatively few advantages to thermal treatment:

- Does not affect the smell and taste of the water.
- Not sensitive to pH-value of the water.
- Well-known and understandable principle.

- No addition of biocides to the water.

On the other hand, there are many disadvantages to thermal treatment:

- Acute risk of scalding if the water outlets are opened during pasteurisation.
- Biofilm is left unaffected, with the result that germs quickly build up again between treatment cycles. There is no long-term effect of the pasteurisation.
- Dead-ends are not treated at all.
- An advanced tap-opening process must be implemented to make sure that all sections of the water system are treated. Needless to say, in large residential and commercial water systems, it is impossible to secure the flushing of all pipes.
- The consequence of heating up large water systems is very high energy consumption.
- The desired temperature of 70 °C can never be achieved in the whole system, because the water cools down before it reaches the water taps.
- The procedure leads to increased limescale deposits in pipes and tanks. This might damage systems and clog water taps.
- Thermal expansion in pipes can cause irreparable damage and leakages in older installations.



The overarching conclusion is that thermal treatment is an inefficient and expensive procedure.

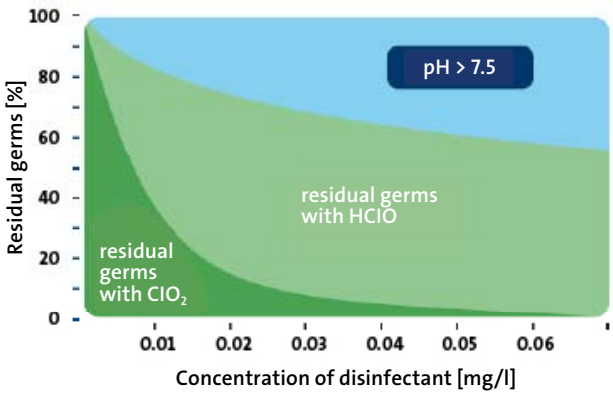
The ability of Legionella bacteria to reproduce as a function of temperature

Chlorination (Hypochlorite solution)

One of the most common ways of water disinfection. Chlorine is often used as a disinfectant in the form of a hypochlorite solution that is injected into the water system.
The most significant advantage of chlorination is that the investment cost is very low.

There are numerous disadvantages:

- The treated water will smell and taste of chlorine. The consumer will cease to drink the water and instead buy bottled water for consumption.



- The procedure is sensitive to the pH-value of the water. At levels above 7.5, the disinfection effect is reduced.
- The long-term effect on bacteria is limited.
- The biofilm in the hot water tank and pipes are left unaffected.

UV radiation

The infected water is subject to ultra-violet rays with a wavelength of 254 nm. The UV rays penetrate the cell wall and damage the genetic information of the bacteria and viruses, disrupting their reproductive systems. A UV-bulb is used for radiation of the water.

Advantages:

- UV-treatment is effective against free bacteria that are actually exposed to the UV-rays.
- It does not affect the smell and taste of the water.
- No chemicals are added to the water.

- UV-treatment is not sensitive to the pH-value of the water.

Disadvantages:
- This method is regarded as a "gatekeeper" - only free bacteria that actually float past the UV-bulb and are therefore exposed to the UV-rays are killed. There is no long-term effect on bacteria populations in the water system.
- Biofilm in the piping network – the basis for the multiplication of Legionella – is unaffected by this procedure and UV-radiation has no effect on bacteria remaining in biofilm.
- The UV-bulb is very sensitive to particles and scale in the water. The addition of carbonic acid, for example, is necessary to avoid scale precipitation.
- The ultraviolet radiation system often includes an activated carbon filter to remove metals and particulates.

Filtration

Ultrafiltration is commonly used for domestic water supply. Ultrafiltration or membrane filtration filters bacteria, viruses, suspended particles and other unwanted elements from the water.

Advantages:
- Effective against free bacteria floating in the water.
- Does not affect the smell and taste of the water.
- Not sensitive to the pH-value of the water.
- No chemicals are added.

Disadvantages:
- This method is regarded as a "gatekeeper". Only free bacteria floating in the water can be removed. There is no long-term effect on bacteria populations in the water system.
- Biofilm in the pipes and water tanks – the basis for the multiplication of Legionella – is unaffected by this procedure.
- In case of malfunction, a large microbiological population can grow in the membranes.

Ozone

Ozone is a sanitiser derived from the surrounding air, which can be dissolved in water for the purposes of disinfection. It is produced by passing oxygen through a high intensity electrical field. Using this method, the oxygen gas is altered to ozone gas - a short-lived oxidiser. Once generated, ozone must be used immediately as it breaks down rapidly when exposed to oxygen.

Advantages:
- Effective against free bacteria floating in the water.
- The smell and taste of the water is not affected.
- Non-sensitive to the pH-value of the water.

Disadvantages:
- This method is also regarded as only a "gatekeeper", owing to the breakdown time. As the retention time is very short there is no residual effect and no long-term effect on bacteria populations in the water system.
- Biofilm in the piping network – the basis for the multiplication of Legionella – is unaffected by this procedure and ozone has no effect on bacteria remaining in biofilm.

Treatment with chlorine dioxide

Chlorine dioxide kills microorganisms in the water by way of irreversible oxidative destruction of the transport proteins in the living cells.
Because of its high redox potential, chlorine dioxide has a much more powerful disinfecting action against all kinds of germs and contaminants such as viruses, bacteria, fungi and algae, compared to other biocides. The oxidation potential is higher than with e.g. chlorine, which means that significantly fewer chemicals are required. Microorganisms that are resistant to chlorine, for example Legionella, can be killed completely by chlorine dioxide.
The significant advantage of chlorine dioxide in relation to chlorine or hypochlorite is the gradual effect it has on degrading biofilm at low doses. A chlorine dioxide concentration of 1 ppm will kill virtually all Legionella in the biofilm within 18 hours. A significant reduction in the biofilm can be achieved within the same timeframe using a concentration of 1.5 ppm. Furthermore, the disinfecting action of chlorine dioxide

is virtually independent of the pH value, meaning that it can also be used without any problems in alkaline environments.

There are many advantages to chlorine dioxide:

- Chlorine dioxide removes biofilm effectively in the entire water system, ensuring the basis for the multiplication of Legionella is removed.
- Effective against free bacteria floating in the water.
- Effective for bacteria and biofilm in dead-legs, as the chlorine dioxide can dilute into dead-legs with no water flow.
- Extensive residual effect. If there are periods with very low or no flow, the chlorine dioxide stays in the water and protects the system for up to a week.
- Chlorine dioxide does not affect the smell and taste of the water.
- Chlorine dioxide is not sensitive to the pH-value of the water.
- Chlorine dioxide generation on the basis of hydrogenic acid (HCl) and natriumhypochlorite (NaClO2) has a very low life cycle cost.

The only disadvantage concerning this procedure is risk during the handling of chemicals. If hydrogenic acid (HCl) and natriumhypochlorite (NaClO2) are mixed, toxic gases are formed.

This chart illustrates how the typical solutions for disinfection perform on a number of parameters. The chlorine dioxide solution of the Oxiperm Pro system is superior to the rest.

= Inferior
= Average
= Superior

Disinfection principle	Benefits							
	Removes biofilm	Effective against bacteria in biofilm	Effective against free bacteria	Affects water taste and smell	Sensitive to water-pH	Life cycle cost	User scalding risk	Long-term effect
Thermal treatment	No	Low	Mid	No	No	High	Yes	No
UV radiation	No	No	High	No	No	Mid	No	No
Filtration	No	No	No	No	No	Mid	No	No
Chlorination (hypochlorite sol.)	No	Mid	High	Yes	Yes	Low	No	Mid
Ozone	No	No	High	No	No	Low	No	No
Chlorine dioxide	Yes	High	High	No	No	Low	No	High

Performance of disinfection technologies and disinfectants on a number of parameters

Which duties and responsibilities concern the operation of water installations?

Almost every country in the world has legislation regarding the prevention and combating of infectious diseases. The German Drinking Water Ordinance express it thus: “Water intended for human consumption must be supplied in such a way that its consumption or use will not adversely affect human health, especially through means of pathogens.”
This means that owners or operators of water systems in public or residential buildings have full responsibility for the quality of the water systems right up to the water outlet. Water utility companies are responsible for the quality of water until the water delivery point. Public health authorities are required to inspect water supply installations that distribute water for the general public. Commercial buildings must be inspected and samples have to be taken. The health authority will usually commission a laboratory to test the water samples. If specified limit values are exceeded, health authorities in most countries are authorised to close down building water supply installations. The quality of drinking water in private buildings is inspected on request, or if there are indications of a problem.

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