Legionnaires' disease

Building services – healthy buildings

INFECTION ROUTE NOW KNOWN TO BE IN FOUR STEPS: MULTIPLICATION OF LEGIONELLA IN WATER, AEROSOLIZATION OF THIS WATER, EXPOSURE TO AEROSOL AND LIKELY SUSCEPTIBILITY OF PERSON TO THE DISEASE

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G.W. Brundrett of the UK's Electricity Council Research Centre reviews and examines the water services within and around buildings, providing detailed conclusions and references.

Introduction

Microbiological research

The cause of the mysterious illness with a fatality of 20% which attacked the delegates attending the American Legion Convention in Philadelphia in July 1976 was the sausage-shaped bacterium *Legionella pneumophila* of a few microns in length. It was identified after intensive research by the Center for Disease Control in Atlanta in January 1977 (ref. 1). This discovery has prompted much microbiological research which shows that the organism is one of a large family of legionella bacteria and that it is commonly found in all water systems although normally at low concentrations. Subsequent investigations of microbiological samples from earlier epidemiological puzzles which had been stored in laboratories showed that the bacteria had been associated with outbreaks for over forty years (ref. 2). The infection was not new, but the detection had been hampered by the unusual inability of the organism to grow on the conventional culture material used in hospital laboratories.

Twenty-three species of *Legionellacae* have been identified and ten named (Table 1). The most virulent one for man is *L. pneumophila*. This species in turn can be divided into eight sero groups. Sub-divisions within the sero groups are now becoming possible (ref. 3). An illustration of the types of legionella which cause sporadic outbreaks of legionellosis is shown in Table 2. Over 60% of the sporadic cases are caused by *L. pneumophila* Sero Group I (ref. 4). The majority of these belong to the first subtype MAB$_1$; most of the legionella bacteria are unlikely to create infection.

Two kinds of illness

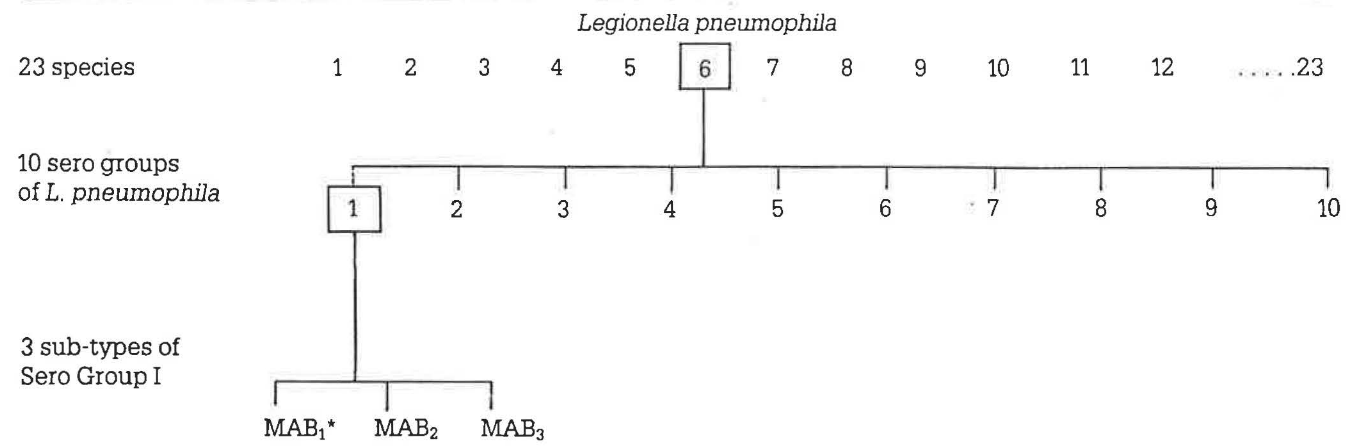
The organism is now known to cause two kinds of illness. The major one is legionnaires' disease. This is characterized by pneumonia, usually together with fever, cough, chills and breathlessness. The incubation time is typically six days, although the range is from two to ten days (ref. 5). There is a seasonal pattern in occurrence, peaking in August and September in the USA (Fig. 1 and ref. 4). There is no record of person-to-person spread of infection. The bacteria are not highly virulent but may infect those susceptible. It is this limited susceptibility which helps make the disease unusual. Studies of outbreaks have shown that 99% or more of the population are not susceptible. This makes the disease an uncommon one with typically 100 to 200 cases per year in England and Wales being reported to the Public Health Authorities Communicable Disease Surveillance Centre. While this is an underestimate because reporting is voluntary, it is believed to be a good indication.

The illness accounts for approximately 2% of primary pneumonias which develop outside hospital. Case fatality is 10%, which is similar to that for all pneumonias. Effective medical treatment is available once the illness has been diagnosed.

The bacteria can also cause a different type of illness which is benign and similar to influenza. The incubation period is very short, typically 36 hours, and the illness lasts three to five days with symptoms of fever, chills and headaches. This is called Pontiac fever. The attack rate of exposed people is very high, greater than 95% (ref. 5). This does not normally require medical attention and is therefore not reported until a major outbreak occurs.

Whenever two or more cases of legionnaires' disease occur, then an epidemiological investigation can search for and identify the source of the bacteria and its transmission route. The majority of cases have been associated with either domestic hot water services in public buildings such as hospitals or hotels, or with evaporative cooling towers serving air-conditioning equipment. Those associated with

***Table 1. The genus* Legionellaceae**



*MAB$_1$ is the most virulent and is closely associated with outbreaks.

Table 2. Causes of sporadic outbreaks of legionella (ref. 4)

Total cases with species and sero group analysis available	146	(100%)
Cases with *Legionella pneumophila*	126	(86%)
of which Sero Group 1	101	(69%)
Sero Group 2	6	(4%)
Sero Group 3	4	(3%)
Sero Group 4	2	(1%)
Sero Group 5	7	(5%)
Cases with *Legionella micdadei*	12	(8%)
Legionella bozemanii	6	(4%)
Legionella longbeachae	2	(1%)
	146	(100%)

Table 3. The presence of legionella in buildings (ref. 7)

Building type	Service	No. of establishments sampled	Proportion in which legionella detected (%)
Hotels	Hot and cold water	104	53
	Cooling water systems	9	67
Hospitals	Hot and cold water	40	70
	Cooling water systems	13	38
Business	Hot and cold water	17	75
	Cooling water systems	24	54
Residential	Hot and cold water	3	67

Table 4. Analysis of system factors for hotels (ref. 8)

	Test for legionella		
	Positive	Not found	Total
(a) No. of hot water supply tanks			
1	9	27	36
2	18	25	43
3+	13	9	22
Likelihood of legionella increases with number of tanks (p = 0.009)			
(b) No. of hot water outlets			
100	5	20	23
101–200	13	19	32
201–700	15	20	35
> 700	10	2	12
Likelihood of legionella increases with number of outlets (p = 0.001)			
(c) Capacity of calorifier			
1125 litres	12	29	41
1125–2250	16	27	43
2250–4500	12	4	16
> 4500	3	0	3
Likelihood of legionella increases with capacity of calorifier			
(d) Piping material for the hot water			
Galvanized	26	22	48
Mild steel	6	15	21
Copper	0	8	8
Other/mixed	11	16	27

Copper pipes are less likely to become contaminated (p = 0.008)

hot water systems have tended to be sporadic cases in holiday hotels in hot countries. Those associated with cooling towers have tended to be epidemics and have raised much press and television attention. Until two years ago the cases were roughly equal but recent epidemics have given supremacy to the cooling tower as the major source of infection. Whirlpool spas have also been implicated (ref. 6).

Public Health Laboratory survey

A survey throughout England and Wales by the Public Health Laboratory Service of 180 hotels, hospitals, residential dwellings and businesses found that *L. pneumophila* was present in 75% of the water services in business premises, in 70% of hospital water services and in over 50% of hotels (ref. 7). The bacteria were most commonly found in hot water systems, particularly in calorifiers. The larger calorifiers tended to have more likelihood of contamination. Two-thirds of the hotel cooling towers were contaminated with *L. pneumophila*, over half of those in business premises and over a third of hospital towers. These results are summarized in Table 3.

An analysis of the associations between the hot water system characteristics and the presence or absence of detectable legionella is illustrated in Table 4 for hotels. There was no systematic effect of hotel age nor of the size of the supply tanks to the hot water system. However, the probability of finding legionella increased with an increasing number of supply tanks, increased with the number of tap outlets and increased with the size of the calorifier (ref. 8).

Hot water system model

A laboratory model of a hot water system incorporating commonly available materials has been inoculated with *L. pneumophila* Sero Group I and examined after ten weeks. Colonization, accompanied by copious quantities of a slime-like debris, was heaviest on the rubber surfaces and rare on the copper surfaces. Colonization was also abundant on the aluminium surfaces and was present in the cells which were attached to the walls of the silicone tubing and stainless steel (ref. 9). This research highlights the new attention being given to surfaces acting as a major source of colonization. Bacterial counts taken from bulk water samples do not reflect the number of bacteria present in the system (ref. 10). Surfaces are now believed to play an important role in the speed of recolonization of systems once they have been nominally disinfected. Fortunately, more than 80% of the sub-types isolated from domestic water services and existing towers belong to sub-types which are rarely associated with human disease.

The infection route is now clear. Contaminated water containing legionella is dispersed as an aerosol. This aerosol is inhaled and the small droplets carry the bacteria deeply into the lung. If this dose overwhelms the natural defence mechanism then the bacteria multiply and infection occurs.

Let us examine the factors affecting this process.

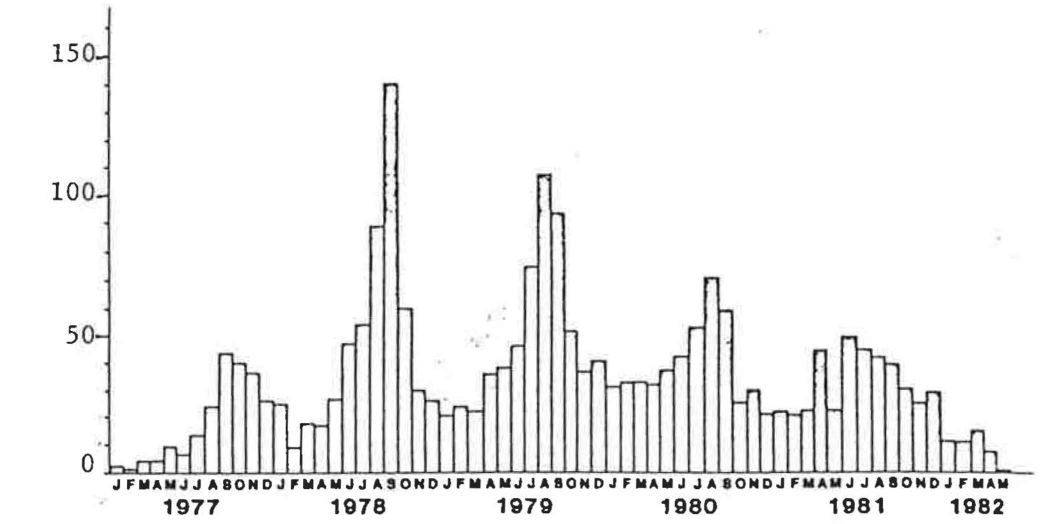


Fig. 1. Sporadic cases of legionellosis 1970–1982, USA (ref. 4)

The four factors determining the risk of infection

The starting assumption is that there are traces of legionella in all water services but their concentration is very low and the water is safe. We need to minimize the risk at each of the four essential steps in the infection route. We need firstly to prevent multiplication of the organism, secondly to minimize the amount of aerosol contamination, thirdly to dilute this aerosol before it reaches people, and fourthly to identify the susceptible groups of people. Let us examine these four factors in depth.

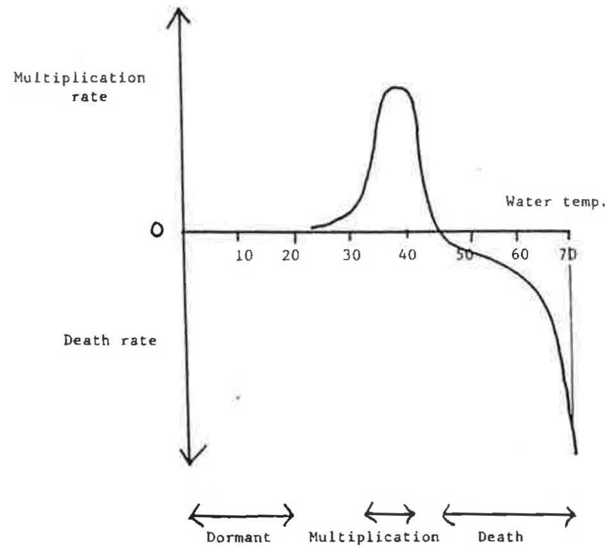


Fig. 2. Schematic illustration of the effect of temperature on legionella

Multiplication of legionella in water

Each family of micro-organisms has a set of environmental conditions under which it multiplies best. Temperature is one of the most crucial factors. Multiplication rates increase with temperature up to an optimum which is particular to that organism. At temperatures above this optimum the rate of multiplication rapidly declines, and above a critical temperature the survival of the organism is a function of time and temperature (Fig. 2).

Within the normal laboratory time-scales of the order of days, not months, experiments with cultures of naturally occurring *L. pneumophila* Sero Group I over the temperature range 5 to 45°C showed that the bacteria would multiply over the temperature range 32 to 42°C in tap water. The organisms increased by a factor of ten in less than three days (ref. 11). An illustration of the speed of colonization is given in Fig. 3. When there is a plentiful supply of nutrient the bacteria can multiply by a factor of two every three to four hours.

At temperatures lower than 32°C legionella can still colonize systems, but the rate at which it does so falls rapidly with the decrease in temperature. Some legionellas have been shown to be capable of colonizing areas at temperatures up to 63°C and down to 6°C (ref. 12). At lower temperatures the bacteria become dormant but remain viable for months. Once favourable temperature conditions return then these cells restart activity and multiply. In practice, surveys of drinking water supplies show that legionella strains are rarely found in water below 15°C (ref. 13).

Laboratory studies suggest that the two critical temperatures for multiplication of *L. pneumophila* are 37°C and 46°C. The optimum temperature is 37°C and once the temperature reaches 46°C then the concentration of organisms in the water remains constant. Above 46°C the cells die and their rate of destruction increases rapidly with increasing temperature. Six minutes of exposure at 58°C will kill 90% of the legionella. The same effect can be achieved by exposing the organism to 54°C for 27 minutes or to 50°C for 111 minutes. This is illustrated in Fig. 4. Other legionella behave differently. *L. micdadei* is more easily killed by higher temperatures, *L. bozemanii* is less affected (ref. 14). Other factors which increase the multiplication rate

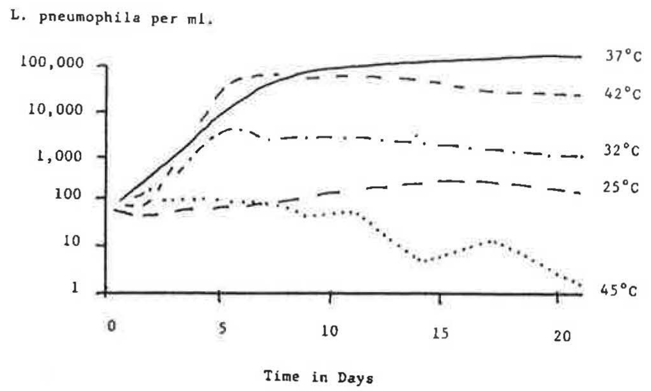


Fig. 3. ***Legionella pneumophila*** ***multiplication in unsterilized tap water (ref. 11)***

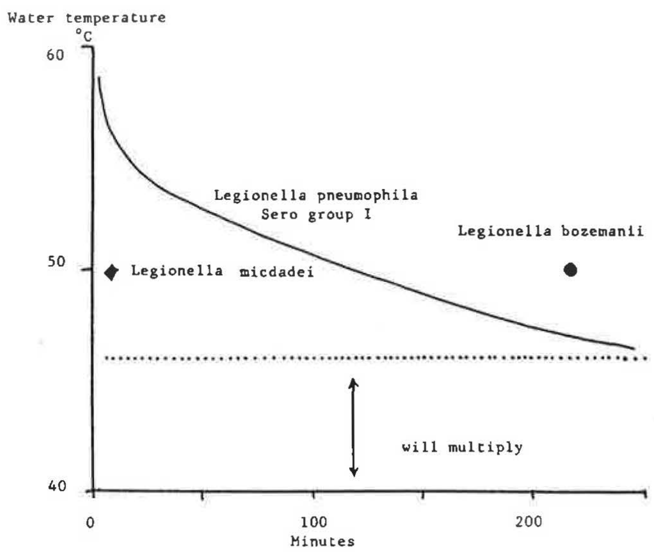


Fig. 4. ***Time needed to kill 90% of the legionella (ref. 14)***

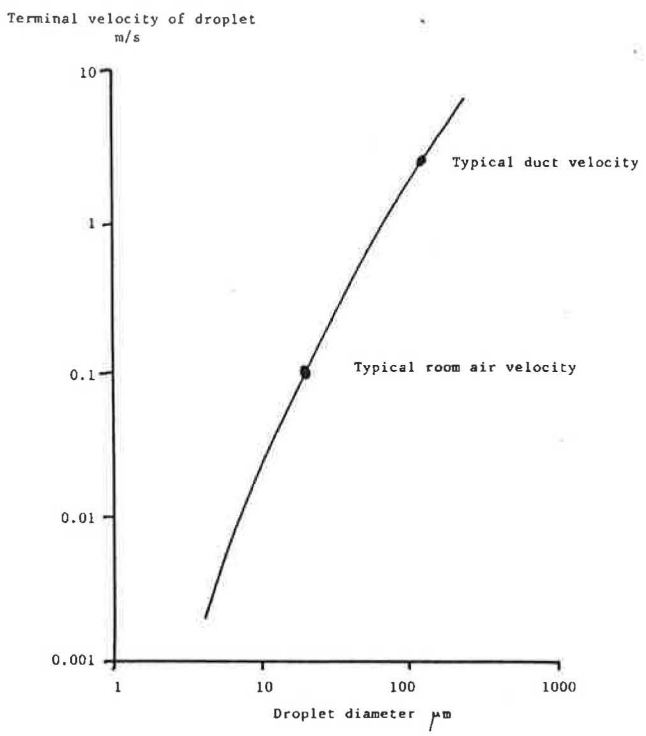


Fig. 5. ***The terminal velocity of a droplet varies with size***

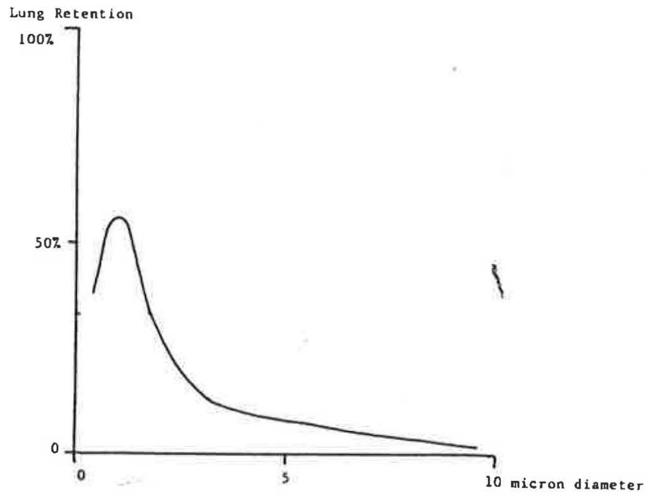


Fig. 6. ***Lung retention as a function of particle diameter (ref. 18)***

are traces of iron oxide in the water, a pH around 6.9 and a plentiful supply of nutrient in the form of any organic material (refs 15 and 16).

Generation of an aerosol

Contaminated water is not a problem until it is dispersed in air. The degree of risk increases as the droplet size reduces. Smaller droplets have lower terminal velocities and therefore remain suspended in the air for longer (Fig. 5 and ref. 17). They also travel further, increasing the risk of contact with people. Smaller droplets also pass more deeply into the lung when inhaled and it becomes increasingly more difficult to expel them (Fig. 6 and ref. 18). However, even large droplets evaporate once dispersed and this results in smaller droplets becoming more concentrated, because they still have the same number of bacteria as the original larger drop.

Aerosols are generated when jets of water break up or hit an obstruction. They also occur when thin unstable films of water collapse. When a water droplet hits a surface it forms a crown-shaped displacement film which quickly breaks up into fine film droplets. This is illustrated in Fig. 7. This occurs whenever a shower or water tap is turned on and when an evaporative cooling tower operates.

Aerosols are also generated by rising bubbles when they burst on the surface (Fig. 8). These form two kinds of drops. The first and smaller come from the bubble film itself. The size range for these drops is from 0.1 to 10 μm diameter. An illustration of the size distribution for the film droplets from small bubbles is shown in Fig. 9 (ref. 19). The second kind of drops are jet drops produced from the jet that rises from the collapsing bubble cavity. These are much larger drops whose size is a function of the bubble itself and typically one-tenth the diameter of the bubble.

The number of jet drops decreases with bubble diameter. Bubbles of less than 0.3 mm diameter produce five or more drops, while those of 6 mm diameter produce only one. However, the number of film drops increases with bubble diameter. Very small bubbles of 0.3 mm diameter have no film drops. Bubbles of 1.7 mm diameter produce from 10 to 20 film droplets, with half of them being smaller than 10 μm diameter. A 6 mm diameter bubble can produce up to 1000 film drops.

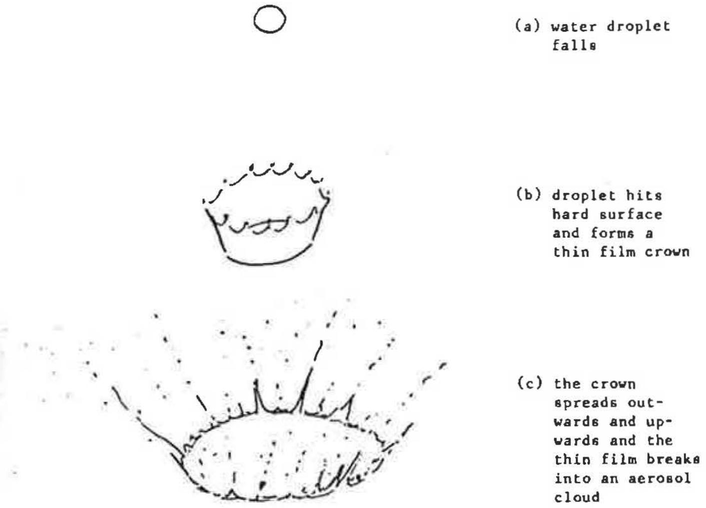


Fig. 7. ***The three stages of aerosol formation from a droplet hitting a hard surface***

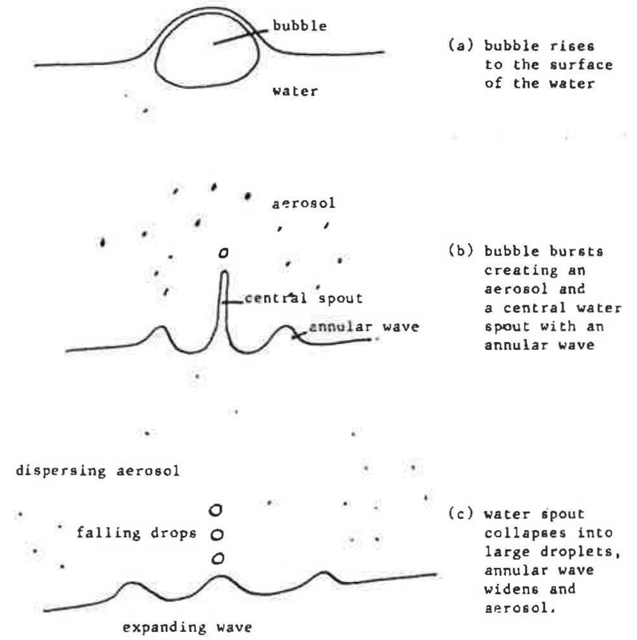


Fig. 8. ***Aerosol and droplet creation from a bubble bursting through a liquid surface***

Bubbles also have one other unusual characteristic. As they travel up through the water they collect particulates in the bubble/air interface. This means that the bubbles which rise through contaminated water will concentrate the bacteria into this very thin layer, which eventually becomes the bubble film. Measurements have suggested enrichment factors varying from unity to 1000, but a recent study showed that even small bubbles rising less than 20 mm have an enrichment factor between 10 and 20; in other words bacteria are 10 to 20 times more concentrated in the bubble film than in the bulk fluid itself (ref. 20).

Experimental measurements from air samples taken inside a shower unit and approximately 600 mm above a hot water tap showed that 90% of the *L. pneumophila* recovered from the shower were trapped in aerosol

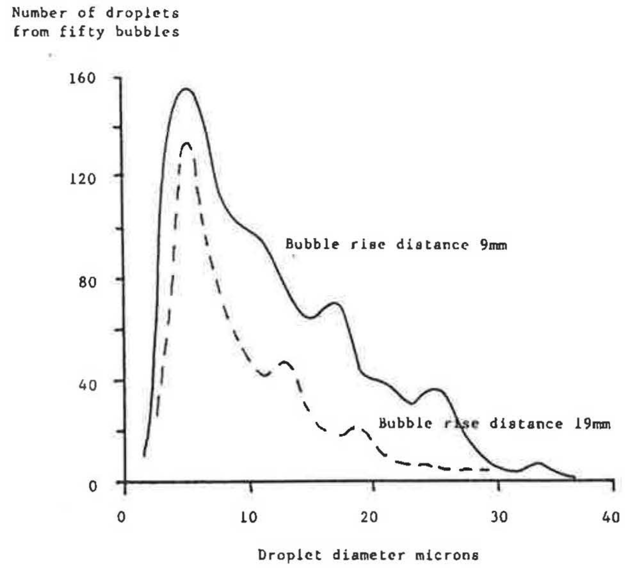


Fig. 9. ***Film drop size distribution from 50 bursting bubbles from 1.7 mm diameter bubble (ref. 19)***

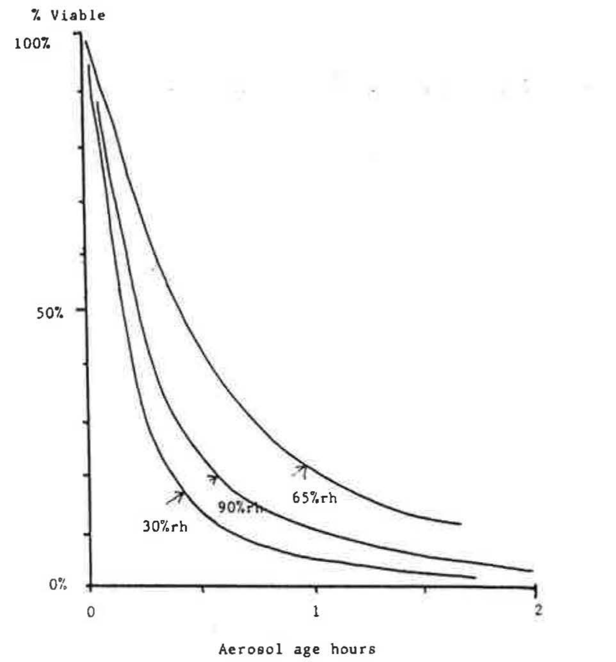


Fig. 10. ***Survival of aerosolized*** **Legionella pneumophila** ***(ref. 22)***

particles of between 1 and 5 μm diameter. Approximately 50% of the organisms trapped above the hot water tap were in droplets between 1 and 8 μm diameter (ref. 21).

The viability of the bacteria in an aerosol is influenced by time, ambient relative humidity and exposure to sunlight. Laboratory experiments have shown optimum viability at 65% r.h., while low values of 30% and high values of 90% hinder viability. The change in viability over time at different relative humidities is shown in Fig. 10 (ref. 22). Sunlight is considered harmful to the organism because of the ultraviolet component of radiation. Distances over which the bacteria can travel and still be able to create infection have grown as the epidemiologists have refined their techniques. It is now believed that the aerosol can travel 500 m and still induce an infection in susceptible persons.

Inhalation

The quantity of bacteria inhaled is determined by the local airborne bacterial concentration and the time the person is exposed to it. The airborne bacterial concentration is in turn influenced by the concentration of bacteria in the water and the amount of water aerosolized. This concentration in air decreases rapidly with distance from the source.

Contamination from cooling towers is usually disseminated by means of a fan. An illustration of a simple vertical turbulent jet from a cooling tower being dissipated by a cross-wind at different velocities is shown in Fig. 11 (ref. 23). This demonstrates the critical importance of the local wind speed. Even in almost sitll air the jet is diluted by a factor of ten in a distance of less than 20 jet diameters downstream. In windy conditions, this distance reduces to approximately five diameters.

Personal exposure time to contaminated air can be continuous when the contaminated air enters the building through the air supply. However, many cases have been reported which follow very short time exposures to a legionella aerosol. These cases include walking in the vicinity of buildings which have a contaminated cooling tower; washing, even without a shower, in hotels; and relaxing in whirlpools or spas.

Susceptibility of individuals

Many people have been exposed to legionella bacteria and their body defence system has responded by producing appropriate antibodies, sufficient to prevent an illness. Whilst previously healthy people may develop legionnaires'

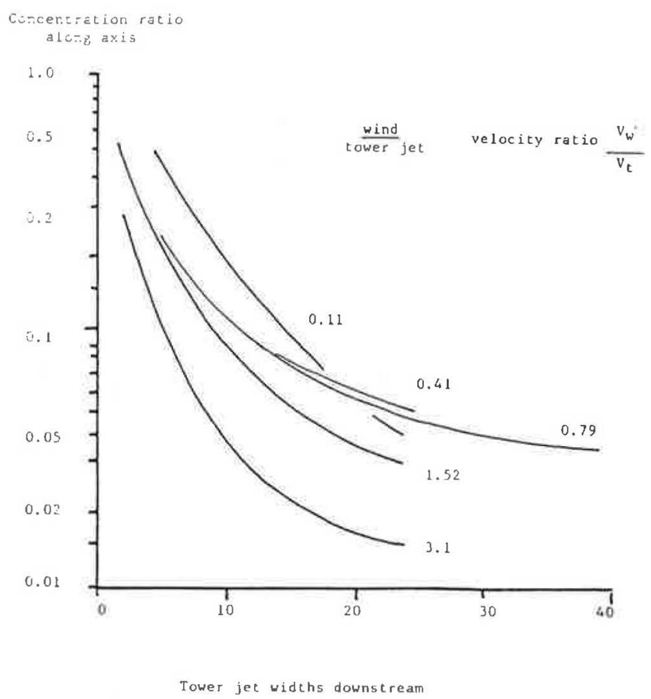


Fig. 11. Experimental measurements of change in contaminant concentration with distance downstream in the jet for different cross-wind velocities (ref. 23)

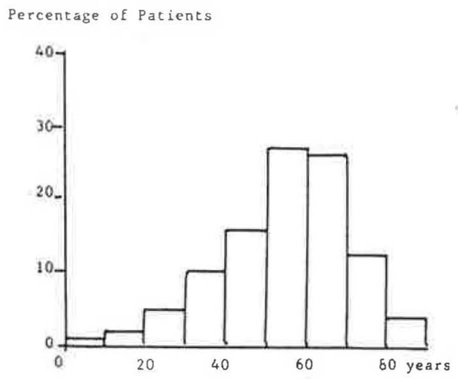


Fig. 12. Sporadic legionellosis by age 1970–1982, USA (ref. 4)

disease, case studies have revealed a number of factors which have been shown to increase susceptibility. These include increasing age, particularly above 50 years. Children are rarely infected. The pattern is illustrated in Fig. 12 (ref. 4). Males are three times more likely to be infected than females. An existing respiratory disease also makes the lungs more vulnerable to infection. Illnesses such as cancer, diabetes, kidney disease or alcoholism also weaken the body's natural defences. Heavy cigarette smoking increases the liability to infection because of the high probability of impaired lung function. There are also very special predisposing factors which would only normally occur in a hospital. These include the use of immuno-suppressant drugs designed to inhibit the body's natural defences, and renal dialysis.

Building services

Illustrative design temperatures for water services in buildings are shown in Fig. 13 (ref. 7). The risk associated with multiplication of legionella is also shown. In general, good engineering practices are adequate for all water services operating below 20°C and above 46°C. However, biocidal treatment is necessary in those services which do operate between 20°C and 46°C.

Let us examine the water services in order of increasing temperature.

Cold water supplies

The public supply is safe, but once the water enters a building then its temperature and residence time depend completely on the plumbing and the use of the building. Drinking water was shown to be the source of an outbreak at the Wadsworth Medical Center in Los Angeles, although the risk was uninfluenced by the amount of water drunk (ref. 24). The outbreak affected 22 people and was associated with a temporary drop in water pressure which resulted in a flow of brown water. Reproducing the pressure drop showed that the colour change was associated with a four- to thirty-fold increase in *L. pneumophila* concentration in the water. Hyperchlorination to 3 mg/litre free chlorine was followed by a marked decrease in cases.

Both hot and cold water supplies were implicated in a cluster of five cases at a hotel in Corby, England (ref. 25). Two cases in the same year were reported from a renal transplant unit in Oxford, England, associated with a

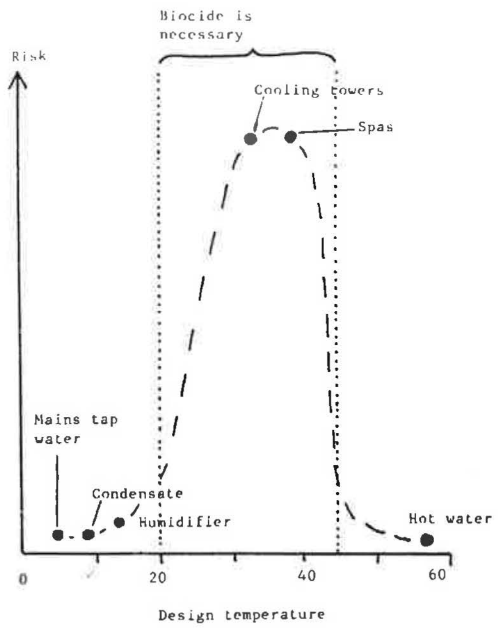


Fig. 13. The risk of multiplication of legionella varies with temperature

shower unit (ref. 26). The domestic water service was also implicated in a nosocomial outbreak of eleven cases at a hospital in Kingston upon Thames, England (ref. 27). Traces of legionella have been found in tap water (ref. 28).

Cooling coil condensate

In summer when the outdoor air is cooled it is normal for some dehumidification to occur. Droplets of water form on the cooling coil surface and drain away through a trap. Typical temperatures are 7°C and therefore too low for the multiplication of legionella. However, in winter, when cooling may not be required, it is possible for the condensate trap to dry out. If this point is upstream of the fan then contaminants can be drawn into the main air supply. Such traps should therefore be maintained full of water and for hospitals it is prudent to use clear glass traps so that the water level can readily be seen.

Spray humidifiers

In winter, when the outdoor water vapour pressure is low, water is added to the fresh air supply. There is a wide variety of methods of adding this water. While there has not yet been a legionellosis outbreak associated with humidifiers used in air conditioning, there have been many cases of humidifier fever, which is an allergic response to inhaling foreign protein. In sensitive applications such as hospital operating theatres, steam humidification is recommended because it is sterile. Direct spray humidifiers have fine spray nozzles which introduce moisture into the ductwork and any unevaporated water runs to drain. These are rarely a source of micro-organisms. However, the most popular and simplest type of humidifier is that which recirculates water and sprays it into the air stream. Such units operate around 15°C and also act as air washers. Draining the small pond each night and over the weekends when the main plant is not working is recommended. Regular cleaning is essential and biocides should not be introduced to the water during normal operation.

There have been legionella infections associated with droplet nebulizers and portable humidifiers, particularly when used in a hospital. Such small self-contained units often use a high-speed pump above a basin of water which generates an aerosol which in turn humidifies the room. Scrupulous cleanliness is needed and sterile water recommended (refs 28 and 29).

Cooling towers

When the refrigeration plant in a building extracts heat to cool the space this heat has to be rejected to the atmosphere. For small cooling loads (<200 kW thermal) this is achieved by refrigerant-to-air heat exchangers. For the large centralized plants serving office blocks the lowest initial cost system is an evaporative cooling tower. This is illustrated in Fig. 14. The heat from the condensing refrigerant heats up a circuit of recirculating water. This water is then distributed over a large surface area filler pack inside the tower. Air is drawn over this water. The latent heat of evaporation of some of the water provides cooling for the remainder. The water lost by evaporation is replaced by fresh water and from time to time the water is drained and replenished to avoid a build-up of salts.

Most towers operate at temperatures within the potentially dangerous multiplication zone for legionella. Biocide treatment is therefore essential. High-performance drift eliminators are also recommended to minimize the dispersal of water droplets. New designs have only 0.004% of the recirculating water lost as drift compared to 0.05% which is typical of earlier eliminator designs (ref. 30).

Field studies have shown that legionella can remain at high concentration in the sludge which forms naturally in the base of the tower. This concentration has been shown to be much more stable (10^7 to 10^8 per gram) than that within the recirculating water. The recirculating water had low concentrations of legionella in winter (10/ml) compared

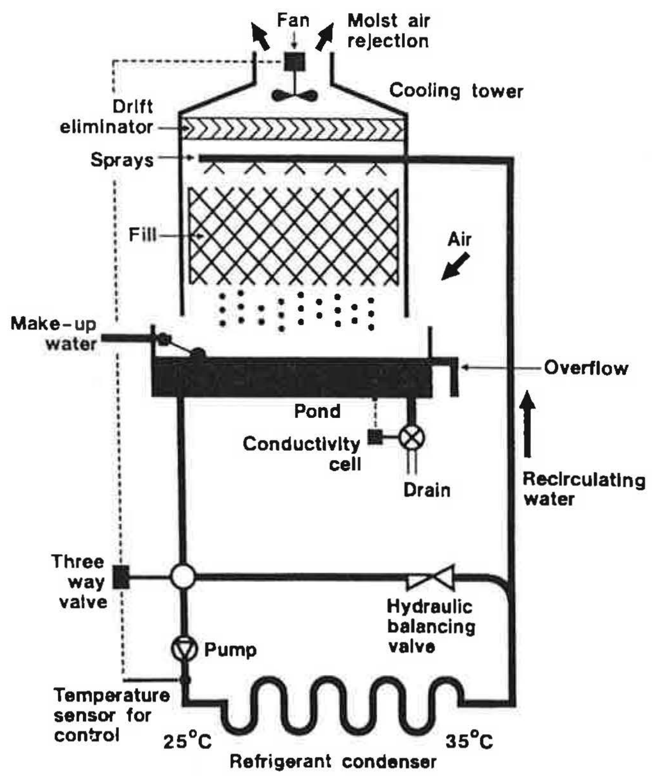


Fig. 14. Schematic outline of a cooling tower circuit

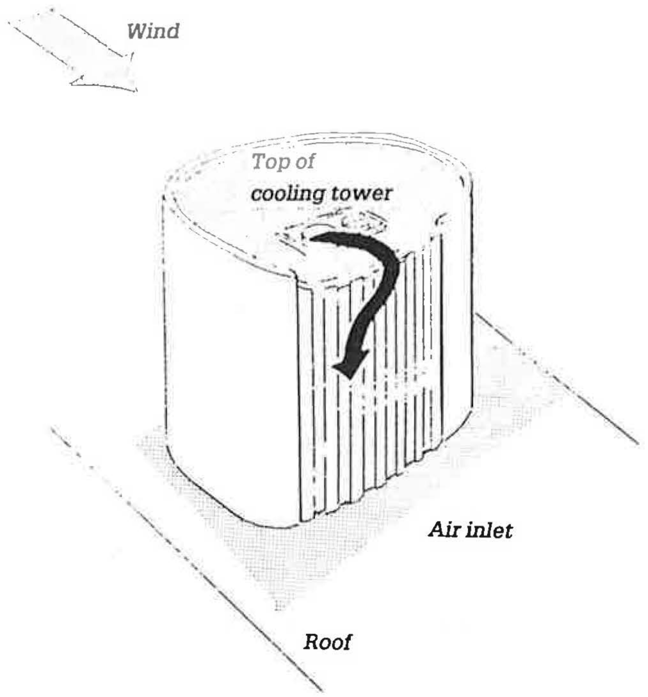


Fig. 15. Take care that cooling tower effluent does not enter the air inlet

with summer conditions of 10^4/ml (ref. 31). Legionella has also been found within amoebae, which may provide a much more protective screen against biocides (ref. 32).

Epidemics were linked at first to the close coupling of the cooling tower and the air inlet to the building (Fig. 15 and ref. 33). This would give the occupants a prolonged exposure to the organisms. However, more evidence suggests that very short exposure times may be sufficient for the most susceptible people to catch the disease. Two outbreaks totalling 85 cases at a large medical centre in Burlington, Vermont, USA, were linked to a contaminated cooling tower located 150 to 200 m from the hospital. The hospital did not have a tower of its own (ref. 34). Fifteen cases in Reading, England were linked to visits to the city centre shopping centre where four of the ten cooling towers present were shown to contain legionella (ref. 35). More recently an outbreak associated with the BBC office in London in 1988 confirmed 58 cases of legionella infection. Of these, 40 had not been in the building (ref. 36). One person was believed to have been some 500 m away from the contaminated tower.

Aerodynamic studies show the complexity of wind flow around buildings. However, for simple, solitary shapes, wind-tunnel experiments reveal a well-mixed eddy zone downstream of the building (Fig. 16).

Guidelines for hospitals in the UK suggest replacing the existing evaporative cooling towers by dry towers whenever the wet towers near the end of their useful life, and avoiding wet towers in new premises (ref. 37).

Guidelines for the maintenance and operation of cooling towers are now available (refs 7 and 38 to 41). Surveys have linked the concentration of legionella in water with increased concentration of dissolved solids and chlorides, higher water temperature, and with the higher conventional bacterial counts (ref. 42). There was no obvious link with corrosion. Brand-new offices have been implicated due to an operating malfunction (ref. 43).

Spas and whirlpools

Small, shallow hot-water spas, which hold typically four adults, are growing in popularity in health resorts, leisure centres and hotels. The water is between 32 and 40°C and is pulsated and aerated. The water recirculates through a filter and is chemically treated, usually with chlorination.

The small volume of water means that accurate and responsive continuous disinfection is essential and that the designed occupancy should not be exceeded. The disinfection procedure requires the pH to be controlled between 7.2 and 7.8 and preferably 7.4 to 7.6 to avoid irritation to the eyes, while the free chlorine is controlled between 3 and 5 ppm and never below 2 ppm. The combined chlorine concentration should be as low as possible and always less than 0.2 ppm. The demand for chlorine is high due to the high water temperature, the aeration and the variable organic load. Under heavy commercial use, a complete water change may be necessary each day (ref. 44).

In practice plant operators do not always manage to maintain these conditions. Dermatitis occasionally occurs

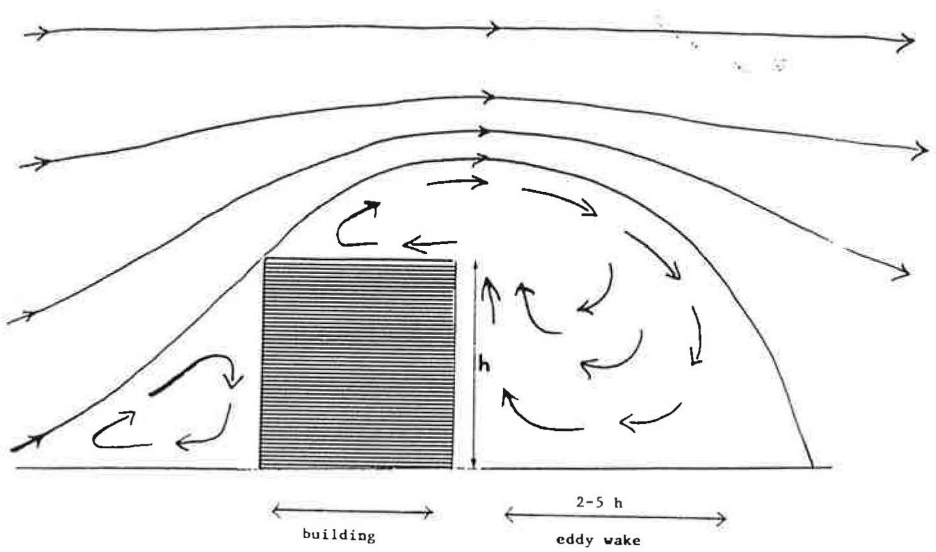


Fig. 16. Illustration of down-stream eddy wake from a building

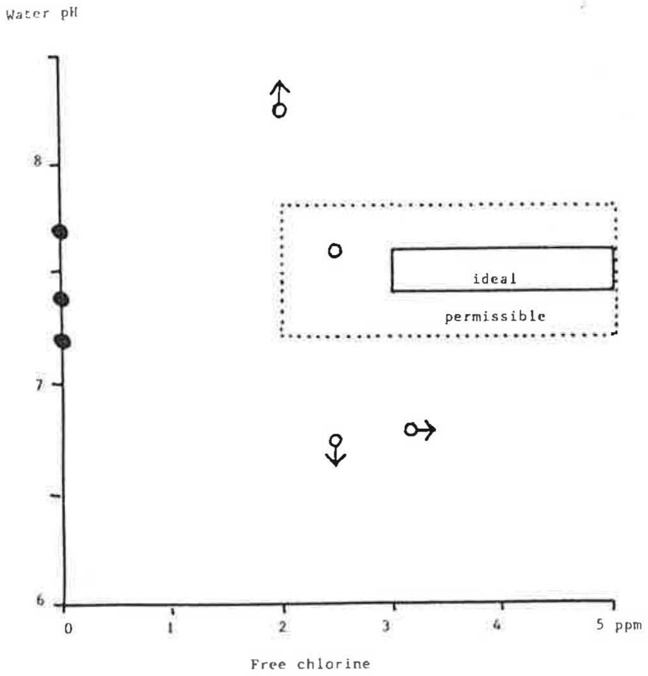


Fig. 17. Tests for the bacteria* Legionella pneumophila *in whirlpool spas (ref. 50)

o No legionella detected; • Legionella detected

and in recent years legionella has been cultured and epidemics linked to such spas. The rising and bursting bubbles concentrate organisms and create a fine aerosol some 0.5 m above the water surface, covering the normal breathing height for a spa occupant.

Pontiac fever has been reported from the United States (refs 45 to 47). Legionnaires' disease itself has been traced to a spa in a hotel in Brighton, England (ref. 48) and associated with two spas in the United States (ref. 49). Field survey data are rare but the Vermont Department of Health, USA carried out a routine epidemiological investigation in connection with a possible legionellosis outbreak at an inn (ref. 50). The survey included water from spas at the inn under suspicion and from six other neighbouring inns. Only one of the spas was operating within the recommended operating conditions and the water in three of them contained no free chlorine. *L. pneumophila* Sero Group I was detected in these three pools.

Scrupulous attention to proper operation and maintenance is essential, in particular regular cleaning of the filter and frequent pool-side monitoring of the actual chlorination and pH of the pool water.

A personal whirlpool is a bath fitted with high-velocity water jets and often air injection. The water is recirculated while the bath is in use and discharged to waste after each use. Modern systems are designed to drain all the water from the system. Such baths do not pose the same degree of hazard and no cases of legionnaires' disease have been reported. Care is needed to ensure that the concealed recirculating water piping is cleaned and disinfected regularly. Professional guidelines are available (refs 48 and 51).

Hot water services

Most hot water services in commercial premises appear to be slightly contaminated with legionella. Outbreaks are associated with hotels and hospitals with only an occasional case linked to domestic housing (ref. 52). The four factors which determine the risk are

- temperature
- materials of construction
- local obstruction to water flow
- operating regime.

Temperature is the most important factor because any residual free chlorine in the mains water supply rapidly disappears on heating. Most hot water systems provide a large heated storage vessel, called a calorifier, to cater for the wide variations in demand for hot water over the day. Electric elements, hot water or steam coils are provided within the vessel at approximately one-third of the way up the vessel. A thermostat is fitted near to the top of the calorifier. Water enters into the lower part of the vessel and is drawn from the top.

In practice the base of the calorifier is lukewarm, while the upper two-thirds of the vessel is up to design temperature. When water is drawn there is a lowering of the water temperature due to the incoming cold water. Surveys suggest that temperatures of 43 to 45°C permit the multiplication of legionella, while temperatures around 60°C prevent colonization, although higher temperatures are needed to eradicate the bacteria (ref. 53).

The water temperature will normally fall slightly along its distribution network. In large buildings the hot water network is usually recirculated to maintain temperature, although there are now techniques which use electric trace heated piping. All this pipework must maintain temperature above 46°C to avoid multiplication of legionella. There are special cases where lower temperatures are required at the point of use to avoid any risk of scalding. These include prisons, geriatric wards and paediatric centres, where the required maximum temperature is then 43°C. This is the highest temperature possible without risk of scalding (ref. 54).

The materials of construction of the pipework and components have been shown to be important (refs 9, 10, 55, 56). Laboratory experiments showed that few cells grew on a copper surface, a few more on stainless steel, some grew on aluminium and appeared cemented to the surface, while the worst growth was on rubber, where it was associated with slime. Occasional flushing dislodged some of this slime, richly contaminated with legionella, into the bulk water supply. This suggests that bulk sampling of the water may not provide an accurate picture of the degree of colonization if much of this colonization is attached to the hidden surfaces of piping.

Materials such as natural rubber, silicone tubing and plasticized PVC hose should be avoided unless they can be shown to be neutral both to toxicity tests and as a nutrient to micro-organisms. In the UK the Water Research Council specify a testing procedure (ref. 57).

One hospital survey associated with an outbreak found that while their calorifiers were contaminated with legionella, the bacteria could not be isolated from the piping or from taps but only from those parts which provided an obstruction to flow, such as a valve or a shower head (ref. 58). Operating patterns were also shown to influence the risk of legionella being present. The conventional operation was for the engineers to provide the hot water supply from any two calorifiers from the five present. The whole five were used on a monthly rota. They changed their procedures to isolate three of the calorifiers and operated on two continuously. The hot water leaving the calorifier was free from legionella, although it was subsequently found in a shower head.

One empirical method of assessing the risk factor associated with hot water supplies is to check ten sites, and if over 30% demonstrate the presence of legionella then there will be a high chance of legionella infection (ref. 59).

Instantaneous domestic water heaters are much smaller and are designed quite differently from the commercial calorifiers. While electric immersion heaters are immersed in the water, oil- or gas-fired heaters supply their heat through the wall of the water vessel. One Canadian survey in Quebec showed that the bases of 81% of electrically heated water heaters were contaminated with legionella, compared with only 6% of those heated by oil or gas. This is attributed to the method of applying the heat (ref. 60).

Miscellaneous water services

Special problems have arisen in industrial sites. An outbreak of Pontiac fever developed at a car assembly plant in Canada following a temporary closure of large sections of the building. The fever commenced two days after re-commencing work and affected all persons working in the vicinity of an oil/water coolant system used in the machining process. The incidence of attack reduced to 8% for those working furthest away from the coolant. A legionella-like organism was isolated from the coolant (ref. 61).

Vehicle-washing equipment, steam turbine condensers during cleaning and the cooling water for dental drills have all been considered as possible sources for airborne infection (refs 36 and 62).

Conclusions

- The infection route for legionnaires' disease is now clear and comprises four steps. Traces of legionella are likely to be present in most water services. The first step is to prevent the multiplication of the bacteria. The second is to minimize the amount of aerosol generated. The third is to minimize human exposure to the aerosol. The last step is to take particular care in those areas such as hospitals which contain susceptible persons.
- The major factor influencing multiplication is temperature and multiplication is expected between 20 and 45°C. This zone should be avoided or if this is not practicable, as in cooling towers, then some biocidal control technique should be used.
- The maintenance of city-centre cooling towers deserves special attention, now that the size of the downwind eddy recirculation zone is recognized.
- The operating conditions of whirlpool spas deserve special attention, because the small water volume means that the disinfection process may easily be overloaded if too many people use the spa at one time.
- The realization that colonization by legionella can take place on the walls and internal surfaces of pipes and tanks casts doubt on the results of analyses based on water samples. Cleaning techniques should aim to remove surface debris. Materials such as washers, gaskets and glands should not support microbiological growth.
- The best technique to minimize the risk of legionnaires' disease is to ensure that all the water services are operating as the designer intended with cold services operating at least below 20°C and if practicable below 15°C and with hot services always hotter than 46°C.

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