Efficacy of anti-Legionella treatments in situ: an investigation of the use of water-electrolysis and chlorine dioxide

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Abstract

Legionnaires’ disease, a pneumonia-like infection, arises from the presence of Legionella bacteria in water systems. Especially large hot water supply systems are recognised as a source for this disease. This paper presents the results of the monitoring of two treatments applied in existing buildings: continuous hyperchlorination using chlorine dioxide, in a hospital and electrolysis of the water in a hotel. These treatments show a certain effectivity. Their dependence upon numerous not yet controlled conditions makes them unreliable for the time being.

Keywords:
Hot water supply systems, Legionnaires’ disease, Legionella, hyperchlorination, chlorine dioxide, electrolysis of water.

1 Introduction

The Legionella bacteria cause Legionnaires’ disease (1), a severe form of pneumonia with mortality up to 20% (2). Susceptible individuals are infected by inhalation of droplets with a size between 3 and 5 micron (aerosol), containing the bacteria. In France, 13 cases of Legionnaires’ disease were reported per 1 million of inhabitants in 2001 (3). This figure is however considered largely underestimated.

Although this bacterium is widespread in all kinds of aquatic environments, the hot water system is actually considered as the primary reservoir for the Legionnaires’ disease (4). This building water system provides suitable conditions for growth: adequate growth temperatures (refer to figure 1), nutrients in the form of corrosion products (iron), sediments and slime layers (biofilm). The sediment and the biofilm, as well as the presence of scale, offer also a protective niche for many microorganisms, including Legionella.
The sensitivity of the bacterium for heat provides in fact a means for its eradication: it suffices to maintain all the time the temperature above 50°C in each point of the system, to avoid the contamination. Although this temperature-means seems to be quite simple to implement in a hot water system, one must take into account the fact that the necessary meticulous application is not possible in many existing installations without changing them considerably. The main reasons for this are:

- The fact that due to considerations of rational use of energy, hot water systems were designed, the last 30 years, to produce and distribute hot water at temperatures below 50°C – in many cases at only 45°C-, so that a temperature of at least 50°C in each point of the distribution pipework can never be reached without changing the heating appliance.
- The fact that the hot water distribution loops were never designed nor equipped correctly: pumps were not calculated taking into account the heat losses, pipes were not insulated in order to limit adequately the heat losses, sub-loops not equipped with valves allowing the hydraulic equilibration of the system…As such it is impossible to realise a good circulation in all sub-loops so that the temperature decrease between the beginning and the return remains limited to 5°C.

The changes to be made to the very great majority of the existing installations are so important and costly, and do have such a great impact on the working conditions of the building (eg changing the pipework in an hospital is difficult without closing the concerned departments), that there is a great search for other measures than thermal disinfection to control the Legionella-problem. Actually different techniques are hereto used, between which the following continuous disinfection techniques:
• The ionisation of copper and silver ions into the water, creating concentrations of respectively 0.2 to 0.4 ppm and 0.02 to 0.04 ppm. In contact with the cell wall of the Legionella bacteria, these ions modify the electrochemical processes of the cell, leading to the death of the microorganism (6).

• The irradiation of the water by ultraviolet light with a wavelength of 254 nm, creating a radiant exposure of about 400 J/m². This dose UVc radiation damages the DNA of the Legionella, blocking the reproduction of the microorganism (7).

• The use of ozone. Ozone is a powerful oxidizing agent, which can inactivate the enzymes of microorganisms (5). As these enzymes are responsible for the multiplication of the cell, their inactivation leads to the killing of the cell itself. Ozone concentrations of 1 to 2 ppm, showed to be effective in eradicating Legionella from water systems (7).

• Chlorination of the water, using for instance chlorine dioxide. Also chlorine dioxide is an oxidizing agent with an effect comparable to that of ozone (5). In laboratory conditions, it showed to be effective against Legionella in concentrations up to 0.4 ppm (8).

• The electrolysis of the water where the passage of an electrical current decomposes the complex solution, which is drinking water, into different active radicals, like: hypochlorite, oxygen and low quantities of ozone and hydrogen peroxide. The intensity of the current is regulated so that the free chlorine lies between 0.1 and 0.3 mg per litre water. In order to be able to reach these concentrations, the chloride concentration in the untreated water must be > 20mg/l, otherwise a brine solution (NaCl) has to be added to the water.

The Belgian Building Research Institute (BBRI) had the opportunity to monitor in situ these last two techniques, for 2 years (2001-2002), in the context of a research conducted with the financial aid of the Belgian federal and regional institutions. The results of this monitoring are presented hereafter. It has to be noticed that the manufacturers, without any interference of BBRI, defined the working conditions of the treatments.

2 Disinfection of a hospital hot water system using chlorine dioxide.

2.1 Description of the hospital and its hot water services

The hospital has about 632 beds spread over 15 buildings, representing a total usable surface of 100,000 m². These different buildings are scattered over a site of 170,000 m² of trapezoidal form, with a diagonal length of about 1 km. The construction of the hospital started in 1914 and the inauguration was in 1923. Within the lifetime of the buildings, the distribution systems for drinking water and for sanitary hot water (both having kilometres of pipe), were modified several times. The result is a mix of lead, steel and galvanised steel pipes.

The hot water is produced in a central boiler room. After injection of a corrosion inhibitor, the cold softened water (7 French degrees residual hardness) is first preheated on its passage through 3 hot water tanks. These tanks are placed in series and heated by the energy recuperated from the fumes of the boilers. An instantaneous heat exchanger brings the water to its setting temperature of 55°C (refer to figure 2). Between 850 and 1000 m³ of hot water are consumed monthly.
The hot water is distributed to the different buildings through 4 loops. Each of these 4 loops having a multitude of sub-loops. The pipes are not thermally insulated so that the temperature is around 30°C at some points.

2.2 The anti-Legionella treatment

In July 2000 it became clear that the hospital had a Legionella problem: they were confronted with cases of legionnaires’ disease and the water showed in certain points Legionella-concentrations up to 2000 CFU/l.

Given the impossibility to modify -in a short term- the hot water distribution, in order to fight against the Legionella by rising in all points the water temperature to at least 50°C, it was decided to install an anti-Legionella treatment based on chlorine dioxide (ClO2). The treatment was put in place on 2000.10.23. The chlorine dioxide being generated within the cold water, by mixing two different chemicals in a vortex chamber: a solution of sodium chlorite and sodium hypochlorite in water on one side and a solution of hydrogen chloride, chlorine and phosphorous pentoxide on the other side. A feed pump, steered by a flow meter, injects each component in a vortex chamber where they are mixed with the water (refer to figure 3).

**Figure 2 – Hospital: hot water production**

The hot water is distributed to the different buildings through 4 loops. Each of these 4 loops having a multitude of sub-loops. The pipes are not thermally insulated so that the temperature is around 30°C at some points.
Initially the ClO2 injection was regulated in order to obtain a level of active products (chlorine dioxide, chlorite and chlorate) up to 1.4 ppm, measured as equivalent chlorine dioxide, in the water just after injection—regulation and measurement by the manufacturer of the treatment-. This concentration was considered to be quite high given the fact the UK regulations allow the use of ClO2 as long as the combined concentration of chlorine dioxide, chlorite and chlorate, does not exceed 0.5 ppm. But given the presumed presence of an important quantity of organic material, in the form of deposits and biofilms, it was to be expected that at the taps, the concentration would remain well below the 0.5 ppm. This presumption was confirmed by the fact that even after 6 months, no ClO2 could be measured at the taps in the buildings with patients. This “high” concentration did even increase the Legionella counts in the water at the taps (see below §2.4). This brought the owner of the installation to request to implement a very high level of product for 2 months, ie during the months May and June, the ClO2 level was brought up to about 6 ppm. At the end of June 2001 the level was then lowered to 3 ppm equivalent chlorine dioxide, till the end of the monitoring (mid March 2002). After the period with very high concentrations Chlorine dioxide could be measured at the distant hot water taps (see figure 4).
Important to notice is that the ClO2 injection was started without any preliminary other disinfection measure.

Figure 4 - Hospital: ClO2 concentrations at the taps

![Hospital: ClO2 Concentration at the taps](image)

**Figure 5 – Evolution of the mean Legionella contamination in the hospital water**


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2.3 The evolution of the Legionella counts in water

The hot water taken at 10 different points was analysed 8 times between 2000.07.31 and 2002.03.02. The determination of the presence of Legionella-bacteria in the water samples of 1 l, taken 1 minute after opening the tap, was done according to the procedure of ISO 1171 (9). The mean results of these analyses are presented in figure 5.

2.4 Comments

It is clear that in the months following the placement of the treatment, with an equivalent chlorine dioxide level up to 1.14 ppm, the Legionella contamination did not decrease. It is obvious that is due the complete consumption of the biocide by the inevitable organic deposits (biofilm) in the piping. Although this was - to a certain extend - awaited, it was however not expected that after six months (April 2001), there would still not be an improvement of the Legionella situation. This lead to the decision to rise drastically the ClO2 concentration for 2 months. After this shock treatment the Legionella values (August 2001) were better than those of before. In December 2001 one could say that the contamination was nearly eradicated. This situation was confirmed by the results of March, although there was a slight increase, which makes us to believe that the situation is still not yet fully under control: one must fear that after the shock-treatment of May and June, the biomass was not completely killed and is maybe restoring slowly its population, leading to the return of the Legionella-problem, although the still very high biocide levels.

2.5 Conclusion

The application of a ClO2 anti-Legionella treatment on a large contaminated system, presenting a huge biofilm, without preliminary disinfection, does not lead to an immediate reduction of the Legionella contamination even in concentrations up to more than 2 times the legal UK values (0.5 ppm). On the contrary, an increase of the Legionella-counts in water could be observed, even after 6 months of treatment.

Rising the ClO2 concentration up to 12 times the legal level in the UK, ie to 6 ppm of ClO2 equivalent, for a period of 2 months, coming then back to a concentration of 3 ppm, resulted in a gradual decrease, so that 1 year after the installation of the treatment the nearly eradication of the Legionella contamination was observed. However, after 3 months a very slight increase in Legionella concentration, might indicate that the adopted ClO2 level is still not sufficient.

Within the concentration (0.05 ppm) specified in the UK for water to supplied for drinking, washing, cooking or food production processes, the actual ClO2 treatment is not appropriate for reducing a Legionella contamination in existing installations with organic deposits. In these installations one must reckon with a period of several months with active biocide levels up to 12 times the UK levels, going then afterwards down to levels which have still to be considered as not potable: >3 ppm. In the given pipe conditions the use of this biocide is thus only to be considered for water systems were there is absolute sureness that the water will not be used for drinking. Anyhow there obviously still a lack of good understanding of the conditions in which the treatment can operate effectively. This treatment remains thus risk full to apply in this stage.
3 The disinfection of a hotel hot water system by an electrolysis treatment

3.1 Description of the hotel and its hot water services

The hotel, situated in the countryside, was constructed in 1986. It has 200, in great majority, double rooms divided over 5 floors. This hotel is mainly a family pension, with a high occupation in weekends and school holiday periods.

The hot water production is centralised in the fireplace. The hot water for the kitchen is produced by two hot water tanks of 2000 l placed in parallel (refer to figure 6). These tanks are heated by a heat exchanger connected to a boiler.

The hot water for the rooms and the laundry is produced by two other hot water tanks of 3000 l placed in parallel (see figure 6) and also heated by a heat exchanger, connected to the same boiler as the one for the kitchen. The water in the bottom of these tanks is extracted by a pump and fed to a preheating boiler heated by the water of the condenser of the air-conditioning.

Three loops with pump circulation distribute the hot water to the rooms (refer to figure 7). Each loop comprises horizontal pipes on which vertical several sub-loops are connected.

These vertical loops serve on each level 2 adjacent rooms. The distribution pipes are in copper.

3.2 The “electrolysis” anti-Legionella treatment

In June 1999 the hotel was confronted with 8 cases of Legionnaires’ disease, which were linked to the presence of Legionella bacteria in the hot water system: Legionella concentrations up to 10^6 CFU/l were detected in the water. The reasons for this contamination were multiple: a production and distribution of the water at too low temperatures, stagnation of the cold water in a huge buffer tank, preheating of the return water by the energy recuperation on the air-conditioning (maximum temperature of 35°C), lack of maintenance,… Immediately after this outbreak –end of June- a shock thermal disinfection was executed: all taps were rinsed during 4 minutes with water at minimum 70°C. This disinfection lead to a certain number of problems:

- Some drainage pipes collapsed as they were not high temperature resistant, leading to water damage in different hotel rooms.
- A thermal dilation devices became leaky and had to be replaced.

It must also be noted that the realisation of the disinfection was quite costly: the hotel had to be closed for 2 days and the disinfection itself required 10 man days of high skilled technicians. Anyhow, this action reduced the presence of Legionella below the detection level.
1: cold water supply  
2: hot water tanks for the rooms  
3: hot water distribution loops  
4: anti-legionella treatment  
5: hot water preheating on chiller of airconditioning  
6: hot water production and distribution for kitchen

**Figure 6 – Hotel: hot water production**
Figure 7: Hotel: hot water distribution loops
Afterwards the temperature of the water was set at 60°C in the hot water tanks and a scheme of monthly analysis of the water was set up. This scheme showed that in September 1999, one of the points checked on Legionella was lightly positive for: 20 CFU/l. This situation remained unchanged till February 2000, when suddenly Legionella concentrations were detected over $10^3$ on most points and up to $10^4$ in some. This made necessary to redo a thermal disinfection, which again gave rise to many considerable water problems. These problems and the cost related to the thermal disinfection lead the owners to decide to install an anti-Legionella treatment based upon the electrolysis of the water. It became operational on 2000.07.12, immediately after another thermal desinfection. The treatment was placed in by-pass on the pipes leading the water from the tanks to the distribution system (figure 6).

**Figure 8 – Hotel: electrolysis anti-Legionella treatment**

1: regulation  
2: electrolysis cell  
3: device for measuring free chlorine  
4: sampler of treated water  
5: sampler for un-treated water  
6: flow rate controller  
7: conductivity sensor  
8: temperature sensor  
9: rinsing pipe  
10: bleed possibility  
11: pump  
12: brine solution (NaCl+H2O)
Part of the water leaving the tanks is lead over the treatment (figure 8). In function of the free chlorine present in this water, and in the water fed to distribution system, the electrical tension and current of the electrolysis cell are so regulated that the mix of by-pass water with the rest of the water, provides a concentration remaining between 0.1 and 0.3 mg of free chlorine per litre of water. The temperature of the water was set at 55°C at the outlet of the hot water tanks.

3.3 The evolution of the Legionella counts in the hot water with the electrolysis treatment

At different dates, during one year, hot water samples were taken at the showers in representative rooms and analysed on the presence of Legionella. The results of these analyses are presented in figure 9, which shows the mean value and the maximum value of the counts for two modes of sampling:

- Water samples of 1 l taken directly when the shower tap is opened: “direct samples”. These samples are indicative for the quality of the pipes immediately before the tap point.
- Samples of 1 l take one minute after opening the tap: “1 minute samples”. These samples are indicative of the water in the main distribution pipes.

Because the “chiller” tank in the hot water production (refer to figure 6), was considered as a zone with a high risk for Legionella development, direct water samples were also taken at the bottom of this tank. The results of these analyses are represented in figure 10.

![Figure 8 – Hotel: Legionella counts in the rooms](image)
3.4 Comments

The detection level of the method for the Legionella counts is 50 CFU/l. The Legionella counts identified in the water in the first months after the installation of the treatment (mean 65, max 130) can thus be considered as low.

Important to know is that in the last week of April 2001, two cases of Legionnaires’ disease were recorded in the hotel. After investigation, it became clear that the treatment had been malfunctioning since only a few days before the outbreak.

The values for the chiller, even 6 months after the treatment became in operation, remained extremely high, indicating that the biocide could not reach the bottom of this tank. This is why at the end of January 2001, it was decided to implement a managerial measure, which consisted in draining off, twice a week for 10 minutes, the bottom of the chiller tank. This measure seemed to be effective.

3.5 Conclusion

From the Legionella counts on the taps on the rooms it is clear that as long as the system is operational, the treatment is effective in reducing the contamination, given the fact that the system had been disinfected previously.

The outbreak of Legionnaires’ disease, after the treatment became inoperative for only a few days, maybe a week, indicates that:

- this kind of treatment has no remanent effect
- the biofilm is probably not completely destroyed and is able to recover so quickly that within a few days a dangerous situation can occur.

This conclusion implies that these treatments must be controlled very closely and the organisation behind it must be able, in case of troubles, to diagnose and intervene within a delay probably not longer than 48 hours.
The problem of the remaining high contamination in the chiller, indicates that the treatment can only be effective in case the biocide reaches in a sufficient concentration each point to be disinfected. This conclusion underlines:

- that a biocide treatment can never eliminate the contamination of death legs, which remain a potential source for recontamination in case the treatment malfunctions
- that in case there is no certainty that all tap points will used regularly, the installation of the treatment has to be completed with managerial measures, implementing for instance a systematic (daily)draining off of the unused tap points.

4 General conclusion

This study showed that there is evidence that anti-Legionella treatments like chlorination with chlorine dioxide and electrolysis of the water, can have an effect on this bacterial contamination.

However, the efficacy of these treatments depends largely upon an important number of boundary conditions, between which:

- the state of purity of the system on which they are applied
- the way in which the hot water system is used
- the level of control of the system and of its treatment
- the level of organisation of the maintenance services
- the extend of knowledge behind the treatment (in which conditions is the technique efficient, in which not?).

From the monitoring of the two systems referred to above, it is obvious that most of these conditions are not correctly assessed for the time being. This leads to a dangerous situation where no guarantee can be given upon the efficacy of a treatment, even if the treatment has proven to be effective. It seems that a successful implementation of anti-Legionella treatments requires imperatively the setting up of a certification scheme allowing to guarantee a minimum level of quality.

5 Symbols and abbreviations

- CFU/l : Colony forming units per litre
- ClO2 : Chlorine dioxide
- J/m² : Joule per square meter
- ppm : Parts per million
6 References


(9) … ISO 11731 Water Quality – detection and enumeration of Legionella.

7 Main author presentation

Karel DE CUYPER is head of the division Building Services of the Belgian Building Research Institute. Since the early nineties, he conducts research on the effect of the hot water system parameters on the Legionella contamination. He is a member of the Legionella working group of the Belgian Health Council.