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LEGIONELLA PREVENTION PLAN IN WATER SYSTEMS AND ITS ENERGETIC CONSEQUENCES

SPOSÓB OCHRONY PRZED BAKTERIAMI LEGIONELLA SYSTEMÓW WODNYCH I JEGO KONSEKWENCJE ENERGETYCZNE

A b s t r a c t

Sporadic cases of Legionnaires' disease continue to occur. Undoubtedly, a considerable number of people have impaired defence against such bacterial infections, and the medical care has recently improved in such a considerable degree that the case-fatality ratio is very low nowadays. Nevertheless, the presence of *Legionella pneumophila* in hot and cold water systems operating in buildings is to be expected. The subject of the paper is the investigation of the Legionella hot water contamination as conducted in a cross-sectional survey in Kosice. The eradication measures based on a chemical, thermal or combined method, usually have a short-term effect (1–2 months), and therefore it is necessary to support them by a system of operating, technical and/or construction measures, the most significant of which is the adjustment of PHW distribution system, maintaining PHW temperature up to 55°C and daily preheating up to 60°C, as well as providing thermal disinfection twice a week at temperature ≥ 70°C.

Keywords: *legionella pneumophila, hot water, thermal disinfection, energy consumption*

S t r e s z c z e n i e

Sporadyczne przypadki występowania choroby legionistów wciąż się zdarzają. Chociaż wiele ludzi ma upośledzoną zdolność obrony przed tymi bakteriami, to jednak wyższy standard opieki medycznej sprawił, że poziom zachorowań jest obecnie bardzo niski. Należy się jednak stale spodziewać obecności bakterii typu legionella w instalacjach wody ciepłej i zimnej. Przedmiotem artykułu są badania skażenia instalacji ciepłej wody bakteriami *Legionella* prowadzone na terenie Koszyc. Sposoby usuwania skażenia polegające na stosowaniu środków chemicznych, wysokiej temperatury lub łączone mają zwykle skutki krótkotrwałe (1–2 miesiące), dlatego też istotne jest opracowanie systemu stałego odkażania instalacji.

Słowa kluczowe: *legionella pneumophila, ciepła woda, dezynfekcja termiczna, zużycie energii*

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Denotations

PWH – potable water hot
CPWH – circulation of potable water hot
PWC – potable water cold
EWGLI – European working group for legionella illness
US CDC – Center for Disease Control and Prevention
DVGW – Deutscher Verein des Gas und Wasserfaches

1. Introduction

Since mid July 2008, 175 people have been hospitalised due to a pneumonia outbreak in the Urals region of Russia. A total of 150 have been diagnosed with Legionnaires' disease, 66 of which were confirmed by laboratory tests. At least four people have died. The start-up of hot water supply following a lengthy shutdown for maintenance is believed to have caused the outbreak. Most apartment buildings in Russia receive hot water from thermal plants rather than from water heaters within buildings. The hot water supplies are typically shut down for a few weeks each summer for maintenance.

1.1. Legionella background

The first evidence of the association between water used for human consumption and nosocomial legionellosis was reported more than 20 years ago [2], whereas a hot water system is thought to be the most frequent source of the outbreaks in a hospital [3], where patients may be exposed to a higher risk of a severe infection [4]. Relatively little is known about sporadically occurring cases of community-acquired legionellosis, which accounts for most infections [5], although the correlation analyses suggest that a substantial proportion of these cases may be residentially acquired and associated with the bacteria existing in a hot water distribution system. Absolute exclusion of these particular types of bacteria from water systems within buildings may not be possible, or necessary. The disease outbreaks generally occur when the bacteria concentration in water systems are high enough to produce aerosol. Therefore, one should aim at minimising the possibility for infectious doses production resulting from the operation of water systems. It seems vital to take appropriate protective measures against conditions which may encourage Legionella multiplication.

Legionella occurs commonly in a natural water environment, in potable water artificial systems and in all systems connected to the potable water supply and distribution network. The disinfection efficiency directly depends on the technical condition of the potable water distribution system, especially respect to hot water. It is mainly a question of fittings and pipes condition, corrosion, incrustation, sludge occurrence as well the regulation of hot and cold water distribution considering temperature and pressure conditions.

The key factor in the possible development of Legionella bacteria in tap water systems is the design and operation of the system. It is commonly known that Legionella thrives in water that is insufficiently flushed, and which is allowed to remain stagnant for too long within the critical temperature range (20ºC to 45ºC). Regular, thorough flushing at 60ºC

or above permanently reduces the Legionella growth. The criteria for the design, operation and maintenance of tap water systems, aiming at the Legionella growth avoidance, are consistently reflected in guidelines and regulations developed in many countries. An overview has recently been published by the European Working Group [9]. The increasing number of cases is presented in Fig. 1.

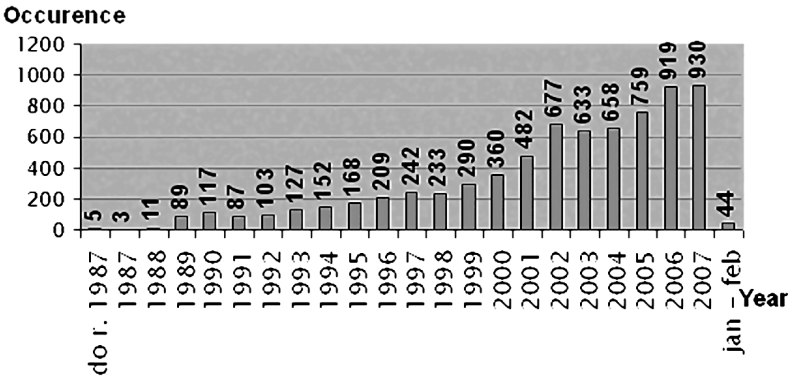

Fig. 1. Cases of Legionellosis by year of Onset (according EWGLI)
Rys. 1. Przypadki zachorowań na chorobę legionistów od momentu jej wystąpienia (wg EWGLI)

1.1.1. Chain of causation

The chain of causation that must exist for Legionnaires' disease to be acquired, involves:

- an environmental reservoir – naturally occurring,
- opportunity for multiplication – stagnation, temperature increase above ambient, nutrients,
- a mechanism for dissemination – devices generating aerosols,
- virulence of the organism – not all strains affect humans,
- inoculation of an infectious dose – inhalation,
- some people are more susceptible than others.

This chain must be broken to ensure a system is safe.

2. Thermal disinfection

WHO, 1996, Health criteria, Vol. 2, as well as EN 806 in force recommends to operate PWH at temperature above 60°C as one of the measures leading to legionella prevention in a potable water distribution network. The subject matter is a periodic temperature increase during a specific period of time in the whole potable hot water (PWH) network including outlet points with a certain time of flushing these points at an increased temperature. The temperature level and the time of flushing the outlet points are crucial.

US CDC (Center for Disease Control and Prevention) recommends thermal disinfection at 71°C (160°F) by flushing network outlets for 5 minutes. The original method design considered 30 minutes flushing, which is financially and technically very difficult, although

very efficient – positivity percentage decreased to zero. As the method's name – "Superheat and flush" indicates, it is essential to follow the recommended temperature level and time of the network outlets' flushing. The effect is short-lasting and must be repeated periodically to avoid the re-colonisation of legionella.

In practice, there are also other thermal disinfection procedures performed, e.g. periodical temperature increasing in PWH systems above 70°C with ten-minute network outlets' flushing with water above 60°C. This process decreases the percentage of network outlets' positivity to zero and the contamination recovery percentage to the previous level within 30 up to 60 days [10].

The German document DVGW (Deutscher Verein des Gas- und Wasserfaches) W 551 and W 552 states that operating and technical measures in potable water distribution systems lead to successful results, unless the water temperature in a whole system falls below 55°C. Pre-heating systems must be heated up to 60°C once a day, periodically (e.g. once a week) thermally disinfected, i.e. the heaters must be set at the temperature above 70°C so that the 70°C hot water flows out of network outlets for a minimum of 3 minutes.

The system of "self-regulating trace heating elements" represents a technical solution for controlling bacterial colonisation at network outlets (mixing faucets, shower roses, etc.). Keeping a constant temperature of 50±1,5°C at these outlet points is recommended even if the temperature in a circulation pipeline decreases to 45°C (this should not occur in adjusted systems – although practice proves the opposite).

For Slovakia, a barrier to effective thermal disinfection is the old national legislation, e.g. STN 83 0616 – quality of hot service water standardises PWH temperature in the range of 45 up to 60 °C, which means that PWH distribution systems do not have to be sized for temperatures above 70 °C.

2.1. Optimal factors influencing legionella spread

The most frequently mentioned factors influencing legionella spread are as follows:

- temperature – optimum range of 20–45°C,
- circulation – usage of unsuitable circulation pumps with lower water capacity causes insufficient temperature difference between taking points. The system start-up time for obtaining a required hot water temperature extends, the system circulation limitation occurs, water even stagnates,
- system adjustment – the start-up time for hot water to obtain the constant temperature should be 30 seconds, while the temperature differences between the endmost PHW system outlets on the same floor at the same HW heating supply should be maximum 3°C after 30 seconds of full water flow. At the same time, the circulation water temperature must not fall at the supply by more than 5°C against the supply outlet temperature.

2.2. Hot Water Adjustment Influence on Legionella Elimination

Adjusted systems satisfy certain thermal and pressure features providing disinfection spreading (e.g. thermal disinfection) into all points of a distribution network at a certain period of time, namely concentration depending on time. In the areas of distribution network beyond the disinfection reach, a contamination source remains, which a new

contamination spreads from. Non-adjusted distribution systems do not provide disinfection neither for a required period of time, nor of a required quality. Such systems lead to fast spreading of legionella in distribution systems. Long-term monitoring shows that legionella contamination regenerates very quickly, usually after 1–2 months.

3. Energy consumption at thermal disinfection

The model circuit of the heat exchanger unit (Fig. 2) is defined by the following data:
– 700 flats,
– 1 × 10 m^3 hot water reservoir in the heat exchanger,
– water volume in the system of flats – 10,4 m^3,
– water volume in the distribution network 24 m^3.

There will be three operating conditions of the system under observation in a period of time with no hot water usage – approximately at 3 a.m.:

1. Only the hot water reservoir heated.
2. Adjusted with measuring modules with exchangers connected at inlets into facilities.
3. Non-adjusted with a direct connection between the supply and flats – with no heat exchanger at the facility inlet.

There will be the following heat demand for hot water heating

$$Q_{\mathrm{HW},d} = \frac{\rho \cdot c \cdot V_{2p}(t_2 - t_1)}{3600} \tag{1}$$

$$E_{\mathrm{HW}} = (1 + z)\, Q_{\mathrm{HW},d}. + 0.8 \cdot ((t_2 - t_{\mathrm{cw.summer}})/(t_2 - t_{\mathrm{cw.winter}})) \cdot N \quad [\mathrm{GJ/year}] \tag{2}$$

where:

$Q_{\mathrm{HW},d}$ – daily heat demand for hot water heating [kWh],
t_2 – water temperature at heater outlet [°C],
t_1 – water temperature at heater inlet [°C],
$t_{\mathrm{cw,summer}}$ – cold water temperature in summer [°C],
$t_{\mathrm{cw,winter}}$ – cold water temperature in winter [°C],
N – number of HW system working days in a year,
V_{2p} – total hot water consumption per day [m^3/day] (for residential buildings the assumed amount is 0.082 m^3/person a day, and the minimum of 0.2 m^3/flat a day),
z – coefficient of the system energy losses for hot water preparation (for common buildings we consider the value of 50 up to 100% according to the distribution variant and time of circulation, distributions in new buildings max 0.5, area distributions max 1.0, distributions in older buildings z = 2 – 4),
ρ – specific weight of water, i.e.1000 [kg/m^3],
c – specific heat capacity of water, i.e. 4186 [J/kgK].

Considering the following thermal conditions in the heat supply in time depending on thermal disinfection, we obtain the following balances for the specific hot water supply circuit. The input data are as follows – heat volume for hot water heating for a whole year with no thermal disinfection for 700 flats. E_{HW} upon heating 55–10°C and volume V_{2p} =140 m^3 = 12345 GJ/year = 3429,2 MWh/year.

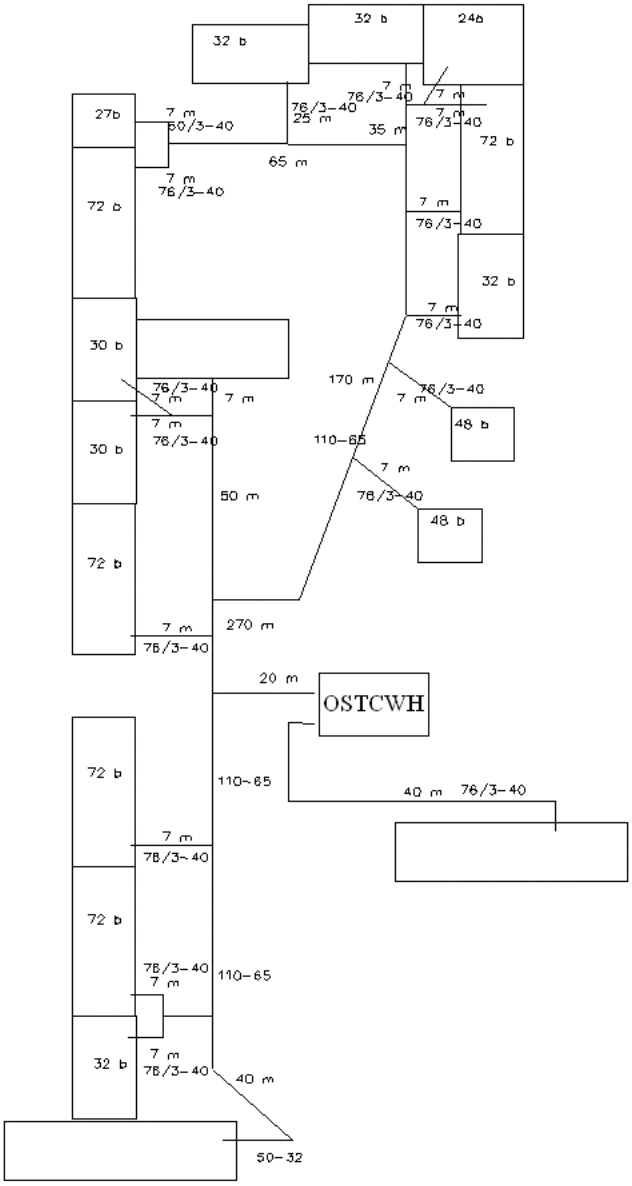

Fig. 2. Model circuit according to the real heat exchanger station in Kosice
Rys. 2. Schemat instalacji w stacji wymienników w Koszycach

3.1. Hot water reservoir

Upon reservoir heating in a period with no take-off to 60°C – for a period of 20 minutes twice a week – 224.4 GJ/year = 62.3 MWh/year 1.8% increase.

Upon reservoir heating in a period with no take-off to 65°C – for a period of 10 minutes twice a week – 252.6 GJ/year = 70.2 MWh/year 2.04% increase.

Upon reservoir heating in a period with no take-off to 70°C – for a period of 5 minutes twice a week – 263.3 GJ/year = 74.0 MWh/year 2.13% increase.

3.2. Adjusted with measuring modules with exchangers connected at facilities inlets – water volume in the network up to facilities footings

Heating in a period with no take-off to 60°C – for a period of 20 minutes twice a week – 488.0 GJ/year = 135.7 MWh/year 3.95% increase.

Heating in a period with no take-off to 65°C – for a period of 10 minutes twice a week – 515.0 GJ/year = 143.2 MWh/year 4.17% increase.

Heating in a period with no take-off to 70°C – for a period of 5 minutes twice a week – 543.2 GJ/year = 150.9 MWh/year 4.4% increase.

3.3. Non-adjusted with a direct connection from the supply up to rising pipes in facilities – with no exchanger at an inlet

Heating in a period with no take-off to 60°C – for a period of 20 minutes twice a week – 813.0 GJ/year = 226.1 MWh/year 6.58% increase.

Heating in a period with no take-off to 65°C – for a period of 10 minutes twice a week – 859.3 GJ/year = 238.7 MWh/year 6.96% increase.

Heating in a period with no take-off to 70°C – for a period of 5 minutes twice a week – 905.3 GJ/year = 251.5 MWh/year 7.33% increase.

3.4. Energy analysis results

The increase of heat demand for thermal disinfection lies in the area of the design values which we shall try to compare with real ones within our future research project. The values are determined only under the defined input conditions mentioned in the model building submission. The efficiency and reliability of the adjusted and non-adjusted HW systems, that would definitely improve the balance in favour of the adjusted circuit, are not under the observation. Neither is herein considered the piping incrustation that does not affects the system efficiency even in the smallest degree.

The most acceptable system is the one adjusted with measuring modules with exchangers connected at facilities inlets – water volume in the network up to the facility footing (the 2nd condition).

Heating in a period with no take-off to 60°C – for a period of 20 minutes twice a week – 488.0 GJ/year = 135.7 MWh/year; 3.95% pre-heating increase, the CPWH circuit distribution network.

4. Conclusions

- Legionella infection sources occur in the technical background, mainly in potable water plumbings and directly continuing distributions.
- Decrease in infection risk can be possibly achieved only by a massive reduction of legionella quantity in water.
- Fixation of the system contamination leads to a significant local contamination reduction.
- The aim is to reduce legionella content values to the level of their natural occurrence in cold water.
- It is required to support **disinfection efficiency** by appropriate technical and operating measures.
- The most frequent eradication method is **thermal disinfection** combined with some of chemical methods, e.g. Ag/Cu ionization or hyperchloration, ClO_2 application or UV radiation are also perspective.
- In order to decrease the legionella risk it is required to keep HW temperature above 50, (55°C).
- To provide efficient disinfection and a long-term effect thereof, water distribution systems should be adjusted as to the temperature and pressure.

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