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RISK MANAGEMENT METHODS IN HOT WATER DISTRIBUTION SYSTEMS TO NEGATE HEALTH RISKS FROM MICROBIOLOGICAL CONTAMINATION

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Abstract. Water distribution systems are exposed to a number of risks, i.e. hazards and hazardous events that may result in bad drinking water quality. Microbiological contamination due to e.g. source water contamination, insufficient treatment; backflow and ingress results in a number of annual outbreaks of illnesses in Europe and other countries. In addition to faecally borne pathogens, other microbial hazards (e.g.; toxic cyanobacteria and Legionella) may be of public health importance under specific circumstances (WHO 2007). For efficient risk management, and to avoid sub-optimization of measures, a holistic view of the water supply system is needed, since hazards in one part of the system may lead to consequences in another part (TECHNEAU 2010). The primary aim of this article is to present our research focused on theoretical and experimental analysis of hot water distribution systems from the point of view of microbiological risk using risk management methods. Case studies show that the water heater tank was identified as a source of microbiological contamination - Legionellas. A simulation model of temperature and water velocity was prepared to avoid the risk of infection. Water temperature is one of the risk factors that encourages the bacterial growth, so we simulated the layering of temperature in boiler by using the software Fluent 6.3

Keywords: Legionella pneumophila, microbiological contamination, hot water, risk analysis, water heater tank, simulation methods.

1. Introduction

We are facing the need to ensure water quality by using technical systems, and thus a basic requirement of life for today's civilization is the treatment, transport, heating and purification water. In spite of the fact that the price of water in Slovakia is 5 times below the EU- average, since 1990 it has increased 40 times and the water supply and sewerage bills are still relatively high. In the future it is expected to increase further. Failure to ensure drinking-water safety may expose the community to the risk of outbreaks of intestinal and other infectious diseases. Research has developed together with the level of science, technology, health care and other scientific fields. Discovery of Legionella pneumophila, its classification and its influence on installations inside buildings is relatively young. In the Slovak Republic a mortality case for Legionella has not been reported up to now, however, Legionella which may cause death in the population is a worldwide problem. For example Western Australia has been notified of six cases. The onsets of the cases have ranged from 10 August 2010 to 1 January 2011. Five of the ten cases have had their onsets since mid-December 2010 (Carnie, 2011).

In the recent years a lot of studies about microbiological contamination in water systems have been taken, especially about the treatment and disinfection methods (Cooper and Hanlona, 2010, Josset et al, 2010, Friedler et al, 2011), the efficiency of disinfection methods (Dupuy et al.; 2011), environmental risk factors (Kuroda Y. and S.Takeuchi, 2010), detection and identification of *Legionella pneumophila* and other pathogens in drinking water (Zhou et al, 2011).The goal of the article is to show the connection between disinfection, simulation and risk management methods.

2. Legislation

Over the last few years particular parts of the 'STN EN 806 Specifications for installations inside buildings conveying water for human consumption' have been accepted by the Slovak Republic. The core of the article consists of part 2: Design and part 5: Maintenance and Operation. Installations have to be operated and maintained without having an adverse effect on conveying water for human consumption and water quality. Safety quality and suitability of procedures accepted for the safeguarding of the systems performance according to EN 806 and EN 1717 should be regularly controlled. Conditions of installation operation have to be compared with conditions of design and assembly in order to insure their functionality.

Potable water is safeguarded by the basic strategies:

- Cold water must remain cold;
- Hot water must remain hot;
- Water must not stagnate in water pipes longer than it is necessary.

Installations inside buildings conveying water for human consumption must involve EN 1487, EN 1488, EN 1489, EN 1490 and EN 1491. The most important factor for the possible development of Legionella bacteria in hot water systems with circulation pipes is the temperature difference between heater output and circulation pipe input to heater of a maximum 5 K (Fig. 1). These criteria are consistently reflected in guidelines and regulations developed in many countries individually for the design, operation and maintenance of tap water systems to avoid the growth of Legionella (the Slovak Republic does not have any guidelines or regulations related to Legionella bacteria).

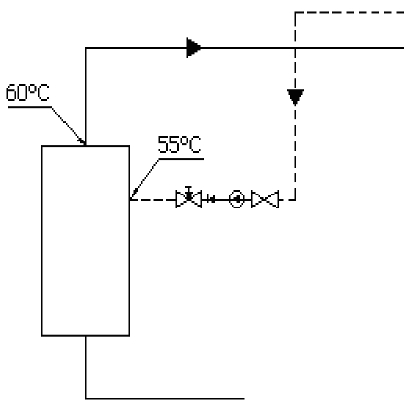

Fig 1. Minimum temperatures in the heater outputs

STN EN 806 provides that 30 seconds after fully opening a draw off fitting, the cold water temperature should not be kept below or equal to 25 °C and the hot water temperature should not be less than 60 °C. Hot water systems should have the facilities to enable the temperature at the extremities of the system to be raised to 70°C for disinfection proposes.

Technical commission TC 164, which creates European standards (as the EN 806), is currently working on the final version of Technical report: Recommendations for prevention of Legionella growth for installations inside buildings conveying water for human consumption, will complete the standard EN 806.

3. *Legionella* contamination in Kosice

Legionella pneumophila is in all likelihood a naturally occurring bacterium in many of the water sources and water supply plants. The number of colonies forming units of Legionella bacteria in potable water distribution systems depends on numerous factors and may vary over time and place. Micro-organisms occurring in water distribution systems are subject to many factors that affect their growth and multiplication, therefore it is important to reduce and monitor them. Risk analysis is one of the methodological procedures to identify possible contamination threats by Legionella pneumophila in water distribution systems. It is an analysis of problems based on the latest scientific- technical knowledge to make a basis for effective decisions and their rationale. The goal is to assess necessary precautionary measures as the specific risk assessment is a prerequisite for any similar measures. Risk analysis assesses specific conditions on the ground of information about current contamination that comprises an assessment of the incidences of transmission, exposure, and the target risk group in each situation (Ocipova 2009). The risk analysis shall at least take the following risk-limiting factors into account:

- water temperatures below 20°C;
- water temperatures between 20°C and 25°C, in so far as water is standing for no more than one week and there is good flow;
- water temperatures above 50°C;
- water temperatures above 60°C (at which bacteria die off);
- flow;
- short residence time.

In cases in which the risk analysis shows that there are favorable circumstances for Legionella growth and the owner chooses to manage this risk by reheating the water or increasing the temperature of the pipe network on a weekly basis (thermal disinfection), the owner shall adhere to one of the following ratios between temperature and time (W.G. van der Schee, 2006).

Table1. Ratios between temperature and time (W.G. van der Schee, 2006)

Temperature	**Reheating time**	**Standing time for weekly thermal disinfection**
60°C	10 minutes	20 minutes
65°C	1 minute	10 minutes
70°C	10 seconds	5 minutes

4. Sample collection

From February to October, a total of 46 water samples were collected from private homes, hospitals and boiler houses of Kosice, representative samples of Eastern Slovakia.

Legionella presence was detected in 8 samples out of analyzed drinking water samples. Positive findings were recorded in 8 samples of PWH (potable water hot) In waters for human consumption PWC (potable water cold) a volume of *Legionella* was detected, from sporadic colonies of 20 Colonies Formed Units - CFU/100 ml up to massive colonization in the quantity 6700 CFU/100 ml per sample. In water for human consumption (PWH) a volume of *Legionella* was detected, from sporadic colonies of 200 CFU/100 ml up to massive colonization in the quantity 14 600 CFU/100 ml per sample. *Legionella* presence was detected in 8 samples of analyzed PWH samples, i.e. in 17.4 %. It was necessary to react promptly due to positive findings in residential areas. The most reliable and available solution was thermal disinfection. However, there are still areas not reached by disinfection which remain as a contamination source. Non-adjustment of systems leads to the fast spread of *Legionella* in distribution systems.

That is why our sampling in contaminated areas was repeated immediately after thermal disinfection the initial results were negative. After 12 days the level of *Legionella* colonies was almost the same as before thermal disinfection. The measures have proved that thermal disinfection is not a suitable system treatment (Kosicanova, 2007).

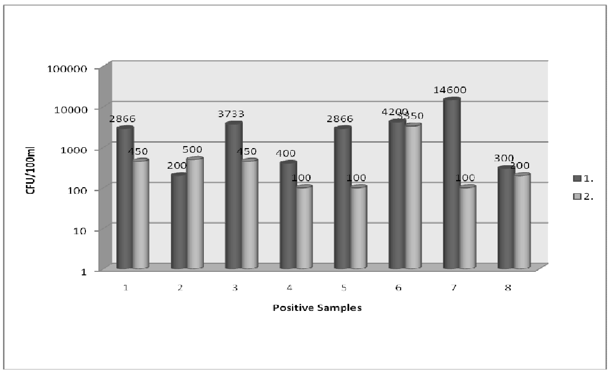

Fig 2. Legionella results – positive samples

Far worse results were obtained in similar survey in Italy or Germany (Botet ML et al 1998). In this case 36 - 68 % of samples were positive. In the case that the thermal disinfection in contaminated places is not done the concentration of bacteria will have an exponential character.

Thermal treatment appeared to be efficient to disinfect most of the biofilm but seemed to promote the biofilm re-growth as well. It was then concluded that the best solution to prevent Legionella contamination in hot water distribution systems would be to have perfect control of the temperature in the networks (temperature > 55°C at all points) (Saby at al. 2005). Domestic hot water systems are allowed to operate at lower temperatures (50 °C rather than 65 °C), as current settings are based on the need to avoid growth of *legionella* bacteria in hot water tanks, which are eliminated in the best practice design (Cullen et al.; 2011). New strategies are towards permanent disinfection due to the fact that spasmodic disinfection is not reliable enough to ensure the required standard.

5. Addressing the Selected Exchange Station - P1

The experimental research was at a fixed boiler room P1 at Lomnicka Street in Kosice. P1 boiler room along with the secondary networks and connections with the new boiler room P2 provides heating and PWH for residential houses in Košice.
Characteristics of boiler room:
P1: Kosice North, Lomnicka Street
Water temperature: 45 to 51 ° C
Water heater tank capacity: 2 x 10 000 l, 1x 6 300 liters
Boilers: 3
Thermal insulation: partially damaged
Note: sludge sample
PWH technology is provided by a pair of control valves. Water heating is made by three stand alone water heaters.

Positive samples
Legionella pneumophila, sampling: 3733KTJ/100ml
Legionella pneumophila, repeated sampling: 450 KTJ/100ml

Laboratory examinations and Legionella analysis were made by the Regional Health Office Referential Centre for potable water in Kosice and with the cooperation of the main Heat supplier TEHO. There were no disinfective or technical measures carried out after the positive sampling. On the basis of experience in risk management in our country and in the world (HACCP, WSP), we used the following method of Risk analysis for individual boiler P1.

6. Proposed Risk Analysis Methodology

Risk analysis consists of 6 parts:
1. Assemble team – includes experts.
2. System characterization – collects all information (design, reports…), the capacity and microbiological examination, diagnostic systems, identification of the most likely hazards.
3. Risk analysis - is technique to identify hazards and critical factors of technical systems.
4. Risk assessment - determines the probability and severity of the consequences associated with each identified risk, and their ranking in terms of priorities.
5. Risk control- determines the control measures to be introduced in the system to reduce or eliminate the risk and consists of the proposals and appropriate technical measures to reduce risk.
6. Monitoring and review

Based on samples of water in which the positive finding of the bacterium Legionella pneumophila was found, we assembled the qualified team for the assessment of system. We applied the proposed Risk analysis methodology gradually in three steps at exchange station P1. First there was the risk analysis, where the incidence of bacteria designated as dangerous, and via accurate determination of the critical points of the system was required. During the risk assessment we identified the probability and severity of the consequences associated with each identified risk. The hazard identification was performed through brainstorming session. Based on the assigned probability and severity of the consequences and by semi-quantitative matrix the resulting level of risk was determined.

7. Results and Discussion

The overall risk assessment shows that water treatment is the most risky. In this case it is just the hot water heater tank. Ideal conditions for colonization are in hot water tanks, where the survival of Legionella directly depends on the quantity and quality of sediment. Experimental hot water heater tank was simulated with the software Fluent 6.3. It is non- isothermal 3D model where thermal radiation is considered. When used for simulating the RNG k - epsilon turbulence model and the thermal radiation has been modified into models of radiation (Fig. 3).

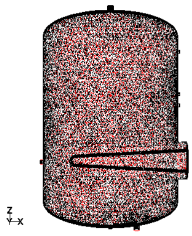

Fig 3. Storage model

We have simulated two conditions: Situation A in standard operation and Situation B for thermal disinfection.

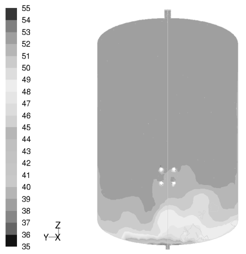

Fig 4. Temperature stratification –situation A

To verify the simulations, we used images from the infrared camera (Fig. 5).

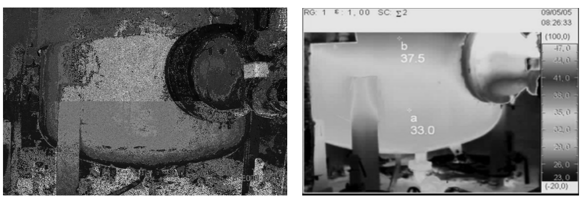

Fig 5. Infrared camera image

Achievements of simulations operating conditions offer an insight into the flow of water and heat transfer in a standing container to assess temperature and water stagnation (Fig. 7). Due to stagnation of very slow water flow and also low overheating of thermal disinfection the point of highest risk is clearly bottom of the tank – the so called sludge blow off (Fig. 6).

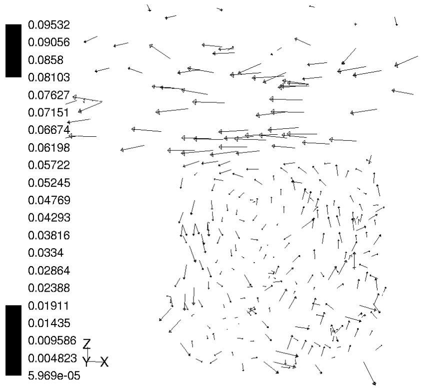

Fig 6. Detail of water flow in closed sludge blow off

Here maintain suitable conditions for growth of *Legionella* bacteria, and if temperatures drop in the tank, may colonize the entire system. The proposed general model of temperature distribution of the water heater tank can be applied to all similar types of tanks. Thermal disinfection was verified not to be the systematic solution and therefore it is inevitable to search for a new complex solution. Expenses on the elimination of *Legionella* from the water distribution systems are very high and the results are often not sufficient (Ocipova 2009).

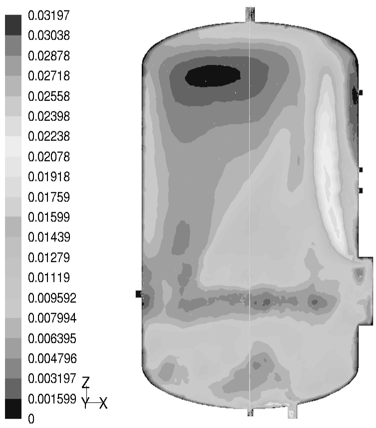

Fig 7. Water velocity – B situation

8. Conclusion

The quality of water must be guaranteed not only for heating and distribution but also for monitoring parameters which were suggested by a designer to support the functioning of the system as a whole as well as the solitary functioning of its critical items.

The exact specification requires the maintenance and operation of the system to be very reliable. It is apparently evident e.g. in hospitals where technical and medical staff must cooperate and perform regular outlet of hot water – PWH in many parts of the distribution system - to explain why it is necessary, to have competence and how to follow the precautionary measures. Keeping records of the current operation state, especially problematic situations, is the best education and management for improving the system for all involved parts such as: a user, a designer and an installing firm. Therefore the designer together with the engineering firm should inspect the quality of water for a longer period. It would be appropriate to assign responsible employees, designer and installing firm.

By application of preventive measures and the use of risk management we get to a secure system which eliminates costly solutions as well as managing to achieve in the test P1 boiler decrease of CFU Legionella bacteria to acceptable levels. By pointing out the heater of hot water as a dangerous source of spreading the bacteria throughout the distribution system, we focused on the investigation of water temperatures and velocity by software simulations. The proposed general model of temperature distribution of the water heater tank can be applied to all similar types of tank.

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References

Borella, P.; *et al.* 2003: Environmental diffusion of Legionella spp. and legionellosis frequency among patients with pneumonia: results of a multicentric Italian survey. *Ann Ig* 15: 493–503.

Botet, M. L. P.; Sabria-Leal, M.; Sopena, N.; Manterola, J. M.; Morera, J.; Blavia, R. *et al.* 1998. Role of immunosuppression in the evolution of Legionnaires' disease. *Clin Infect Dis* 26:14–9.

Carnie, J.2011. *Legionnaires' disease cluster associated with travellers to Bali - January 2011 [02.02.2011]* Available on the Internet: http://www.health.vic.gov.au/chiefhealthofficer/alerts/alert-2011-01-legionnaires.htm.

Cooper, I. R.; Hanlon, G. W. 2010. Resistance of Legionella pneumophila serotype 1 biofilms to chlorine-based disinfection. *Journal of Hospital Infection* 74(2): 152–159.

Cullen, J. M. *et al.* 2011: Reducing Energy Demand: What Are the Practical Limits. *Environmental Science and Technology* 45(4): 1711–1718.

Dupuy, M.; *et al.* 2011: Efficiency of water disinfectants against Legionella pneumophila and Acanthamoeba. *Water Research* 45(3): 1087–1094.

Friedler, E.; Yardeni, A.; Gilboa, Y.; Alfiya Y. 2011. Disinfection of greywater effluent and regrowth potential of selected bacteria. *Water Science & Technology* 63(5): 32–941.

Information and consulting services to protect health and life by reducing the risk of waterborne pathogens [18.12.2010], Available on the Internet: http://www.hcinfo.com/outbreaks-news.htm

Josset, S.; *et al.* 2010: UV-A photocatalytic treatment of Legionella pneumophila bacteria contaminated airflows through three-dimensional solid foam structured photocatalytic reactors, *Journal of Hazardous Materials* 175(1-3): 372–381.

Kosicanova, D.; Vranayova, Z. 2007. Hot water thermal disinfection in transfer station circuit and her energy consumption, in *Selected Scientific papers*. Technical university of Kosice, Slovakia. 32–36.

Kuroda, Y.; Takeuchi, S. 2011: Legionnaires' Disease: Environmental Risk Factors, in *Encyclopedia of Environmental Health*. 448–452.

Ocipova, D. 2009. Teoretická a experimentálna analýza distribučných systémov teplej vody z hľadiska ich mikorbiologického znečistenia [Theoretical and Experimental analzsis of hot water distribution systems from the microbiological view]. *Dissertation work*. Košice, TUKE.

Saby, S.; Vidal, A.; Suty, H. 2005. Resistance of Legionella to disinfection in hot water distribution systems. *Water Science & Technology* 52(8): 15–28.

Van der Schee, W. G. 2005. Regulation on legionella prevention in collective water systems, in *Proceedings – 31st International Symposium CIB W062 Water Supply and Drainage for Buildings*. Brussels, Belgium.

TECHNEAU (2009). Project Website: http://www.techneau.eu.

WHO 2007 Legionella and prevention of Legionellosis, Frade Jamie Bartram, Yves Chartier, John V Lee, Kathy Pond and Susanne Surman-Lee (eds). Internet: www.who.org.

EN 806 Specifications for installations inside buildings conveying water for human consumption 2007.

TC 164 WI 164353 Technical report: Recommendations for prevention of Legionella growth for installations inside buildings conveying water for human consumption.

Zhou, G.; *et al.* 2011: Development of a DNA microarray for detection and identification of Legionella pneumophila and ten other pathogens in drinking water, *International Journal of Food Microbiology* 145(1): 293–300.