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# Negative Impact of Bacteria Legionella Pneumophila in Hot Water Distribution Systems on Human Health

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***Abstract***—Safe drinking water is one of the biggest issues facing the planet this century. The primary aim of this paper is to present our research focused on theoretical and experimental analysis of potable water and in-building water distribution systems from the point of view of microbiological risk on the basis of confrontation between the theoretical analysis and synthesis of gathered information in conditions of the Slovak Republic. The presence of the bacteria Legionella in water systems, especially in hot water distribution system, represents in terms of health protection of inhabitants the crucial problem which cannot be overlooked. Legionella pneumophila discovery, its classification and its influence on installations inside buildings are relatively new. There are a lot of guidelines and regulations developed in many individual countries for the design, operation and maintenance for tap water systems to avoid the growth of bacteria Legionella pneumophila, but in Slovakia we don't have any. The goal of this paper is to show the necessity of prevention and regulations for installations inside buildings verified by simulation methods.

***Keywords*—**Legionella pneumophila, water temperature, distribution system, risk analysis, simulations.

## I. 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 becoming a treatment, transport, heating and water purification. Providing adequate water supply and sanitation, particularly in urban areas, is a challenging task for governments through the world. This task is made even more difficult due to predicted dramatic global changes [1]. As we deal with environmental change, the security of our water supply is becoming one of the most important concerns for mankind. Safe drinking water in particular is neither guaranteed nor universal. Main objective of the Drinking Water Directive is to protect the health of the consumers in the European Union and to make sure the water is wholesome and clean (The Drinking Water Directive (DWD), Council Directive 98/83/EC) [2]. Studies have shown [3] that water meeting typical end-of-pipe standards, may in fact, cause disease. It is not feasible to test for all pathogens directly and indicators of microbial contamination are imperfect. Important pathogens like Cryptosporidium, may be present when the indicator E. Coli is absent [4]. Failure to ensure drinking-water safety may expose the community to the risk of outbreaks of intestinal and other infectious diseases.

Legionellosis is an infectious disease caused by gramnegative bacteria, legionella. The disease could manifest as life threatening atypical pneumonia, Legionnaires´ disease or as flu-like nonpneumonic form, Pontiac fever, sometimes is the infection asymptomatic. It is caused by inhalation of water aerosol contaminated by legionella [5]. In Europe about 5 000 – 6 000 legionella cases are notified per year (incidence rate of 10 – 11 per million population), in Slovakia this infection is rare, 0 – 9 cases were notified per year (incidence rate of 0,2 – 1,7 per million population) [6]. According to publication of Water Health Organisation (WHO) from the World Water Day 2010 [5] the widespread implementation of WSPs (adapted Water Safety Plan Manual (WSP) [7] was upgraded to WSPs approach) can contribute to reducing the portion of the global disease burden attributed to poor drinking-water and inadequate sanitation and hygiene. For these reasons, the WHO Guidelines for Drinking-water Quality and the IWA Bonn Charter recommend pro-active efforts to reduce risks and prevent contamination before water reaches the consumer [5].

The EU water supply sector was for the first time incorporated 5 years ago in the currently largest EU project on drinking water called TECHNEAU - an integrated project funded by the European Commission, challenges the ability of traditional system and technology solutions for drinking water supply to cope with present and future global threats and opportunities. This was initiated through rethinking of current water supply options and by providing researched and demonstrated new and improved technologies for the whole water supply chain [8]. This project is pointing out the main challenges, trends and adaptation of water supply and it is reaching the Millennium Development Goals.

These days, fast, sensitive and reliable monitoring [9] of the chemical and microbiological parameters in drinking water is expected. The Drinking Water Directive, Council Directive

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98/83/EC - Sets quality standards for drinking water quality at the tap (microbiological, chemical and organoleptic parameters) and the general obligation that drinking water must be wholesome and clean [3].

## II. Aims and Methods

To assess the potential public health impact of Legionella colonization in potable water and in-building distribution a study was undertaken to identify and qualify the levels of the microorganism in boiler houses of Kosice, representative samples of Eastern Slovakia.

We addressed 4 specific aims:

1. to identify the potential risk factors for contamination related to potable water and in-building distribution systems
2. to investigate the real situation of potable water hot (PWH) pollution by Legionella pneumophila in Košice
3. to implement proposed methodology of risk management in polluted system
4. to use simulation methods in real operating conditions (to propose a general distribution model of temperatures in the heater applicable to similar types of heaters ).

## III. Conditions for Growth of Legionella

The conditions that encourage the bacterial grow are presented at Fig. 1 so we must break this chain to ensure that system will be safe.

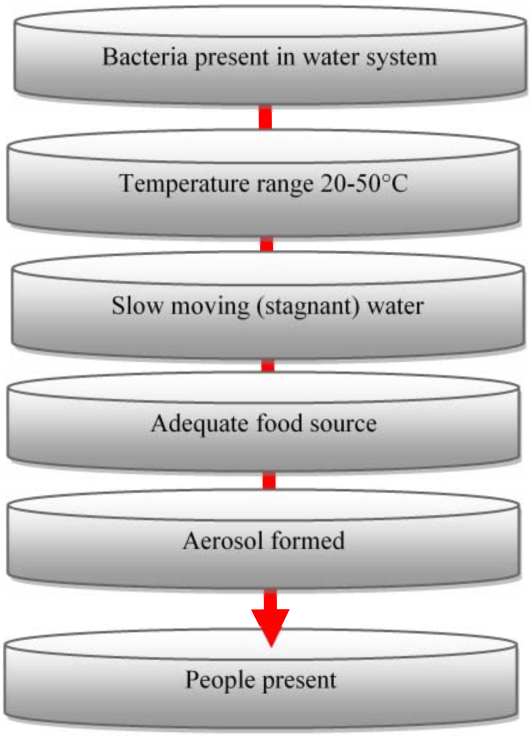


Fig. 1 Chain of causations that must occur for Legionnaires' disease to be acquired

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. This building water system provides suitable conditions for growth: adequate growth temperatures, nutrients in the form of corrosion products (iron), sediments and slime layers.

## IV. Monitoring and Control of Legionella Pneumophila in Drinking Water Systems

Monitoring and control technologies are inevitable for the production of safe drinking water [7]. The multidisciplinary Legionella research has developed hand in hand with the level of science and technology, health care and other scientific fields.

According to TECHNEAU approach of WA3 report the following purposes for water quality monitoring were considered:

1. Catchment characterisation
2. Source water characterisation
3. Performance of treatment technologies
4. Overall treatment effect/water quality status (before entering distribution network)
5. Detection of quality changes during distribution
6. Monitoring of water quality at consumers' tap [9].

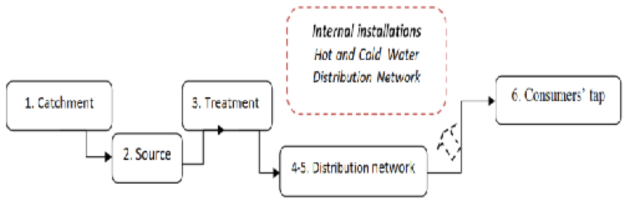


Fig. 2 Monitoring scheme

Legionella pneumophila occurring in water distribution systems affect their growth and multiplication, therefore it is important to reduce and monitor them. The in-building distribution system is an important part of water network that has a big influence on the water quality at consumers tap. The approach [10] is to avoid the growth of Legionella colonies by eliminating the conditions that support their multiplication. The "source-to-tap" approach of the TECHNEAU project leads to monitoring of quality at consumers' tap to ensure that no changes will occur during distribution or in in-building installation. The question is: Is it too late to control the bacteria, Legionella colonies, at the end user? In spite of ensuring the distribution network from "source-to-tap" we often stop at inlet to building.

## V. Legionella Contamination - Sample Collection

Missing the regulations for controlling the *Legionella bacterium* and the risk management approach in water distribution systems in Slovakia resulted in our investigation and positive findings of Legionella in water samples.

Total of 50 water samples were collected from boiler houses of Kosice, representative samples of Eastern Slovakia. The selection was made on the basis of the water distribution systems inside the town and buildings and heater types in each area. After we identified each building, we asked a random family, or a work collective to participate in the study, i.e. to complete our questionnaire and give informed consensus for water collection. The hot water samples were drawn from the bathroom outlets in the case of residential houses (shower heads or bathroom taps), from the botton of boiler and at exchanger in the boiler houses. Water and aerosols samples survey to legionella presence according their outcomes is connected with saprophytic and thermotolerant amebas presence monitoring. Sampling verified that in waters for human consumption (potable water cold - PWC) volume of legionella were detected, from sporadic colonies 20 CFU/100ml up to massive colonization in the quantity 6700 CFU/100ml of a sample, in potable water hot - PWH volume of legionella were detected, from sporadic colonies 200 CFU/100ml up to massive colonization in the quantity 14600 CFU/100ml of a sample.

*Legionella* presence was detected in *17,4* of total samples.

There was a necessity 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 the contamination source, like dead ends -sediment and sludge in the tank and pipes. Non-adjustment of systems leads to fast spreading of Legionella in distribution systems. That is why our sampling in contaminated places was repeated immediately after thermal disinfection which was at first almost negative. After 12 days the level of Legionella colonies was almost the same as before this measure. The measures have proved that the thermal disinfection is not a systematic solution (periodically use is effective but in some cases it is not possible to use this treatment, thereto it raises the energy consumption and costs).

### A. *Critical Control Points of the System*

Using methods of analysis and risk management contributes to the safety of potable water and human health protection by completing water quality assessment for consumers to control the processes involved in the drinking water quality. Experience shows that these methods are also good for other stakeholders, such as: legislative staff, operators of water systems, organizations providing independent control of water supply (usually but not always, health organizations), consumers [11] Effective risk management requires identification of potential hazards and their sources, to estimate or determine the presence of potentially hazardous events and to assess the level of risk that is posed.

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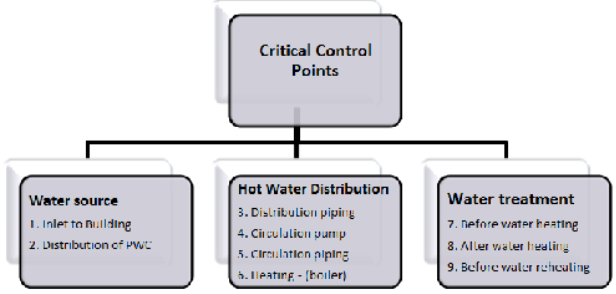


Fig. 3 Critical control points of the system

## VI. Risk Management and Simulation Methods in Real Operating Conditions

The experimental research was fixed at 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. On the basis of risk management approach in the world (HACCP, WSP), a method of Risk analysis for individual boiler P1 was proposed.

Proposed Risk Analysis of P1 is presented by Fig. 4.

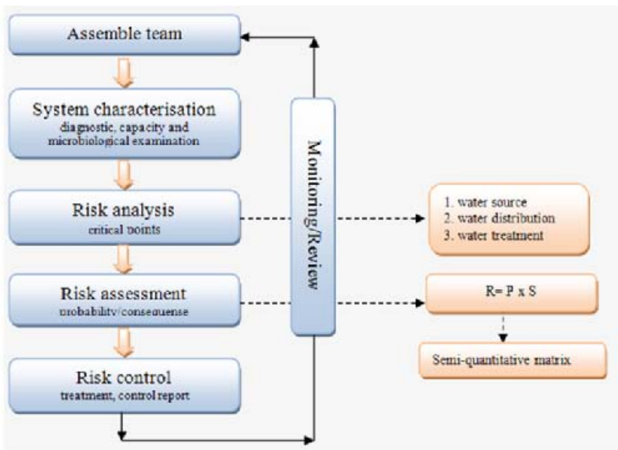


Fig. 4 Flow diagram - Proposed Risk Analysis

The resulting risk is expressed as the product of these two values. This will enable to distinguish between significant and less significant risks as well as to establish priorities in terms of implementation of measures to reduce or eliminate them.

The resulting risk:

$\boldsymbol{R = P \times S}$ → assignment of risk exposure (L, M, H, E) (1)

L - low risk (coped with normal procedures)
M- medium risk (preventive sampling, equipment inspection)
H- high risk (needed management attention, prevention, measures)
E- extreme risk (immediate solution, action steps, identification of responsible person)

TABLE I
COMPARATIVE MATRIX TO RANK ORDER OF RISK [12]

| Probability of occurrence | Severity of consequences | | | | |
|---|---|---|---|---|---|
| | 1 negligible | 2less significant | 3 medium | 4 critical | 5 catastrophic |
| 1 rare | 1 L | 2 L | 3 M | 4 H | 5 H |
| 2 improbable | 2 L | 4 L | 6 M | 8 H | 10 E |
| 3 medium | 3 L | 6 M | 9 H | 12 E | 15 E |
| 4 probable | 4 M | 8 H | 12 H | 16 E | 20 E |
| 5 almost certain | 5 H | 10 H | 15 E | 20 E | 25 E |

The processed data from Risk analysis create the resulting risk matrix (Tab.1), which shows the most dangerous part of the water distribution system and the need for immediate management attention. Using semi-quantitative evaluation may determine the order of control measures to reduce or eliminate the risk in terms of its importance Table I [12].

The overall risk assessment shows that water treatment is the most risky. Ideal conditions for colonization are in hot water tanks, where the survival of Legionella directly depends on the quantity and quality of sediment. These reservoirs are pumped heated to about 50 ° C as the upper layers of the reservoir, while the bottom water temperature is around 29 ° C, allowing the survival of Legionella.

## VII. RESULTS AND DISCUSSION

In April 2009, new samples were collected. The laboratory results were negative for the bacterium Legionella pneumophila (colony forming units dropped almost to zero values), which confirmed the effectiveness of implemented measures. As a precautionary measure we recommended to the supplier of PWH to implement the other proposed changes, and to avoid possible recolonization in the future.

In the experimental boiler room proposed and approved by the supplier of PWH measures were implemented as follows:

- removal of disused pipes
- circulation pumps replacement –in this exchange the system was discharged
- immediate sludge blow off and cleaning of heaters, ensuring periodical sludge blow off
- flushing the pipe by drinking water –the whole distribution system
- thermal disinfection of the system at 75°C (partial –local overheating of the system)
- replacement of damaged insulation on the pipes and water heater tanks
- proper placement of temperature sensors in the tank.

According to the results of the risk analysis extreme risk has been assigned to the water heater tank. In terms of a complex approach the implemented measures should be sufficient to eliminate Legionella (if the water heater tank was considered as a local source).

The water heater tank with a capacity of 6300 l (Fig. 5), located in the boiler room P1, is designed for heating and hot water accumulation.

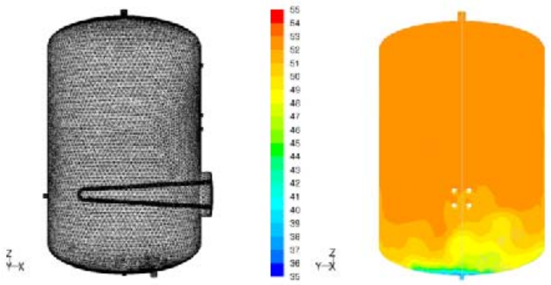

Fig. 5 a)Storage model b)Water heater tank

Experimental storage was simulated with the software Fluent 6.3 This is non- isothermal 3D model where thermal radiation is considered. The change of water density and temperature is given by the regression function - polynomial 5th degree. When used for simulating the RNG k - epsilon turbulence model and the thermal radiation has been modified into models of radiation Fig. 5a.

Temperature (or temperature stratification) and the stagnation of water in the tank are factors that we decided to explore. Based on the temperature stratification of the first simulation in Fig. 5b, exactly the bottom of the water heater tank belongs to the range of temperatures from 35 °C to 45 °C, which are risky. For simulation control, we used a thermovision camera. After removing the insulation, we scanned the bottom of the tank during standard operation. In connection with the sediments, and inlay, which are located at the bottom of the storage, the riskiest places become sludge blow off and surrounding areas of drinking water supply. Eliminating of death legs and the unused outlets can prevent stagnation. Simulated temperatures are consistent with the actual condition.

The simulated model can be used as a general model (tolerance ± 2 °C) of temperature layering for vertical type of water heater tank (boundary conditions can be changed if necessary). The simulation of B condition (thermal disinfection) shows that layering has changed, but the risky places did not change. The temperature in a closed sludge blow off is approximately from 3 to 4 K lower than the temperature in the tank.

This means that bacteria can survive and colonize the whole system. Stagnation of water in B situation occurs in the same places as with A situation (due to almost zero flow speed, and water circulation).

Sludge blow off, where almost zero flow speed offers ideal conditions for bacterial growth. Trajectory of peak water flow in the tank is definitely not going through blind connections, where the flow is very slow about: 0.004823 $m.s^{-1}$as shown in Fig 6 [14].

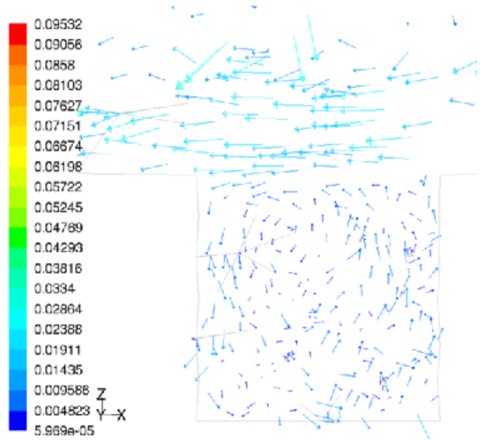


Fig. 6 Detail of Sludge – blow off

## VIII. Conclusion

A wide range of factors support growth of Legionella and other microorganisms in a distribution system. For the health significance given to these organisms it is necessary to pay particular attention to issues of design and implementation of preventive medical and technical measures. While respecting the basic parameters of hot water, it is required for a water supplier and operator of a building to ensure the prescribed quality and water temperature at each sampling site. The measures have proved that the thermal disinfection is not a systematic solution (periodically use is effective but in some cases it is not possible to use this treatment, thereto it raises the energy consumption and costs). By application of preventive measures and the use of risk management we get to a secure system which eliminates costly solutions as well as we have managed to achieve in test P1 boiler decrease of CFU Legionella bacteria to acceptable levels.

By implementing the technical guideline or standard in Slovak republic that will intend the designers and construction companies to build systems in a way to avoid the Legionella growth it will be not too late to control the Legionella bacteria at the end user and ensure the distribution network from "source-to-tap".

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