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Water Quality Control in the Water Supply System for the Purpose of Preventing Legionnaires' Disease

Anita Rakić

Additional information is available at the end of the chapter

Abstract

The contamination of drinking water presents an important public health concern throughout the world. Microbial hazards make the largest contribution to waterborne disease in developed and developing countries. *Legionella* bacterium, the fundamental agent of Legionnaires' disease, is a water-based organism that causes infection when inhaled in an aerosol form. Main factors influencing the survival of *Legionella* spp. are: physical and chemical properties of the water (pH value, mineral content, and presence of heavy metals), materials used in the system, system design, furring, corrosion, and dead-ends. These bacteria are transmitted during the showering by inhalation of contaminated water droplets and the highest risk of infection with a subsequent death is encountered among immunocompromised and elderly water consumers. The control of the disease has been one of the major problems in countries with low- and middle-income economies, including Croatia. The most frequently used approach to disinfect the system is a daily increase of water temperature in the heating coil. However, due to the economic issues, the residents frequently request house managers to decrease the temperature of hot water systems leading to an increased system contamination and subsequent human infections.

Keywords: *Legionella* spp, drinking water distribution system, risk assessment

1. Introduction

Environmental component research (food, water, air, and waste…) is a part of public health preventive activities with the aim of preserving the health of the population [1]. The quality as well as the quantity of water in the public supply is important for public health. Care for the health of people through environmental monitoring is a state`s obligation and should, when it comes to public health care, be funded from the budget, which will enable health professionals

to work independently [2]. Water is the most valuable natural substance, which is being necessary for the survival of all living organisms. The quality as well as the quantity of water in the public supply is important for public health. Fouling is the undesired deposition of material on surface drinking water within distribution systems.

- Inorganic fouling (precipitation of inorganic crystals), "Scaling".

- Organic fouling (deposition of fat, oil, and protein etc.)

- Particle fouling (deposition of silt, clay, and humic particles etc.)

Biofouling can be formed in the water supply system during different stages of preparation and distribution of drinking water on surfaces where the water is touched by hard surfaces. Biofouling is the undesired deposition and growth of microorganisms on surfaces and particles, which can multiply on the expense of nutrients [3]. Biofouling is a complex community of autotrophic and heterotrophic microorganisms, including detritus, present on different types of substrata in all aquatic environments. The most common microorganisms present in biofouling are: *Campylobacter* spp., *Legionella* spp., *Cryptosporidium* spp., and *H. pylori*.

In aquatic ecosystems, biofouling plays an important role regarding the primary production of biofilm and its growth at the expense of nutrients from the water supply system. The growth of biofouling depends on several factors, including nutrients, hydrodynamic conditions, and sediment accumulation. Thus, nutrients have to be considered as a potential biomass for biofilm. It is an excellent indicator of ecological changes, and it increases habitat availability [4]. Also, biofouling presents a serious problem for cooling cycle in energy industry:

- Heat transfer ↓.

- Drag resistance ↑.

- Biocorrosion [3].

2. Water contamination inside the water supply system

During the operation of the water supply system, water losses, pressure or flow reduction, and water quality deterioration may be caused by increasing concentrations of various organic, inorganic, or organometallic compounds and contaminants with various microorganisms. All of these changes may be due to the interaction between water and water in the tubular and reinforced wall elements and due to the various physical, chemical, and biological reactions in the water itself during its journey from the water supply system to the consumer. A disinfectant is typically added at the end of water treatment to give a disinfectant residual to provide some protection against microbial growth and limit the effects of contamination while the water is being conveyed through the distribution system. Changes in water quality may be of greater or lesser magnitude, for example, formation of deposits or sludge, which contributes to poor smell and taste of water, and therefore, the questionable health of drinking water [5, 6]. These phenomena depend on various factors: on deposits of sediments on the walls (various oxide and oxyhydroxide products of corrosion, water solids, and organic sediments), water

flow, water age, water usage dynamics, water temperature, pH, and water hardness disinfectant etc. [7]. Inside the pipeline, over time, different deposits and corrosion products are produced. At these phenomena, the highest influence is given to temperature, pH, hardness, and other chemical nutrients of water, as well as the construction material of the pipeline that distributes water to the consumer [8]. Therefore, the water supply system should be viewed as a unique biocenosis, a very complex chemical-biological reactor in which a whole series of interrelated reactions exist **Figure 1 (a)** and **(b)**.

Water pipe and the flow of water within can be considered as a bio-chemical reactor as depicted in **Figure 1**. The presence of corrosion in the water supply system increases the available surface for the colonization of microorganisms and the creation of biofilms. For the purpose of providing microbial quality, the design and operation of water supply network should prevent introduction of contaminants; disinfectant residual concentrations should be kept within a locally predetermined range, and the transit time (or age of the water after leaving the treatment plant) should be minimized. Many of the above factors also influence the biological stability of water primarily due to the formation of biofilm in which *Legionella* species (*Legionella* spp.) can be found under certain conditions.

Therefore, the most common causes of drinking water contamination in the water supply system are:

- corrosion of metal pipes and fittings [10]

- precipitation of biofilms on the inner walls of water pipes [11].

2.1. Corrosion in the drinking water distribution system

Corrosion within the water distribution system can cause water leakage, capacity loss, and deterioration of the chemical and microbiological quality of drinking water. Corrosion represents the process of unintentional destruction of construction material by physical, chemical, and
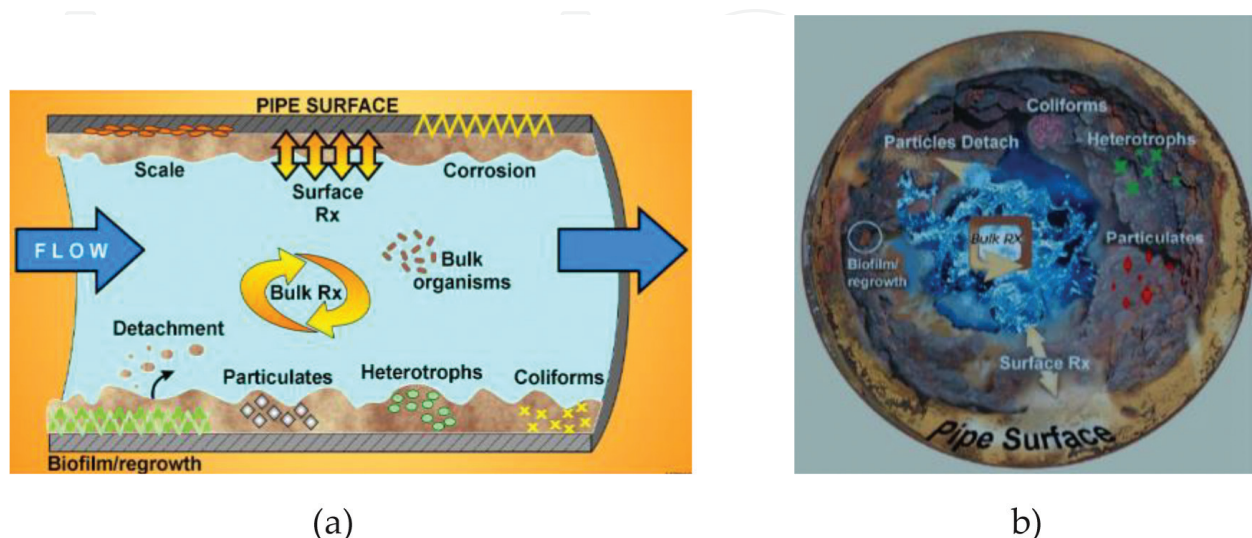

(a)   b)

Figure 1. Schematic diagram of longitudinal (a) and cross section (b) water pipe as chemical-biological reactor [9].

biological environmental action, changing the structure of the material from the surface to the interior [12].

The corrosion process, metal parts within the water supply system, is influenced by a number of external and internal factors:

– **the type of metal** – less noble metals are easier to oxidize in water.

– **pH value of water** – metals and their oxides are easier to dissolve in acidic water.

– **buffer capacity** – if the relationship between H_2CO_3 and Ca is not stoichiometric, lower buffer capacity and stronger metal dissolution occur.

– **water flow** – at a higher flow, there are less concentrations of metal ions in water.

– **water temperature** – higher the temperature faster the corrosion reaction.

– **oxygen concentration** – dissolved oxygen in water is one of the most aggravating factors of corrosion.

– **electrical conductivity** – presents a danger to various metal joints (galvanized tubes) representing potential corrosion sites [13, 14].

Also, certain types of bacteria (sulfate-reducing bacteria) in the aqueous medium affect the changes in metal tube construction materials, thus encouraging and enhancing corrosion (biocorrosion) of metal surfaces. Microbially induced corrosion causes the displacement of the corrosion system with a two-component mechanism (metal-medium) into a corrosion system with a three-component mechanism (metal-medium-biofilm) [15].

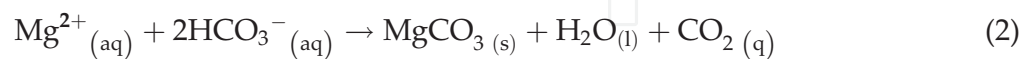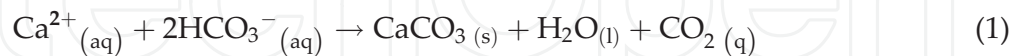### 2.1.1. The presence of heavy metal ions in the drinking water

The corrosion of metal pipes increases the concentration of the heavy metal ions having harmful effects on human health. It has been found that important factors for the occurrence of *Legionella* spp. are the drinking water distribution system and the corrosion of pipes, pumps, valves, other appurtenances, and cooling towers [16]. It has been proven that some metal ions retard while others have a biostimulating effect on the growths of *Legionella* spp. Heavy metals include metal groups having a relative density greater than 5.0 g/cm^3. In the atmosphere, water and soil fall short of a variety of natural sources, mostly due to urbanization and industrial processes. Water is deposited at the bottom of the water surface as a hard soluble carbonate, sulfate, or sulfide. They are not biodegradable and have the ability to bioaccumulate in living organisms. Drinking water may come to an end if water sources are contaminated with heavy metals, but the main source of corrosion products are metal structures in the water supply system [17, 18].

Heavy metals falling into human organisms can lead to:

- blocking of basic biological functional groups of biomolecules (e.g., proteins and enzymes).

- the displacement of essential metal ions (Fe, Cu, and Zn).

- modification of active forms of biomolecules.

2.2. Creating deposits in the drinking water distribution system

Deposit represents the mineral deposit, which consists primarily of calcium and magnesium carbonate. In pipes in urban water supply systems, lime deposition occurs, primarily on the surfaces of the heat transfer system, and this is particularly evident in water distribution pipelines causing water hardness. The most responsible for the deposit formation in the hot water supply systems is the transitory deposit. Namely, by heating the water, the soluble bicarbonates convert into the hard soluble carbonates by reactions:

$$Ca^{2+}{}_{(aq)} + 2HCO_3^-{}_{(aq)} \rightarrow CaCO_{3\,(s)} + H_2O_{(l)} + CO_{2\,(q)} \tag{1}$$

$$Mg^{2+}{}_{(aq)} + 2HCO_3^-{}_{(aq)} \rightarrow MgCO_{3\,(s)} + H_2O_{(l)} + CO_{2\,(q)} \tag{2}$$

Due to deposition of the deposit, that is, hard soluble calcium and magnesium carbonate and release of CO_2 (Eqs. 1 and 2), the corrosive action of water is increased, particularly above 60°C. Deposits can cause many problems in heating systems and in the distribution network. Its deposition on heat exchanger walls reduces heat transfer and water flow, which can lead to clogging of certain parts of the system. The heating efficiency can be reduced by up to 2–6%, which means increased heating costs and higher CO_2 emissions. Because of the unequal deposition of the lime over the water pipes, local overheating, water vapor, and difficulties in the operation of boiler plants (creating noise in the system) occur. Due to the heat released during the operation of the pump, the deposition of the deposits and the inside of the pump housing can occur, which reduces the flow of water. The porous structure of the deposit favors the propagation of microorganisms by protecting them from the influence of disinfectants and the influence of hot water. Also, water heating increases electrical conductivity and galvanic corrosion [19].

2.3. Creating biofilms in the drinking water distribution system

The water supply system is made of the following main groups of objects: source water, treatment, storage, and distribution system. *Legionella* spp. has been shown to be harbored within biofilms formed within different parts of drinking water supply [20].

In the water supply system, biofilms can be created in different stages of preparation and distribution of drinking water on surfaces where the water is touched on a solid substrate (**Figure 2**). For example, locations for biofilm growth in drinking water systems are:

- **inner walls of wells**, well plumbing, plumbing pump, etc.

- **treatment for waters**: surfaces of filter media (sand, activated carbon), membranes, etc.

- **drinking water distribution**: inner walls of pipes made of mineral, metallic and polymer surfaces, hoses, etc.

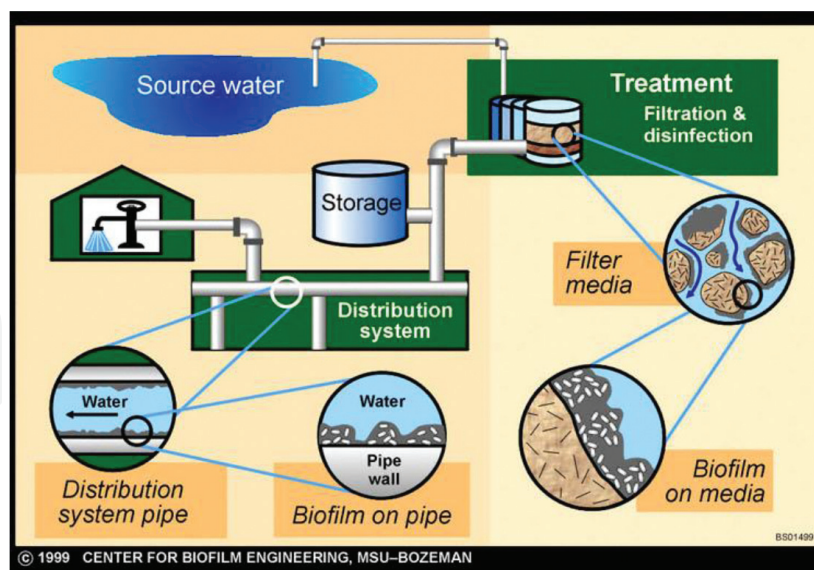- **drinking water reservoirs**: walls, floors, ceilings.

Figure 2. Scheme drinking water distribution system [21].

The risk of significant surge, and hence water quality problems, is greater in long unbranched pipes than in branched pipes, because branched pipes reduce surge. Microbial growth in water depends on temperature, nutrient content, and disinfectant concentration. In a network, it will also depend on the composition of the internal pipe surfaces, but this effect cannot be predicted. It is relatively easy to predict the temperature and nutrient content in the mixed water, as they are derived from the flow-weighted average of the values in the constituent waters [22]. Disinfectant concentration is dependent on the degree of decay that the constituent waters contain up to the point of mixing and the type of disinfectant, which was used in the constituent waters, the blending proportions and the chemical reactions, which occur between the disinfectant species [23]. Environmental conditions in the aqueous fluid, which are favorable for growth (e.g., which contain sufficient substrate and growth nutrients) of the attached cells will lead to the growth, division, and formation of new cells and produce a matrix of extracellular polymeric substances (EPS), which adhere to each other and to the surface (substratum). Such accumulation of cells and EPS, along with any trapped inert particles and organic matter, is termed "the biofilm". Products of cell metabolism and biotransformation are passed back into the aqueous phase together with the cells that become detached from the biofilm [4]. Biofilms as microorganism reservoirs depend on nutrients from the water. Hygienically relevant bacteria detected in drinking water biofilms were as follows: *Campylobacter jejuni*, *Campylobacter coli*, *Faecal streptococci*, *Escherichia coli*, *Helicobacter pylori*, *Legionella pneumophila*, *Mycobacterium avium*, and *Pseudomonas aeruginosa* [4]. Low temperature and high disinfectant levels generally inhibit microbial growth, which otherwise depends on nutrient level. Thus, a particular water may exhibit low microbial growth at low temperature and low disinfectant residual, as may another water at a higher temperature with a higher residual, but a mix of the two may support high microbial growth [24]. In **Figure 3**, the biofilm formation within the plumbing tube is shown schematically.
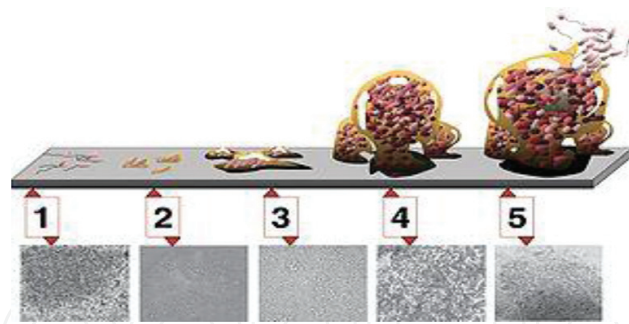
Figure 3. Representation of biofilm formation [25].

Biofilm formation on solid surfaces involves multiple stages (**Figure 3**) and five steps in biofilm formation are:

1. In the environment free-living microorganisms – Primary adhesion, reversible, and irreversible.

2. Formation of microcolonies, Irreversible attachment.

3. Development of a continuous biofilm, Maturation I.

4. Sloughing off of biofilm parts, Maturation II.

5. Transport of biofilm particles (flocs) throughout the system, initiation of further biofilm formation, Dispersion.

2.3.1. Influence of environmental factors on the development of biofilms in the pipeline

Environmental conditions and sites that favor the emergence of biofilms and the reproduction of different species and numbers of microorganisms in water supply systems are the subject of many scientific researches [26, 27]. Changes may be the result of permanent or intermittent influences of physicochemical factors of the water environment [28, 29], which can be directly influenced by a particular microbiological population or indirectly through interactions between members of the microbiological community. While being transported through a pipeline network, treated water gets in contact with a number of different surfaces. Therefore, no materials to which the drinking water is exposed in the network should promote microbial growth or discharge any contaminants, which can support microbial growth into the water. The degree to which microorganisms attach to the wall of the tubes, their growth, and reproduction depend on environmental conditions [30–32].

The rate of biofilm growth depends on:

•   the physicochemical properties of water (temperature, pH, hardness, organic materials, nutrients, disinfection residual concentrations, and heavy metals), water flow velocity, andcorrosion of distribution system pipes and fittings.

2.3.1.1. Impact of the surface roughness of the pipe inside the water supply system on biofilm development

The roughness of the surface of the water piping material is essential for the development of biofilms within them [33]. The roughness of the pipe surface can be a result of the corrosion process of the piping material, thereby enhancing the colonization of microorganisms and the creation of biofilms on such surfaces [34, 35]. Materials used to make pipes within a water supply network should have: a small roughness of walls and joints; resistance to internal and external pressures; resistance to corrosion and the impact of aggressive groundwater; resistance to decaying currents; and waterproofing inwards and outwards. Smaller concentration of microorganisms on the surfaces of smooth tubes (plastic materials) was found in comparison to rugged surfaces (cast iron, copper, and galvanized tubes) [32, 35]. Plastic materials are resistant to corrosion and the concentration of heavy metals in drinking water is excluded due to corrosion [36, 37]. Their surface roughness is lower than other materials, and since the tubes do not corrode, the inside of the pipe surface remains smooth, and has a longer life span.

2.3.1.2. Influence of chemical composition, nutrient content, and disinfectant of these water temperatures on the development of biofilms

The presence and concentration of nutrients, oxygen concentration, and optimal temperature and pH within biofilms provide support for growth and propagation of different microorganisms of heterogeneous populations. Bacterial biofilms change their properties depending on the concentration and composition of the nutrients in the water, which is mutated, thus increasing their ability to survive in the most difficult conditions. Microorganisms present in biofilms often develop increased tolerance to biocides [38–40]. The resulting biofilms are difficult to remove by disinfection, especially with the hardest available surfaces (pipe edges, T – profiles of water pipes, rough surfaces in water pipes) or the surface where water retention occurs.

2.3.1.3. Hydrodynamic conditions in the water supply system

Drinking water supplies from water to the point of consumption depends on topography and a mixture of gravity and pressure pipes is often used in the process. The purpose of a system of pipes is to supply water at adequate pressure and flow.

The conditions of the laminar flow of flow media are always present in the water supply network. In the laminar flow, a boundary layer is formed along the wall of the pipe in which the flow rate is smaller and decreases with a reduction of the distance from the surface. The result is a quiet microclimate of biofilm. At higher water flows, greater shear forces and biofilm removal from the surface occur. The consequence of this is the weaker development of biofilms on the surface of water pipes. However, if the biofilms develop at a high friction in turbulent flow, they are stronger, more strongly attached to the substrate, having higher density and physiological activity than with low friction or laminar flow [41]. The increased flow rate in the pipes often causes rupture of the incrustation from the inner surface of the tubing or the partial

mobilization of the deposits that mingle with the water and create additional pressure on the filtration systems leading to a reduction in the quality of drinking water. The created biofilms are difficult to remove with slow flow of water and hard-sided surfaces, and thus encourage additional microcorrosion on metal walls beneath the biofilm layer [42, 43]. Reduced flow and/ or stagnation of the flow may cause uncontrollable growth of biofilms, which can lead to mechanical seizures of water pipes, greater risk of microorganism development, disruption of heat transfer, increased friction resistance and metal biocorrosion. For the purposes of maintaining microbial quality, it is important to minimize transit times and avoid low flows and pressures [44]. It is highly recommended to avoid low-flow dead-ends and loops, although it is not always possible in practice. Low-flow sections of dead-ends should be as short as possible. Problems can be caused by both dead-ends and loops in the system, as they create long residence times and sections in which sediments are likely to collect. The risk may be elevated in seasons with greater rainfall, where soil moisture conditions will increase the likelihood of a pressure gradient developing from the soil to the pipe. Water quality may also deteriorate on recharging where surges may dislodge biofilm, leading to esthetic problems. Due to the fact that intermittent systems are intrinsically vulnerable, hazards should be controlled in the immediate vicinity of pipes. In the longer term, it is important to reduce intermittence; in certain areas, this can be easily achieved by using or rehabilitating service reservoirs. A backflow event will be a sanitary problem if there is cross-connection between the potable supply and a source of contamination. Reviews of waterborne disease outbreaks in municipal systems often identify backflow events as a causative factor.

2.4. Microbiological composition of biofilms

The emerging biofilms in drinking water distribution systems can be transient or long-lived habitats for sanitary–hygienically important microorganisms. Biofilm is composed of a large number of bacteria including *Legionella* spp., *Klebsiella* spp., *Pseudomonas* spp., *Mycobacterium*, *E. coli*, and other organisms such as protozoa (amoebae), parasites, and enteroviruses [27, 28, 45]. These microorganisms can be linked to an already existing biofilm, where so integrated can survive for several days or weeks, depending on the biology and ecology of the organism and environmental conditions. Microorganisms in biofilm are often resistant to biocides and it is hard to remove them, especially from hard-to-access places such as pipe edges, T – joints, and rough inner surfaces. In this way, they pose a potential danger of drinking water contamination, and thus a health hazard for humans [4, 42, 43]. There are several reasons why biofilms are of interest in medical, industrial, and natural contexts [46]. For example, they sometimes act as reservoirs from which pathogens are disseminated **Table 1**.

In the food industry, the development of biofilms on machine surfaces serves as a protection against pathogenic microorganisms from disinfectants. Likewise, in many industries, biofilms are responsible for major economic losses. *Legionella* spp. is frequently found in biofilms formed within drinking water pipelines. Also, biofilms are the cause for the contamination of water systems by legionellae. Legionellae regularly colonize water supply systems and devices, and people are infected through the inhalation of a contaminated water aerosol.

Industry	Problems
Potable water distribution	Reduction of flow rates Taints Unacceptably high bacterial numbers
Structural steelwork, pipelines	Accelerated corrosion
Heating and cooling operation	Reduced efficiency
Food processing	Reservoir of spoilage and potentially pathogenic microorganisms; possible survival of pathogens through underprocessing
Fluid transfer (general)	Reduction of flow rates and blocking of pipes

Table 1. Examples of industrial problems caused by biofilm formation.

2.4.1. Legionella spp.

As noted previously, *Legionella* bacteria thrive in biofilms. There are numerous advantages to bacteria growing in biofilms. For example, they can act as reservoirs from which the dissemination of pathogens may occur. *Legionella* spp. has been shown to be harbored within biofilms formed within drinking water pipelines. This investigation attempted to define these metal requirements and to adjust the composition of our defined medium accordingly. Defining the metal requirements of *Legionella* spp. is an important step in understanding its metabolism and in devising special media for isolation and maintenance. These findings suggest that metal plumbing components and associated corrosion products are important factors in the survival and growth of *Legionella* spp. [47]. Microbial hazards make the largest contribution to waterborne disease in developed and developing countries. Nevertheless, chemicals in water supplies can cause serious health problems – whether the chemicals are naturally occurring or derive from sources of pollution. *Legionella* spp. are ubiquitous intracellular microorganisms, an opportunistic human pathogen whose natural environment is aquatic environment [27, 46]. Supporting growth and survival of *Legionella* spp. in the environment is enhanced by their ability to form symbiotic relationships with other larger microorganisms including protozoa (*Acanthamoeba, Hartmanella, Valkampfia, Naegleria*, …). Actually, *Legionella* spp. lives inside protozoa (amoebae), which can be found in domestic water supplies [48, 49]. Biofilms can occlude pipework, resulting in areas of poor flow and stagnation with higher risk of *Legionella* growth. Also, the presence of both biofilms and amoebae has a twofold protective effect for the bacteria in the system [50]. For example, it increases the organic load and inactivates residual chloride levels of disinfectant. Likewise, biofilms and bacteria within them (including *Legionella* spp.) grown inside amoebae are more tolerant to chlorine and other antimicrobial agents at concentrations above those commonly used to disinfect water supplies [48]. Because bacteria in biofilms are relatively resistant to standard water disinfection procedures, *Legionella* are able to enter and colonize potable water supplies [40].

Enhanced resistance against are disinfectants by adaptation to biofilm conditions, intracellular localization in cells and cysts (resting stages of protozoa), *Legionella* spp. are typical biofilm-related pathogens as they survive in protozoa, which graze on biofilms.

2.5. Legionnaires' disease

Bacteria of the genus *Legionella* are important causes of the both community-acquired and nosocomial pneumonia. Legionnaires' disease (LD) is a form of interstitial pneumonia that is normally transmitted via aerosol, for example, from the environment to humans mainly through the inhalation of contaminated aerosols (e.g., mist droplets containing the bacteria) [32]. Contaminated water sources such as domestic hot-water systems, swimming and spa pools, respiratory therapy equipment, cooling towers, fountains, and other devices that utilize public water supply can produce the aerosol containing legionella bacteria. Legionnaires' disease affects all age groups and more often elderly people, particularly those with chronic cardiac, pulmonary and renal diseases. Immunocompromised patients are particularly at high risk. Immunosuppression is commonly associated with nosocomial infection with legionella (90%) compared with community-acquired cases [51–53]. Legionnaires' disease involves multiple organs but pneumonia is the most common presentation, especially in immunocompromised patients [33]. Legionella is responsible for 2–15% of pneumonias in the general population. There are no reliable clinical, laboratory, or radiological indicators that could with certainty differentiate Legionnaires' disease from other pneumonias. Consequently, clinical doubts should be always confirmed with special laboratory tests (culture, detection of antigen in respiratory secretion or urine, serologic tests, and molecular diagnostics) [34]. LD is an important cause of hospital-acquired pneumonia [35]. The appropriate antibiotic should be administered in the treatment of Legionnaires' disease as early as possible. New macrolides, azithromycin, and fluoroquinolones, doxycycline, and rifampicin are traditionally recommended for the treatment of Legionnaires' disease [34]. Therefore, all patients with a more severe clinical picture or severe accompanying chronic diseases and compromised immunity require an antibiotic efficient against legionella during the onset of the treatment [36, 37]. In epidemiology, we divide diseases into antroponoses and zoonoses, and legionary disease is neither, because it is related to the environment as a source, so we can call it econoses. Mainly, it is related to human dwellings and conditions that man created by its activities attempting to please himself, because the occurrence of disease in natural conditions is extremely rare. It is the price of progress and punishes any omission in technical performance of building, but particularly punishes inadequate maintenance of humid air conditioning and water supply systems in buildings of public importance.

2.5.1. Travel-associated Legionnaire's disease

Tourism is a growing economy sector. According to the data from the World Health Organization, 940 million of people were traveling in 2010. Millions of people cross international borders every day, traveling in various parts of the world exposing them to a different health environment [54, 55]. Climate change, globalization, and other outcomes of industrialization change the epidemiology of infectious diseases, but even more noticeable, the appearance of old and forgotten diseases in areas where they have not previously occurred, with new clinical features, resistance to antimicrobial therapy, and risk for human health. Tourism, uncontrolled expansion of cities, exotic animals as pets, the uncontrolled import of food and population movements, opens the real possibility of the introduction of new pathogens. Over recent years

in our country, there are a growing number of tourists, who expect, when arriving in a new environment, this issue to be monitored [56, 57]. These can be epidemics caused by contagious diseases with the multiple causal pathways. The most common are viral infections of the upper respiratory tract, colds, but poor sanitation and unregulated water supply may also be related to epidemics of acute intestinal infectious diseases, in the last few years. However, it has become less frequent due to the significant improvements in water supply and the availability of fecal isolation. While spreading of contagious diseases can be hardly prevented via general precautions, including intestinal contagious diseases particularly with the drinking water transfer route, our responsibility is to ensure proper water supply to provide sufficient quantities of potable drinking water that must be constantly chlorinated as required by sanitary regulations in all developed countries. Nevertheless, epidemic incidents occur in the form of hydraulic epidemics. As a rule, they occur at small alternative water supply systems used in the peak season when existing water supply systems do not meet the amount of water needs due to the high consumption. Weather conditions can also affect waterborne epidemics – if there should be lack of timely reaction of expert services in watercools regarding the increased chlorination of drinking water in the case of large amounts of precipitation [58]. Legionnaire's disease has public health significance because of hard clinical picture and possible lethal issue. For objects where the disease is found, it means negative reputation and special requirements for continual epidemical measures. Implementation of preventive measures in different accommodation sites is the key to control of travel-associated Legionnaires' disease, which occurs after exposure to contaminated water aerosols. Therefore, it is important to monitor these facilities and educate their staff to implement preventive measures. In hotels with year around operation, the water system is continuously rinsed thus reducing the concentration of Legionella bacteria in the system. In hotels with seasonal work, water is stagnating while the property is closed and, if preventive measures before the opening of the facility are not implemented, the risk of Legionnaires' disease is increased. All hotels before opening have to pursuit epidemical measures to decrease risk of legionary disease [58]. Sampling and analysis of water is often carried out in order to gain orientation on the potential risk of the accommodation site under surveillance. Those arrangements are persuiting by virtue decree of sanitary inspection and with expert control employees from epidemiological department. Each epidemiological method used for disease prevention and health protection of its population is of all significance and vital to providing quality and safety in the tourism sector. Tourism industry and its workers should be aware of the public health safety importance being an inevitable requirement for the improved service quality ensuring high-quality guest experiences as well as competitive advantage of tourism industry.

2.5.2. Health risks associated with potable water on ships

Waterborne outbreaks have been associated with bunkering water of poor quality and causes such as:

- contaminated water supplied at the port.

- contaminated bunkered water.

- cross-connections between potable and non-potable water.

- poor design and construction of potable water storage tanks.

- unadequate disinfection.

In those ports which do not have a safe source of water, contaminated water bunkered from port can lead to a number of outbreaks due to enterotoxigenic *Escherichia coli, Giardia lamblia*, and *Cryptosporidium.* Legionnaires' disease is one of the most widely known forms of legionellosis. It is a type of pneumonia one acquires by inhaling aerosols, which contain an excessive quantity of *Legionella* bacteria. There are several reasons why ships are considered high-risk environments for the proliferation of *Legionella* spp. [46]. Firstly, source water quality can pose a health concern if it is treated only with a residual disinfectant prior to or upon bunkering, or untreated at all. Secondly, water storage and distribution systems on ships are complex, potentially providing numerous opportunities for bacterial contamination, as the risk of surge and back-siphonage increases due to ship movement [59]. Thirdly, there might be considerable variations in the temperature of potable water (caused, for example, by high temperatures in the engine room). High-water temperatures characteristic of some tropical regions can enhance the risks of bacterial growth and occurrence of *Legionella* contamination in cold water systems. Finally, proliferation is further stimulated by long-term storage and stagnation in tanks or pipes. It should be noted that *Legionella* spp. can proliferate in warm-water temperatures (ranging between 25 and 50°C), such as those encountered in showerheads and pools, which can lead to exposure through aerosolization occurring in showers and other plumbing fixtures. The production of water on ships can sometimes yield its own potential health problems. There are several different processes by means of which water can be produced on ships, such as reverse osmosis or seawater evaporation. Seawater gets demineralized through desalination, thus becoming more corrosive and capable of shortening the life of containers and conduits. Desalinated water can also cause health issues associated with a lack of minerals in seafarers' diets or the consumption of dissolved metals (e.g., lead, nickel, iron, cadmium, or copper) from corrosion products. Also, passengers and crew often characterize desalinated water as bland, flavorless and therefore unacceptable. Ships' evaporation systems are supplied with seawater, which is usually led directly into the evaporator after having been sucked in through sea chests. Reverse osmosis involves pretreatment and transport of water across membranes under pressure so that salts are excluded.

2.5.2.1. Drinking water supply and transfer chain on ships

Generally, the ship drinking-water supply and transfer chain consists of three major components:

1. the source of water coming into the port.

2. the water transfer and delivery system (including hydrants, hoses, water boats, and water barges), which provides numerous opportunities for the ingress of contaminants into the drinking water

3. the ship water system, which includes storage, distribution and onboard production of drinking water from overboard sources, such as seawater

To obtain reliable and comparable information about the sanitary status of the potable water installation, it is recommended that samples be taken at the same places (e.g., always at the tank and from the bridge deck) [60].

3. Conclusions

The presence of *Legionella* spp. in water is considered to pose a health risk for consumers, therefore monitoring and determination of risk factors on *Legionella* spp. presence is important for water quality preservation. The aim is to significantly improve health and well-being of populations, as well as to reduce health inequities and to ensure sustainable people-centered health systems [61–63].

In order to prevent the spread of epidemics, the European Working Group for Legionella Infections (EWGLI) was established. In the hotel accommodation, the most frequent preventive measure to reduce the risk of Legionnaires' is the implementation of pasteurization. The scientific approach proved the dependence of *Legionella* spp. presence with the concentration of metals and pointed to the potential public health problem. Water supply organizations should adopt network design and operating strategies that prioritize issues closely linked to water supply hygiene.

3.1. Monitoring: the key to successful antifouling strategies

Monitoring is crucial for timely detection of biofilms and countermeasure optimization. Because, technical systems are not sterile, carry biofilms (cleaning is more important than killing biofilm organisms), nutrients are potential biomass (nutrient limitation), disinfection is not cleaning and biofilm management: keeping biofilm formation below threshold of interference. Too, it is therefore important to carry out regularly preventive measures to reduce the risk of Legionnaires' disease for tourists and facility staff.

It is also important to list some of the recommendations for prevention:

- identify and prevent low pressures (particularly negative pressures) in the system.

- prevent pressure surges in the network and use low capacity hot water tanks.

- network design, which minimizes the risks of contamination during operational activities and avoids water stagnation, prevent cross-connections and backflow.

- design and operate service reservoirs to avoid stagnation and contamination by ingress.

- select construction materials that do not promote microbial growth.

- constructions or pipelines with less curvature, dead zones,

- body installation material – polymeric or copper-based pipes.

- use softened water for depositing the pipes, water must not be excessively hard (Ca^{2+} and Mg^{2+}).

- it is necessary to maintain hot water temperatures above 50°C and a cold water temperature below 20°C.

- use of disinfectants that penetrate biofilms, to limit the risk of re-contamination.

- shock treatment often inadequate (hyperchlorination, heat treatment, hydrogen peroxide plus peracetic acid, etc.) to eradicate legionellae contained in biofilms.

3.2. Future prospects for the prevention of Legionnaires' disease

With the development of new technologies and the spread of new findings related to *Legionella* spp., new perspectives for the prevention of Legionnaires' disease are opening up.

Therefore, it would be beneficial to carry out projects and/or research that would be based on finding the relationship between energy savings for water heating in households, hotels, ships, and risks associated with the occurrence of Legionella spp. It would also be useful to develop mathematical models (based on risk analysis) to predict the occurrence of Legionella as well as to determine the long-term effect of currently used disinfection strategies on Legionnaires' disease in the world. Therefore, it is advisable to provide:

1. Development of methods for *Legionella* spp. enumeration in water distribution system sediments, in suspension and in protozoa.

2. Assessment of the main economic, environmental, and genetic factors associated with *Legionella* colonization and persistence in households, hotels, boats, etc. within their water distribution systems.

3. Assessment of the burden of legionellosis associated with water contamination.

4. Determination of the effect of various disinfection methods on *Legionella* persistence in pilot scale studies.

5. Development of a mathematical model for *Legionella* colonization based on monitoring and pilot scale data and validation of the mathematical model in full scale studies.

6. Development of the evidence-based risk management strategy for *Legionella* in households, hotels, boats, etc. within their water distribution systems.

It is to be expected that the results obtained will provide a fresh insight into Legionelle's ecology in hot water supply systems. They will present new information necessary for the control of *Legionella* in the in-house water distribution systems of low economic regions. Main factors affecting the multiplication and persistence of these bacteria will be established. The potential control mechanisms (optimal disinfection conditions and predictive modeling) will be established. The obtained data will be useful not only scientifically but also for epidemiological control, clinical diagnostics and household, hotel or ship management.

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