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Thermodynamic And Biologic Modelling Of *Legionella Pneumophila* In Biofilms In Domestic Hot Water Systems

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INTRODUCTION

Legionella control determines DHW energy savings

The production of Domestic Hot Water (DHW) dominates the total energy demand. One of the main reasons for the high energy demand is that DHW is stored and distributed at temperatures above 55°C to mitigate the risk of infecting the DHW system with *Legionella pneumophila*. At these temperatures, *Legionella* bacteria are effectively killed. For most of the applications of DHW temperatures of only 30-40°C are required. This disparity (between 55 and 30-40°C) doubles the temperature difference between the DHW system and the environment and has a detrimental effect on the efficiency of DHW production units.

The aim of this research is to develop a simulation model that allows assessing the infection risk for *Legionella pneumophila* in the design phase of a DHW system in dynamic conditions. With the validated simulation model HVAC designers will be able firstly to thoroughly assess the infection risk associated with their design and secondly to optimize the temperature regimes, choose better hydronic controls and reduce the energy demand for DHW production.

However, developing a simulation model requires a better understanding of *Legionella*-containing biofilms. To get better knowledge, two methodologies are followed:

1. Predicting *Legionella pneumophila* in biofilms based on thermodynamic and biologic equations (in simulation model)
2. Measuring of *Legionella pneumophila* in biofilms (in test rig)

METHODOLOGIES

Predicting *Legionella pneumophila* in biofilms based on thermodynamic and biologic equations (in simulation model)

A simulation model is developed that allows to investigate the infection risk for *Legionella* in the design phase of a DHW system and to test the effectiveness of disinfection techniques on an infected system. *Legionella pneumophila* species appear in water and in biofilm. This biofilm structure is composed of a consortium of microbial cells that are attached to the surface and associated together in a matrix. Modelling of the biofilm is really important because 95% of *Legionella* are surface-associated (Flemming, 2002). Furthermore, *Legionella* bacteria present in the biofilm are protected against environmental factors and water disinfection treatments (Cervero-Aragó, 2015). For example, research reported a better resistance of *Legionella pneumophila* to higher temperatures. Therefore, the association established between *Legionella pneumophila* and amoebae in biofilms in domestic hot water systems indicate an increased health risk.

Figure 1 shows the temperature dependent growth function of *Legionella pneumophila* bacteria in water and in biofilm.

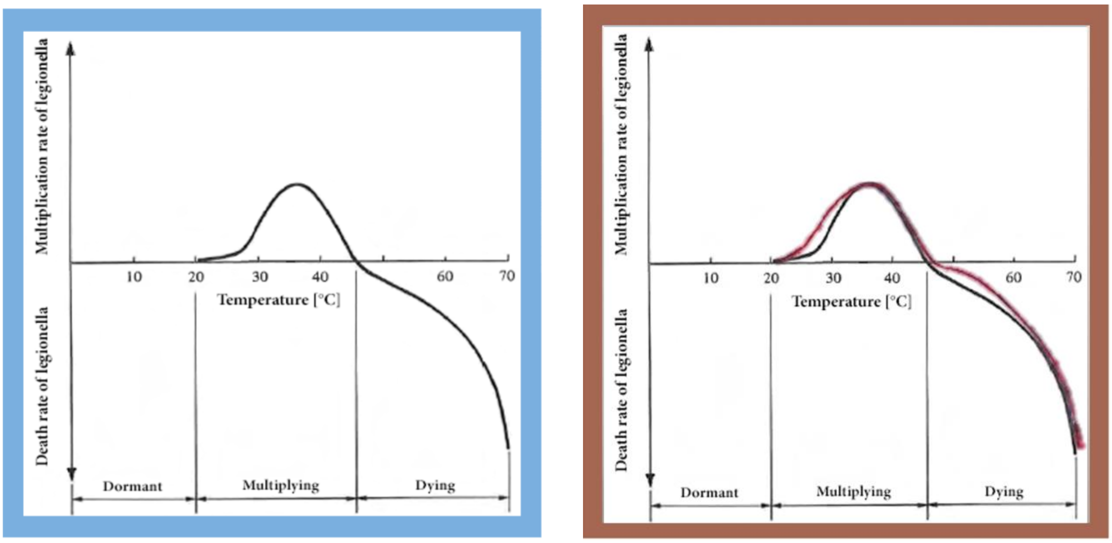

Figure 1. Growth function of *Legionella pneumophila* in water (left, black line) and in biofilm (right, red line) (Brundrett, 1992)

Figure 2 shows the modelling approach of *Legionella* concentrations in pipe models.

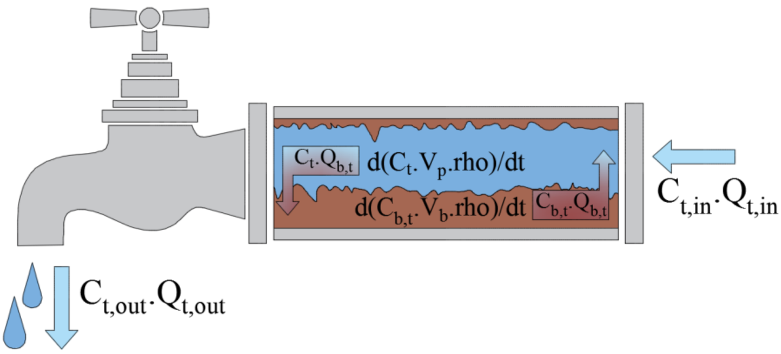

Figure 2. Concentration of *Legionella pneumophila* in DHW pipe

An example of modification of one of the adapted pipe models can be seen in *Figure 3*. The grey rectangles represent the addition of biofilm and the black circles the exchange of bacteria between biofilm and water.

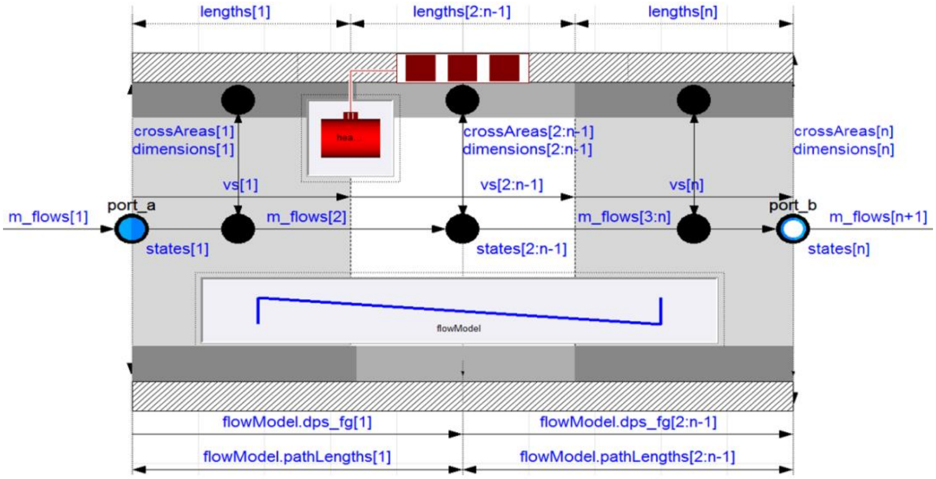

Figure 3. Dynamic Pipe model in Modelica library with addition of *Legionella pneumophila* growth equations

When implementing the adapted pipe model in a DHW recirculation system (*Figure 4*), simulation results of one apartment building case study show that it is possible to lower the DHW production temperature from 61°C to 50°C, while adding shock disinfection every 12 days at 70°C for 3 minutes. According to the simulations this measure does not increase infection risk and reduces energy use by 34%.

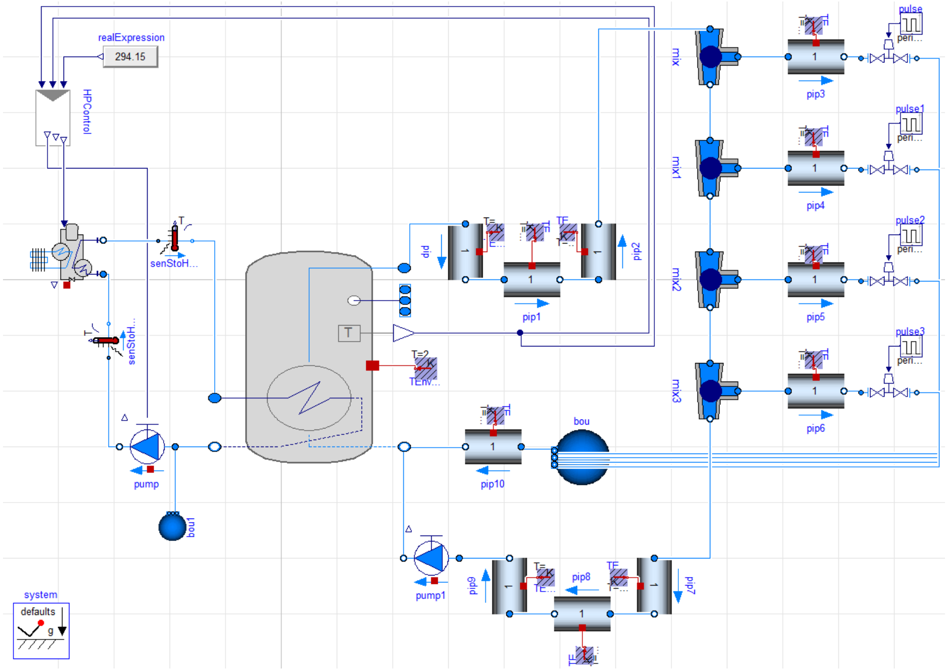

Figure 4. Simulation model of DHW recirculation system of an apartment building

Measuring of *Legionella pneumophila* in biofilm (in test rig)

Eradication of *Legionella* requires a better understanding of *Legionella*-containing biofilms. That is why in addition to the modelling work, a test rig is built. The test rig is 23m high and consists of 2 real hot water distribution systems which are contaminated with *Legionella pneumophila* (*Figure 5*). A "biofilm box" system composed of coupons is installed in the distribution system to collect the biofilm. Parameters for biofilm and *Legionella pneumophila* growth and removal are validated in the simulation model based on the biofilm studies performed in the test rig.

The test rig part of the 'Instal2020' project and is constructed in collaboration with the Belgian Building Research Institute (BBRI/WTCB/CSTC) in their accredited laboratory. The test rig serves to run experiments that allow testing, validating and improving the simulation model, to see if all relevant parameters for the prediction of *Legionella* growth are accurately predicted and to test the assumptions that are made to close the gaps in the available knowledge. Therefore, the test rig met the following specifications:

1. be composed of realistic elements of DHW systems,
2. have flexibility to test different system configurations,
3. allow to apply dynamic use patterns,
4. monitor water velocity and temperature at the inlet and outlet of each specific section of the DHW system,
5. have a number of *Legionella* sampling points that allow to take samples without being exposed to contaminated water,
6. allow easy disassembly, to decontaminate the whole system between tests,
7. have a large contaminated water storage.

The test rig is up and running and two system configurations will be simulated and tested. For each configuration, an 'as is' test will be followed by a set of 2 additional tests, the first with altered temperatures for low energy use (and high infection risk), the second running a decontamination procedure on the infected system. This test rig allows model validation under different operating conditions.

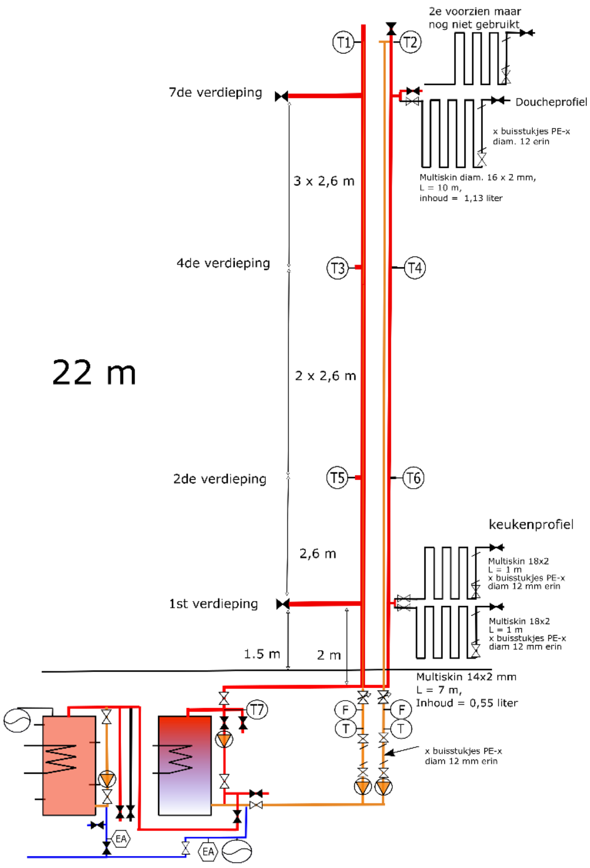

Figure 5. Configuration of the test rig with in red supply and in bleu retour pipes. There are two systems: a pipe-in-pipe system on the left and a recirculation system on the right

A comparable pilot scale system located at the Scientific and Technical Building Centre (CSTC) in France showed that although *Legionella* diversity was reduced, *Legionella pneumophila* remained after the heat shock and chemical treatments, respectively. The biofilm was not removed, and the bacterial community structure was transitorily affected by the treatments. Their findings state that *Legionella spp.* seem to resist and proliferate in spite of the different treatment procedures applied. The authors of this work suspect that they measured living and dead DNA together. Furthermore, the test rig was not conducted out of often used DHW system materials.

PRACTICAL IMPLICATIONS

With the thermodynamically validated simulation model new system design guidelines will be proposed based on an optimization study that looks for the trade-off between infection risk and energy efficiency.

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