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Modelling bacterial biomass in a non-chlorinated drinking water distribution system

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Abstract

Water quality can deteriorate as it travels through a drinking water distribution system (DWDS). The DWDS offers reaction surfaces and contact time and, thus, acts as a bioreactor where biofilms develop that influence biomass dynamics. Under normal operational conditions the biofilm is in a steady state and the exchange of biomass between the biofilm and the bulk water phase is in equilibrium. When this equilibrium is disturbed, e.g. by a hydraulic incident, there is a potential of release of biomass from the biofilm leading to higher concentrations of biomass in the drinking water. This could lead to a discolouration event and may have an impact on microbial water quality. The main issue for a water company is to know where in the network the risk of these disturbances of the equilibrium is the largest and what control measures can be taken. The goal of our research is to combine and improve water quality models and a hydraulic network model to determine high and low risk locations in the DWDS with respect to bacterial biomass. As a first result a conceptual model, with parameter values based on internationally published laboratory and in situ measurements in the DWDS, has been developed.

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Keywords: drinking water distribution; water quality modelling; bacterial growth; risk based modelling

1. Introduction

1.1 Problem definition

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In the Netherlands, the distributed drinking water does not rely on residual disinfectants. To control and minimize growth of micro-organisms, the drinking water is produced with low concentrations of degradable substances (i.e. assimilable organic carbon (AOC)). Some dynamics of increase and decrease of micro-organisms in the water (biomass) during residence in the DWDS is to be expected [1]. Micro-organisms can multiply and accumulate in the water phase but also on the interface between the water phase and surfaces (particulate material and the pipe wall) in the DWDS, leading to the development of biofilms.

Under normal operational circumstances in the DWDS the biofilm is in equilibrium with its environment and there is little net exchange of biomass between water and biofilm. In case of a disturbance of the equilibrium there is a risk of biomass detachment which may result in discolouration, increased biological active particulate material and/or detachment of biofilm related opportunistic pathogens such as *Legionella pneumophila*.

The goal of our research is to identify areas of high risk of potential release of biomass and to evaluate mitigation strategies. Risk is defined as the combination of probability of a disturbance and its effect. We are aiming at determining the typical circumstances in which, and where in the distribution network, increases in total microbial biomass in the drinking water may occur, and also how much increase is considered a large effect.

1.2 A modelling approach

There are three basic alternative approaches to obtain knowledge on the growth of biomass in a given DWDS, namely based on measurements, expert knowledge (operational expertise, literature, scientists), or models. All approaches have their own merits and most is learned from combining information from all three. The pros and cons regarding these three different approaches are: 1) Measurements provide information of the reality, allow validation and are therefore of great value. However, they have the drawback of restricted availability, a limited number of locations and circumstances that can be studied, and have limited elucidative capacity. 2) Expert knowledge based on the combination of theory and observations has an advantage when it is not available from any other source, provides an integral view, and can be used for validation. However, it is difficult to translate this knowledge to specific/different DWDS. Also, there is the risk of bias towards specific situations due to generalization of assumptions and missing insights. In addition, operational expertise is not fool proof as it tends to overly focus on some areas and ignore others. 3) Models allow an integral approach to processes, extrapolation to locations without data, predictive capacity, and therefore sensitivity analyses and evaluation of management strategies. They also provide information on additionally required data or identify knowledge gaps. The most important drawback of models is that the quality of models depends on the quality of data and understanding of the complex physical, chemical and biological processes. Therefore a combination of measurements and theoretical modelling will add to expert knowledge for future optimization of drinking water quality.

1.3 Existing models

Available models from the literature are either statistical models e.g. [2], based on regression analyses, or deterministic models, based on a theoretical approach (e.g. RIGA [3], ZHANG [4], SANCHO [5], and PICCOBIO [6]). Both types of models have pros and cons, resulting from the different approaches that are used. Where statistical models are based on observations, deterministic models use understanding of physics, chemistry and biology. Most of the existing models are not yet applied in non-chlorinated conditions. Most available models have the drawback that they are very complex and often contain (too) many interdependent parameters, making it difficult to validate [3]. Even if good predictions are obtained it is hard to tell why and if this will be the same under different conditions, making these models less suited for sensitivity analyses or water management. Other drawbacks are that calculating times can be substantial and not all existing models are translated to a water quality model in a DWDS. Although existing models have drawbacks from a perspective of risk identification, they serve as a valuable starting point.