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A comparison of additional treatment processes to limit particle accumulation and microbial growth during drinking water distribution

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ABSTRACT

Water quality changes, particle accumulation and microbial growth occurring in pilot-scale water distribution systems fed with normally treated and additional treated groundwater were monitored over a period of almost one year. The treatment processes were ranked in the following order: nanofiltration (NF) > (better than) ultrafiltration (UF) > ion exchange (IEX) for limiting particle accumulation. A different order was found for limiting overall microbial growth: NF > IEX > UF. There were strong correlations between particle load and particle accumulation, and between nutrient load and microbial growth. It was concluded that particle accumulation can be controlled by reducing the particle load in water treatment plants; and the microbial growth can be better controlled by limiting organic nutrients rather than removing biomass in water treatment plants.

The major focus of this study was on microbial growth. The results demonstrated that growth occurred in all types of treated water, including the phases of bulk water, biofilm and loose deposits. Considering the growth in different phases, similar growth in bulk water was observed for all treatments; NF strongly reduced growth both in loose deposits and in biofilm; UF promoted growth in biofilm, while strongly limiting growth in loose deposits. IEX had good efficiency in between UF and NF, limiting both growths in loose deposits and in biofilm. Significant growth was found in loose deposits, suggesting that loose deposit biomass should be taken into account for growth evaluation and/or prediction. Strong correlations were found between microbial growth and pressure drop in a membrane fouling simulator which proved that a membrane fouling simulator can be a fast growth predictor (within a week). Different results obtained by adenosine triphosphate and flow cytometry cell counts revealed that ATP can accurately describe both suspended and particle-associated biomass, and flow cytometry files of TCC measurements needs to be further processed for particle loaded samples and/or a pretreatment protocol should be developed.

1. Introduction

Treated drinking water enters distribution systems with a physical load (particles), a microbial load (biomass) and a nutrient load (biomass and nutrients, Fig. 1). As a result of biological and physiochemical processes during drinking water distribution, the water at consumers' taps has, in general, a lower quality than the treated water at the treatment

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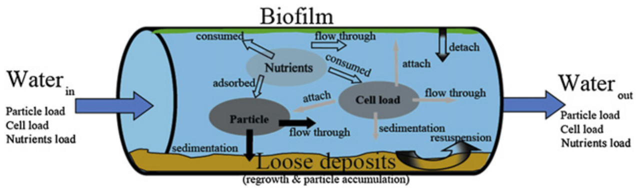

Fig. 1 – Schematic drawing of processes of particle accumulation and growth in drinking water distribution system, interaction between particle load, cell load and nutrients load in treated water.

plant (Hoehn, 1988; Jones and Tuckwell, 1993; Lee et al., 1980; Matsui et al., 2007; Verberk et al., 2007; Vreeburg and Boxall, 2007; Wable and Levi, 1996). There is a wide consensus that the final goal of water utilities should be to offer good quality drinking water at customers' taps rather than at the treatment plant. The two main processes that threaten tap water quality are particle accumulation (Vreeburg and Boxall, 2007) and microbial growth (Van Der Kooij, 2000).

Particle accumulation can cause a number of negative effects on drinking water quality. Looking at it physicochemical, studies on particles in drinking water distribution systems found an accumulation of both organic (Gauthier et al., 1999; Lehtola et al., 2004b; Zacheus et al., 2001) and inorganic contaminants (Lytle et al., 2004; Peng et al., 2010; Vreeburg et al., 2009). From a biological standpoint, by offering nutrients and a surface area for bacteria to grow on and by protecting bacteria from disinfectant residuals, accumulated particles can enhance growth (Gauthier et al., 1999). Moreover, the resuspension of accumulated particles causes discoloration events that are directly linked to customer complaints (Vreeburg and Boxall, 2007). It has been shown that water quality can be improved by removing loose deposits from the distribution system (Lehtola et al., 2004b).

Microbial growth during water distribution is undesirable because growth can lead to hygienic, aesthetic and technical problems, such as the proliferation of opportunistic pathogenic bacteria (Feazel et al., 2009), deterioration of taste and odor (Hoehn, 1988), and bio-corrosion of pipe material (Lee et al., 1980).

Since distribution systems are complex systems, limited operational action can be taken to improve the water quality after the water leaves the treatment plant. The best way to maintain high water quality throughout the distribution system is to produce high quality water that limits particle accumulation and microbial growth. In the last few decades, a number of additional drinking water treatment processes such as membrane filtration (Peltier et al., 2003; Wable and Levi, 1996) and ion exchange (Bolto et al., 2002) have been developed and applied to improve the produced water quality. To limit particle accumulation, loose deposits can be efficiently controlled by reducing the particle load in the treated water, for example by ultrafiltration (Vreeburg et al., 2008). Growth can be controlled when the assimilable organic carbon (AOC) is lower than 10 μg c/l without disinfectant residual (Van der Kooij, 1992) or 50–100 μg c/l with disinfectant residual (LeChevallier et al., 1987) or biodegradable organic carbon (BDOC) lower than 160 μg/l with disinfectant residual (Servais et al., 1995). However, the relationship between AOC/BDOC and growth in the distribution system is still being investigated. Low AOC/BDOC levels can be achieved by using existing treatment systems, including sand filtration, but sometimes additional treatment, such as ion exchange, ultrafiltration or nanofiltration, can be necessary.

Such additional technologies have been used or are considered for use in new treatment plants or for the upgrading of existing treatments. In order to optimize water quality at an acceptable cost, there is a clear need to evaluate and compare how these technologies will improve treated and distributed water quality. Recently, research comparing different treatment streams on optimizing bacteriological water quality has been done. However, in the research only the treated water quality has been considered (Ho et al., 2012).

The processes of particle accumulation and growth are not independent of each other, but are closely related and influence each other. The multidimensional quality aspects of treated water should be evaluated to determine the deterioration potential of water treated by different additional treatments. The primary objective of this study was to evaluate and compare the performance of three additional treatment systems on limiting particle accumulation and microbial growth. The particle accumulation and growth were directly correlated with parameters which can be used to design new treatments or improve the current ones. The major focus of this current work was on microbial growth. Overall, growth was evaluated by taking into account growth in all phases: bulk water, biofilm and loose deposits. At the same time, the influence of removing nutrients and/or reducing biomass on growth was studied. Additional consideration was given to a fast prediction tool for the potential of overall growth.

2. Material and methods

A pilot system was set up at pumping station de Laak of Oasen Water Company, in the Netherlands. The pumping station uses groundwater as source water. After abstraction, the water is treated by aeration, filtration, softening, carry-over sand filtration, activated carbon filtration and UV disinfection. The water produced by this treatment train is referred to as feed water in this paper. To study their effects, more additional treatment processes were added to further improve the water quality. The selected processes were nanofiltration (NF), ion exchange (IEX) and ultrafiltration (UF) (Figure S1, supplementary data). UF was selected with the aim to strongly reduce the number of particles/cells. The UF membrane was an S1.5 MB 2.0 membrane (pore size 0.02 μm, tubular UF module manufactured by Dizzer). IEX was selected as it can reduce the concentration of organic nutrients. The IEX resin used was Purolite 860 resin. In order to maintain a low organic nutrient concentration (DOC < 0.5 mg/l), 3 parallel IEX-columns were used. Resins were renewed every 3 weeks (one column each week). NF was selected as it can strongly reduce both the particles/cells and the organic nutrients. The nanofiltration membrane was NP90-2540 (manufactured by FILMTEC, spiral wound NF membrane). Since the treatment