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Estimates of microbial quality and concentration of copper in distributed drinking water are highly dependent on sampling strategy

Markku J. Lehtola[a,*], Ilkka T. Miettinen[a], Arja Hirvonen[c], Terttu Vartiainen[b,c], Pertti J. Martikainen[c]

[a]*Laboratory of Environmental Microbiology, National Public Health Institute, Department of Environmental Health, P.O. Box 95, FI-70701, Kuopio, Finland*
[b]*Laboratory of Chemistry, National Public Health Institute, Department of Environmental Health, Kuopio, Finland*
[c]*Department of Environmental Sciences, University of Kuopio, Kuopio, Finland*

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Abstract

The numbers of bacteria generally increase in distributed water. Often household pipelines or water fittings (e.g., taps) represent the most critical location for microbial growth in water distribution systems. According to the European Union drinking water directive, there should not be abnormal changes in the colony counts in water. We used a pilot distribution system to study the effects of water stagnation on drinking water microbial quality, concentration of copper and formation of biofilms with two commonly used pipeline materials in households; copper and plastic (polyethylene). Water stagnation for more than 4 h significantly increased both the copper concentration and the number of bacteria in water. Heterotrophic plate counts were six times higher in PE pipes and ten times higher in copper pipes after 16 h of stagnation than after only 40 min stagnation. The increase in the heterotrophic plate counts was linear with time in both copper and plastic pipelines. In the distribution system, bacteria originated mainly from biofilms, because in laboratory tests with water, there was only minor growth of bacteria after 16 h stagnation. Our study indicates that water stagnation in the distribution system clearly affects microbial numbers and the concentration of copper in water, and should be considered when planning the sampling strategy for drinking water quality control in distribution systems.

Keywords: Drinking water; Stagnation; Bacteria; Biofilms; Copper; Plastic; Distribution system; Quality control

Introduction

The number of microbes in drinking water generally increases in a distribution system (Zacheus et al., 2001; Pepper et al., 2004). Most of the microbial growth in drinking water distribution systems occurs in biofilms (Laurent et al., 1993; Zacheus et al., 2001) and detachment of bacteria from biofilms has been noted to account for a major proportion of the planktonic cells present in drinking water (Van der Wende et al., 1989; Stoodley et al., 2001). Pepper et al. (2004) claimed that the household distribution system, for example the

*Corresponding author. Tel.: +358 17 201159; fax: +358 17 201155.
E-mail address: markku.lehtola@ktl.fi (M.J. Lehtola).

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household taps, are the most critical source of bacteria in drinking water distribution systems.

Many papers have demonstrated that environmental, autochthonous bacteria growing in drinking water are not a threat to human health at any concentration (Allen et al., 2004; Bartram et al., 2004; Edberg and Allen, 2004). However, many bacteria growing in drinking water have potentially pathogenic features, and thus can act as opportunistic pathogens (Pavlov et al., 2004). This may pose a risk, especially for those consumers with an impaired immune system (Pavlov et al., 2004).

The European Union has issued a drinking water directive (Council directive 98/83/EC, 1998), but there is no numeric limit value for colony counts in drinking water. However, there are indicator parameters and it is stated that there should be no abnormal changes in the colony counts of drinking water. Also, according to the directive, water quality should be monitored from those taps that are normally used for human consumption. In the USA, the acceptable level for heterotrophic plate counts (HPC) in drinking water is less than 500 CFU/ml, and in Canada, the guideline for HPC is 500 CFU/ml (Robertson and Brooks, 2002). In Australia, the guideline is 100 CFU/ml for disinfected supplies and 500 CFU/ml for undisinfected supplies (Robertson and Brooks, 2002).

There are several papers indicating that if water stagnates in pipelines then this can affect the concentration of metals like iron, copper and lead in drinking water (Lytle and Schock, 2000; Zietz et al., 2001; Merkel et al., 2002; Sarin et al., 2004). Merkel et al. (2002) showed that the concentration of dissolved copper increased to a maximum after 10 h of stagnation of the water in the pipe-rig system and thereafter decreased. Lytle and Schock (2000) found that the concentration of copper increased with stagnation time in a pipe loop system until dissolved oxygen in the water declined it below 1 mg/l. However, there are no systematic studies on the effects of stagnation on microbial counts in drinking water distribution systems.

In Kuopio, Finland, we have set up a pilot scale drinking water distribution system consisting of pipes made from two commonly used materials in households: copper and plastic (polyethylene, PE). This pilot distribution system is built inside the building and simulates the cold-water plumbing systems present in domestic households. We have shown that the formation rate and the microbial community structure of biofilms were different in PE and copper pipes (Lehtola et al., 2004b). In this study, we tested the effects of different stagnation times on microbial counts in water and the effects of stagnation and flushing, simulating normal water consumption, on the growth of biofilms in copper and plastic pipes.

Materials and methods

Distribution system

The pilot scale distribution system consists of two parallel 10 mm (ID) copper (Tub-e by Outokumpu, SFS-EN 1057:1996, R290) and two parallel 12 mm (ID) composite (polyethylene-aluminum-polyethylene) plastic tubings (PE-RT/AL/PE-RT, Uponor–Unipipe) (Lehtola et al., 2004b). The length of the pipes is 100 m and the volume of the PE pipe is 11.3 l and that of the copper pipe is 7.8 l. The pilot distribution system was built 3.5 years before these experiments and has been used for studying the effects of disinfection and flow regime on biofilms and water quality (Lehtola et al., 2004b, 2005, 2006). The drinking water was produced from lake water in a pilot scale waterworks, where water treatment included chemical coagulation with ferric sulphate (Kemwater PIX-322, Kemira Finland), flotation and rapid sand filtration. Water hardness, alkalinity and pH were adjusted with lime and carbon dioxide. Water was finally disinfected with chlorine (NaOCl 0.6 mg/l) and UV-irradiation (approximately 70 mWs/cm^2). The waterworks produced water at a flow rate of 1.2 m^3/h. The purified water was collected into a 4 m^3 stainless steel tank before pumping to the pilot distribution network. Overflow was drained to the sewer. Pilot water samples were taken after the water tank, just before the pilot pipelines. Water pressure ranged from 3.0 to 3.5 bars.

Before starting the stagnation experiment, the pilot system was run at a constant water flow (0.2 l/min) for 2 months. In the stagnation experiment, water was left to stagnate in the pipeline system for 15 h 40 min (later termed as 16 h), then for 4 h, 2 h, 1 h and 40 min (twice). This stagnation program was modified from the German standard DIN 50931, 1999 which is used in metal stagnation studies. After each stagnation period, water was flushed through the pipeline for 5 min at a flow rate of 2.6–3.2 l/min. This flow rate corresponds to a flow velocity of 0.55–0.68 m/s (*Re* 5482–6747, turbulent flow) through the copper pipes and 0.38–0.47 m/s (*Re* 4505–5545, turbulent flow) through the PE pipes. This program was run daily. Water samples were taken once every 2–3 weeks, all in all 9 times. During the sampling, water samples were taken after each stagnation period into one litre bottles 30 s after the start of the water flow. The stagnation experiment lasted for 127 days.

Stagnation experiment with water in the laboratory

We studied microbial growth also in water samples. One litre water samples ($n = 4$) were taken from the PE and copper pipes after the last 40 min of stagnation and transferred into acid washed and sterile glass bottles.