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Effects of temperature and biodegradable organic matter on control of biofilms by free chlorine in a model drinking water distribution system

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Abstract

This study used annular reactors (AR) to investigate, under controlled laboratory conditions, the effects of temperature and biodegradable organic matter (BOM) on the free chlorine residual needed to control biofilm accumulation, as measured by heterotrophic plate count (HPC) bacteria. Biofilm was grown on PVC coupons, initially in the absence of chlorine, at 6, 12, and 18 °C, in the presence and absence of a BOM supplement (250 μg C/L) added as acetate. During the early stages of chlorine addition, when no measurable free chlorine residual was present, a reduction in biofilm HPC numbers was observed. Subsequently, once sufficient chlorine was added to establish a residual, the biofilm HPC numbers expressed as log CFU/cm^2 fell exponentially with the increase in free chlorine residual. Temperature appeared to have an important effect on both the chlorine demand of the system and the free chlorine residual required to control the biofilm HPC numbers to the detection limit (3.2 Log CFU/cm^2). For the water supplemented with BOM, a strong linear correlation was found between the temperature and the free chlorine residual required to control the biofilm. At 6 °C, the presence of a BOM supplement appeared to substantially increase the level of free chlorine residual required to control the biofilm. The results of these laboratory experiments provide qualitative indications of effects that could be expected in full-scale systems, rather than to make quantitative predictions.
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Keywords: Biofilm; Drinking water; Distribution system; Annular reactor; Biodegradable organic matter; Chlorine; Heterotrophic plate count

1. Introduction

Biofilms on drinking water distribution system pipes may lead to a number of unwanted effects on the quality of the distributed water. Bacterial growth may affect the turbidity, taste, odour and colour of the water (Servais et al., 1995). Biofilm growth and detachment could contribute cells to the bulk water (van der Wende et al., 1989; Chandy and Angles, 2001). One full-scale study showed that the fixed bacteria were linearly correlated to the suspended bacteria (Servais et al., 1995). Investigations of biofilms in a full-scale drinking water distribution system indicated that coliforms in the distribution system originated from the pipeline biofilms (LeChevallier et al., 1987). Biofilm may promote the deterioration of metallic pipe surface through a process known as microbially influenced corrosion (MIC) or biocorrosion (LeChevallier et al., 1993). Biofilms induce a disinfectant

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demand and consequently promote disinfectant decay in distribution systems (Chandy and Angles, 2001; Lu et al., 1999).

Various methods have been used to quantify biofilm. Several studies used adenosinetriphosphate (ATP) e.g. (van der Kooij et al., 1995; Boe-Hansen et al., 2002). Laurent and Servais (1995) have used potential exoproteolytic activity (PEPA). Work undertaken by Boe-Hansen et al. (2002) on low substrate water (AOC approximately 6 μg ac-C/L) showed that Acridine Orange Direct Count method (AODC) best described biofilm formation. Total protein and total carbohydrate were used by Chandy and Angles (2001) to monitor biofilm development. Heterotrophic plate count (HPC) accounts only for the culturable bacteria, which are a fraction of the total bacteria population (Block, 1992). However HPC counts are of interest because of their regulatory significance in some jurisdictions, and their wide use in biofilm investigations (e.g. Camper and Jones, 2000; LeChevallier et al., 1990; Zacheus et al., 2000; Ollos et al., 2003). The work discussed in this paper focussed on the enumeration of viable biofilm cells measured as HPC.

The factors that may influence the development of biofilm in drinking water distribution systems include the concentration of biodegradable organic matter (BOM), the disinfectant residual, the temperature, the pipe material, the presence of corrosion, and the shear at the biofilm–liquid interface (Ollos, 1998; LeChevallier et al., 1990, 1993). In the work of Ollos (1998) and Servais et al. (1995), it appeared that the key controlling factors of the biofilm level were the biodegradable organic matter and the disinfectant residual. Lund and Ormerod (1995) reported that the maintenance of a free chlorine residual of 0.05 mg/L was able to prevent biofilm formation on new plastic pipes during an 18-month investigation period.

The influence of pipe material on biofilm development has been investigated by a number of authors. It has been found that pipe material has a strong influence on disinfection efficiency (LeChevallier et al., 1990, 1993). Niquette et al. (2000) showed that the densities of bacterial biomass fixed on gray iron were from 10 to 45 times higher than those measured on plastic-based materials (PE and PVC), and cement-based materials had intermediate values. These results were obtained using a set of incubation devices placed in a distribution system, at a site where the chlorine residual was all the time less than 0.03 mg/L. Another survey conducted by Hallam et al. (2001) showed no evident relationship between the potential of biofilm to develop and the type of pipe material (glass, cement, MDPE, PVC) when chlorine concentrations were greater than 0.3 mg/L. When chlorine concentrations were less than 0.3 mg/L the biofilm potential was in the order glass < cement < MDPE < PVC; however, these differences were small in comparison with the impact of disinfection.

Lund and Ormerod (1995) found that biofilm formation appeared to be closely related to the fluctuations in water temperature. During the early stages of their pilot distribution system experiments, biofilm measured as dry weight was not produced until the temperature rose above 5 °C. Subsequently, during the next winter when the temperature dropped below 5 °C, biofilm production stopped in the ozonated and UV (ultraviolet) irradiated waters. The work of Ollos (1998) showed possible interactions between temperature, BOM, and shear stress on the biofilm level. For example, when easily degradable BOM was absent from the test water, temperature appeared to have essentially no effect while shear appeared to be important. In the presence of easily degradable BOM, temperature was important at lower shear stress.

In managing the distribution system as a bioreactor (Huck and Gagnon, 2004) the maintenance of a disinfectant residual is often chosen as the approach for controlling biofilm levels. Although a number of studies have demonstrated the importance of disinfectant residual and BOM in the control of biofilm accumulation, relatively little quantitative information is available regarding the combined effect of temperature and BOM on the control of biofilm by free chlorine. Consequently, the purpose of this study was to investigate, under controlled laboratory conditions, the effects of temperature and BOM on the free chlorine residual needed to control biofilm accumulation, as measured by heterotrophic plate count (HPC).

2. Materials and methods

2.1. Annular reactors

This study was performed using two jacketed annular reactors (ARs) Model 920LJ (BioSurface Technologies Corporation, Bozeman, Montana) operated in parallel. Nutrients were fed to one AR, but not to the other. Fig. 1 shows the experimental set-up of the annular reactor system. Basically, the ARs consist of two concentric glass cylinders and a rotating inner drum that houses 20 flush-mounted removable coupons. The test water flows in the region between the inner drum and the internal glass cylinder with biofilm accumulating on the coupons mounted on the inner drum wall. Each coupon has an exposed surface area of 19.5 cm^2 for biofilm growth. A temperature controller was used to maintain the temperature inside the ARs at the desired level by circulating a refrigerating liquid between the two concentric glass cylinders. Throughout the course of this study, the ARs were operated at a detention time of 2 h and a fixed rotational speed of 92 RPM. The surface area is an important factor for a reactor used to study

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