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Volatile organic compounds in natural biofilm in polyethylene pipes supplied with lake water and treated water from the distribution network

Ingun Skjevrak[a,*], Vidar Lund[b], Kari Ormerod[b], Hallgeir Herikstad[a]

[a]*Norwegian Food Safety Authority (Mattilsynet), Kyrkjevegen 325, N-3428 Sandnes, Norway*
[b]*Norwegian Institute of Public Health, P.B. 4404 Nydalen, 0403 Oslo, Norway*

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Abstract

The objective of this work was investigation of volatile organic compounds (VOC) in natural biofilm inside polyethylene (HDPE) pipelines at continuously flowing water. VOC in biofilm may contribute to off-flavour episodes in drinking water. The pipelines were supplied with raw lake water and treated water from the distribution network. Biofilm was established at test sites located at two different drinking water distribution networks and their raw water sources. A whole range of volatile compounds were identified in the biofilm, including compounds frequently associated with cyanobacteria and algae, such as ectocarpene, dictyopterene A and C′, geosmin, beta-ionone and 6-methyl-5-hepten-2-one. In addition, volatile amines, dimethyldisulphide and 2-nonanone, presumably originating from microorganisms growing in the biofilm, were identified. C8-compounds such as 1-octen-3-one and 3-octanone were believed to be products from microfungi in the biofilm. Degradation products from antioxidants such as Irgafos 168®, Irganox 1010® and Irganox 1076® used in HDPE pipes, corresponding to 2,4-di-tert-butylphenol and 2,6-di-tert-butylbenzoquinone, were present in the biofilm.

Keywords: Biofilm; Volatile organic compounds (VOC); Off-flavour; Lake water; Distributed water; Polyethylene pipes; Algae

1. Introduction

Biogenic volatile organic compounds responsible for offensive odours in fresh water are associated with many types of microorganisms. Fresh water algae produce a variety of volatile organic compounds (VOC) (Jüttner, 1988, 1995; Cotsaris et al., 1995) and bacterial degradation of organic material is known to produce odourous organic sulphides (Zechman et al., 1986; Gibson et al., 1997) and volatile amines (Larsson et al., 1978; Klochenko, 1996). Actinomycetes, which are responsible for the production of well-known odorous secondary metabolites such as geosmin and 2-methylisoborneol, are present in raw water reservoirs as well as in distribution systems (Niemi et al., 1982; Jensen et al., 1994).

The role of natural biofilm inside pipe lines as a potential source and reservoir for odorous VOC is, however, sparsely documented in the literature, and more knowledge on VOC present in biofilm at the distribution network is needed. Release of VOC from natural biofilm present in the distribution network may

*Corresponding author.
E-mail address: ingun.skjevrak@mattilsynet.no (I. Skjevrak).

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cause odour episodes in the drinking water supply. The aim of this project was to survey the presence, identity and origin of VOC in natural biofilms established within plastic pipes manufactured of high-density polyethylene (HDPE) at turbulent water flow. Test pipes for biofilm development were placed at the raw water sources and at different test sites on the water distribution system in order to compare VOC in the biofilm from the raw water sources with VOC in the biofilm from distant parts of the distribution network.

Materials used in pipes and coatings may promote microbial growth due to leaching of chemical compounds which microorganisms may use as nutrients (van der Kooij and Veenendaal, 1993; Schwartz et al., 1998). Thus, attention has also been paid to potential migration of specific compounds from the HDPE pipe material into biofilm.

2. Methods and materials

Natural biofilm was established within HDPE pipelines under turbulent water flow conditions. The biofilm was sampled at regular intervals over 1 year and analysed with respect to VOC.

2.1. Raw water supply and treatment of distributed water

Raw water was supplied from two lakes, Hagavatn and Langevatn. Hagavatn lake is an ultraoligotrophic lake whereas Langevatn lake is oligotrophic. The content of chlorophyll *a* in mixed water samples from Hagavatn at 1–4 m depth was on average $<1.7\,\mu g/l$, and the total number of bacteria (22 °C) corresponds to 167/ml at 0.5 m depth. The number of algae and cyanobacteria for both lakes is normally low. Typical algal species are *Dinobryon* spp. (*Chrysophyceae*), *Peridinium* spp., *Gymnodium* spp. (*Dinophyceae*) and *Tabellaria flocculosa* (diatoms). The temperature at the surface vary between 12 and 18 °C during summer, whereas the temperature at 25 m depth is 7 °C. During winter, the temperature at the surface is around 4 °C for both lakes. Turbidity of both lakes is low, and average TOC in Hagavatn and Langevatn was 0.7 and 1.7 mg/l C, respectively. The pH of raw water from Langevatn lake was 5.6–5.7. After treatment water from these two raw water reservoirs was distributed on two separate distribution networks. Water from Langevatn lake was filtered by gravitation through a $CaCO_3$ filter bed and chlorinated prior to distribution. The amount of sodium hypochlorite used for disinfection was adjusted in order to maintain a chlorine residue at 0.05 ppm after 30 min contact time. The pH of distributed water was 8.2–8.3, and the concentration of calcium corresponded to 20 mg/l. Water from Hagavatn lake was simply chlorinated and pH was adjusted to approximately 8 with NaOH prior to distribution. The pH of water from the distribution network supplied by Hagavatn lake varied from 5.5 to 6.5. Residual chlorine was not detected in water from any of the two distribution network test sites where the biofilm was sampled.

2.2. HDPE testpipes used for biofilm production

HDPE pipeline test sites, four in total, were located at the raw water sources and at the drinking water distribution system. Two of the four test locations were supplied with raw water from Lake Langevatn and Lake Hagavatn, respectively. Another two test sites were located at remote positions on the distribution networks. The distance from both treatment plants and the test sites at the distribution networks is approximately 30 km. The test sites on the distribution networks were located at Hinna and supplied with treated water from Langevatn, and at Sirevaag supplied with treated water from Hagavatn lake. The HDPE pipes were mounted in May 1999 and left with a continuous and constant water flow until the end of test period in October 2000. The first sampling of biofilm took place in September 1999, and sampling was repeated every 6–7 week until the end of the test period.

The HDPE pipeline assembly used for biofilm growth consisted of nine 20 cm pieces of HDPE pipe (i.d. 20.4 mm, PN 10) connected with brass unions. The quickfit unions provided easy detachment and replacement of test pieces for sampling of produced biofilm. At each of the four biofilm test locations, two pipelines, each assembled of nine HDPE test pieces, were mounted in parallel. One pipeline was made up of HDPE pieces (''Upoten'') previously used for similar testing under flowing water conditions for a period of 20 months. These HDPE pipe sections are referred to as ''aged'' in the forthcoming text. The other HDPE pipeline was assembled of a different brand of HDPE (''Selplast''), not previously used in contact with water. These pipe sections are referred to as ''new'' HDPE test pieces. This arrangement was applied in order to investigate migration of compounds from the HDPE material into biofilm. A water flow of 0.20–0.25 l/s through each of the HDPE pipelines was chosen to ensure turbulent flow conditions for this pipe dimension (Lund and Ormerod, 1995). The outlets of the HDPE pipes were put at a higher level than their inlets to avoid air bubbles in the pipeline.

2.3. Sampling of biofilm and water from the distribution network

Upon sampling, one test piece of HDPE pipe containing biofilm in the HDPE pipeline assembly was substituted by an identical, clean HDPE pipe section. This arrangement provides information on the time scale