Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Effect of water composition, distance and season on the adenosine triphosphate concentration in unchlorinated drinking water in the Netherlands

Paul W.J.J. van der Wielen, Dick van der Kooij*

KWR Watercycle Research Institute, P.O. Box 1072, 3430 BB Nieuwegein, The Netherlands

ARTICLE INFO

Article history:
Received 23 March 2010
Received in revised form
17 June 2010
Accepted 8 July 2010
Available online 16 July 2010

Keywords:
Adenosine triphosphate (ATP)
Drinking water
Microbial activity
Drinking water distribution system
Aeromonas
Heterotrophic plate count

ABSTRACT

The objective of our study was to determine whether water composition, distance to the treatment plant and season significantly affect the adenosine triphosphate (ATP) concentration in distributed drinking water, in order to resolve the suitability of ATP as an indicator parameter for microbial regrowth. Results demonstrated that the ATP concentration in distributed water averaged between 0.8 and 12.1 ng ATP L^{-1} in the Netherlands. Treatment plants with elevated biofilm formation rates in treated water, showed significantly higher ATP concentrations in distributed drinking water and ATP content was significantly higher in the summer/autumn compared to the winter period at these plants. Furthermore, transport of drinking water in a large-sized distribution system resulted in significantly lower ATP concentrations in water from the distal than the proximal part of the distribution system. Finally, modifications in the treatment significantly affected ATP concentrations in the distributed drinking water. Overall, the results from our study demonstrate that ATP is a suitable indicator parameter to easily, rapidly and quantitatively determine the total microbial activity in distributed drinking water.

1. Introduction

Regrowth of microorganisms in drinking water is undesired because multiplication of potentially pathogenic bacteria like *Legionella pneumophila* (Lawrence et al., 1999), nontuberculous mycobacteria (Falkinham et al., 2001; Torvinen et al., 2004), or *Pseudomonas aeruginosa* (Edberg et al., 1996; Lee et al., 2006) might occur. In addition, regrowth might result in esthetic problems, e.g. biofilm formation (van der Kooij, 2003), deteriorated taste and odor (Hoehn, 1988), growth of invertebrates (Levy et al., 1986; van Lieverloo et al., 2004), and/or technical problems, e.g. corrosion of pipe material (Lee et al., 1980). Growth of microorganisms in the drinking water distribution system can be prevented by maintaining a disinfectant residual in drinking water or by limiting the concentration of growth-promoting compounds in water that enters the distribution system.

Bacterial concentrations and microbiological changes in treated and distributed drinking water are mainly monitored by determining heterotrophic plate counts (HPC) on solid agar media (Bartram et al., 2003). The HPC method was originally developed by Robert Koch in 1881, and soon after introduction of the method, information became available about HPCs in drinking water (Frankland and Frankland, 1894). Nowadays, a wide diversity of methods is used to determine HPC values, which makes it difficult to compare results obtained from different countries (van der Kooij, 2003). Although HPC has proven its value as an indicator for the microbiological quality in drinking water (Bartram et al., 2003), there are some limitations related to the use of HPC. The microorganisms that are

* *Corresponding author*. Tel.: +31 30 60 69 642; fax: +31 30 60 61 165.
E-mail address: paul.van.der.wielen@kwrwater.nl (P.W.J.J. van der Wielen).
0043-1354/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.watres.2010.07.016

obtained with HPC represent only a small fraction (<1%) of the total microbial community in drinking water that is enumerated with microscopic or flow cytometric methods (Maki et al., 1986; Siebel et al., 2008). In addition, HPC methods can be time-consuming and usually require 3–10 days before results are available.

Adenosine triphosphate (ATP) is an energy-rich metabolic compound that is produced in all active organisms and, therefore, can be used as a parameter to determine the active microbial biomass in water (Holm-Hansen and Booth, 1966). An early study reporting ATP values in drinking water demonstrated that unchlorinated drinking water samples contained ATP-levels between 1 and 23 ng ATP L^{-1}, with free ATP concentrations being negligible (van der Kooij, 1992). In addition, it was also observed that ATP values correlated only weakly with HPC in drinking water (van der Kooij, 1992). Furthermore, a reference database with ATP concentrations of drinking water from 241 different treatment plants in the Netherlands is available (van der Kooij, 2003). Recently, ATP measurements in drinking water has regained interest (Berney et al., 2008; Deininger and Lee, 2001; Delahaye et al., 2003; Siebel et al., 2008), and results from most of these studies confirmed the absence of a strong relationship between HPC values and ATP concentration. Moreover, a strong relationship between total cell concentration and ATP was observed in drinking water samples (Deininger and Lee, 2001; Siebel et al., 2008). Although these studies provided valuable information on ATP in drinking water, there were some limitations in the different studies. Sampling methods, sample storage and transport conditions were poorly described (Siebel et al., 2008), sampling method was inaccurate to determine ATP reliably (Delahaye et al., 2003), a low number of drinking water samples was analyzed (Berney et al., 2008) or drinking water samples from only one facility or treatment plant were analyzed (Berney et al., 2008; Siebel et al., 2008).

The objectives of our study were to determine (i) the effect of water composition on the ATP concentration in unchlorinated distributed drinking water from six treatment plants, (ii) the effect of distance to the treatment plant on the ATP concentration in unchlorinated drinking water in the distribution systems, (iii) the effect of season on ATP concentrations in distributed drinking water and (iv) the relationship between ATP concentration, total cell numbers, HPC and *Aeromonas* plate count in distributed drinking water samples.

2. Materials and methods

2.1. Sample locations

The selection of water types analyzed in this study was based on source water used for drinking water production, total organic carbon (TOC) content in finished water, and size of the distribution system (Table 1). The unchlorinated distributed drinking water of four treatment plants that used groundwater (plant A, B, E and F) and of two plants that used surface water (plant C, D) were analyzed. The TOC content, easily assimilable organic carbon (AOC) concentration and biofilm formation rate in treated water of plants A, B, and C are low for drinking water in the Netherlands. In contrast, these concentrations in treated water of plants D, E and F are considered high in the Netherlands. The distribution systems of these six drinking water treatment plants were sampled during the periods June 2006, October/November 2006 and February/March 2007. In June 2006 nine treated water samples were taken at each treatment plant, together with drinking water samples taken from the tap of 18 different houses connected to the distribution system of the treatment plant. Nine houses were connected to the central part and nine houses were connected to the distal part of the distribution system. In October/November 2006 and February/March 2007, 27 different houses connected to the distribution system were sampled: nine to the proximal part, nine to the central part and nine to the distal part. Besides these 27 samples, three samples of the treated water were taken at each plant. The average distance of the proximal, central and distal part of the distribution system to each of the production plants is shown in Table 1. Before samples were taken for analysis of ATP, HPC, *Aeromonas*, total cell count and temperature, the tap was flushed until the water temperature remained stable for 30 s. Water samples were transported and stored at 4 °C and analyses were performed within 24 h after water sample collection.

Table 1 – The water source used for drinking water production and the biofilm formation rate and AOC level in the finished drinking water of six treatment plants.

Treatment plant	Water source	TOC (mg C L^{-1})	AOC (μg C L^{-1})	BFR (pg ATP cm^{-2} day^{-1})	Distribution system[b]		
					Proximal (km)	Central (km)	Distal (km)
A	Oxic groundwater	< 0.5	1.9	0.21	1.1 ± 0.4	4.0 ± 0.8	10.4 ± 1.5
B	Suboxic groundwater	1.0	ND[a]	ND	0.4 ± 0.4	3.3 ± 1.6	9.6 ± 1.1
C	Surface water	2.4	6.0	0.64	1.0 ± 0.5	5.7 ± 1.6	8.1 ± 1.9
D	Surface water	2.9	14.2	4.5	5.4 ± 2.2[c]	6.8 ± 1.3	13.7 ± 2.1
E	Anoxic groundwater	8.0	10.6	33.1	5.3 ± 0.9	17.3 ± 2.1	41.2 ± 2.4
F	Anoxic groundwater	3.8	8.0	17.6	3.0 ± 0.6	4.8 ± 0.4	11.2 ± 0.4

a ND is not determined.
b The average distance of the ten sampling locations in the proximal, central and distal part to the production plant.
c The difference in distance between proximal and central is not significant, because it was not possible to sample the distribution system near the treatment plant (distance < 2.0 km).