JOURNAL OF ENVIRONMENTAL SCIENCES XX (2017) XXX–XXX

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/jes

JES JOURNAL OF ENVIRONMENTAL SCIENCES

www.jesc.ac.cn

Occurrence and formation of disinfection by-products in the swimming pool environment: A critical review

*Rhys A.A. Carter, Cynthia A. Joll**

Curtin Water Quality Research Centre, Department of Chemistry, Curtin University, Perth, Western Australia 6102, Australia

ARTICLE INFO

Article history:
Received 31 January 2017
Revised 11 June 2017
Accepted 13 June 2017
Available online xxxx

Keywords:
Disinfection by-products
Disinfection
Swimming pool
Spa
Water quality
Health effects

ABSTRACT

Disinfection of water for human use is essential to protect against microbial disease; however, disinfection also leads to formation of disinfection by-products (DBPs), some of which are of health concern. From a chemical perspective, swimming pools are a complex matrix, with continual addition of a wide range of natural and anthropogenic chemicals *via* filling waters, disinfectant addition, pharmaceuticals and personal care products and human body excretions. Natural organic matter, trace amounts of DBPs and chlorine or chloramines may be introduced by the filling water, which is commonly disinfected distributed drinking water. Chlorine and/or bromine is continually introduced *via* the addition of chemical disinfectants to the pool. Human body excretions (sweat, urine and saliva) and pharmaceuticals and personal care products (sunscreens, cosmetics, hair products and lotions) are introduced by swimmers. High addition of disinfectant leads to a high formation of DBPs from reaction of some of the chemicals with the disinfectant. Swimming pool air is also of concern as volatile DBPs partition into the air above the pool. The presence of bromine leads to the formation of a wide range of bromo- and bromo/chloro-DBPs, and Br-DBPs are more toxic than their chlorinated analogues. This is particularly important for seawater-filled pools or pools using a bromine-based disinfectant. This review summarises chemical contaminants and DBPs in swimming pool waters, as well as in the air above pools. Factors that have been found to affect DBP formation in pools are discussed. The impact of the swimming pool environment on human health is reviewed.

Contents

* *Corresponding author*. E-mail: C.Joll@curtin.edu.au (C.A. Joll).

http://dx.doi.org/10.1016/j.jes.2017.06.013
1001-0742/© 2017 The Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. Published by Elsevier B.V.

Introduction

Swimming pool chemical water quality is currently a topic of interest, with many studies occurring in both the United States and Europe. Swimming pool chemical water quality is of possible public health concern due to the formation of disinfection by-products (DBPs), where total DBP concentrations have been shown to progressively increase in pools and spas (up to 610% and 900%, respectively) compared to their respective filling waters (Daiber et al., 2016). Swimming pool DBPs are unwanted consequences from the reactions of components of the swimming pool water and the disinfectant, during the swimming pool disinfection process. There is an increased potential risk to babies and small children where the health effects of DBPs may be more pronounced. Uptake of DBPs are likely increased in children compared to adults due to higher breathing rates of children (up to twice those of adults) and their lesser developed gastrointestinal tracts and blood brain barriers possibly leading to higher absorption of DBPs (Thompson, 2004). Additionally, children's organs are not fully developed, particularly the liver and kidneys, which have been shown to be two to nine times slower in the breakdown of chemical compounds compared to adults, and, in combination with immature metabolite breakdown mechanisms, may not be able to metabolise and remove DBPs sufficiently (Thompson, 2004). DBPs in swimming pools have been potentially linked to several health issues, including asthma, bladder cancer, liver and kidney issues (Villanueva et al., 2007; Villanueva and Font-Ribera, 2012). Swimming pool waters have shown increased genomic DNA damage effects on Chinese hamster ovary cells than the corresponding filling water (Liviac et al., 2010b), which is likely due to more than one mutagen (Honer et al., 1980). Respiratory issues, such as asthma, wheeze, cough and lower respiratory tract infections, have been correlated with swimming pool attendance, which is likely due to chlorinated volatile DBPs, such as chloramines (Bernard et al., 2006; Ferrari et al., 2011; Jacobs et al., 2007; Kaydos-Daniels et al., 2008; Rosenman et al., 2015; Uyan et al., 2009). However, these studies are not conclusive and Goodman and Hays (2008) suggested that "it is premature to draw conclusions about the causal link between swimming and asthma", warranting further investigation of the health effects of the swimming pool environment.

Indoor swimming pools are of particular concern since they may be more regularly used all year round, and volatile DBPs can become trapped within the environmental air of indoor swimming pool complexes. The higher the concentration of these volatile DBPs in the swimming pool water, the higher their concentration in the air above the pool. Volatile compounds of potential health concern in the air pose a risk not only to regular swimmers, but also to regular non-swimmers, such as swimming pool workers and non-swimming visitors.

Please cite this article as: Carter, R.A.A., Joll, C.A., Occurrence and formation of disinfection by-products in the swimming pool environment: A critical review, J. Environ. Sci. (2017), http://dx.doi.org/10.1016/j.jes.2017.06.013