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Concentrations of disinfection by-products in swimming pool following modifications of the water treatment process: An exploratory study

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ABSTRACT

The formation and concentration of disinfection by-products (DBPs) in pool water and the ambient air vary according to the type of water treatment process used.

This exploratory study was aimed at investigating the short-term impact of modifications of the water treatment process on traditional DBP levels (*e.g.*, trihalomethanes (THMs), chloramines) and emerging DBPs (*e.g.*, Halonitromethanes, Haloketones, NDMA) in swimming pool water and/or air. A sampling program was carried to understand the impact of the following changes made successively to the standard water treatment process: activation of ultraviolet (UV) photoreactor, halt of air stripping with continuation of air extraction from the buffer tank, halt of air stripping and suppression of air extraction from the buffer tank, suppression of the polyaluminium silicate sulfate (PASS) coagulant.

UV caused a high increase of Halonitromethanes (8.4 fold), Haloketones (2.1 fold), and THMs in the water (1.7 fold) and, of THMs in the air (1.6 fold) and contributed to reducing the level of chloramines in the air (1.6 fold) and NDMA in the water (2.1 fold). The results highlight the positive impact of air stripping in reducing volatile contaminants. The PASS did not change the presence of DBPs, except for the THMs, which decrease slightly with the use of this coagulant.

This study shows that modifications affecting the water treatment process can rapidly produce important and variable impacts on DBP levels in water and air and suggests that implementation of any water treatment process to reduce DBP levels should take into account the specific context of each swimming pool.

Abbreviations: 11DCPone, 1,1-dichloro-2-propanon; 111TCPone, 1,1,1-trichloro-2-propanone; BCAA, Bromochloroacetic acid; BCAN, Bromochloroacetonitrile; CAMs, Chloramines; CDBM, Chlorodibromomethane; CPK, Chloropicrin or trichloronitromethane; DBA, Dibromoacetic acid; DBAN, Dibromoacetonitrile; DBPs, Disinfection by-products; DCAA, Dichloroacetic acid; DCAM, Dichloramine; DCAN, Dichloroacetonitrile; DCBM, Dichlorobromomethane; eDBP, Emerging disinfection by-products; HAAs, Haloacetic acids; HANs, Haloacetonitriles; HKs, Haloketones; HNM, Halonitromethane; MBA, Monobromoacetic acid; MCAA, Monochloroacetic acid; MCAM, Monochloramine; NDMA, *N*-nitrosodimethylamine; PASS, Polyaluminium silicate sulfate; TBM, Tribromomethane or bromoform; TCAA, Trichloroacetic acid; TCAM, Trichloramine; TCAN, Trichloroacetonitrile; TCM, Trichloromethane or chloroform; THMs, Trihalomethanes; TTHMs, Total trihalomethanes.

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Introduction

The evidence of the presence of contaminants of water and air at swimming pools by disinfection by-products (DBPs) resulting from water chlorination, such as chloramines (CAMs) trihalomethanes (THMs) and haloacetic acids (HAAs) and have been the subject of several reviews (Jacobs et al., 2007; Teo et al., 2015; Chowdhury et al., 2014; Silva et al., 2012; Zwiener et al., 2007; Richardson et al., 2014; Manasfi et al., 2017). Their presence raises concerns about the respiratory effects on employees and bathers, and suspected carcinogenic and mutagenic potentials of these environments (Richardson et al., 2007; Plewa et al., 2008; Bougault et al., 2009; Liviac et al., 2010; Daiber et al., 2016; Hang et al., 2016). Even though there are several approaches to prevent the formation of these DBPs or their extraction from pool's air and water, only a limited number of studies have addressed the impact of those swimming pool water treatment processes on DBP contamination using a full-scale approach. Indeed, several reported studies consist of laboratory experiments, and explore the mechanistic aspect of the formation of certain groups of DBPs by looking at the chemistry of the precursors and the adjustment of various operational parameters (Glauner et al., 2005; Hansen et al., 2013a, 2013b; Soltermann et al., 2013; Weng et al., 2012). A number of other studies have compared the contamination profiles (speciation) and levels observed in various swimming pools according to water treatment type or various other characteristics (*e.g.*, disinfectant type) (Lee et al., 2010; Righi et al., 2014). It is uncommon to find case studies describing changes in contamination profiles and levels, under real conditions in a single swimming pool where the treatment processes are modified (Cassan et al., 2006). A relevant work with respect to the impact of the various procedures on the (types and levels) contamination portrait comes from France, where the issue of reducing CAM exposure, recognized as a source of occupational asthma in lifeguards, has led to numerous studies. In particular, they have investigated the implementation of stripping procedures and ultraviolet (UV) ray systems. Stripping procedures act through aeration to promote the extraction of CAM by volatilization (Gérardin et al., 1999, 2001, 2005b). The action of UV photoreactor, or dechloraminator, however, has not been as clear-cut as expected in terms of results and the advantages of these systems may be offset by an increased formation of THMs (Gérardin et al., 2005a). For instance, Hamel (2007) explored the impact of these means of reduction by enlarging the list of compounds studied to include CAMs and THMs in water and air, and enhanced the understanding of how operating conditions influence the formation of these DBPs. All these studies led ANSES (France's Agency for Food, Environmental and Occupational Health and Safety) to publish guidelines for authorization requests to implement treatment procedures, in particular, dechloraminators using UV, which must first undergo laboratory trials and experiments in a real environment (ANSES, 2015). Weng et al. (2012) and Hansen et al. (2013b) remark that the impact of UV rays on THMs is a source of contradiction in the literature. While the study by Cassan et al. (2006) reported an increase in levels of THMs following the installation of a UV system at a swimming pool, Beyer et al. (2004) observed the opposite effect at a swimming pool that had switched to a similar system and, at a third swimming pool, Kristensen et al. (2009), did not see any notable difference in THM levels whether the UV rays were on or off. Spiliotopulou et al. (2015) recently reported that DBPs are not formed in the UV reactor but during reactions that occur after chlorine addition and, that UV treatment followed by chlorination increased the formation of DBPs but that this impact was not observable on the long term with continuous UV treated water. The impact of UV rays continues to be the subject of laboratory investigations, providing an exclusive perspective on DBP levels in the water. These studies broaden the sample of DBPs studied and underscore the various consequences of operating conditions. Weng et al. (2012) documented the impact of UV rays on nitrogenous DBPs and concluded that UV rays appear to increase concentrations of some and decrease concentrations of others. Hansen et al. (2013b) assessed the impact of UV on 12 different compounds and considered that UV application could help lower levels of brominated haloacetonitriles (HANs) and brominated THMs. Using water samples from a distribution network, Shah et al. (2011) highlighted the contrasting effects of different types of lamps on HANs and HNMs. Soltermann et al. (2013) documented the effects of UV on *N*-nitrosamines, pointing out that the degradation of these compounds depends on the UV dosage applied and on the initial concentrations of these compounds and their precursors. They concluded that this type of swimming pool water treatment could lead to the formation of *N*-nitrosodimethylamine (NDMA) that counterbalances and surpasses the expected level of degradation. Finally, whereas Afifi and Blatchley (2016) reported that continuous use of UV (low pressure of medium pressure) over a year resulted in lower levels of DBPs, more recently Cheema et al. (2017) showed that UV treatment results in short-term increase of several DBPs.

In a previous study we showed that the occurrence and speciation of traditional and emerging DBPs measured in air and water of a group of 41 public swimming pools varied highly from one pool to another (Tardif et al., 2015b, 2016). In addition, levels were relatively high compared to current guidelines or reference values.

The management of a swimming pool involves the use of several systems and processes whose normal operations may be momentarily altered by maintenance procedures or failures. This exploratory study was the opportunity to provide data for an initial assessment of what could be the short-term impact of modifications to water decontamination process on the occurrence of DBPs in water and air at a typical swimming pool during the following hours/days.

Specifically, we investigated the variations in the levels of DBPs before and after modifications to the water treatment process at full-scale conditions and compare the impact of such modifications with respect to the levels measured after 24 hr and 6 days. The exploratory study was conducted under controlled operational conditions based on various field successive sampling campaigns carried out in different locations within the pool (from the drinking water supplying the facility to the pool air environment) and in the presence of bathers.

1. Methodology

The facility under study is an indoor swimming pool in the greater Montréal region (Canada), which was built in 1990. The

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