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Fate of geosmin and 2-methylisoborneol in full-scale water treatment plants

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ABSTRACT

The increasing frequency and intensity of taste and odour (T&O) producing cyanobacteria in water sources is a growing global issue. Geosmin and 2-methylisoborneol (MIB) are the main cyanobacterial T&O compounds and can cause complaints from consumers at levels as low as 10 ng/L. However, literature concerning the performance of full-scale treatment processes for geosmin and MIB removal is rare. Hence, the objectives of this study were to: 1) estimate the accumulation and breakthrough of geosmin and MIB inside full-scale water treatment plants; 2) verify the potential impact of sludge recycling practice on performance of plants; and, 3) assess the effectiveness of aged GAC for the removal of these compounds. Sampling after full-scale treatment processes and GAC pilot assays were conducted to achieve these goals. Geosmin and MIB monitoring in full-scale plants provided the opportunity to rank the performance of studied treatment processes with filtration and granular activated carbon providing the best barriers for removal of total and extracellular compounds, correspondingly. Geosmin was removed to a greater extent than MIB using GAC. Geosmin and MIB residuals in water post GAC contactors after two years of operation was 20% and 40% of initial concentrations, correspondingly. Biological activity on the GAC surface enhanced the removal of T&O compounds. These observations demonstrated that a multi-barrier treatment approach is required to ensure cyanobacteria and their T&O compounds are effectively removed from drinking water.

1. Introduction

The increasing frequency and intensity of harmful cyanobacterial proliferation in water sources is a growing global issue (Chorus and Bartram, 1999; Kommineni et al., 2009; Merel et al., 2013). Climate change effects, for example rising water temperature and human activities including agricultural nutrient loads, enhance the bloom events (Wiedner et al., 2007; Elliott, 2012; Paerl and Paul, 2012). Several cyanobacterial species are potent producers of taste and odour (T&O) compounds and toxins (Lloyd et al., 1998; Chorus and Bartram, 1999; Carmichael et al., 2001; Hobson et al., 2010). Earthy musty geosmin (molecular formulae: $C_{12}H_{22}O$) and 2-methylisoborneol (MIB –molecular formulae: $C_{11}H_{20}O$) are the most frequently identified T&O compounds associated with cyanobacterial blooms (Lalezary et al., 1988; Suffet et al., 1999; Hobson et al., 2010; Smith, 2011). Several studies have documented the presence of geosmin and MIB and their producing cyanobacteria in surface water bodies (Kommineni et al., 2009; Hobson et al., 2010; Smith, 2011; Zamyadi, 2014).

Unpleasant T&O in treated water could significantly influence customer perception of potable water and health risk associated with consumption of tap water (Smith, 2011), which could in turn lead to loss of customer confidence with water utilities and their capacity to provide safe water. Dissolved geosmin and MIB are detectable by humans in very low concentration, ≤10 ng/L (Hobson et al., 2010); hence, the presence of these compounds in water is one of the major causes of customer complaints to water utilities worldwide (Ridal et al., 2001; Rao et al., 2003; Smith, 2011; Hobson

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et al., 2010) requiring proper management strategies including tight operation of water treatment plants (WTPs). Furthermore, the intracellular to extracellular ratio of these metabolites varies (a) between water bodies, (b) within the water profile, (c) depending on the bloom age and the producers present, and (d) the compounds present (Hobson et al., 2010; Su et al., 2015). For example, in water samples from Canadian side of Lake Ontario, 100% of T&O compounds were extracellular; while in South Australian water bodies the intracellular to extracellular ratio of T&O compounds varied from 70 to 80% during the early stages of the bloom to 20% towards the end of the bloom due to cell lysis (Hobson et al., 2010; Zamyadi et al., 2013a). Additionally, in mesotrophic and oligotrophic water bodies dominated by benthic cyanobacteria like *Oscillatoria* sp. and *Planktothrix* sp., intracellular T&O compounds are not likely to be a problem for WTPs with surface or elevated water intakes as the benthic species are attached to the ground (Catherine et al., 2013; Su et al., 2015). Conversely, in more temperate regions with ice coverage the water intakes are located in the ground; hence the WTPs are not immune to breakthrough of benthic cyanobacteria and their metabolites. These variations in intracellular to extracellular ratio of T&O compounds and their producers influence the treatment performance. This is because, while the removal efficiency of conventional chemical-physical (coagulation-flocculation, clarification and filtration) and disinfection treatment processes for the removal of extracellular geosmin and MIB is very low, at less than 20% (Jung et al., 2004; Persson et al., 2007; Newcombe et al., 2010; Srinivasan and Sorial, 2011), their removal within the intact cells as intracellular compounds is highly efficient. Cell damage during the treatment processes including hydraulic stress from pumps or pre-oxidation, and subsequent release of intracellular T&O compounds to cause further treatment issues, is therefore a major risk (Peterson et al., 1995; Schmidt et al., 2002, 2009). Finally, the release of T&O compounds from damaged cells could be an indicator of the release of other harmful metabolites from the cells, including cyanotoxins (Zamyadi et al., 2010).

Water forms over 80% of the spent filter backwash water, clarification sludge and sludge from dewatering process in WTPs. In dry climate conditions, such as those found in South Australia, recycling the recovered water from the “spent filter backwash water and sludge treatment facilities” is a common practice. This resource recovery practice provides the opportunity to decrease the demand for raw water and improves the efficiency of potable water production following the regulations to ensure the quality of distributed water (Arora et al., 2001; Cornwell and Macphee, 2001). Hence, the handling and treatment of spent filter backwash water and sludge has proved to be an operational challenge (Ho et al., 2012, 2013). The sludge bed of sedimentation tanks, filter media and sludge handling basins have been the main sites of cell accumulation and could be sources of toxin release within WTPs (Schmidt et al., 2002; Kommineni et al., 2009; Schmidt et al., 2009; Ho et al., 2012; Zamyadi et al., 2012, 2013b; Ho et al., 2013). While these studies have mainly focused on toxins produced by cyanobacterial cells, the fate of cyanobacterial T&O compounds within full-scale WTPs and the associated impact on the aesthetic quality of the treated water has not been studied extensively.

Activated carbon is considered an efficient treatment barrier for removal of natural organic matter (NOM) and micropollutants including T&O compounds from water (Newcombe et al., 1997, 2002a, 2002b; AWWA, 2006; Smith, 2011). Water utilities have invested heavily in capital and operational costs to enable the application of granular and powdered activated carbon (GAC and PAC, respectively) for the removal of geosmin and MIB from water. Despite the proven performance of virgin GAC for removal of these compounds, several questions still remain unanswered concerning the effectiveness of aged GAC for the removal of geosmin and MIB concentrations to below 10 ng/L, including the impact of ageing on carbon surface characteristics and adsorption capacity, biofilm formation and biodegradation, particularly under different operational and water quality conditions (Lalezary et al., 1988; Ridal et al., 2001; Newcombe et al., 2002a, 2002b; Ho, 2004; Persson et al., 2007). These questions are especially pertinent for the maintenance of operational GAC contactors.

The overall objective of this study was to document the accumulation and fate of cyanobacteria and their associated geosmin and MIB in full scale WTPs. The specific objectives of this study were to: 1) estimate the accumulation and breakthrough of total and extracellular geosmin and MIB in water, scum and sludge inside full-scale WTPs; 2) verify the potential impact of sludge recycling practice on performance of WTPs; and, 3) assess the effectiveness of aged GAC from operational WTPs for the removal of geosmin and MIB in varying source water quality conditions. While there are many papers that report fundamental studies of MIB and geosmin adsorption to activated carbon, there remains a paucity of information relating to the performance of full-scale treatment processes to remove total and extracellular geosmin and MIB. This paper presents a novel data set quantifying the vulnerability of WTPs to peaks of geosmin and MIB concentrations resulting from breakthrough and accumulation of cyanobacterial cells under realistic operational conditions. These results will help define the scale of cyanobacterial related T&O monitoring and treatment challenges in full-scale WTPs.

2. Material and methods

2.1. Water source and site description

The presence of geosmin and MIB was monitored in raw water and after several full-scale treatment processes within six operational WTPs in South Australia (WTP#1 to WTP#6) from 2010 to 2012. The monitoring and sampling events correspond to the T&O producing cyanobacterial bloom in the source water for these plants. The treatment trains used in the WTPs and characteristics of each treatment process are presented in Table 1. Fig. 1a shows the schematic of source pre-treatment and water recycling procedures used in the six studied WTPs. More information regarding the spent filter backwash water and sludge treatment facility is provided in Supplementary information (SI), Fig. SI-1. Sludge supernatant is pumped to the head of the treatment train and mixed with the inlet raw water at a continuous rate of 8%–10% of the total raw water volume. GAC samples were also taken from four WTPs in South Australia and a WTP in the north shore of Lake Ontario (Canada) for further bench and pilot scale assessment of activated carbon performance.

2.2. Procedure for water and sludge supernatant sampling in full-scale WTPs

A total of 17 field visits were conducted to the six studied WTPs upon detection of geosmin and MIB and/or T&O producing species at the source by the utility monitoring team. Note that the WTPs design only permits water sampling from the raw water prior to injection of the supernatant and post addition of PAC. This situation demonstrates the challenges of sampling within full-scale operational WTPs. The sampling points for each WTP are as follows:

- WTP#1: (1) Raw water, (2) post addition of PAC, (3) post dissolved air floatation (DAF), (4) post filtration, (5) chlorinated water, (6) filter backwash water, and (7) sludge supernatant in sludge handling basin