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Potential of a biologically activated carbon treatment to remove organic carbon from surface waters

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ABSTRACT

This paper shows there is excellent potential to remove organic carbon by biological activated carbon (BAC). In surface waters, the reported biodegradable dissolved organic carbon (BDOC) is low (5–21%) which matches with the removal efficiency of most BAC after prolonged operation. Hence, it is thought that organic carbon removal by BAC cannot be further improved. To understand the full potential, water was incubated over a long period with granules obtained from a column of saturated BAC, i.e., exposed to the same source water over 9 months. The prolonged incubation removed between 43 and 52% of dissolved organic carbon (DOC), out of which physical adsorption accounted for 14–17%. The traditional BDOC method removed only 12–15% of DOC. Highest percentage removal was obtained for waters from the smallest reservoir with the lowest retention time. However, a significant amount of biodegradable organic matters (BOM) are still present in the reservoirs having longest storage time. Lowest possible DOC at the end of incubation was controlled by the adsorbed organic matter on BAC granules as confirmed by the aseptic desorption test with Milli-Q water. The results indicated there is a significant potential of a BAC treatment to remove organic carbon, but the traditionally experienced limitations of BAC should be overcome.

1. Introduction

Natural organic matter (NOM) is a major concern in drinking water since it causes several problems in water quality such as colour, taste, odour and act as a substrate for microbial regrowth and negatively affects the performance of water treatment processes. Furthermore, NOM is the major reservoir of organic precursors for the formation of carcinogenic disinfection by-products (DBPs) such as trihalomethanes (THM) and haloacetic acids (HAA) in disinfected (with chlorine, chloramine, chlorine dioxide and ozone) drinking water systems (Chang et al., 2001; Lou et al., 2010; Richardson, 2011; Trang et al., 2012). The NOM substantially decreases the effectiveness of the disinfectants and oxidants and promotes microbial regrowth in distribution systems (Gang et al., 2003; Sadiq and Rodriguez, 2004).

The amount, composition, and properties of the NOM vary considerably with the location, seasonal changes and human activities (Fabris et al., 2008; Teixeira and Nunes, 2011). In general, NOM includes a larger portion of high molecular weight (MW) hydrophobic compounds collectively termed as humic substances and a small portion of low MW hydrophilic compounds such as carboxylic acids, carbohydrates, sugars and amino acids (Sillanpää, 2015). The NOM can also be divided into two fractions as biodegradable and refractory.

The biodegradable organic matter (BOM) is usually measured as the biodegradable dissolved organic carbon (BDOC). If BOM is not removed during the water treatment, it supports microbial growth in distribution systems (Servais et al., 1995; van der Kooij, 1992) and leads to an establishment of a food web and development of undesirable microorganisms including pathogens (AWWA, 1995; Jjemba et al., 2010). The organic matters which are refractory to biodegradation (non-biodegradable) have little effect on bacterial regrowth but may still react with disinfectants and form DBP or BOM which eventually supports microbial regrowth.

The BOM is mainly related to the NOM with low MW and hydrophilic in nature (Hem and Efraimsen, 2001). During the disinfection, chlorination process rapidly oxidizes bromide (Br^-) to $HOBr^-/OBr^-$ and chloramination process oxidizes iodide (I^-) to HOI (Liu et al., 2017; Westerhoff et al., 2004; Zhu and Zhang, 2016). This $HOBr^-/OBr^-$ and HOI are more reactive with hydrophilic and low

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MW fraction of NOM and form brominated and iodinated DBPs (Hua and Reckhow, 2007; Zhai et al., 2014). These Br-DBPs and I-DPBs are significantly more cytotoxic, genotoxic and mutagenic than their chlorinated analogues (Echigo et al., 2004; Liu and Zhang, 2014; Yang and Zhang, 2013). At the same time, hydrophilic NOM in world water sources reported to increase with time (Fabris et al., 2008).

Coagulation is one of the major processes used in water treatment industry to remove colloidal particles and organic compounds. The conventional water treatment process removes mostly the hydrophobic and the higher MW compounds (Korshin et al., 2009; Matilainen et al., 2005; Sharp et al., 2006a, 2006b). Therefore, the BOM is typically not affected by the coagulation (Ribas et al., 1997; Volk, 2001). As with the problems caused by the BOM, the removal of this organic matter fraction should be an increasingly important goal during water treatment process.

Several biological treatment methods have been investigated to remove BOM from source water. Membrane bioreactor process using bioactive powdered activated carbon had shown high assimilable organic carbon (AOC) removal from pre-ozonated water (Williams and Pirbazari, 2007). The biofiltration using either anthracite/sand (Joret et al., 1991; Wert et al., 2008) or granular activated carbon (GAC) (Chien et al., 2008) filter was effective in reducing BOM concentration in source water. Joret et al. (1991) used prewashed sand as a medium to grow attached microbes and achieved 10–30% BDOC removal within 3–5 days. However, GAC media can support three to eight times more biomass than sand or anthracite media and biologically activated carbon (BAC) can perform better in removing BOM (Wang et al., 1995).

The BAC process offers several benefits over traditional water treatment methods (Korotta-Gamage and Sathasivan, 2017) and this is an effective and cost-competitive means for removing BOM by the microbes colonizing on the activated carbon (AC) surface (Dussert et al., 1994; Scholz and Martin, 1997; Servais et al., 1994). Interestingly, after continuously running for about five months when the adsorption capability of AC was exhausted, BAC had desirable removal efficiency for the adsorbable and biodegradable fraction of dissolved organic carbon (DOC) (Zhang et al., 2010). Concurrently, the biological activity mostly targets on removing low MW NOM whose molecular size mainly in the range 3-1 kDa and <0.5 kDa (Zhang et al., 2010) and more hydrophilic compounds such as DBP precursors of N-nitrosodimethylamine (NDMA) (Asami et al., 2009). The removal of dissolved organic matters including the biodegradable compounds by the BAC process produces water that is more easily disinfected with lower chlorine demand and thereby, lowers the formation of undesirable DBPs including the brominated and iodinated DBPs (Graham, 1999; LeChevallier et al., 1992; Prévost et al., 1998). Moreover, the removal of the BOM reduces the bacterial regrowth in the water distribution system (Hijnen et al., 2014; LeChevallier et al., 1992).

When the adsorption capacity of AC is exhausted DOC removal by BAC reaches the relative steady state with a reported DOC removal of about 15–20% which is supposed to be mostly removed by microbes (Korotta-Gamage and Sathasivan, 2017; Lohwacharin et al., 2011; Servais et al., 1994). Further, the BAC filters become apparently (in terms of measured influent and effluent DOC) ineffective after about two years of continuous operation (Dong et al., 2015). On the other hand, the amount of measured BDOC in surface waters are usually low range generally from 5 to 21% of the DOC (Joret et al., 1991; Volk, 2001). This situation implies that the BAC or any other biological treatment methods cannot biologically remove organic carbon beyond BDOC. This could be the reason why the water treatment industry mostly uses BAC as a polishing process after ozonation and rarely in any other point of the treatment train.

The biodegradable organic carbon is traditionally measured by BDOC method which relies on using bacterial population growing in suspended media (Servais et al., 1987) or attached to sand particles (Joret and Levi, 1986; Volk et al., 1994). The BAC, on the other hand, offers a large internal surface area for the adsorption and bioactivity on its surface and removes a significant amount of DOC by biodegradation. Hence, there should be much more potential for BAC to biologically remove organic carbon. In this context, the traditional BDOC tests are not sufficient to tell the potential of a BAC treatment process.

In this paper, a new test was performed to investigate whether the BAC still has the capacity to biologically remove more organic carbon than the BDOC. In this test, granules from a BAC acclimatized to the source water and fully saturated with the organic matter were used as a support medium instead of a single strain of test organism (van der Kooij, 1992) or bacteria inoculum contained in a small volume of surface water (Joret and Levi, 1986; Servais et al., 1987). Then the DOC removal is measured by prolonged biodegradation without any pre-treatment such as ozonation to produce more BDOC. The physical and biological processes governing the end result of total organic carbon removal by BAC granules are understood by varying the experimental design.

2. Materials and methods

2.1. Source water

Untreated surface water taken from three different water treatment plants; Nepean, Wyong, and Orchard Hills, NSW, Australia were used in this study. Water from Nepean Dam of capacity 67.7 GL which is located within the Upper Nepean Catchment Area is pumped to Sydney Water's Nepean water filtration plant whereas water from Mardi dam of capacity 7.4 GL is transferred to the Wyong water treatment plant. Similarly, the water released from the Warragamba Dam (2027 GL) is pumped to the Orchard Hills filtration plant. All the three treatment plants use direct filtration treatment after coagulation.

2.2. BAC reactor set-up and operation

A laboratory scale BAC column was employed in this study. The BAC column was operated as a continuous up-flow reactor (Fig. 1). The inner diameter of the column was 5 cm. In this study, commercially available untreated activated charcoal which was made from peat bog was used to prepare the BAC columns. The GAC was washed with tap water for several times to remove ash and

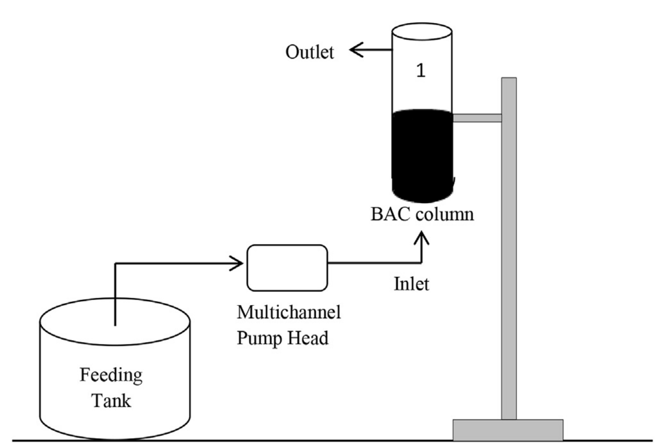

Fig. 1. BAC reactor set-up.