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Review

A review: Potential and challenges of biologically activated carbon to remove natural organic matter in drinking water purification process



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HIGHLIGHTS

- BAC removes low molecular weight NOM and trace level organics.
- BAC treatment is slow and effluent can contain soluble microbial products and microbes.
- Surface modification adopted elsewhere may expedite the removal of organics.
- Issues arising from effluent quality could be solved, if used as a pre-treatment.
- Some BAC regeneration techniques are promising but need further development.

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ABSTRACT

The use of biologically activated carbon (BAC) in drinking water purification is reviewed. In the past BAC is seen mostly as a polishing treatment. However, BAC has the potential to provide solution to recent challenges faced by water utilities arising from change in natural organic matter (NOM) composition in drinking water sources - increased NOM concentration with a larger fraction of hydrophilic compounds and ever increasing trace level organic pollutants. Hydrophilic NOM is not removed by traditional coagulation process and causes bacterial regrowth and increases disinfection by-products (DBPs) formation during disinfection. BAC can offer many advantages by removing hydrophilic fraction and many toxic and endocrine compounds which are not otherwise removed. BAC can also aid the other downstream processes if used as a pre-treatment. Major drawback of BAC was longer empty bed contact time (EBCT) required for an effective NOM removal. This critical review analyses the strategies that have been adopted to enhance the biological activity of the carbon by operational means and summarises the surface modification methods. To maximize the benefit of the BAC, a rethink of current treatment plant configuration is proposed. If the process can be expedited and adopted appropriately, BAC can solve many of the current problems.

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Contents

1. Introduction	121
2. Biologically activated carbon	122
2.1. Removal of organic substances by BAC	123
2.1.1. The stages of DOC removal	123
2.1.2. Mechanisms of bio-degradation of NOM	123
2.1.3. Bacteria/biofilm adhesion to surface	123
2.1.4. Physicochemical properties of BAC	124
2.1.5. Organic matter composition of BAC effluent	125
2.2. Biofilm growth and stabilization	126

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2.2.1.	Biofilm growth	126
2.2.2.	Stabilization of biomass	126
2.3.	Biofilm growth requirements	127
2.3.1.	Amount of nutrient	127
2.3.2.	DO and pH level	128
2.3.3.	Temperature	128
2.4.	Operational interventions	128
2.4.1.	Backwashing	128
2.4.2.	pH and DO	129
2.4.3.	Empty bed contact time (EBCT)	129
2.4.4.	Chemical disinfection/residual disinfectant	129
2.4.5.	BAC effluent quality	130
2.5.	BAC regeneration	130
2.6.	Cost analysis of BAC with other treatments	131
2.7.	Surface modification strategies	131
2.8.	BAC versus other physicochemical processes	132
2.8.1.	BAC after advanced oxidation	132
2.8.2.	BAC as a pre-treatment	133
3.	Further research	133
4.	Conclusion	134
	References	134

1. Introduction

All surface and ground water sources contain natural organic matters (NOM). The NOM is a complex mixture of organic compounds that can cause problems in drinking water quality and in treatment processes (Owen et al., 1995). The composition, properties and amount of the NOM vary with the location and seasonal changes as the NOM is derived from the surrounding environment (Fabris et al., 2008; Teixeira and Nunes, 2011; Ritson et al., 2014).

The NOM is mainly composed of humic substances such as humic acids (HA), fulvic acids (FA) and humins (Sillanpää et al., 2015). These humic substances are considered to be the largest fraction which makes 50% of the total organic carbon (TOC) in water (Sillanpää, 2015). However, recent studies revealed that the humic substances represent only a small fraction of total organic matter in soil and what is extracted as humic acids may be of fire derived (Schmidt et al., 2011; Lehmann and Kleber, 2015). Fire-derived carbon was suspected to be more stable in soil than other organic matter because of its fused aromatic ring structures and the old radiocarbon ages of fire residues isolated from soil (Schmidt and Noack, 2000). These fire-derived carbon does undergo oxidation and transport, and constitutes a major portion of dissolved organic carbon (DOC) in the natural water sources (Kim et al., 2004b; Ziolkowski and Druffel, 2010).

The components of the NOM could also be divided into hydrophobic and hydrophilic fractions (Sillanpää et al., 2015). The hydrophobic organic matter is largely composed of high molecular weight (MW) organics while hydrophilic organic matter is composed of low MW ones and has low charge density (Matilainen et al., 2010). The humic substances are comprised of hydrophobic fraction of NOM. The non-humic substances such as carboxylic acids, carbohydrates, sugars and amino acids (proteins) are components of hydrophilic fraction of NOM (Owen et al., 1995; Sillanpää et al., 2015).

When chlorine is applied as a disinfectant, chlorine reacts with NOM and diminishes the chlorine concentration and forms disinfection by-products (DBP) (Gang et al., 2003; Świetlik et al., 2004). The loss in chlorine has to be compensated by adding additional chlorine increasing the chance to form more DBPs. Not only with the chlorine, DBPs are also formed with other disinfectants such as ozone, chlorine dioxide, chloramines and bromine (Richardson,

2011; Yang and Zhang, 2013; Park et al., 2016). More than 600 DBPs have been reported in the literature from the use of major disinfectant and/or their combinations (Krasner et al., 2006; Richardson, 2011). Among the identified DBPs, trihalomethanes (THMs) and haloacetic acids (HAAs) are the two major groups found in higher concentrations in drinking water (Krasner et al., 2006; Yang et al., 2016). In chlorinated waters, the THM constitute only about 50% of the total organic halogen (TOX) and HAA 22–28% (Heller-Grossman et al., 1993). Mainly, these compounds are carcinogenic and genotoxic and associated with, spontaneous abortions and birth defects (King and Marrett, 1996; Singer, 2006; Pals et al., 2013; Liu and Zhang, 2014). Therefore, these DBPs have been regulated.

Both hydrophobic and hydrophilic fractions contributed to DBP formation (Lin et al., 2000; Hua and Reckhow, 2007; Bond et al., 2009; Yang et al., 2016). Generally hydrophobic fraction exhibited about two times THM formation potential (THMFP)/DOC of hydrophilic fraction (Lin et al., 2000; Chang et al., 2001; Kim et al., 2004a). During chlorination, bromide was oxidized to HOBr/OBr⁻ and chloramination process oxidizes iodide to HOI (Zhai et al., 2014; Zhu and Zhang, 2016). The hydrophilic NOM fractions are more reactive with those HOBr/OBr⁻ and HOI (Hua and Reckhow, 2007) and form brominated and iodinated DBPs (Zhai et al., 2014; Richardson and Kimura, 2016). These bromine and iodine containing DBPs are considered to be cytotoxic, genotoxic and mutagenic than their chlorinated counterparts (Hsu and Singer, 2010; Yang and Zhang, 2013; Liu and Zhang, 2014). Echigo et al. (2004) observed that the activity inducing chromosomal aberrations of the mixture of brominated DBPs per unit TOX was 2–6 times higher than that of chlorinated DBPs. Mainly, on the other hand, there is not a feasible method to remove bromide and removal is also limited by the presence of other anions such as bicarbonate and chloride (Hsu and Singer, 2010). Hence, irrespective of the molecular weight the organic matter has to be removed by the treatment process.

The presence of NOM also contributes to the coloration of water, causes unpleasant taste and odour problems (Hem and Efraimsson, 2001). Further, the NOM significantly increases the coagulant dose requirement when a certain DOC level is to be achieved to stabilise the chlorine decay (Eikebrokk et al., 2004; Fisher et al., 2004; Sharp et al., 2006b). The NOM, especially the hydrophilic

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