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Performance of novel media in stratified filters to remove organic carbon from lake water

Maebh A. Grace, Eoghan Clifford*, Mark G. Healy

Civil Engineering, College of Engineering and Informatics, National University of Ireland, Galway, Ireland

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ABSTRACT

Disinfection by-products (DBPs) are an ever-increasing occurrence in water networks, particularly those which abstract water from peatland areas. Although much research has been carried out to discover novel methods to remove specific DBPs, the removal of natural organic matter (NOM) from source water may provide a more sustainable solution in many areas. This study focuses on the removal of NOM by novel filters, which could be retrospectively fitted to any conventional water treatment facility. The filters comprised stratified layers of a variety of media, including sand, Bayer residue, granular activated carbon (GAC), and pyritic fill. The filters were operated under two loading regimes, continuous and intermittent, at loading rates similar to recognised design standards. The most successful filter design comprised stratified layers of sand, GAC, and pyritic fill. Over the duration of a 240 day study, these filters obtained average dissolved organic carbon removal rates of 40%, and achieved average specific ultra-violet absorbance reductions from 2.9 to 2.4 L mg^{-1} m^{-1}. The study demonstrates that these novel filters may be used to reduce NOM levels, thus reducing the potential for DBP formation. Such designs can incorporate the use of waste media, making the overall design more sustainable and robust.

1. Introduction

The majority of water treatment plants (WTPs) use ground water or surface water, which can contain fluctuating amounts of total organic carbon (TOC), as their source. Organic carbon enters water bodies by leaching from land, particularly from peatlands, and concentrations in source water can fluctuate depending on temperature, rainfall and depth to water table (Grand-Clement et al., 2014). Organic carbon in a WTP can increase disinfection demand, act as a precursor to disinfection by-products (DBPs), and be responsible for membrane fouling and corrosion (Matilainen et al., 2010; Velten et al., 2011). The presence of DBPs in drinking water may have numerous ill-effects on human health. These include bladder cancer, genetic mutations, and foetal abnormalities (Grellier et al., 2015; Richardson et al., 2007).

Disinfection by-products are a concern internationally, with many countries supporting the implementation of more stringent legislation regarding DBPs in potable water (Ecorys, 2015), and are responsible for the majority of non-compliance with regulatory standards in many WTPs (EPA, 2015). Disinfection by-products occur when microparticles in water react with disinfection chemicals, such as chlorine (Kim et al., 2002). There are over 600 identified DBPs, but most are not currently regulated (Deborde and von Gunten, 2008; Hrudey, 2009). The most common-forming DBPs occur when natural organic matter (NOM) reacts with chlorine, forming compounds such as trihalomethanes (THM) and haloacetic acids (HAA) (Deborde and von Gunten, 2008). Currently, HAA, bromate, chlorite, and THM are regulated in the USA, where the maximum allowable concentrations (MACs) are 0.06. 0.01, 1.0 and 0.08 mg L^{-1}, respectively (USEPA, 2009). However, to date, THM and bromate are the only DBPs regulated by the European Union (EU), where the limit for THM is 0.1 mg L^{-1} and the limit for bromate is 0.01 mg L^{-1} (SI No 278 of 2007, 2007).

The composition of NOM is important when assessing the potential for formation of DBPs (Tran et al., 2015). Natural organic matter is commonly measured as organic carbon, either total (TOC) or dissolved organic carbon (DOC). Dissolved organic carbon is the most concerning element, as the larger particles are much easier to remove in a standard treatment process such as coagulation or straining by filtration (Matilainen et al., 2010), thus smaller particles and dissolved matter are more likely to form DBPs (Gopal et al., 2007).

* Corresponding author.
E-mail address: eoghan.clifford@nuigalway.ie (E. Clifford).

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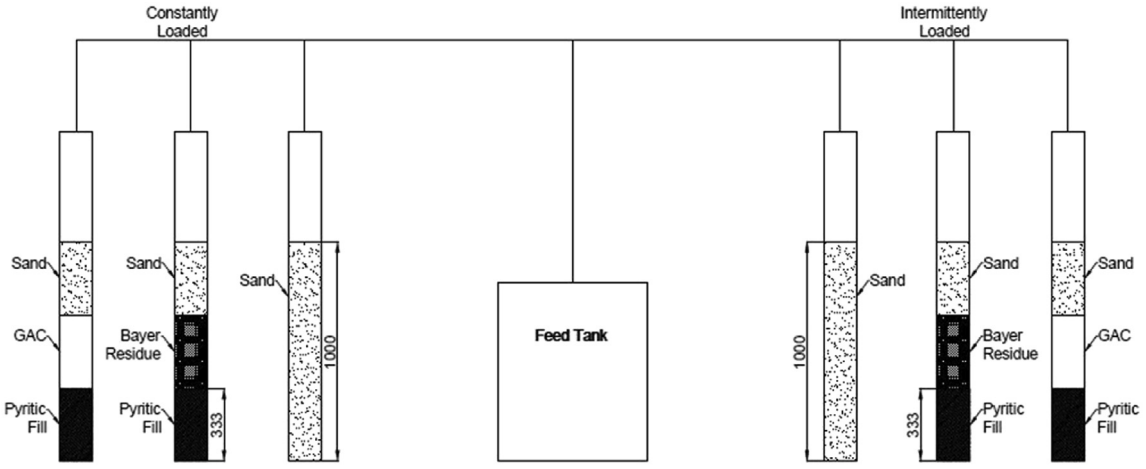

Fig. 1. Schematic of filter set-up.

As research into the process of DBP formation and removal intensifies, there has been much investigation into NOM fractionation and characterisation, to specify which molecules are more likely to react with chlorine, and to form DBPs (Tran et al., 2015). A disadvantage to this approach is that the methods used to fractionate NOM are generally costly and/or require specific expertise. A more accessible indicator is the relationship between ultraviolet absorbance at a wavelength of 254 nm (UVA_{254}) and DOC, known as specific ultraviolet absorbance (SUVA) (Hua et al., 2015). SUVA can be used to investigate the potential for formation of DBPs by acting as an indicator of the aromaticity and hydrophobicity of the water (Anumol et al., 2015; Christy et al., 1999), as it is most commonly found that the hydrophobic organic compounds have higher THM reactivity than hydrophilic organic compounds (Tran et al., 2015). It also has the practical advantage of using commonly available laboratory instruments (Hua et al., 2015). Hydrophobic acids, as well as hydrophilic acids with high SUVA, have high DBP formation potential (Zhang et al., 2009). Both the United States and the Irish Environmental Protection Agency (EPA) use SUVA analysis to determine the level of treatment required to avoid DBP formation (EPA, 2011; USEPA, 2006).

Many treatment technologies, such as dissolved air flotation, membrane filtration, ultra-filtration, and oxidation (Matilainen et al., 2010), have been designed to focus on the removal of organic carbon or DBPs. Although these technologies can prove successful under some operational conditions (for example, ultra-filtration is prone to fouling under high suspended solids and turbidity conditions (Tian et al., 2013), many have high capital and maintenance costs. A relatively low cost alternative in WTPs is the use of traditional sand filters, but they are not as successful in DOC removal (e.g., 10–50%) (Kim and Kang, 2008; Teksoy et al., 2008). The use of alternative media may allow the use of such low-cost technologies, while achieving DOC removal. Based on adsorption testing carried out by Grace et al. (2015), it was decided to investigate the use of Bayer residue (a waste product from the aluminium processing industry) and pyritic fill (a waste product of the construction industry), with granular activated carbon in a filter system, in the current study.

The aim of this study was to design, operate and monitor the performance of filters, operated in intermittent and continuously loaded regimes at pilot-scale, containing media chosen to optimise DOC removal and to prevent surface clogging. Two configurations were chosen, one containing equal layers of sand, Bayer residue and pyritic fill, and the other containing sand, GAC and pyritic fill. The filter configurations were based on bench- and laboratory-scale studies (Grace et al., 2015), and were operated at a WTP.

Table 1
Media characteristics (Grace et al., 2015).

Media	Coarse sand[a]	Pyritic fill[b]	Bayer residue[c]	GAC[d]
Chemical (%)				
SiO_2	97.72	74 ± 10	8.9	–
Fe_2O_3	1.26	2.9 ± 1.5	43.8	–
Al_2O_3	0.21	7.6 ± 0.9	15.04	–
K_2O	0.05	1.05 ± 0.15	–	–
L.O.I[e]	0.36	–	9.5	–
CaO	–	5.4 ± 5.1	6.6	–
MgO	–	0.6 ± 0.14	0.09	–
Na_2O	–	0.3 ± 0.15	5.32	–
TiO_2	–	0.3 ± 0.03	9.2	–
MnO	–	0.05 ± 0.05	–	–
SO_4	–	7.6 ± 5.7	0.41	–
P_2O_5	–	–	0.36	–
Iodine No (mg gm^{-1})		–	–	1100
Moisture (%)		–	–	5
Ash (%)		–	–	4
Effective size (mm)	1.31	0.34	0.06	0.58

[a] Irwin's Quality Aggregates.
[b] Sandberg LLP.
[c] Rusal Aughinish.
[d] Indo German Carbons Ltd.
[e] Loss on Ignition.

2. Materials and methods

2.1. The study site and context

The WTP examined in this study has a source which contains NOM and has existing practices in place for mitigating THM formation. It currently uses ozonation, followed by GAC filtration to reduce the chlorine consumption of treated water, by removing biodegradable organics (Bourbigot et al., 1986), thereby reducing the likelihood of DBP formation. However, GAC exhausts quickly and requires excessive capital, which can make be costly and unsustainable to operate (Corwin and Summers, 2010).

2.2. Filter construction

Two novel filter configurations, each constructed in triplicate (i.e. n = 3 for each configuration), were operated under intermittent