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Characterising biofilm development on granular activated carbon used for drinking water production

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ABSTRACT

Under normal operation conditions, granular activated carbon (GAC) employed in drinking water treatment plants (DWTPs) for natural organic matter (NOM) removal can be colonised by microorganisms which can eventually establish active biofilms. The formation of such biofilms can contribute to NOM removal by biodegradation, but also in clogging phenomena that can make necessary more frequent backwashes. Biofilm occurrence and evolution under full-scale-like conditions (i.e. including periodic backwashing) are still uncertain, and GAC filtration is usually operated with a strong empirical component. The aim of the present study was to assess the formation and growth, if any, of biofilm in a periodically backwashed GAC filter. For this purpose, an on-site pilot plant was assembled and operated to closely mimic the GAC filters installed in the DWTP in Sant Joan Despí (Barcelona, Spain). The study comprised a monitoring of both water and GAC cores withdrawn at various depths and times throughout 1 year operation. The biomass parameters assessed were total cell count by confocal laser scanning microscopy (CLSM), DNA and adenosine triphosphate (ATP). Visual examination of GAC particles was also conducted by high-resolution field emission scanning electron microscopy (FESEM). Additionally, water quality and GAC surface properties were monitored. Results provided insight into the extent and spatial distribution of biofilm within the GAC bed. To sum up, it was found that backwashing could physically detach bacteria from the biofilm, which could however build back up to its pre-backwashing concentration before next backwashing cycle.

1. Introduction

Granular activated carbon (GAC) adsorption has long being recognised as one of the most effective technologies at removing natural organic matter (NOM) from water in drinking water treatment plants (DWTPs) (Emelko et al., 2006; Simpson, 2008). The removal of NOM by GAC basically takes place via adsorption of soluble compounds and filtration of particulate solids. The good suitability of GAC is due to its large specific surface area and well-developed porous structure, which provide a high sorption capacity towards organic molecules (Simpson, 2008; Buchanan et al., 2008; Putz et al., 2005). The sorption capacity of GAC arrives at its end when all sorption sites become eventually saturated with organic matter and regeneration is needed.

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Both filtration and adsorption by and onto GAC ultimately result in the progressive irreversible clogging of GAC filters and impoverishment of water effluent quality, making it necessary to apply periodic backwashes to restore head losses and ensure long-term performance of the GAC filters (Zhu et al., 2010; Zheng et al., 2011; Putz et al., 2005). These backwashes are accomplished by the application of water and/or air in an up-flow manner through the GAC filter. During backwashing, the GAC filter is cleaned through fluid shear of the trapped suspended solids and/or abrasion of the GAC media. The effect of backwashing results in a partial recovery of the hydraulic filtration performance.

An issue that adds complexity to GAC performance is the possible formation of biofilm onto GAC particles. In fact, GAC surface can be colonised by microorganisms which may eventually establish active biofilms, giving rise to the so-called biological activated carbon (BAC) (Kasuga et al., 2007; Huang and Chen, 2004; Velten et al., 2011). Bacterial colonisation and proliferation may result in beneficial and/or detrimental effects: (a) it can contribute to NOM removal by biodegradation of organic compounds; (b) it can plug, over time, the filter making necessary more frequent backwashing; (c) it can cause anaerobic and/or dead zones; (d) it can impoverish the filtered water quality by the undesirable detachment of microorganisms from BAC (Emelko et al., 2006; Laurent et al., 2003; Putz et al., 2005).

The rate and extent of biofilm formation depends on many factors including water quality (particularly the concentration of growth-promoting substrates), type of GAC, hydraulic conditions, temperature, backwashing regime, among others (Zhu et al., 2010; Urfer and Huck, 2001; Moll et al., 1999; Emelko et al., 2006; Velten et al., 2011). The effects of these factors on biofilm growth have not been extensively researched and are still not well known. Most past studies have, moreover, been limited to bench-scale experiments run under tightly controlled conditions, and their findings are not always applicable to GAC units installed in full-scale plants. Studies mimicking full-scale-like filters are scarce. Furthermore, some of these studies are limited by the low number of samples taken and/or the short periods of operation of the GAC filter. An added difficulty is the wide array of methods to quantify biofilm that provide information in a broad range in values and formats, making comparisons difficult (Lazarova and Manem, 1995; Magic-Knezev and van der Kooij, 2004; Velten et al., 2011). For all this, predicting biofilm occurrence and behaviour in GAC filters under full-scale-like conditions is still uncertain and clearly an open research field (Putz et al., 2005). This is so much the case that GAC filters in drinking water treatment plants are usually operated with a strong empirical component.

In view of the above, the aim of the present study was to determine the formation and growth, if any, of biofilm in a GAC bed under full-scale-like operation conditions. For this purpose, an on-site pilot plant was assembled and operated in a periodically backwashed regime to closely mimic the GAC filters installed in the DWTP in Sant Joan Despí (Barcelona, Spain). This plant treats surface water and/or groundwater through an advanced treatment process including pre-chlorination, coagulation/flocculation and sedimentation, sand filtration, ozonation, GAC filtration, and post-chlorination. The study comprised a monitoring of both water and GAC cores withdrawn at various depths and times throughout the 1 year operation of the pilot. Therefore, the evolution of biofilm formation and growth as well as effluent water quality were studied not only along time but also along GAC bed height.

2. Material and methods

2.1. *Column set-up and operation*

The configuration and operation of the GAC pilot plant (with regards to the type and bed height of GAC, origin of feedwater, hydraulics, backwash frequencies, etc.) were selected to mimic as closely as possible the full-scale filters in Sant Joan Despí DWTP.

The pilot plant consisted of a transparent methacrylate column (i.d. of 22 cm and length of 1.90 m) packed with 1.50 m height of GAC (approx. 24 kg). The GAC bed was placed on a 6 cm layer of spherical glass beads (average diameter of 7 mm) supported in turn on a flat plastic grill to hold the GAC in place and to prevent losses of carbon particles. The column material was transparent methacrylate in order to facilitate visual observations of events occurring within it.

The thermally regenerated GAC used was of bituminous coal-based type (Chemviron F400) identical to that employed in the full-scale DWTP. GAC characteristics are summarised in Table 1.

Feedwater was pumped from the ozonation units of the Sant Joan Despí plant to the top of the column, from which it flowed by gravity in a downflow mode. The ozonated water showed ranges of 1.1–5.5 mg/L for DOC, 0.01–0.57 mg/L for residual O_3, 1.7–7.7 Abs/m for UV_{254} and 0.02–0.78 NTU for turbidity. The flow rate was controlled to an average of 3.0 L/min by keeping constant the water height (approx. 30 cm) above the surface of the bed. This flow rate corresponded to an average hydraulic loading of 4.8 m/h and an average empty bed contact time (EBCT) of 19.0 min, which are similar to those in the DWTP filters. Due to the retention of suspended solids within the GAC bed by filtration, a gradual decay of the flow rate (typically from 4.3 to 2.0 L/min) was observed during

Table 1 – Physico-chemical properties of the virgin and regenerated F400 GAC used for this study.

F400 GAC characteristics	
Origin	Bituminous coal
Iodine index of virgin GAC[a]	>1050 mg/g
Iodine index of regenerated GAC[b]	768 mg/g
Methylene blue index	>260 mg/g
Dry density	0.44–0.54 g/cm^3
Effective granule size	0.6–0.7 mm
Coefficient of uniformity	2.0
BET apparent surface area of virgin GAC[a]	1000 m^2/g
BET apparent surface area of regenerated GAC[b]	886 m^2/g

a Provided by the manufacturer.
b Determined in plant on reception after regeneration.