Adsorption/reduction of bromate from drinking water using GAC: Effects on carbon characteristics and long-term pilot study

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Abstract

This study investigated the feasibility of using granular activated carbon (GAC) to remove bromate (BrO_3^-) from drinking water through batch experiments, rapid small-scale column tests (RSSCT) and a pilot-scale study. The results indicated that the GAC capacity for BrO_3^- removal was dependent on the GAC surface characteristics and empty-bed contact time (EBCT). The GAC with a high number of basic groups and higher pH_{pzc} values showed an increased BrO_3^- removal capacity. On the other hand, BrO_3^- removal was improved by increasing EBCT. In the GAC pilot plant, a GAC column (operating with 15 min EBCT) preload for 12 months achieved a BrO_3^- and assimilable organic carbon (AOC) removal rate ranging between 7 and 96 % and between 41 and 85 %, respectively. The amount of BrO_3^- removed was found to be proportional to the influent BrO_3^- concentration. Based on the results of our long-term experiment, the BrO_3^- and AOC removal rate during the transition from initial GAC to biological activated carbon (BAC) was calculated as 0.12 % w/w and 0.27 % w/w, respectively. However, the BrO_3^- removal rate apparently decreased with increasing operating time (after 3 months). This may be a result of the contribution of the bacterial biomass being adsorbed on the GAC surface which hindered BrO_3^- reduction by GAC, either by blocking the pores or adsorbing on the activated sites for BrO_3^- reduction.

Keywords: granular activated carbon, biological activated carbon, bromate, assimilable organic carbon

Introduction

Bromate (BrO_3^-) is a genotoxic carcinogen (Kurokawa et al., 1986) which may be present in drinking water when ozonation is applied in the treatment of bromide-containing water (Haag and Hoigne, 1983). Concentrations of 5 to 10 mg/ℓ have been observed after treatment in full-scale drinking water production plants (Krasner et al., 1993). The bromate concentration in drinking water corresponding with a cancer risk of 10^{-5} (life-time exposure) is 3 µg/ℓ (WHO, 1993). The USEPA criteria document for ozone and its by-products used the linearised multistage model to estimate 10^{-6}, 10^{-5}, and 10^{-4} life-time excess cancer risks of 0.05, 0.5, and 5 µg/ℓ bromate, respectively.

Furthermore, ozonation of drinking water transforms natural organic matter (NOM) into a more biodegradable form. This can cause significant bacterial regrowth in the distribution system if biodegradable organic matter (BOM) is not removed by subsequent treatment steps (Van der Kooij and Hijnen, 1984). The concentration of BOM, expressed in terms of assimilable organic carbon (AOC) or biodegradable dissolved organic carbon (BDOC), increases with increasing ozone dosage (Van der Kooij et al., 1982; Servais et al., 1989).

For the removal of BrO_3^- several techniques have been investigated. Batch-scale experiments have shown that BrO_3^- can be reduced to Br^- by ultraviolet irradiation, high energy electron beam irradiation and heterogeneous redox catalysis (Siddiqui et al., 1994; Mills and Meadows, 1995), but the practical performance of these techniques to remove BrO_3^- from ozonated waters appears uneconomical at present. Through jar-test experiments, Siddiqui et al. (1994) reported that the reduction of BrO_3^- to Br^- by the addition of ferrous iron as a reducing agent was feasible if the coagulation process followed ozonation treatment. Several studies have investigated the use of activated carbon (granular or powder) filtration for removing BrO_3^- from water reporting poor to effective BrO_3^- removal. Through bench-and pilot-scale column testing, BrO_3^- could be effectively removed by virgin GAC, but the GAC capacity was found to be carbon-specific and dependent on source waters (Gerz and Schneider, 1993; Siddiqui et al., 1996).

GAC in actual water treatment processes naturally breeds a bacterial population on its surface, and eventually it functions as biological activated carbon (BAC). With the help of the bioactivity on BAC, the reduction of total organic carbon (TOC) and other biodegradable organic matter is considered to maintain a longer service time before GAC regeneration. The combination of ozonation and biological treatment with BAC enhances the degradation removal of organic substances, although it only slightly degrades trihalomethane precursors and aldehydes (Cipparone et al., 1997). On the other hand, there have been some reports of BrO_3^- reduction by BAC (Asami et al., 1999), but results obtained from surveys of various European water utilities have shown low efficiency of GAC for BrO_3^- removal in full-scale plants (Lefebvre, 1995; Legube, 1996).

At present, the number of reports on activated carbon adsorption and removal of ozonation by-products, especially on BAC, are limited. It would be desirable to use GAC for BrO_3^- and AOC removal, since GAC is already in use at many drinking water treatment plants. This study deals with the behaviour of BrO_3^- and AOC in a GAC/BAC filter. The effect of carbon type, EBCT and influent concentration on BrO_3^- removal by activated carbon was assessed.

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