Biological Removal of UV and VUV Pre-treated Natural Organic Matter

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ABSTRACT

It has long been recognised that in many parts of the world, the problematic factor in the production of potable water is natural organic matter (NOM). It is a key component in controlling the cost of treatment and final water quality (Drikas, 1997). NOM interferes with most treatment processes (Morran *et al.*, 1996), it produces unpleasant odours and tastes, may contribute to discolouration, may act as an energy source or substrate for bacterial growth within distribution systems (Gottschalk *et al.*, 2000), and may contribute to the formation of disinfection by-products which toxicological studies suggest may be potential carcinogens (Suffet and MacCarthy, 1989; Bull and Kopfler, 1991). Therefore, effective removal of NOM is a major challenge for the water treatment industry. As a result, novel treatment processes are being examined to complement and enhance the performance of conventional methods.

Novel processes generating interest are ultraviolet (UV) and vacuum ultraviolet (VUV) irradiation. These advanced oxidative processes have been reported to increase the biodegradable content of natural waters by breaking down large organic moieties to lower molecular weight organic compounds. Hence, the main objective of the current work was to conduct a systematic investigation into the effectiveness of utilising UV (254 nm) or VUV (254 nm + 185 nm) irradiation followed by biological treatment for the removal of NOM from drinking water.

The conditions of UV and VUV pre-treatment required to achieve maximum biological removal were determined. Positive correlations were observed between the production of lower molecular weight molecules as shown by high performance size exclusion chromatography (HPSEC) and a decrease in dissolved organic carbon with increasing radiation dose. Similarly, the reduction of UV absorbance at 254 nm was found to correlate well with the observed increase in biodegradability as determined by the biodegradable dissolved organic carbon (BDOC) test.

UV pre-treatment resulted in the accumulation of biodegradable compounds from the breakdown of chromophoric material. A maximum of 40% biodegradability was achieved after the largest UV dose (140 $J.cm^{-2}$), although significant concentrations of DOC remained. VUV pre-treatment resulted in a more rapid rate of mineralisation and formation of biodegradable compounds than UV pre-treatment. VUV doses larger than 96 $J.cm^{-2}$ were observed to reduce the apparent effectiveness of biological treatment as determined by the decrease in BDOC. After the experimentally determined optimal VUV dose (64 - 96 $J.cm^{-2}$) approximately 80% of remaining DOC was biodegradable. The lower doses of radiation required to generate greater bioavailability make VUV more effective than UV pre-treatment.

The characteristics of NOM after UV *or* VUV irradiation followed by biological treatment were investigated. Treated NOM samples were fractionated into four components: very hydrophobic

acid (VHA), slightly hydrophobic acid (SHA), hydrophilic charged (CHA) and hydrophilic neutral (NEU). The VHA fraction was found to be very susceptible to both UV and VUV irradiation, and the fragmentation products of the high molecular weight VHA and SHA molecules contributed to the CHA and NEU fractions to form a pool of biodegradable, non-UV absorbing, low molecular weight moieties. The NEU fraction was the most difficult to remove, as most of the components in this fraction were refractory to both the biological and photo-oxidative processes. This NEU fraction has also been proven to be problematic in many common water treatment processes.

To give an indication of the potential health risks associated with UV or VUV pre-treatment of NOM, irradiated samples were analysed for potentially hazardous by-products, such as trihalomethanes (THM), haloacetic acids (HAA) and formation of nitrite and hydrogen peroxide. The total THM formation potential (THMFP) was found to decrease with increasing UV and VUV dose, although there was a linear increase in bromoform formation. Determination of the THMFP of NOM fractions obtained after irradiation showed that the hydrophobic fraction was dominated by chlorinated species, which were the major contributors to the total THMFP, while bromoform was observed only in the hydrophilic fraction of NOM.

VUV irradiation reduced the HAA formation potential (HAAFP) with increasing dose. In contrast, UV irradiation had a limited effect on the overall HAAFP. Following UV or VUV irradiation, the chlorinated species accounted for the majority of HAAFP; however, significant formation of brominated halo acetic acid (HAA) was observed. The nitrate concentration of the untreated water was found to directly influence the concentration of nitrite produced as a consequence of UV and VUV irradiation. Hydrogen peroxide formation was greater during VUV irradiation than during UV irradiation; however, subsequent biological treatment decreased the concentration of both hydrogen peroxide and nitrite to below detection limits. NOM samples exposed to various doses of UV or VUV irradiation (up to 138 $J.cm^{-2}$) were deemed non-cytotoxic (to African green monkey kidney cells) and non-mutagenic (Ames test).

The combination of VUV pre-treatment and biologically activated carbon (BAC) decreased the overall DOC concentration by 54% and 44% for two different types of carbon. Furthermore, the two BAC types were equally successful in decreasing the formation potential of disinfection by-products, with a 60-70% decrease in the THMFP and a 74% decrease in the HAAFP. The VUV-BAC treatment process compares well with reported ozone-BAC treatments for the removal of DOC and the decrease in disinfection by-product formation. By combining VUV pre-treatment with BAC rather than BDOC (an estimate of biodegradability), the effectiveness of this novel treatment process was enhanced. VUV-BAC is seen as an attractive process due to the lack of process chemicals required. Furthermore, VUV pre-treatment does not contribute to the formation of the suspected carcinogenic by-product bromate, unlike ozonation.

Preliminary calculations for the exposure times examined suggest that the electrical energy input (E_{EI}) and electrical energy per order of magnitude for DOC removal (EE/O) is a little higher than for other treatment processes. However, these energy requirements may be significantly reduced with further process improvements. Therefore with further research and development, VUV irradiation followed by biological treatment may become a viable water treatment option.