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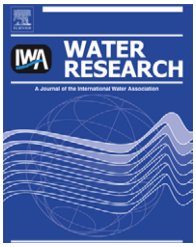

Photoinitiated oxidation of geosmin and 2-methylisoborneol by irradiation with 254 nm and 185 nm UV light

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ABSTRACT

The degradation of geosmin and 2-methylisoborneol (2-MIB) by UV irradiation at different wavelengths was investigated under varying boundary conditions. The results showed that conventional UV radiation (254 nm) is ineffective in removing these compounds from water. In contrast to the usual UV radiation UV/VUV radiation (254 + 185 nm) was more effective in the removal of the taste and odour compounds. The degradation could be described by a simple pseudo first-order rate law with rate constants of about $1.2 \times 10^{-3}\ \mathrm{m^2\,J^{-1}}$ for geosmin and 2-MIB in ultrapure water. In natural water used for drinking water abstraction the rate constants decreased to $2.7 \times 10^{-4}\ \mathrm{m^2\,J^{-1}}$ for geosmin and $2.5 \times 10^{-4}\ \mathrm{m^2\,J^{-1}}$ for 2-MIB due to the presence of NOM. Additionally, the formation of the by-product nitrite was studied. In the UV/VUV irradiation process up to $0.6\ \mathrm{mg\,L^{-1}}$ nitrite was formed during the complete photoinitiated oxidation of the odour compounds. However, the addition of low ozone doses could prevent the formation of nitrite in the UV/VUV irradiation experiments.

1. Introduction

Taste and odour compounds affect substantially the esthetic quality and consumer acceptability of drinking water. The compounds responsible for most of the reported taste and odour events in drinking water reservoirs are geosmin and 2-methylisoborneol (2-MIB). The odour threshold concentrations for geosmin and 2-MIB are extremely low; reported values are in the range of 4–10 and 9–42 $\mathrm{ng\,L^{-1}}$, respectively (Suffet et al., 1999; Watson et al., 2000). Geosmin and 2-MIB are produced by several groups of benthic and pelagic aquatic microorganisms, mainly cyanobacteria and actinomycetes (Jüttner and Watson, 2007) which are found in eutrophic surface waters such as drinking water reservoirs.

In Central Europe the appearance of taste and odour events is mostly seasonal. For example, in 2007 the concentrations of geosmin and 2-MIB in a monitored drinking water reservoir in Saxony, Germany, reached their maxima already in the early summer with concentrations of 46 and 58 $\mathrm{ng\,L^{-1}}$, respectively. These relatively high concentrations in the raw water could not be completely removed during the conventional treatment procedure of the drinking water plant (flocculation, filtration, chlorination). Therefore, tap water concentrations up to 7 $\mathrm{ng\,L^{-1}}$ for 2-MIB could be measured which required the additional application of powdered activated carbon to avoid consumer complaints.

In general, the removal of geosmin and 2-MIB has proved to be difficult. Conventional drinking water treatment processes typically used for reservoir water, including flocculation, filtration, aeration and disinfection/oxidation by chlorine, are more or less ineffective in removing these taste and odour compounds. Only the adsorption on activated carbon has been applied successfully to reduce the concentration below the threshold odour concentration. In the last few years the

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research on the removal of taste and odour compounds has been focused on oxidative techniques and advanced oxidation processes (AOPs). However, the oxidation techniques showed mixed success because of the resistance of the tertiary alcohols geosmin and 2-MIB towards oxidation (Rosenfeldt et al., 2005). In particular oxidation processes based on UV irradiation have attracted interest. A special advantage of the UV treatment consists in the simultaneous disinfection of the raw water besides the oxidation of micropollutants. A drinking water facility equipped with a UV system for disinfection is able to switch easily from normal disinfection mode to disinfection and additional taste and odour control when higher concentrations of geosmin and 2-MIB are measured (Sarathy and Mohseni, 2006).

In the literature a number of studies on UV and UV/oxidant treatment of taste and odour compounds have been published. Table 1 summarizes these publications including the UV conditions under investigation, the addition of oxidants, and the results of the studies. From the literature it can be stated that UV irradiation alone is inefficient for the oxidation of geosmin and 2-MIB unless high UV doses are applied. The addition of hydrogen peroxide or ozone that results in advanced oxidation conditions enhances the removal distinctly. Although vacuum UV irradiation (VUV) is expected to show a higher efficiency in oxidation than UV irradiation to our knowledge there is yet no study focused on the removal of geosmin and 2-MIB with VUV irradiation using a low-pressure lamp.

A problem connected with the application of UV and, in particular, VUV consists in the formation of undesired by-products. The main by-product under investigation is nitrite. The Environmental Protection Agency (EPA) has set 1 $mg\,L^{-1}$ nitrite as the maximum contaminant level (MCL) for regulated public water systems. In Germany, the maximum permitted concentration of nitrite in drinking water is set to 0.5 $mg\,L^{-1}$ and the concentration at the outlet of drinking water plants is limited to 0.1 $mg\,L^{-1}$ (German Drinking Water Rule, 2001). During UV radiation nitrite can be formed by the direct photolysis of nitrate present in the raw water. In the VUV process the hydrogen atoms and hydrated electrons generated by the photolysis of water (see Section 2) can also contribute to the production of nitrite (Gonzalez and Braun,

Table 1 – Publications on the treatment of taste and odour compounds with UV irradiation and UV based advanced oxidation processes.

Publication (author, year)	Water matrix	UV source, applied UV fluence	Addition of oxidant	Result
Glaze et al. (1990)	Water from treatment plant	Low-pressure lamp, 0.56 W UV dose	5 $mg\,L^{-1}$ H_2O_2	40% reduction of geosmin, 29% reduction of 2-MIB
Linden et al. (2002)	Lake water	Low-pressure or medium-pressure UV irradiation		Not effective
		10,000 $J\,m^{-2}$	2 $mg\,L^{-1}$ H_2O_2	2-MIB reduced to non-detectable concentration
		<3000 $J\,m^{-2}$	2 $mg\,L^{-1}$ H_2O_2	Geosmin reduced to non-detectable concentration
Modifi et al. (2002)	Pre-treated natural water	101,000 $J\,m^{-2}$		97% removal of geosmin, 92% removal of 2-MIB
		26,000 $J\,m^{-2}$		28% removal of geosmin, 9% removal of 2-MIB
		11,000 $J\,m^{-2}$	5.5 $mg\,L^{-1}$ H_2O_2	Complete removal
		270 $J\,m^{-2}$ (typical for virus disinfection)	5.5 $mg\,L^{-1}$ H_2O_2	46% removal of geosmin, and 57% removal of 2-MIB; residual H_2O_2 concentration: up to 96% of the initial dose
Collivignarelli and Sorlini (2004)	Surface water	Low-pressure lamp, 5000–6000 $J\,m^{-2}$	1.5–3 $mg\,L^{-1}$ ozone, 2–3 min contact time	Complete removal of geosmin and 2-MIB
Korategere et al. (2004)	Finished water from a water plant	Low-pressure high-output reactor with 8 UV lamps		12–45% removal of 2-MIB, same trend for geosmin
		Medium-pressure reactor with 4 UV lamps		20–48% removal of 2-MIB, same trend for geosmin
Rosenfeldt et al. (2005)	Raw blend water	Low-pressure lamp, 1000 $J\,m^{-2}$		10% removal of geosmin and 2-MIB
		Medium-pressure lamp, 1000 $J\,m^{-2}$		25–50% removal of geosmin and 2-MIB
		1000 $J\,m^{-2}$ (low-pressure and medium-pressure lamps)	7.2 $mg\,L^{-1}$ H_2O_2	Up to 70% removal of geosmin and 2-MIB; faster degradation with medium-pressure lamp