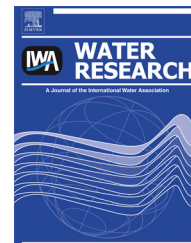


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Factors affecting the formation of disinfection by-products during chlorination and chloramination of secondary effluent for the production of high quality recycled water

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ABSTRACT

During the production of high quality recycled water by reverse osmosis membrane filtration secondary effluent must be disinfected to limit biofouling on the membrane surface. Advanced Water Treatment Plants in South East Queensland, Australia use disinfectant contact times ranging from 30 min up to 24 h. Disinfectants such as chlorine and chloramines react with effluent organic matter to generate disinfection by-products (DBPs) which could be potentially hazardous to human health if the water is destined for supplementing public water supplies. In this context, secondary effluents are of concern because of their high total organic carbon content which can act as DBP precursors. Also, effluent organic matter may form different DBPs to those formed from natural organic matter during conventional drinking water treatment, either in quantity, identity or simply in the abundance of different DBPs relative to each other. It cannot be assumed per se with certainty that DBP formation will be affected in the same way by operational changes as in drinking water production.

Response surface modelling has been employed in this study at the bench scale to investigate the effect of reaction time (0–24 h), pH (5.5–8.5), temperature (23–35 °C), disinfection strategy (chlorine vs chloramines used prior to membrane treatment) and the interaction between these different parameters on DBP formation during disinfection of secondary effluent.

The concentration of halogenated DBPs formed during the first 24 h of reaction with the different disinfectants followed the order chlorination >> in line-formed monochloramine > pre-formed monochloramine. Contact time with chlorine was the major influencing factor on DBP formation during chlorination, except for the bromine-containing trihalomethanes and dibromoacetonitrile for which pH was more significant. Chlorination at high pH led to an increased formation of chloral hydrate, trichloronitromethane, dibromoacetonitrile and the four trihalomethanes while the opposite effect was observed for the

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other targeted DBPs. Temperature was identified as the least influencing parameter compared to pH and reaction time for all DBPs in all the disinfection strategies, except for the formation of chloral hydrate where pH and temperature had a similar significance and bromoform that was similarly affected by temperature and reaction time. Chloramines employed at pH 8.5 reduced the concentration of all studied DBPs compared to pH 5.5. Furthermore, reaction time was the most significant factor for trichloronitromethane, chloroform, trichloroacetonitrile, dichloroacetonitrile and bromochloroacetonitrile formation while pH was the most influencing factor affecting the formation of the remaining DBPs.

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Acronyms		IC	ion chromatography
ANOVA	analysis of variance	DHAN	dihalogenated acetonitrile
AWTP	advanced water treatment plant	DHAN-Br	bromine-containing dihalogenated acetonitrile
BrClAN	bromochloroacetonitrile	HAN-Cl	chlorine-containing haloacetonitrile
Br ₂ AN	dibromoacetonitrile	HAAs	haloacetic acid
BrCl ₂ CH	bromodichloromethane	HAN	haloacetonitrile
Br ₂ ClCH	dibromochloromethane	HAN4	haloacetonitriles (Cl ₃ AN, Cl ₂ AN, BrClAN, Br ₂ AN)
Br ₃ CH	tribromomethane	HK	haloketone
CH	chloral hydrate	MLR	multivariate linear regression
Cl ₂ AN	dichloroacetonitrile	RO	reverse osmosis
Cl ₃ AN	trichloroacetonitrile	RSM	response surface modelling
Cl ₃ CH	trichloromethane	TKN	total Kjeldahl nitrogen
Cl ₃ NM	trichloronitromethane	THM	trihalomethane
DBP	disinfection by-product	THM4	trihalomethanes (Cl ₃ CH, BrCl ₂ CH, Br ₂ ClCH, Br ₃ CH)
DOC	dissolved organic carbon	THM-Br	bromine-containing trihalomethanes
DON	dissolved organic nitrogen	UV	ultraviolet
GC-ECD	gas chromatograph with electron capture detector	1,1-DCP	1,1-dichloro-2-propanone
HQRW	high quality recycled water	1,1,1-TCP	1,1,1-trichloropropanone

1. Introduction

Disinfection is an important practice to control biological contamination in both drinking water and treated wastewater. As an unintentional consequence of this treatment, disinfection by-products (DBPs) are formed by the reaction between organic/inorganic matter and disinfectants. DBPs in drinking water have been associated with possible public health risks (Richardson et al., 2007; Sedlak and Von Gunten, 2011) through routes of ingestion, inhalation and dermal adsorption and, therefore, the control of their formation is required. Many countries regulate certain DBPs in drinking water, particularly trihalomethanes (THMs) and haloacetic acids (HAAs). However, a large number of other potentially harmful DBPs have been detected after chlorination or chloramination of secondary effluent, including haloacetonitriles (HANs), haloketones (HKs), trichloronitromethane (Cl₃NM) and chloral hydrate (CH) (Krasner et al., 2009).

In response to population growth and increasing uncertainty surrounding future rainfall patterns, many urban centres are looking into new strategies for meeting current and future demands for potable water. One such approach is the indirect potable reuse of high quality recycled water (HQRW), whereby highly treated secondary effluent is used to augment

existing water supplies at Advanced Water Treatment Plants (AWTP) (Rodriguez et al., 2009). Reverse osmosis (RO) membranes are commonly used to generate HQRW from secondary effluent but require disinfection during the pretreatment stages to limit biofouling on their surface. The formation of DBPs during the production of HQRW is, therefore, of critical concern since secondary effluent holds a high concentration of DBP precursors contained in the dissolved organic carbon (DOC) content (Farré et al., 2011). Unfortunately, the RO membranes cannot be relied upon to effectively remove all DBPs. For example, it has been shown that RO rejection of chloroform, bromoform and N-nitrosodimethylamine can be negligible (Farré et al., 2012; Steinle-Darling et al., 2007; Fujioka et al., 2012). Therefore, the control of DBP formation prior to membrane treatment might be a necessary addition to the HQRW production process. Effective control strategies can only be implemented if the key drivers for DBP formation from secondary effluents are well understood.

The majority of previous DBP research has focused on the study of operational parameters affecting their formation during the production of drinking water. It is well known that during chlorination of drinking water, THM formation increases with pH (Liang and Singer, 2003) and temperature (Stevens et al., 1976) as well as with chlorine dose and reaction

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