Original Article

Mutagenic and Estrogenic Effects of Organic Compounds in Water Treated by Different Processes: A Pilot Study

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Abstract

Objective In this study, a pilot-scale investigation was conducted to examine and compare the biotoxicity of the organic compounds in effluents from five treatment processes (P1-P5) where each process was combination of preoxidation (O_3), coagulation, sedimentation, sand filtration, ozonation, granular activated carbon, biological activated carbon and chlorination (NaClO).

Methods Organic compounds were extracted by XAD-2 resins and eluted with acetone and dichlormethane (DCM). The eluents were evaporated and redissolved with DMSO or DCM. The mutagenicity and estrogenicity of the extracts were assayed with the Ames test and yeast estrogen screen (YES assay), respectively. The organic compounds were detected by GC-MS.

Results The results indicated that the mutation ratio (MR) of organic compounds in source water was higher than that for treated water. GC-MS showed that more than 48 organic compounds were identified in all samples and that treated water had significantly fewer types and concentrations of organic compounds than source water.

Conclusion To different extents, all water treatment processes could reduce both the mutagenicity and estrogenicity, relative to source water. P2, P3, and P5 reduced mutagenicity more effectively, while P1 reduced estrogenicity, most effectively. Water treatment processes in this pilot plant had weak abilities to remove Di-n-butyl phthalate or 1, 2-Benzene dicarboxylic acid.

Key words: Water treatment processes; Organic compounds; Yeast estrogen screen (YES assay); Ames test; GC-MS

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INTRODUCTION

Disinfection by-products (DBPs) of chlorination have drawn special attentions since the 1970s due to their potentially mutagenic or carcinogenic effects. In 1974, reports of DBPs forming during water treatment were presented by Rook and others[1-2]. Mutagenic DBPs may be formed when chlorine reacts with organic matter or pollutants in source water. Since those earliest reports, a number of studies about DBPs and their adverse effects have been performed[3-5], and methods to decrease organic compounds in source water and consumption of chlorine and DBPs in treated water have been carefully considered. In order to decrease mutagenic compounds in drinking water as much as possible and still ensure biosafety, advanced treatments such as ozone oxidization, granular active carbon (GAC) and/or biological activated carbon

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(BAC) have been combined with conventional drinking water treatment (DWT), which usually consists of coagulation, sedimentation, sand filtration, and chlorination. Combinations of these advanced and conventional treatment steps may lead to a better way to control mutagenic organic compounds formed during water treatment processes[6-8].

Another potential threat to public health is the estrogenic activity of some organic compounds in water. The so-called environmental estrogens (EEs) include insecticides, herbicides, industrial chemicals, and compounds associated with plastics (bisphenol A, phthalates)[9-10]. Currently, various types of EEs can be detected in a wide range of natural and engineered environments all over the world, including surface water, ground water, wastewater, seawater, and sediments[11-14]. Studies have revealed correlations between exposure to EEs and the health of humans and wildlife, including many complicated adverse effects based on toxicological tests[15-17]. Hence, control of the types and amounts of EEs in drinking water is as important as the control of mutagens.

At present, pollution of the source water is a serious and ever-growing problem in China, especially in the most rapidly developing areas, such as the Zhujiang River delta in Southern China. Recently, the water quality in this area has drawn considerable attention of the local people because of concerns over industrial pollution.

In this study, we constructed a pilot plant near the Beijiang River, a main branch of the Zhujiang River system. We extracted organic compounds from the source water and effluents from the pilot plant under five combination processes, detected and evaluated mutagenic and estrogenic effects, and analyzed chemical component changes with GC-MS. This work offers a new approach for selecting a water treatment process, through comparison of biological toxicity of organic compounds in effluents. Furthermore, this work also helped to evaluate the quality of source water from the Beijiang River.

MATERIALS AND METHODS

Reagents

Amberlite XAD-2 resins, 17β-estradiol (E2), dimethyl sulfoxide (DMSO), and chlorophenol red-β-D-galactopyranoside (CPRG) were purchased from Sigma (St. Louis, MO USA). Acetone and dichlormethane (DCM) were analytically pure and obtained from Shanghai Chemicals Company (Shanghai, China). The S-9 fraction prepared from rat liver was induced by Aroclor 1254 and purchased from Sigma (St. Louis, MO USA).

Water Treatment Process of the Pilot Plant

The pilot plant was operated with a total flux of 6 m^3/h, and consisted of conventional DWT and advanced treatment processes, including peroxidation (O_3), coagulation and sedimentation, sand filtration, ozonation, GAC adsorption, BAC adsorption, and chlorination (NaClO). A flow chart describing the five water treatment processes is shown in Figure 1.

The detailed parameters of each water treatment unit and process are shown in Table 1. The difference between P4/P5 and P2 is that the GAC in P4/P5 was back-flushed by air [intensity 12-14 L/(m^2·s), time 3-5 min] and water [intensity 8 L/(m^2·s), time 5-7 min], while P2 was not back-flushed. The operation time of BAC and GAC columns was no more than three months. Table 2 presents the water quality parameters of the source water during the experimental time.

Samples Preparation

Water samples were collected in stainless steel tanks and treated *in situ*. The volume of each sample was 100 L. The solid phase extraction (SPE) step was performed as described by Shen, et al. with some modification[18]. In brief, water samples were filtered through glass fiber filters (pore size=1 μm) to filter out suspended matter and the filtrate was applied onto XAD-2 resin columns. The resins were blown dry under gentle nitrogen flow and eluted with acetone and DCM. The acetone and DCM eluates were blown dry with nitrogen, dissolved and diluted with DMSO (for the Ames test) or ethanol (for the YES assay) to various concentrations. The samples were stored at −80 °C for further experiments. Deionized water was extracted with the same steps as a control.

Ames Test

The Ames test for mutagenic potential utilizes mutant histidine-dependent strains of *Salmonella typhimurium*, which may revert back to histidine independence and grow as viable colonies following contact with a suitable mutagen. *Salmonella* strains TA97, TA98, TA100, and TA102 were kindly gifted by