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Comparison of different combined treatment processes to address the source water with high concentration of natural organic matter during snowmelt period

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ABSTRACT

The source water in one forest region of the Northeast China had very high natural organic matter (NOM) concentration and heavy color during snowmelt period. The efficiency of five combined treatment processes was compared to address the high concentration of NOM and the mechanisms were also analyzed. Conventional treatment can hardly remove dissolved organic carbon (DOC) in the source water. $KMnO_4$ pre-oxidization could improve the DOC removal to 22.0%. Post activated carbon adsorption improved the DOC removal of conventional treatment to 28.8%. The non-sufficient NOM removal could be attributed to the dominance of large molecular weight organic matters in raw water, which cannot be adsorbed by the micropore upon activated carbon. O_3 + activated carbon treatment are another available technology for eliminating the color and UV_{254} in water. However, its performance of DOC removal was only 36.4%, which could not satisfy the requirement for organic matter. The limited ozone dosage is not sufficient to mineralize the high concentration of NOM. Magnetic ion-exchange resin combined with conventional treatment could remove 96.2% of color, 96.0% of UV_{254} and 87.1% of DOC, enabling effluents to meet the drinking water quality standard. The high removal efficiency could be explained by the negative charge on the surface of NOM which benefits the static adsorption of NOM on the anion exchange resin. The results indicated that magnetic ion-exchange resin combined with conventional treatment is the best available technology to remove high concentration of NOM.

Introduction

Natural organic matter (NOM) is a complex mixture of organic materials and presents ubiquitously in all natural water, particularly surface waters (Matilainen et al., 2010). NOM affects many esthetic aspects of water quality, such as annoying color, taste and odor problems (Matilainen et al., 2002, 2011). Moreover, NOM has been noted as a major contributor to the disinfection byproduct (Krasner et al., 2006; Liu et al., 2012). Thus, NOM has been regarded as a focus in water industry throughout the world.

Depending on the biogeochemical cycles of the surrounding environments, the properties of NOM differ considerably in waters of different origins (Nissinen et al., 2001; Fabris et al., 2008). The quantity and quality of NOM, which change seasonally due to the change of weather, vegetation and humification, have impacts on the selection, design and operation of water treatment processes (Chen et al., 2008).

The practical drinking water treatment processes for NOM removal include enhanced coagulation, activated carbon adsorption, O_3 + granular activated carbon (GAC) or biological activated carbon

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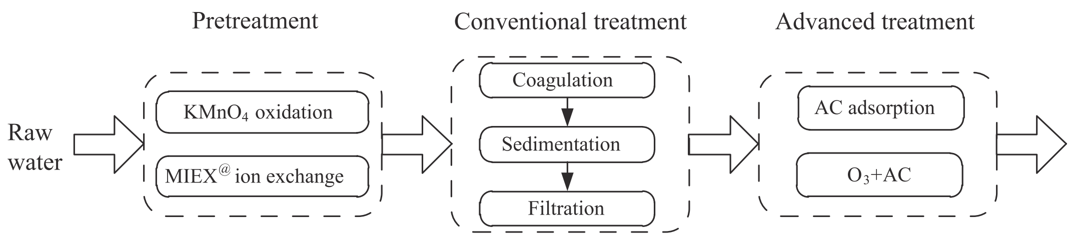

Fig. 1 – Relationship of the water treatment units for the NOM removal.

(BAC) treatment process, ion exchange, and membrane filtration. Among these treatment processes, enhanced coagulation is the most widely-applied method (Jiang and Graham, 1996; Zhan et al., 2010). Its efficiency for DOC removal varies from 20% to 60% (Jacangelo et al., 1995). Activated carbon (AC) is effective in adsorbing the hydrophobic compounds with small molecular weight (MW) (Drikas et al., 2009). AC has the dissolved organic carbon (DOC) removal efficiency of 30% ± 12% in one pilot test (Chen et al., 2007). Currently, ozone and BAC treatment process is more and more popular for NOM and other organic matter removal. In the ozone and BAC treatment, NOM could be oxidized and probably decomposed into smaller compounds by ozone and then biodegraded during biological activated carbon filtration (Boere, 1992; Chen et al., 2011; Qian et al., 2013). Anion exchange resin has high efficacy of combining or adsorbing the negatively charged NOM (Humbert et al., 2005). One promising anion exchange technology, i.e. magnetic ion-exchange resin (MIEX), has a high capacity for NOM and could precipitate quickly with aid of magnetic force, which benefits the application in water treatment plants (Gan et al., 2013; Kingsbury and Singer, 2013).

The source water in one forest region of the Northeast China suffered a high concentration of NOM, which was chosen as the raw water in this study. The NOM in the source water was brought by the snowmelt water flowing through the forest. Heavy brown color was observed due to the high load of NOM. Meanwhile, the concentration of organic matter is over 10 mg/L. The conventional treatment processes could hardly handle the NOM-rich source water. Besides, the temperature of snowmelt water was close to ice point, which restrained the biodegradation in the BAC process. Thus, the investigation of process choice is requested by the local water company.

This study focused on the following objectives: (1) Characterizing of the properties of NOM in the source water. The MW distribution, surface charge distribution and fluorescence were determined for NOM property characterization. (2) Comparing the removal efficiency of different water treatment processes and giving the suggestions for process selection. (3) Investigating the mechanisms of the different treatment processes for the NOM removal.

1. Materials and methods

1.1. Source water

The source water was sampled from the Gulian River, which runs through the Great Xing'an Mountain Forest, Heilongjiang Province in Northeast China. The snowmelt water brought high concentration NOM from the forest and took it into the river. The water sample was stored in ice box and delivered to the lab in Tsinghua University, Beijing within two days. The working temperature (12°C) is lower down to approach the real temperature of snowmelt water (2–4°C). Actually, the influence of temperature on water treatment process could be described by the Arrhenius law, i.e.

$$k = Ae^{-(E_a/RT)}$$

Table 1 – Combined water treatment processes for the NOM removal.

Process name	Processes combination	Parameters and notes
Conventional treatment process (CTP)	Coagulation and sedimentation	Simulated with a jar tester[a]. Coagulation was conducted by 300 r/min fast mixing for 1 min and slow agitation at 60, 45, and 30 r/min for 5 min, respectively. Coagulant: polymeric aluminum chloride (PAlC) 3 mg/L measured as Al Sedimentation time: 30 min
	Filtration	Simulated with the 0.45 μm membrane filter
$KMnO_4$ enhanced conventional process	$KMnO_4$ pre-oxidation	Dosage: 2.0 mg/L Contact time: 30 min
	CTP	Same as above mentioned
MIEX enhanced conventional process	MIEX pretreatment	MIEX resin[b] dosage: 10 mL/L (6 g/L in dry resin); contact time: 30 min
	CTP	Same as above mentioned
Conventional and activated carbon (AC) process	CTP	Same as above mentioned
	AC adsorption	Simulated with 80 mg/L of powder activated carbon (milled F400 activated carbon with size of 200 mesh); contact time: 120 min
Conventional and O_3 + AC process	CTP	Same as above mentioned
	O_3	O_3[c] dosage: 1 mg/L; contact time: 10 min
	AC adsorption	Simulated with 80 mg/L of powder AC; contact time: 120 min

[a] The jar tester (model ZR4-6) was made by Zhongrun Water Industry Technology Development Company, Shenzhen, China.
[b] MIEX® resin was made by Orica Watercare, Melbourne, Australia.
[c] Ozone was produced onsite by a DHX-SS-1G ozone generator, Jiujiu Electronic Chemical Engineering and Technology Company, Harbin, China.