ISSN 1001-0742
CN 11-2629/X

JES

JOURNAL OF ENVIRONMENTAL SCIENCES

March 1, 2014 Volume 26 Number 3
www.jesc.ac.cn

ELSEVIER
Science Press

Sponsored by
Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences

ISSN 1001–0742 **Journal of Environmental Sciences** Vol. 26 No. 3 2014

CONTENTS

Aquatic environment

Metal composition of layered double hydroxides (LDHs) regulating ClO_4^- adsorption to calcined LDHs via the memory effect and hydrogen bonding
Yajie Lin, Qile Fang, Baoliang Chen ····· 493
Limitation of spatial distribution of ammonia-oxidizing microorganisms in the Haihe River, China, by heavy metals
Chao Wang, Baoqing Shan, Hong Zhang, Yu Zhao ····· 502
Temperature sensitivity of organic compound destruction in SCWO process
Yaqin Tan, Zhemin Shen, Weimin Guo, Chuang Ouyang, Jinping Jia, Weili Jiang, Haiyun Zhou ····· 512
Influence of moderate pre-oxidation treatment on the physical, chemical and phosphate adsorption properties of iron-containing activated carbon
Zhengfang Wang, Mo Shi, Jihua Li, Zheng Zheng ····· 519
Reduction of DOM fractions and their trihalomethane formation potential in surface river water by in-line coagulation with ceramic membrane filtration
Pharkphum Rakruam, Suraphong Wattanachira ····· 529
N_2O emission from nitrogen removal via nitrite in oxic-anoxic granular sludge sequencing batch reactor
Hong Liang, Jiaoling Yang, Dawen Gao ····· 537
Influence of stabilizers on the antimicrobial properties of silver nanoparticles introduced into natural water
Aleksandra Burkowska-But, Grzegorz Sionkowski, Maciej Walczak ····· 542
Addition of hydrogen peroxide for the simultaneous control of bromate and odor during advanced drinking water treatment using ozone
Yongjing Wang, Jianwei Yu, Dong Zhang, Min Yang ····· 550
Nitric oxide removal by wastewater bacteria in a biotrickling filter
Hejingying Niu, Dennis Y C Leung, Chifat Wong, Tong Zhang, Mayngor Chan, Fred C C Leung ····· 555
Elucidating the removal mechanism of *N,N*-dimethyldithiocarbamate in an anaerobic-anoxic-oxic activated sludge system
Yongmei Li, Xianzhong Cao, Lin Wang ····· 566
Influencing factors of disinfection byproducts formation during chloramination of Cyclops metabolite solutions
Xingbin Sun, Lei Sun, Ying Lu, Jing Zhang, Kejing Wang ····· 575

Atmospheric environment

Sources of nitrous and nitric oxides in paddy soils: Nitrification and denitrification
Ting Lan, Yong Han, Marco Roelcke, Rolf Nieder, Zucong Cai ····· 581
Upper Yellow River air concentrations of organochlorine pesticides estimated from tree bark, and their relationship with socioeconomic indices
Chang He, Jun Jin, Bailin Xiang, Ying Wang, Zhaohui Ma ····· 593
Mechanism and kinetic properties of NO_3-initiated atmospheric degradation of DDT
Cai Liu, Shanqing Li, Rui Gao, Juan Dang, Wenxing Wang, Qingzhu Zhang ····· 601
Sorption and phase distribution of ethanol and butanol blended gasoline vapours in the vadose zone after release
Ejikeme Ugwoha, John M. Andresen ····· 608

Terrestrial environment

Effects of temperature change and tree species composition on N_2O and NO emissions in acidic forest soils of subtropical China
Yi Cheng, Jing Wang, Shenqiang Wang, Zucong Cai, Lei Wang ····· 617

Environmental biology

Influence of sunlight on the proliferation of cyanobacterial blooms and its potential applications in Lake Taihu, China
Qichao Zhou, Wei Chen, Kun Shan, Lingling Zheng, Lirong Song ····· 626
Bioavailability and tissue distribution of Dechloranes in wild frogs (*Rana limnocharis*) from an e-waste recycling area in Southeast China
Long Li, Wenyue Wang, Quanxia Lv, Yujie Ben, Xinghong Li ····· 636

Environmental health and toxicology

Unexpected phenotypes of malformations induced in *Xenopus tropicalis* embryos by combined exposure to triphenyltin and 9-*cis*-retinoic acid
Jingmin Zhu, Lin Yu, Lijiao Wu, Lingling Hu, Huahong Shi ····· 643
Expression of sulfur uptake assimilation-related genes in response to cadmium, bensulfuron-methyl and their co-contamination in rice roots
Jian Zhou, Zegang Wang, Zhiwei Huang, Chao Lu, Zhuo Han, Jianfeng Zhang, Huimin Jiang, Cailin Ge, Juncheng Yang ····· 650

Environmental catalysis and materials

Reaction mechanism and metal ion transformation in photocatalytic ozonation of phenol and oxalic acid with Ag^+/TiO_2
Yingying Chen, Yongbing Xie, Jun Yang, Hongbin Cao, Yi Zhang ····· 662
Effect of TiO_2 calcination temperature on the photocatalytic oxidation of gaseous NH_3
Hongmin Wu, Jinzhu Ma, Changbin Zhang, Hong He ····· 673
Effects of synthesis methods on the performance of Pt + Rh/$Ce_{0.6}Zr_{0.4}O_2$ three-way catalysts
Zongcheng Zhan, Liyun Song, Xiaojun Liu, Jiao Jiao, Jinzhou Li, Hong He ····· 683
Catalytic combustion of soot over ceria-zinc mixed oxides catalysts supported onto cordierite
Leandro Fontanetti Nascimento, Renata Figueredo Martins, Rodrigo Ferreira Silva, Osvaldo Antonio Serra ····· 694
Effects of metal and acidic sites on the reaction by-products of butyl acetate oxidation over palladium-based catalysts
Lin Yue, Chi He, Zhengping Hao, Shunbing Wang, Hailin Wang ····· 702
Mechanism of enhanced removal of quinonic intermediates during electrochemical oxidation of Orange II under ultraviolet irradiation
Fazhan Li, Guoting Li, Xiwang Zhang ····· 708

Serial parameter: CN 11-2629/X*1989*m*223*en*P*26*2014-3

Journal of Environmental Sciences 26 (2014) 550–554

Available online at www.sciencedirect.com

Journal of Environmental Sciences

www.jesc.ac.cn

Addition of hydrogen peroxide for the simultaneous control of bromate and odor during advanced drinking water treatment using ozone

Yongjing Wang[1], Jianwei Yu[1,*], Dong Zhang[2], Min Yang[1]

1. State Key Laboratory of Environmental Aquatic Chemistry, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

2. Shanghai National Engineering Research Center of Urban Water Resources Co., Ltd., Shanghai 200082, China

ARTICLE INFO

Article history:
Received 27 March 2013
revised 05 May 2013
accepted 07 May 2013

Keywords:
ozonation
H_2O_2
BrO_3^- suppression
septic/swampy odor
flavor profile analysis

DOI: 10.1016/S1001-0742(13)60409-X

ABSTRACT

Complete removal of the characteristic septic/swampy odor from Huangpu River source water could only be achieved under an ozone dose as high as 4.0 mg/L in an ozone-biological activated carbon (O_3-BAC) process, which would lead to the production of high concentrations of carcinogenic bromate due to the high bromide content. This study investigated the possibility of simultaneous control of bromate and the septic/swampy odor by adding H_2O_2 prior to the O_3-BAC process for the treatment of Huangpu River water. H_2O_2 addition could reduce the bromate concentration effectively at an H_2O_2/O_3 (g/g) ratio of 0.5 or higher. At the same time, the septic/swampy odor removal was enhanced by the addition of H_2O_2, although optimization of the H_2O_2/O_3 ratio was required for each ozone dose. At an ozone dose of 2.0 mg/L, the odor was removed completely at an H_2O_2/O_3 ratio of 0.5. The results indicated that H_2O_2 application at a suitable dose could enhance the removal of the septic/swampy odor while suppressing the formation of bromate during ozonation of Huangpu River source water.

Introduction

Ozonation integrated with biological activated carbon (O_3-BAC) has been widely used for drinking water treatment because of its effectiveness in removing disinfection byproduct precursors (Chu et al., 2012; Ratasuk et al., 2008), odorants such as 2-methylisoborneol (2-MIB), geosmin and β-ionone (Peter and von Gunten, 2007), and many other odor causing compounds. The discovery of the formation of potentially carcinogenic bromate (BrO_3^-) during ozonation of bromide-containing source water (von Gunten and Hoigné, 1994), however, has greatly compromised the merits of ozone. Many efforts have thus been devoted to the control of bromate formation during ozonation (von Gunten and Oliveras, 1998).

Addition of ammonia or hydrogen peroxide (H_2O_2) has been proposed as a practical approach in controlling the formation of bromate (von Gunten and Hoigné, 1994; Mizuno et al., 2011). Ammonia could react with $HOBr/OBr^-$, an important ozonation intermediate for bromate production (von Gunten and Oliveras, 1998), to form bromamines (NH_2Br, $NHBr_2$ and NBr_3) (Hofmann and Andrews, 2001). Although quite effective in suppressing bromate formation, this approach may compromise the oxidation power of ozone due to the consumption of ozone by bromamines, resulting in the release of Br^- and NO_3^- (Hoigné and Bader, 1978; Haag et al., 1984). On the other hand, H_2O_2 addition at certain H_2O_2/O_3 ratios has been proved to be effective in reducing bromate formation by decomposing molecular ozone and consuming $HOBr/OBr^-$ (Mizuno et al., 2011; Croue et al., 1996). The combination of O_3 and H_2O_2, at the same time, has been known as an advanced oxidation process, which was widely used for micropollutant removal (von Gunten and

* Corresponding author. E-mail: jwyu@rcees.ac.cn

jesc.ac.cn

Oliveras, 1998). Therefore, compared with the ammonia addition approach, the addition of H_2O_2 may have the potential merit of enhancing the oxidation of pollutants in source water through the generation of hydroxyl radicals.

Odor control has long been an important issue for drinking water treatment. Ozonation has been proved to be effective for some odor problems (Peter and von Gunten, 2007). In a previous study, however, ozonation could only reduce the earthy-musty odor intensity from 10 to 6 according to the flavor profile analysis method (Bruchet et al., 2004). H_2O_2 addition was found to be able to enhance the reduction of odor intensity by ozonation (Glaze et al., 1990; Bruchet et al., 2004). Thus there is the possibility to control the formation of bromate and enhance the removal of odorants at the same time by adding H_2O_2 in an ozonation process.

The Huangpu River, which is known for its septic/swampy odor associated with seasonal earthy/musty odor (Yu et al., 2009), is an important drinking water source for Shanghai. The removal of odor has long been an important issue for the treatment of Huangpu River source water. However, with a high bromide concentration (204.9–394. 6 μg/L) (Huang et al., 2010), bromate control must be considered if ozone is adopted for odor removal. In this study, the possibility of simultaneous control of bromate and odor by adding H_2O_2 prior to the O_3-BAC process was evaluated in a pilot study, and a suitable H_2O_2/O_3 (g/g) ratio was proposed. The results of this study will be helpful for better application of ozone for drinking water treatment.

1 Materials and methods

1.1 Setup for the pilot study

Figure 1 shows the schematic diagram of the O_3-BAC system (120 L/hr) used for this study. Huangpu River water was treated in a conventional treatment process including coagulation, sedimentation and sand filtration, and then fed into the O_3-BAC system. Ozone gas was supplied into the ozonation column (height, 1500 mm; inner diameter, 130 mm; effective volume, 18.1 L) from the gas diffuser located at the bottom. The hydraulic retention time (HRT) was 9.1 min for ozonation. H_2O_2 was added into water before ozonation using a pump. Ozonated water flowed into the BAC column (carbon height, 1000 mm; inner diameter, 130 mm) in a down-flow mode with an empty bed contact time of 12.0 min. BAC of approximately 2.5 years age was taken from the BAC tank of a full scale waterworks using surface water as raw water.

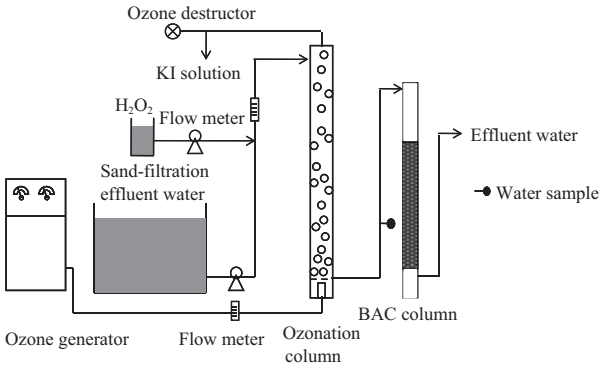

Fig. 1 Schematic diagram of the O_3-BAC system.

The experiment was performed from September to November in 2010 after a two-month pre-operation. The characteristics of raw water and sand filtered water are shown in **Table 1**. All the samples were stored at 4°C and analyzed in one week.

1.2 Analytical methods

All reagents applied in the experiment were of analytical grade, and all stock solutions were prepared with Milli-Q water (Millipore).

The indigo method was employed to measure the aqueous ozone concentrations (Bader and Hoigné, 1981), and gaseous phase ozone was quantified by the iodometric method (APHA, 1995). Ozone consumption was defined as the difference between the influent and effluent gaseous ozone. Hydrogen peroxide was determined by the peroxidase-DPD method (Bader et al., 1988). The DOC was determined using a Shimadzu TOC analyzer (TOC-Vcph). Bromate and bromide concentrations were analyzed by ion chromatography (Dionex 3000) using an AC9-SC analytical column with a detection limit of 2.0 μg/L and 10.0 μg/L, respectively.

The taste & odor intensity of water samples was determined using the flavor profile analysis method, which was described in standard methods (APHA, 1995). In this test, four panelists were trained for the panel. They assigned an intensity rating to each water sample using a

Table 1 Characteristics of Huangpu River raw water and sand filtered water

Parameter	Raw water	Sand filtered water
Temperature (°C)	13–18	14.2–18.5
Turbidity (NTU)	16.4–39.6	0.26–0.96
Ammonia (mg/L)	0.51–0.84	0.17–0.23
DOC (mg/L)	4.98–5.21	3.44–3.71
THMFP (μg/L)	207.7–286.2	103.7–236.1
HAAFP (μg/L)	256.2–291.9	178.31–202.0
2-MIB (ng/L)	6.13–17.08	6.86–20.66
Geosmin (ng/L)	2.68–3.79	1.95–4.06
Bromide (μg/L)	215.2–417.3	215.2–380.5
Septic/swampy odor intensity	8.0–10.0	6.0–9.0

* Septic/swampy odor intensity was analyzed by the flavor profile analysis method. THMFP: trihalomethane formation potential; HAAFP: haloacetic acid formation potential.

jesc.ac.cn

7-point category scale: 0 = not detectable odor, 2 = very weak, 4 = weak, 6 = weak-to-moderate, 8 = moderate, 10 = moderate-to-strong, 12 = strong. The descriptor and intensity for each sample was then evaluated and recorded. 2-MIB and geosmin concentrations of water samples were analyzed based on the processes of a previous study (Yu et al., 2009).

2 Results and discussion

2.1 Odor removal and bromate formation during O_3-BAC treatment

Offensive odor of the septic/swampy type was found to be the characteristic odor in Huangpu River water (Yu et al., 2009), with an intensity of 8.0–10.0 during the study, which was decreased slightly to 6.0–9.0 after conventional treatment (**Table 1**). As shown in **Fig. 2**, the septic/swampy odor was removed from an intensity of 6.8 to 2.6 with an ozone dose of 3.8–4.9 mg/L, showing that this odor was very difficult to remove. The subsequent BAC treatment could remove the odor effectively from an intensity of 6.8 to 2.4 even without ozonation. It is not clear that what were the major compounds responsible for the septic/swampy odor, although some sulfur-containing compounds such as dimethyl trisulfide were suspected to contribute to this odor (Yu et al., 2009). It has been found that dimethyl trisulfide could be removed effectively by a biologically active sand filter (Lundgren et al., 1988). At the same time, adsorption may also be important for the odor removal (Hrudey et al., 1995). However, even with the combination of O_3 and BAC, complete odor removal was only achieved at an ozone dose of 4 mg/L.

2-MIB was detected with a concentration of 6.86–20.66 ng/L in sand-filtered water. As shown in **Fig. S1**, the 2-MIB concentration in both ozonated and BAC-treated water decreased with the increase of ozone dose, and was below detection limit in the BAC-treated water at an ozone dose of 2.0 mg/L.

Figure 3 shows the formation of bromate as a function of ozone dose. With bromide concentration of 215.2–380.5 μg/L in the sand-filtered water, the bromate concentration increased quickly with increasing ozone dose. The bromate concentration corresponding to a frequently applied ozone dose of 3.0 mg/L was 17.2 μg/L, much higher than the standard level of 10 μg/L. Even at an ozone dose of 2.0 mg/L, the bromate concentration (11.4 μg/L) could exceed the standard level, and it could not be removed during the BAC treatment processes. However, an ozone dose of 2.0 or 3.0 mg/L could not remove the septic/swampy odor effectively by ozonation alone, as exhibited in **Fig. 2**. Weak septic/swampy odor could be detected even after the BAC treatment. Thus further efforts are required to remove the septic/swampy odor while controlling the bromate formation simultaneously.

2.2 Effects of H_2O_2 addition on odor removal and bromate control

Figure 4 displays the bromate concentration as a function of H_2O_2/O_3 ratio at two ozone doses (2.0 and 3.0 mg/L). With an H_2O_2/O_3 (g/g) ratio of 0.5, the bromate concentration decreased significantly from 11.5 μg/L and 17.2 μg/L to 1.9 μg/L and 1.8 μg/L, respectively, at the two ozone doses, indicating that H_2O_2 addition was very effective in suppressing bromate formation (Daniel et al., 1995). This H_2O_2/O_3 ratio was lower than that suggested by Mizuno et al. (2011), which may result from the relatively high residual H_2O_2 in the reaction system. After ozonation, more than 30% of H_2O_2 remained in the treated water (inset **Fig. 4**) and H_2O_2 could react with $HOBr^-/OBr^-$, which is an important intermediate in forming bromate, with

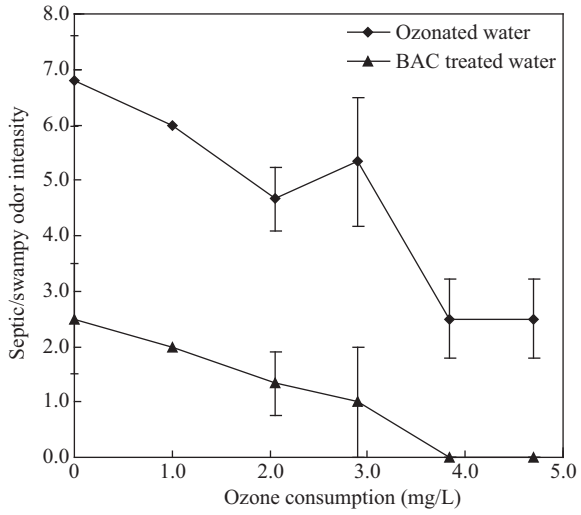

Fig. 2 Change of septic/swampy odor intensity as a function of ozone dose.

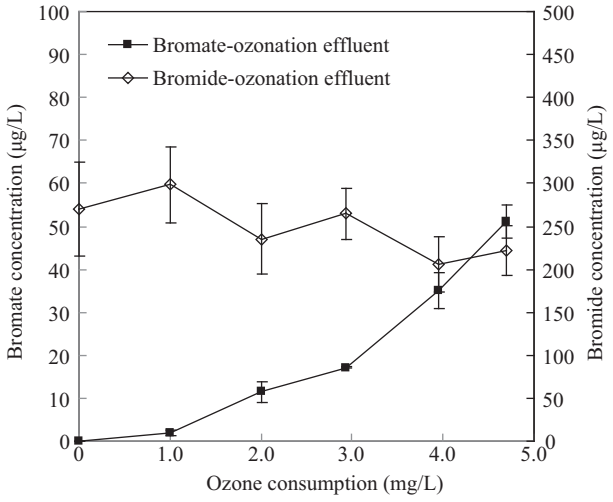

Fig. 3 Bromate formation as a function of ozone dose.

jesc.ac.cn

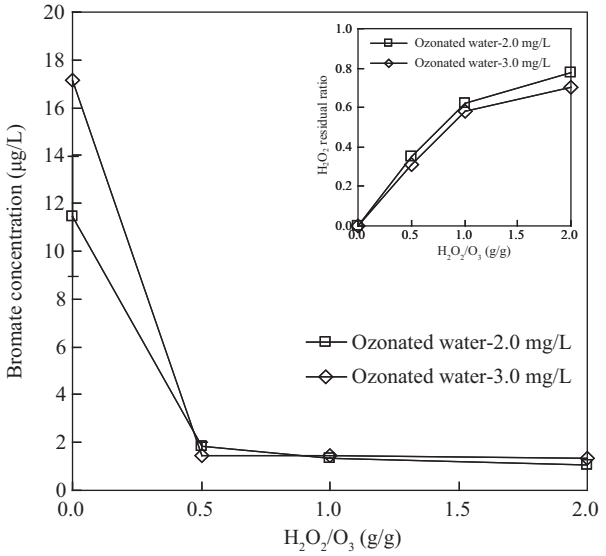

Fig. 4 Effect of H_2O_2 addition on bromate control. The inset is the H_2O_2 residual ratio H_2O_2 concentration/initial H_2O_2 concentration at different H_2O_2/O_3 (g/g) ratios.

reaction rate constant of 7.6×10^8 mol/(L·sec) (von Gunten and Oliveras, 1997), inducing the lower concentration of bromate. The optimal H_2O_2/O_3 ratio for bromate control may be different for different source water because many factors such as bromide, ammonia, background natural organic materials, and temperature could affect the ozone decomposition and hydroxyl radical concentration in water (von Gunten and Oliveras, 1998; von Gunten and Hoigné, 1994).

Figure 5 displays the decrease of the septic/swampy odor intensity as a function of H_2O_2/O_3 ratio. It was clearly demonstrated that the addition of H_2O_2 could enhance the removal of the septic/swampy odor. However, there existed an optimum H_2O_2/O_3 ratio for each ozone dose. At an ozone dose of 2.0 and 3.0 mg/L, the best odor removal efficacy was obtained at an H_2O_2/O_3 ratio of 0.5 and 1.0, respectively. The enhancement in odor removal decreased at higher H_2O_2/O_3 ratio, which might be the consequence of reactions between excessive amounts of H_2O_2 (inset **Fig. 4**) and OH radicals (von Gunton and Oliveras, 1998; Kleiser and Frimmel, 2000).

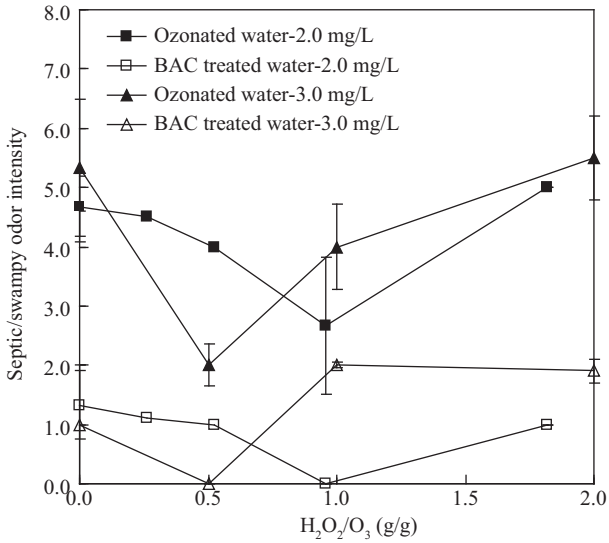

Fig. 5 Effect of H_2O_2 addition on septic/swampy odor removal.

Figure S2 displays the 2-MIB residual ratio (2-MIB/2-MIB_0) in the H_2O_2-O_3 treated water at the ozone doses of 2.0 and 3.0 mg/L. The residual ratio decreased as the H_2O_2 doses increased from 0 to 1.0, indicating that the removal of 2-MIB by ozonation was enhanced as H_2O_2 was applied. However, MIB could not be detected in the BAC treated water at the different H_2O_2 doses.

As discussed above, the addition of H_2O_2 could not only suppress the formation of bromate, but also enhance the removal of the septic/swampy odor. However, a suitable H_2O_2 dose should be determined to achieve the best performance.

3 Conclusions

This study investigated the possibility of simultaneous control of bromate and odor by adding H_2O_2 into an ozonation process for the treatment of Huangpu River water. The following conclusions were obtained: (1) Septic/swampy odor as the major odor problem for Huangpu River water could be completely removed by the combination of O_3 and BAC at an ozone dose as high as 4 mg/L, which would produce high concentrations of bromate. (2) By adding H_2O_2 with an H_2O_2/O_3 ratio of 0.5, it was possible to remove the septic/swampy odor and suppress the formation of bromate by the combination of O_3 and BAC at an ozone dose of 2.0 mg/L. The suitable H_2O_2 dose should be determined according to raw water quality and the ozone dose.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (No. 50938007), the Funds for Major Science and Technology Program for Water Pollution Control and Treatment (No. 2012ZX07403-002-02), and the Shanghai Committee of Science and Technology Project (No. 11XD1420500).

Supporting materials

Supplementary data associated with this article can be found in the online version.

REFERENCES

APHA, AWWA, WEF, 1995. Standard methods for the examination of water and wastewater. American Public Health Association, 19th

jesc.ac.cn

ed. Washington, DC.

Bader, H., Hoigné, J., 1981. Determination of ozone in water by the indigo method. Water Res. 15(4), 449–456.

Bader, H., Sturzenegger, V., Hoigné, J., 1988. Photometric method for the determination of low concentrations of hydrogen peroxide by the peroxidase catalyzed oxidation of *N,N*-diethyl-*p*-phenylenediamine (DPD). Water Res. 22(9), 1109–1115.

Bruchet, A., Duguet, J. P., Suffe, I. H., 2004. Role of oxidants and disinfectants on the removal, masking and generation of tastes and odours. Rev. Environ. Sci. Biotechnol. 3(1), 33–41.

Chu, W., Gao, N., Yin, D., Deng, Y., Templeton, M. R., 2012. Ozone-biological activated carbon integrated treatment for removal of precursors of halogenated nitrogenous disinfection by-products. Chemosphere 86(11), 1087–1091.

Croue, J. P., Koudjonou, B. K., Legube, B., 1996. Parameters affecting the formation of bromate ion during ozonation. Ozone: Sci. Eng. 18(1), 1–18.

Daniel, P. A., Zafer, M. A., Meyerhofer, P. F., 1995. Bromate control: Water quality, engineering, and operational considerations. Water Suppl.13(1), 169–176.

Glaze, W. H., Schep, R., Chauncey, W., Ruth, E. C., Zarnoch, J. J., Aieta, E. M. et al., 1990. Evaluating oxidants for the removal of model taste and odor compounds from a municipal water supply. J. Amer. Water Works Assoc. 82(5), 79–84.

Haag, W. R., Hoigné, J., Bader, H., 1984. Improved ammonia oxidation by ozone in the presence of bromide ion during water treatment. Water Res. 18(9), 1125–1128.

Hofmann, R., Andrews, R. C., 2001. Ammoniacal bromamines: A review of their influence on bromate formation during ozonation. Water Res. 35(3), 599–604.

Hoigné, J., Bader, H., 1978. Ozonation of water: kinetics of oxidation of ammonia by ozone and hydroxyl radicals. Environ. Sci. Technol.12(1), 79–84.

Hrudey, S. E., Huck, P. M., Mitton, M. J., Kenefick, S. L., 1995. Evaluation of odour removal by pilot-scale biological treatment process trains during spring runoff in an ice-covered river. Water Sci. Technol. 31(11), 195–201.

Huang, X., Mei, H., Ding, G., Lu, N., 2010. Bromate formation during ozonation in bromide-containing Huangpu River water. J. Shanghai Univ. (Nat. Sci. Ed.) 16(5), 498–502.

Kleiser, G., Frimmel, F. H., 2000. Removal of precursors for disinfection by-products (DBPs)-differences between ozone-and OH-radical-induced oxidation. Sci. Total Environ. 256(1), 1–9.

Lundgren, B. V., Grimvall, A., Sävenhed, R., 1988. Formation and removal of off-flavour compounds during ozonation and filtration through biologically active sand filters. Water Sci. Technol. 20(8-9), 245–253.

Mizuno, T., Ohara, S., Nishimura, F., Tsuno, H., 2011. O_3/H_2O_2 process for both removal of odorous algal-derived compounds and control of bromate ion formation. Ozone: Sci. Eng. 33(2), 121–135.

Peter, A., von Gunten, U., 2007. Oxidation kinetics of selected taste and odor compounds during ozonation of drinking water. Environ. Sci. Technol. 41(2), 626–631.

Ratasuk, C., Kositanont, C., Ratanatamskul, C., 2008. Removal of haloacetic acids by ozone and biologically active carbon. J. Sci. Soc. Thai 34, 293–298.

von Gunten, U., Hoigné, J., 1994. Bromate formation during ozonization of bromide-containing waters: interaction of ozone and hydroxyl radical reactions. Environ. Sci. Technol. 28(7), 1234–1242.

von Gunten, U., Oliveras, Y., 1997. Kinetics of the reaction between hydrogen peroxide and hypobromous acid: Implication on water treatment and natural systems. Water Res. 31(4), 900–906.

von Gunten, U., Oliveras, Y., 1998. Advanced oxidation of bromide-containing waters: Bromate formation mechanisms. Environ. Sci. Technol. 32(1), 63–70.

Yu, J., Zhao, Y., Yang, M., Tsair-Fuh, L., Guo, Z., Gu, J. et al., 2009. Occurrence of odour-causing compounds in different source waters of China. J. Water Supp. 58(8), 587–594.

jesc.ac.cn

Supporting materials

This supplementary information provides the effectiveness of O_3-BAC treatment and H_2O_2 addition on the odors removal.

Parameters of the conventional treatment processes

The pilot-scale conventional drinking water treatment processes consisted of coagulation, sedimentation and sand filtration. Coagulation was performed in a four-chamber mechanical flocculation system under the following conditions: 6.0 mg/L of polyaluminium chloride (Al_2O_3 content, 11%); fast mixing (200 r/min) for 1min; slow mixing for 15 min (150 r/min, 100 r/min and 50 r/min for 5 min respectively). The sedimentation time was 48 min. Sand filtration was conducted in a stainless-steel column (inner diameter, 300 mm; sand depth, 900 mm; sand diameter, 0.95-1.35 mm) at a filtration velocity of 8.0 m/hr.

Removal of 2-MIB by O_3-BAC treatment

Although 2-MIB was detected with concentrations of 6.86--20.66 ng/L in the sand-filtered water, earthy/musty odor was very weak to be detected because of the high septic/swampy intensity. **Figure S1** shows the results of 2-MIB removal by O_3-BAC process. Ozonation alone could remove 2-MIB effectively for the oxidation of OH radicals produced by ozone decomposition (Westerhoff et al., 2006), with the destruction percent of about 60% at the 1.0 mg/L ozone. The oxidation efficacy of 2-MIB increased with greater ozone doses, which was consistent with other research (Westerhoff et al., 2006). At the ozone dose of 2.0 mg/L, no 2-MIB could be detected in the BAC treated water.

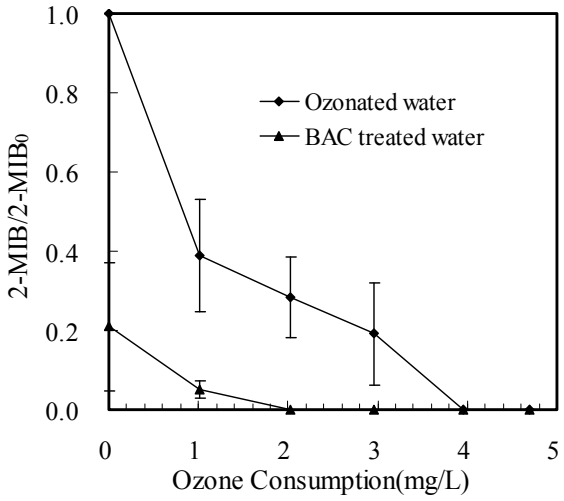

Fig. S1 2-MIB degradation in the O_3-BAC treated water as a function of ozone doses.

jesc.ac.cn

Effect of H_2O_2 addition on the 2-MIB removal

Figure S2 displays the 2-MIB remaining ratio (2-MIB/2-MIB_0) in the ozonated water at the ozone doses of 2.0 and 3.0 mg/L. The remaining ratio decreased as the H_2O_2 doses increased from 0 to 1.0, and then increased. However, MIB could not be detected in the BAC treated water at different H_2O_2 doses.

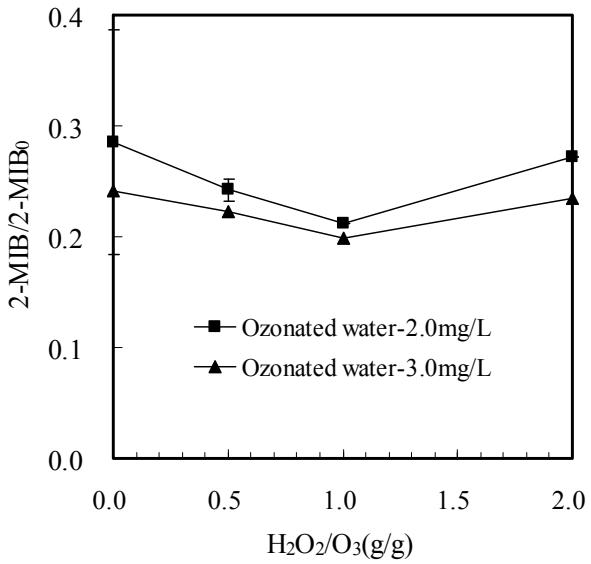

Fig. S2 2-MIB degradation in the ozonated water as a function of H_2O_2/O_3 (g/g) ratio.

Bromate concentration in ozonated water and BAC treated water

During the period of experiment, different ozone doses (0-4.6mg/L) and H_2O_2/O_3 (g/g) ratios were applied for the sand filtrated water treatment. Thus bromate concentration in ozonated water and BAC treated water varied as different doses of oxidant used. **Figure S3** displays the bromate concentration in both waters during the period. It shows that BAC treatment could not remove bromate effectively.

jesc.ac.cn

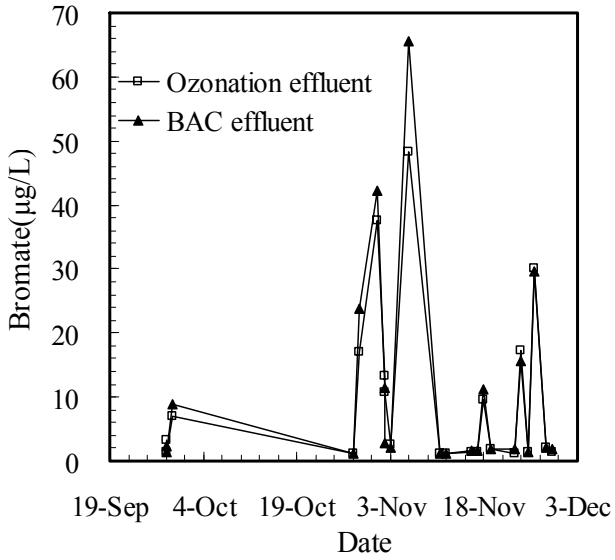

Fig. S3 Bromate concentration in the ozonated water and BAC treated water.

References

Westerhoff, P., Nalinakumari, B., Pei P, 2006. Kinetics of MIB and geosmin oxidation during ozonation. Ozone: Science & Engineering 28(5): 277-286.

jesc.ac.cn

Supporting materials

This supplementary information provides the effectiveness of O_3-BAC treatment and H_2O_2 addition on the odors removal.

Parameters of the conventional treatment processes

The pilot-scale conventional drinking water treatment processes consisted of coagulation, sedimentation and sand filtration. Coagulation was performed in a four-chamber mechanical flocculation system under the following conditions: 6.0 mg/L of polyaluminium chloride (Al_2O_3 content, 11%); fast mixing (200 r/min) for 1min; slow mixing for 15 min (150 r/min, 100 r/min and 50 r/min for 5 min respectively). The sedimentation time was 48 min. Sand filtration was conducted in a stainless-steel column (inner diameter, 300 mm; sand depth, 900 mm; sand diameter, 0.95-1.35 mm) at a filtration velocity of 8.0 m/hr.

Removal of 2-MIB by O_3-BAC treatment

Although 2-MIB was detected with concentrations of 6.86--20.66 ng/L in the sand-filtered water, earthy/musty odor was very weak to be detected because of the high septic/swampy intensity. **Figure S1** shows the results of 2-MIB removal by O_3-BAC process. Ozonation alone could remove 2-MIB effectively for the oxidation of OH radicals produced by ozone decomposition (Westerhoff et al., 2006), with the destruction percent of about 60% at the 1.0 mg/L ozone. The oxidation efficacy of 2-MIB increased with greater ozone doses, which was consistent with other research (Westerhoff et al., 2006). At the ozone dose of 2.0 mg/L, no 2-MIB could be detected in the BAC treated water.

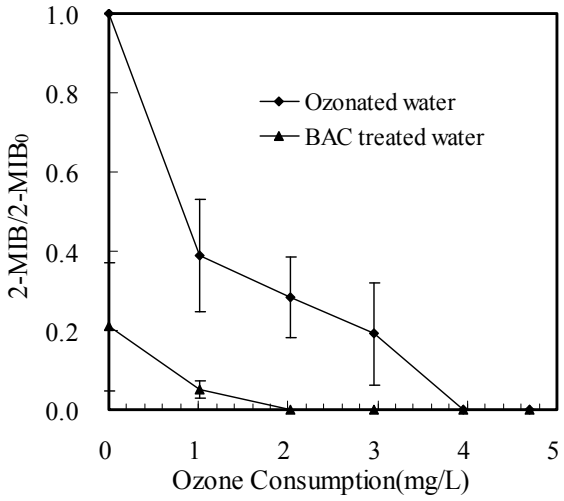

Fig. S1 2-MIB degradation in the O_3-BAC treated water as a function of ozone doses.

jesc.ac.cn

Effect of H_2O_2 addition on the 2-MIB removal

Figure S2 displays the 2-MIB remaining ratio (2-MIB/2-MIB_0) in the ozonated water at the ozone doses of 2.0 and 3.0 mg/L. The remaining ratio decreased as the H_2O_2 doses increased from 0 to 1.0, and then increased. However, MIB could not be detected in the BAC treated water at different H_2O_2 doses.

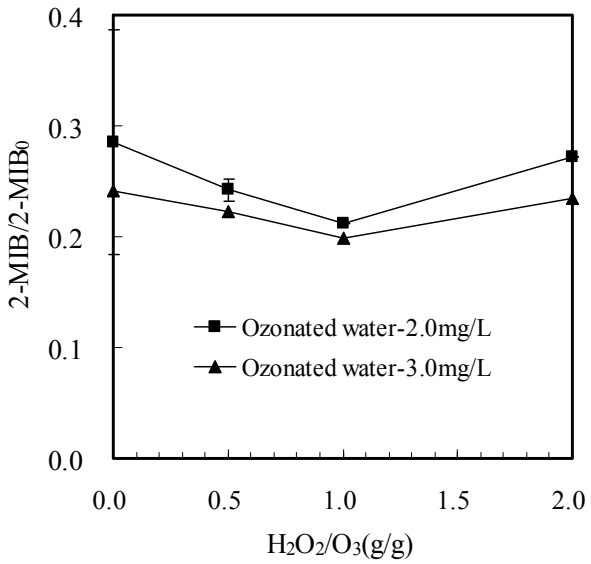

Fig. S2 2-MIB degradation in the ozonated water as a function of H_2O_2/O_3 (g/g) ratio.

Bromate concentration in ozonated water and BAC treated water

During the period of experiment, different ozone doses (0-4.6mg/L) and H_2O_2/O_3 (g/g) ratios were applied for the sand filtrated water treatment. Thus bromate concentration in ozonated water and BAC treated water varied as different doses of oxidant used. **Figure S3** displays the bromate concentration in both waters during the period. It shows that BAC treatment could not remove bromate effectively.

jesc.ac.cn

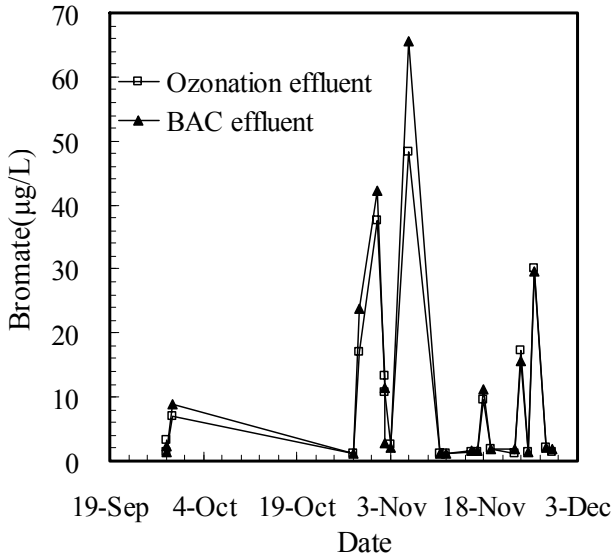

Fig. S3 Bromate concentration in the ozonated water and BAC treated water.

References

Westerhoff, P., Nalinakumari, B., Pei P, 2006. Kinetics of MIB and geosmin oxidation during ozonation. Ozone: Science & Engineering 28(5): 277-286.

jesc.ac.cn

Editorial Board of Journal of Environmental Sciences

Editor-in-Chief

Hongxiao Tang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Associate Editors-in-Chief

Jiuhui Qu Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Shu Tao Peking University, China
Nigel Bell Imperial College London, United Kingdom
Po-Keung Wong The Chinese University of Hong Kong, Hong Kong, China

Editorial Board

Aquatic environment

Baoyu Gao
Shandong University, China
Maohong Fan
University of Wyoming, USA
Chihpin Huang
National Chiao Tung University
Taiwan, China
Ng Wun Jern
Nanyang Environment &
Water Research Institute, Singapore
Clark C. K. Liu
University of Hawaii at Manoa, USA
Hokyong Shon
University of Technology, Sydney, Australia
Zijian Wang
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China
Zhiwu Wang
The Ohio State University, USA
Yuxiang Wang
Queen's University, Canada
Min Yang
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China
Zhifeng Yang
Beijing Normal University, China
Han-Qing Yu
University of Science & Technology of China

Terrestrial environment

Christopher Anderson
Massey University, New Zealand
Zucong Cai
Nanjing Normal University, China
Xinbin Feng
Institute of Geochemistry,
Chinese Academy of Sciences, China
Hongqing Hu
Huazhong Agricultural University, China
Kin-Che Lam
The Chinese University of Hong Kong
Hong Kong, China
Erwin Klumpp
Research Centre Juelich, Agrosphere Institute
Germany
Peijun Li
Institute of Applied Ecology,
Chinese Academy of Sciences, China
Michael Schloter
German Research Center for Environmental Health
Germany
Xuejun Wang
Peking University, China
Lizhong Zhu
Zhejiang University, China

Atomospheric environment

Jianmin Chen
Fudan University, China
Abdelwahid Mellouki
Centre National de la Recherche Scientifique
France
Yujing Mu
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China
Min Shao
Peking University, China
James Jay Schauer
University of Wisconsin-Madison, USA
Yuesi Wang
Institute of Atmospheric Physics,
Chinese Academy of Sciences, China
Xin Yang
University of Cambridge, UK

Environmental biology

Yong Cai
Florida International University, USA
Henner Hollert
RWTH Aachen University, Germany
Jae-Seong Lee
Hanyang University, South Korea
Christopher Rensing
University of Copenhagen, Denmark
Bojan Sedmak
National Institute of Biology, Ljubljana
Lirong Song
Institute of Hydrobiology,
the Chinese Academy of Sciences, China
Chunxia Wang
National Natural Science Foundation of China
Gehong Wei
Northwest A & F University, China
Daqiang Yin
Tongji University, China
Zhongtang Yu
The Ohio State University, USA

Environmental toxicology and health

Jingwen Chen
Dalian University of Technology, China
Jianying Hu
Peking University, China
Guibin Jiang
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China
Sijin Liu
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China
Tsuyoshi Nakanishi
Gifu Pharmaceutical University, Japan
Willie Peijnenburg
University of Leiden, The Netherlands
Bingsheng Zhou
Institute of Hydrobiology,
Chinese Academy of Sciences, China

Environmental catalysis and materials

Hong He
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China
Junhua Li
Tsinghua University, China
Wenfeng Shangguan
Shanghai Jiao Tong University, China
Yasutake Teraoka
Kyushu University, Japan
Ralph T. Yang
University of Michigan, USA

Environmental analysis and method

Zongwei Cai
Hong Kong Baptist University,
Hong Kong, China
Jiping Chen
Dalian Institute of Chemical Physics,
Chinese Academy of Sciences, China
Minghui Zheng
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China

Municipal solid waste and green chemistry

Pinjing He
Tongji University, China

Environmental ecology

Rusong Wang
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China

Editorial office staff

Managing editor Qingcai Feng
Editors Zixuan Wang Suqin Liu Zhengang Mao
English editor Catherine Rice (USA)

Copyright© Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. Published by Elsevier B.V. and Science Press. All rights reserved.

JOURNAL OF ENVIRONMENTAL SCIENCES

环境科学学报(英文版)

(http://www.jesc.ac.cn)

Aims and scope

Journal of Environmental Sciences is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

For subscription to electronic edition

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via http://www.elsevier.com/locate/jes.

For subscription to print edition

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

Submission declaration

Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The submission should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Submission declaration

Submission of the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The publication should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Editorial

Authors should submit manuscript online at http://www.jesc.ac.cn. In case of queries, please contact editorial office, Tel: +86-10-62920553, E-mail: jesc@263.net, jesc@rcees.ac.cn. Instruction to authors is available at http://www.jesc.ac.cn.

Journal of Environmental Sciences (Established in 1989)

Vol. 26 No. 3 2014

Supervised by	Chinese Academy of Sciences	**Published by**	Science Press, Beijing, China
Sponsored by	Research Center for Eco-Environmental		Elsevier Limited, The Netherlands
	Sciences, Chinese Academy of Sciences	**Distributed by**	
Edited by	Editorial Office of Journal of	Domestic	Science Press, 16 Donghuangchenggen
	Environmental Sciences		North Street, Beijing 100717, China
	P. O. Box 2871, Beijing 100085, China		Local Post Offices through China
	Tel: 86-10-62920553; http://www.jesc.ac.cn	Foreign	Elsevier Limited
	E-mail: jesc@263.net, jesc@rcees.ac.cn		http://www.elsevier.com/locate/jes
Editor-in-chief	Hongxiao Tang	**Printed by**	Beijing Beilin Printing House, 100083, China

CN 11-2629/X **Domestic postcode: 2-580** **Domestic price per issue RMB ¥ 110.00**

ISSN 1001-0742

03>

9 771001 074147