

CONTENTS

Aquatic environment

- Performance and microbial diversity of an expanded granular sludge bed reactor for high sulfate and nitrate waste brine treatment
Runhua Liao, Yan Li, Xuemin Yu, Peng Shi, Zhu Wang, Ke Shen, Qianqian Shi, Yu Miao, Wentao Li, Aimin Li 717
- Pollutant removal from municipal wastewater employing baffled subsurface flow and integrated surface flow-floating treatment wetlands
Tanveer Saeed, Abdullah Al-Muyeed, Rumana Afrin, Habibur Rahman, Guangzhi Sun 726
- Removal of polycyclic aromatic hydrocarbons from aqueous solution by raw and modified plant residue materials as biosorbents
Zemin Xi, Baoliang Chen 737
- Hybrid constructed wetlands for highly polluted river water treatment and comparison of surface- and subsurface-flow cells
Yucong Zheng, Xiaochang Wang, Jiaqing Xiong, Yongjun Liu, Yaqian Zhao 749
- Minimization of methabenzthiazuron residues in leaching water using amended soils and photocatalytic treatment with TiO₂ and ZnO
José Fenoll, Pilar Flores, Pilar Hellín, Joaquín Hernández, Simón Navarro 757
- Enhanced struvite recovery from wastewater using a novel cone-inserted fluidized bed reactor
Awoke Guadie, Siqing Xia, Wei Jiang, Lijie Zhou, Zhiqiang Zhang, Slawomir W. Hermanowicz, Xiaoyin Xu, Shuang Shen 765
- Evaluating the effectiveness of marine actinobacterial extract and its mediated titanium dioxide nanoparticles in the degradation of azo dyes
S Priyragini, S Veena, D Swetha, L Karthik, G Kumar, K V Bhaskara Rao 775
- Effect of ozone on the performance of a hybrid ceramic membrane-biological activated carbon process
Jianning Guo, Jiangyong Hu, Yi Tao, Jia Zhu, Xihui Zhang 783
- Removal of perchlorate from aqueous solution by cross-linked Fe(III)-chitosan complex
Long Lv, Yanhua Xie, Guoming Liu, Guo Liu, Jing Yu 792

Atmospheric environment

- Origin of major ions in monthly rainfall events at the Bamenda Highlands, NorthWest Cameroon
Mengnjo J. Wirmvem, Takeshi Ohba, Wilson Y. Fantong, Samuel N. Ayonghe, Jonathan N. Hogarh, Justice Y. Suila, Asobo Nkengmatia E. Asaah, Seigo Ooki, Gregory Tanyileke, Joseph V. Hell 801
- Ionic composition of submicron particles (PM_{1.0}) during the long-lasting haze period in January 2013 in Wuhan, central China
Hairong Cheng, Wei Gong, Zuwu Wang, Fan Zhang, Xinming Wang, Xiaopu Lv, Jia Liu, Xiaoxin Fu, Gan Zhang 810
- Understanding the sources and composition of the incremental excess of fine particles across multiple sampling locations in one air shed
Jerome E. McGinnis, Jongbae Heo, Michael R. Olson, Andrew P. Rutter, James J. Schauer 818
- Characterization of particle size distribution of mainstream cigarette smoke generated by smoking machine with an electrical low pressure impactor
Xiang Li, Haohui Kong, Xinying Zhang, Bin Peng, Cong Nie, Guanglin Shen, Huimin Liu 827

Terrestrial environment

- Differential responses of short-term soil respiration dynamics to the experimental addition of nitrogen and water in the temperate semi-arid steppe of Inner Mongolia, China
Yuchun Qi, Xinchao Liu, Yunshe Dong, Qin Peng, Yating He, Liangjie Sun, Junqiang Jia, Congcong Cao 834
- Effects of bile salts and divalent cations on the adsorption of norfloxacin by agricultural soils
Xuesong Kong, Shixiang Feng, Xu Zhang, Yan Li 846
- Tannic acid and saponin for removing arsenic from brownfield soils: Mobilization, distribution and speciation
Zygmunt Mariusz Gusiatiń 855

Environmental biology

- Molecular analysis of long-term biofilm formation on PVC and cast iron surfaces in drinking water distribution system
Ruyin Liu, Junge Zhu, Zhisheng Yu, DevRaj Joshi, Hongxun Zhang, Wenfang Lin, Min Yang 865
- Effect of a high strength chemical industry wastewater on microbial community dynamics and mesophilic methane generation
Harish Venkatakishnan, Youming Tan, Maszenan bin Abdul Majid, Santosh Pathak, Antonius Yudi Sendjaja, Dongzhe Li, Jerry Jian Lin Liu, Yan Zhou, Wun Jern Ng 875
- Effects of cathode potentials and nitrate concentrations on dissimilatory nitrate reductions by *Pseudomonas alcaliphila* in bioelectrochemical systems
Wenjie Zhang, Yao Zhang, Wentao Su, Yong Jiang, Min Su, Ping Gao, Daping Li 885
- Arsenic dynamics in the rhizosphere and its sequestration on rice roots as affected by root oxidation
Weisong Pan, Chuan Wu, Shengguo Xue, William Hartley 892

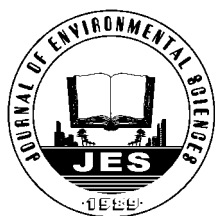
Environmental health and toxicology

Alterations of endogenous metabolites in urine of rats exposed to decabromodiphenyl ether using metabonomic approaches Weijin Yang, Jianjie Fu, Thanh Wang, Hanxia Liu, Yawei Wang, Qunfang Zhou, Guibin Jiang	900
Integrated biomarkers in wild crucian carp for early warning of water quality in Hun River, North China Binghui Zheng, Kun Lei, Ruizhi Liu, Shuangshuang Song, Lihui An	909
T-2 toxin induces developmental toxicity and apoptosis in zebrafish embryos Guogang Yuan, Yimei Wang, Xiaoyan Yuan, Tingfen Zhang, Jun Zhao, Liuyu Huang, Shuangqing Peng	917

Environmental analytical methods

Determining short chain fatty acids in sewage sludge hydrolysate: A comparison of three analytical methods and investigation of sample storage effects Victor Ibrahim, Tobias Hey, Karin Jönsson	926
--	-----

Serial parameter: CN 11-2629/X*1989*m*217*en*P*24*2014-4

Available online at www.sciencedirect.com

Journal of Environmental Sciences

www.jesc.ac.cn

Characterization of particle size distribution of mainstream cigarette smoke generated by smoking machine with an electrical low pressure impactor

Xiang Li¹, Haohui Kong², Xinying Zhang², Bin Peng¹, Cong Nie^{1,*}, Guanglin Shen^{2,*}, Huimin Liu¹

1. Key Laboratory of Tobacco Chemistry, Zhengzhou Tobacco Research Institute of CNTC, Zhengzhou 450001, China. E-mail: lixiang79ben@hotmail.com

2. Technology Center, Guangdong Branch of China Tobacco Industry Corporation, Guangzhou 510145, China

ARTICLE INFO

Article history:

Received 28 May 2013

revised 22 July 2013

accepted 26 July 2013

Keywords:

aerosol

mainstream cigarette smoke

particle size

DOI: 10.1016/S1001-0742(13)60472-6

ABSTRACT

Cigarette smoking is a particle-related exposure. Studying the characteristics of the particle size distribution of cigarette smoke can aid in providing knowledge of smoke aerosol attributes. We used an electrical low pressure impactor (ELPI) to measure the particle size distribution of mainstream cigarette smoke generated by a smoking machine and provided a continuum of particle sizes of cigarette smoke from a whole cigarette. The results showed that the aerodynamic diameters (D , geometric mean of a channel) of particles ranged from 0.021 to 1.956 μm , and the number concentrations were on the order of 10^5 – 10^9 cm^{-3} for different sizes of particles. The particle number of the size category below 0.1 μm approximated that of the category 0.1–2.0 μm , and the particles in the size category of 0.1–2.0 μm contributed extremely heavily to total particulate mass. In addition, the results with small samples indicated that the tar yields normalized per milligram of nicotine showed an approximately linear increase with increasing concentration of total particles.

Introduction

Cigarettes are the most-used combusted tobacco products by far, and the burning of tobacco during smoking causes smokers to be exposed to thousands of toxicants. The health effects of cigarette smoking have been of more and more concern to the public and the government (FSPTCA, 2011; IOM, 2001). Mainstream cigarette smoke, which emerges from the butt end of a puffed cigarette, is a dynamic and complex aerosol composed of more than 5000 chemical constituents (Rodgman and Perfetti, 2008). The majority of constituents exist in the particulate phase and the minority is found in the gas vapor phase, while some constituents dynamically distribute in both phases. The chemical compounds, formed by pyrolysis and distillation during tobacco combustion, coagulate and form various

sizes of particles which are small enough to be inhaled and deposit in the respiratory tract and the lung of smokers. The particles in smoke aerosol have been reported to play important roles in smoking-related diseases, such as lung cancer, chronic obstructive pulmonary disease (COPD) and cardiovascular disease (US DHHS, 1989; IARC, 2004; Sherman, 1991; Yoshida and Tuder, 2007).

Cigarette smoking is a particle-related exposure (Sangani and Ghio, 2011). The health consequences of smoking are mainly attributable to inhalation of particles. The particle size distribution of cigarette smoke aerosol is an important parameter in predicting the deposition of inhaled particles in different regions of the smoker's airways. Studying the characteristics of the particle size distribution of cigarette smoke can aid in providing knowledge about smoke aerosol (Alderman and Ingebretsen, 2011; Anderson et al., 1989; Hinds, 1978; McCusker et al., 1983), understanding the retention and deposition of cigarette smoke particles in the respiratory tract (Bernstein, 2004;

* Corresponding authors. E-mail: congnie@yahoo.com.cn (Cong Nie), shengl@gdzygy.com (Guanglin Shen)

Kane et al., 2010), and performing modification of product design (Wayne et al., 2008). In addition, the measurements of particle size distribution associated with the data from smoke chemical analysis and biological assays can provide a comprehensive insight into the adverse effects of cigarette smoke and the health risk following smoking. Over the past decades, the tobacco industry has long been involved in harm reduction for tobacco products. Smoke aerosol particle size manipulation has been evaluated both as a means of controlling physical and sensory product attributes and as a possible approach to reducing health risk related to exposure (Wayne et al., 2008).

The differences in the measurements of particle size distribution of cigarette smoke, which have been reported previously, are attributed to differences in measurement methods. Hinds (1978) measured the aerodynamic size distribution of cigarette smoke by using an aerosol centrifuge and a cascade impactor, and observed that mass median diameter decreased from 0.52 to 0.38 μm with increasing dilution. Anderson et al. (1989) reported that mass median diameter measured by the electrical aerosol analyzer was smaller than in previous data. Recently, with the development of advanced aerosol analysis technology, some of the instruments used in the fields of aerosol measurement and sampling have been applied in combustion research, including cigarette smoke (Adam et al., 2009; Aldermana and Ingebretsen, 2011; Becquemin et al., 2009; Kane et al., 2010). Kane et al. (2010) used an electrical low pressure impactor (ELPI) to investigate effects of smoking parameters on the particle size distribution and predicted airway deposition of mainstream cigarette smoke, and they determined that higher puff flow rates and reduced filter ventilation decreased the count median diameter of cigarette smoke. Aldermana and Ingebretsen (2011) used a DMS500 fast particulate spectrometer to characterize the particle size distribution of mainstream cigarette smoke.

In this study, an ELPI was employed to measure the particle size distribution of mainstream cigarette smoke generated by a smoking machine. The purpose of this study was: (1) to provide a continuum of particle sizes of cigarette smoke from a whole-cigarette measurement, and (2) to compare the particle distribution between the size category below 0.1 μm and the category of 0.1–2.0 μm . In addition, the correlation between the concentration of particles and tar yields or nicotine yields was studied preliminarily.

1 Materials and methods

1.1 Cigarettes

Kentucky reference cigarettes 3R4F from the University of Kentucky (Lexington, Kentucky, USA) and seven brands of commercial cigarettes purchased from the Chinese mar-

ket were used in this study. The cigarettes were conditioned at $22 \pm 1^\circ\text{C}$ and $60\% \pm 3\%$ relative humidity for at least 48 hr before being smoked.

1.2 Mainstream cigarette smoke particle size distribution measurement

The particle size distribution of fresh smoke aerosol was measured with an ELPI (Dekati, Tampere, Finland). The ELPI is a real-time particle size spectrometer for real-time monitoring of aerosol particle size distribution (Keskinen et al., 1992). The main components of this instrument are a corona charger, 13 stage cascade low-pressure impactor and multichannel electrometer. The ELPI operates at 10 L/min air flow, and measures particle size ranging from 7 nm with filter stages to 10 μm .

Cigarettes were smoked by a Borgwaldt LM1 smoking machine (Borgwaldt KC, Hamburg, Germany) under the International Organization for Standardization (ISO) smoking regimen (35/60/2 without blocking of filter ventilation) (ISO, 2000). When a puff was generated, a sample of smoke passed through the axial diluter (Dekati) by means of a vacuum pump, and then the diluted smoke passed through the second diluter (Dekati), in which it was mixed with clean air. After being twice diluted, a sample of diluted smoke was introduced into the inlet of the ELPI for particle size distribution measurement (Fig. 1). Total dilution ratios between 600 and 1000 were achieved for whole system.

The charged particles in smoke aerosol collected on the 13 collection plates of the impactor according to their aerodynamic diameter were recorded on 12 electrometer channels. The measurement data were processed by ELPI XLS4.05 software. The particle size measured by impact was equivalent to the aerodynamic diameter of a particle. In this study, the aerodynamic diameter was addressed using D (geometric mean of a channel). The particle size range and D corresponding to each impactor stage are shown in Table 1.

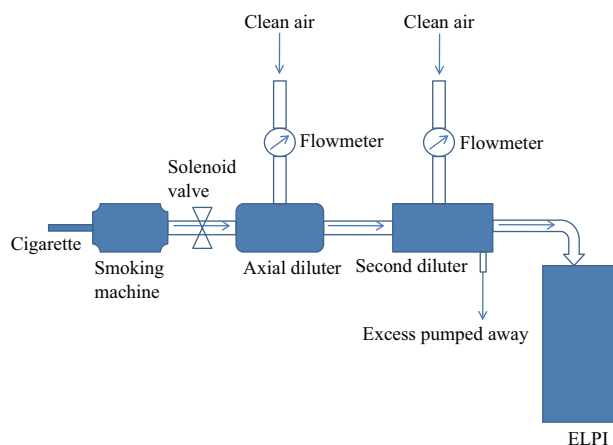


Fig. 1 Schematic diagram of the smoking machine and dilution system for the electrical low pressure impactor (ELPI) measurements.

Table 1 Particle size range and D corresponding to each impactor stage

Impactor stage	Particle size range (μm)	D (μm)
1	0.007–0.029	0.021
2	0.029–0.057	0.039
3	0.057–0.101	0.070
4	0.101–0.165	0.119
5	0.165–0.255	0.201
6	0.255–0.393	0.315
7	0.393–0.637	0.483
8	0.637–0.990	0.761
9	0.990–1.610	1.231
10	1.610–2.460	1.956
11	2.460–3.970	3.088
12	3.970–10.150	6.285

1.3 Chemical analysis

The yields of tar and nicotine were determined according to ISO 4387 (ISO, 2000).

1.4 Statistical analysis

The data were expressed as mean \pm SD. One-way ANOVA analysis was applied to compare the results from experiments. The value of $P < 0.05$ was considered as statistically significant.

2 Results

2.1 Particle size distribution and concentration of mainstream cigarette smoke from a whole cigarette

Figure 2 shows the particle size distribution and concentration of mainstream cigarette smoke from 3R4F reference cigarettes generated by the smoking machine. The aerodynamic diameters (D) of particles ranged from 0.021 to 1.956 μm . For different sizes of particles, the number concentrations were on the order of 10^5 – 10^9 cm^{-3} .

Figure 3a shows the particulate mass concentration of smoke aerosol, and there were large differences in the particulate mass concentrations among different size particles. The mass of particles of 0.021, 0.039, 0.070 or 0.119 μm was less than 1% of total particulate mass, respectively. The respective contribution to total particulate mass for particles of 0.315, 0.483 or 0.761 μm was all more than 10%. And the mass of particles of 0.201, 1.231 or 1.956 μm was less than 10% but more than 1% of total particulate mass, respectively (**Fig. 3b**).

Table 2 shows the comparison of the particle distributions between the size category below 0.1 μm and the category of 0.1–2.0 μm . Seven brands of commercial cigarettes and 3R4F reference cigarettes were used for analysis. The “Tar” yields of these cigarettes as labeled on

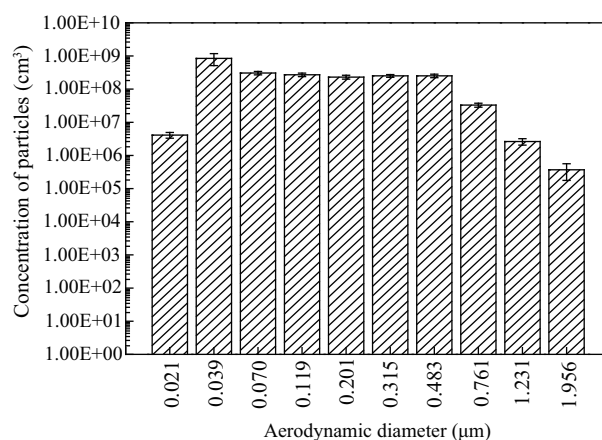


Fig. 2 Particle size distribution and concentration of mainstream cigarette smoke from 3R4F reference cigarettes. Mainstream cigarette smoke from 3R4F reference cigarettes generated by smoking machine was measured with the ELPI. The measurements were carried out in six independent experiments, and the data are expressed as mean \pm SD.

the packages ranged from 5 to 12 mg/cigarette. The total particulate mass concentrations of mainstream cigarette smoke from these cigarettes were between 27.88 and 48.38 $\mu\text{g}/\text{cm}^3$, and the total particle number concentrations of smoke aerosol were between 1.34×10^9 and 2.73×10^9 cm^{-3} . There was no significant difference in particle number between the size category below 0.1 μm and the category of 0.1–2.0 μm . However, there was significant difference in particulate mass between the two categories of particles ($P < 0.01$), and the particles in the size category of 0.1–2.0 μm contributed extremely heavily to total particulate mass.

2.2 Particle size distribution and concentration of puff-by-puff mainstream cigarette smoke

Figure 4 shows the particle size distribution and concentration of puff-by-puff mainstream cigarette smoke from 3R4F reference cigarettes generated by the smoking machine. The 3R4F reference cigarette was smoked seven puffs under the ISO smoking regimen. For every puff of smoke, the aerodynamic diameters of particles ranged from 0.021–1.956 μm . The particle size distribution and concentration of puff-by-puff smoke were similar to those of smoke aerosol generated from a whole cigarette. There was no difference in the characteristics of particle size distribution among puffs. The particulate mass concentration of every puff of smoke was similar to that of the whole-cigarette smoke aerosol, as was the contribution of different size particles to the total particulate mass for every puff (**Fig. 5**).

2.3 Correlation between the concentration of particles and tar yields or nicotine yields

Seven brands of commercial cigarettes and 3R4F reference cigarettes were used for analysis. There was no linear

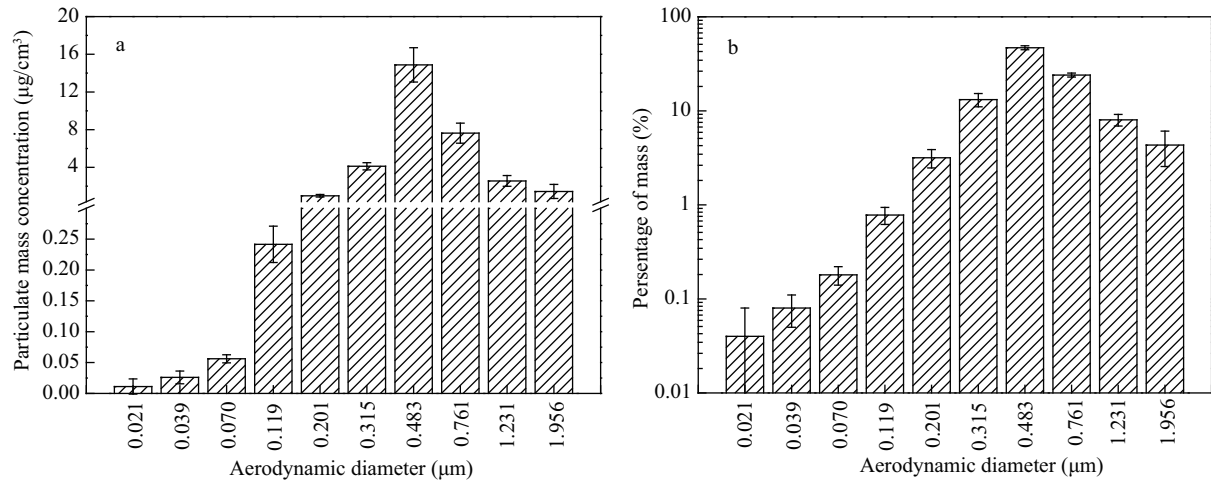


Fig. 3 Particulate mass concentration of smoke aerosol (a) and the contribution of different size particles to total particulate mass (b). Mainstream cigarette smoke from 3R4F reference cigarettes generated by smoking machine was measured with the ELPI. The measurements were carried out in six independent experiments, and the data are expressed as mean \pm SD.

Table 2 Comparison of the particle distribution between the size category below 0.1 μm and the category of 0.1–2.0 μm

Cigarette ID	“Tar” [#] (mg/cigarette)	Replicates (n)	Particulate mass concentration ($\mu\text{g}/\text{cm}^3$)	Concentration of particle ($\times 10^9 \text{ cm}^{-3}$)	Percentage of number (%)		Percentage of mass (%)	
					< 0.1 μm	0.1–2.0 μm ^a	< 0.1 μm	0.1–2.0 μm ^b
3R4F	9.5	6	37.71 \pm 3.73	2.19 \pm 0.28	51.8 \pm 7.8	48.2 \pm 7.8	0.3 \pm 0.1	99.7 \pm 0.1
DB (blended type)	10	5	37.77 \pm 1.74	2.32 \pm 0.22	47.1 \pm 7.2	52.9 \pm 7.2	0.3 \pm 0.0	99.7 \pm 0.0
ZHNN (blended type)	10	5	33.03 \pm 2.59	1.87 \pm 0.21	45.8 \pm 11.8	54.2 \pm 11.8	0.3 \pm 0.0	99.7 \pm 0.0
TF (Virginia type)	12	6	40.36 \pm 4.55	1.83 \pm 0.40	43.5 \pm 10.7	56.5 \pm 10.7	0.1 \pm 0.0	99.9 \pm 0.0
WBL (blended type)	12	6	37.82 \pm 3.86	2.48 \pm 0.71	52.1 \pm 13.3	47.9 \pm 13.3	0.2 \pm 0.1	99.8 \pm 0.1
ZHH (Virginia type)	12	3	48.38 \pm 4.86	1.87 \pm 0.33	34.4 \pm 0.8	65.6 \pm 0.8	0.1 \pm 0.0	99.9 \pm 0.0
CHBS (Virginia type)	5	3	31.21 \pm 5.83	1.34 \pm 0.25	35.0 \pm 0.9	65.0 \pm 0.9	0.1 \pm 0.0	99.9 \pm 0.0
ZHNN (blended type)	5	3	27.88 \pm 7.55	2.73 \pm 0.37	67.2 \pm 2.4	32.8 \pm 2.4	0.4 \pm 0.0	99.6 \pm 0.0

The data were expressed as mean \pm SD.

[#] The “Tar” values are as labeled on packages of cigarettes.

^a No significant difference between particle number of size category < 0.1 μm and 0.1–2.0 μm ($P = 0.29$), ^b significant difference between particulate mass of size category < 0.1 μm and 0.1–2.0 μm ($P < 0.01$).

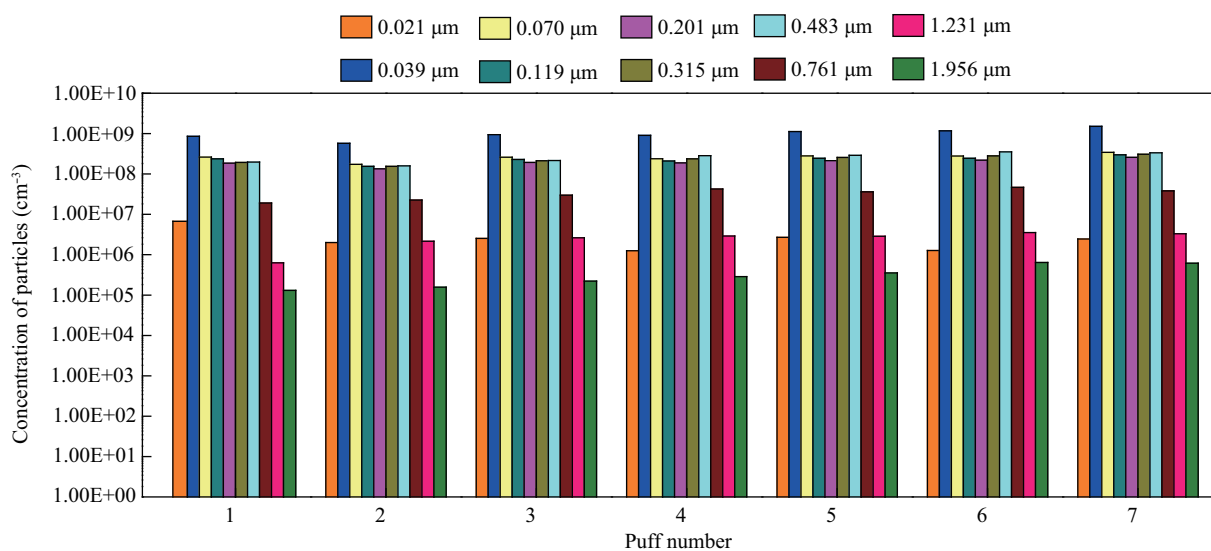


Fig. 4 Particle size distribution and concentration of puff-by-puff mainstream cigarette smoke.

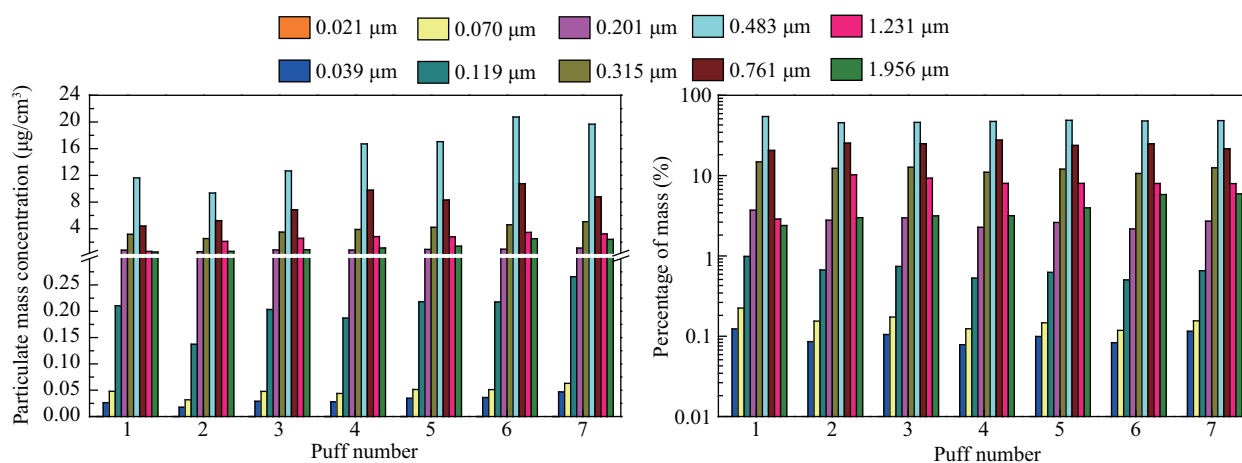


Fig. 5 Particulate mass concentration of puff-by-puff mainstream cigarette smoke (a) and the contribution of different size particles to total particulate mass for every puff (b).

correlation between the concentration of total particles and tar yields per cigarette (**Fig. 6a**), nor between the concentration of total particles and nicotine yields per cigarette (**Fig. 6b**). When tar yields were expressed on a per-mg of nicotine basis, the tar yields showed an approximately linear increase with increasing concentration of total particles ($R^2 = 0.684$) (**Fig. 6c**).

3 Discussion

Cigarette smoke is a complex aerosol comprised of a particulate phase and gas vapor phase. Particles in smoke, carrying toxicants, are inhaled into the respiratory tract and cause smoking-related diseases. The particle size distribution of smoke aerosol is related closely to the chemical composition and biological effects of particulate matter. The ELPI is a real-time particle size spectrometer designed at the Tampere University of Technology for measurement of aerosol particle size distribution (Keskinen et al., 1992). This instrument can monitor airborne particle size distributions

in the range of 7 nm with filter stages to 10 μm , and is qualified for different applications, such as automotive exhaust emissions (Liu et al., 2011), pharmaceutical studies (Ali, 2010) and combustion research (Nussbaum et al., 2009). In this study, the particle size distribution of mainstream cigarette smoke generated by a smoking machine was measured by an ELPI. The results showed that the aerodynamic diameters (D) of particles ranged from 0.021 to 1.956 μm , and the number concentrations were on the order of 10^5 – 10^9 cm^{-3} for different sizes of particles. The total particle number concentration was on the order of 10^9 cm^{-3} , which is consistent with previous reports (Bernstein, 2004; Kane et al., 2010). Large differences in the particulate mass concentration were observed among different size particles.

An interesting result was found when all particles in smoke were classified into two categories, the size category below 0.1 μm and the category of 0.1–2.0 μm . There was no significant difference in particle number between the two categories, while the particulate mass of particles in the category of 0.1–2.0 μm was more than 99% of total particulate mass. These results were consistent in all

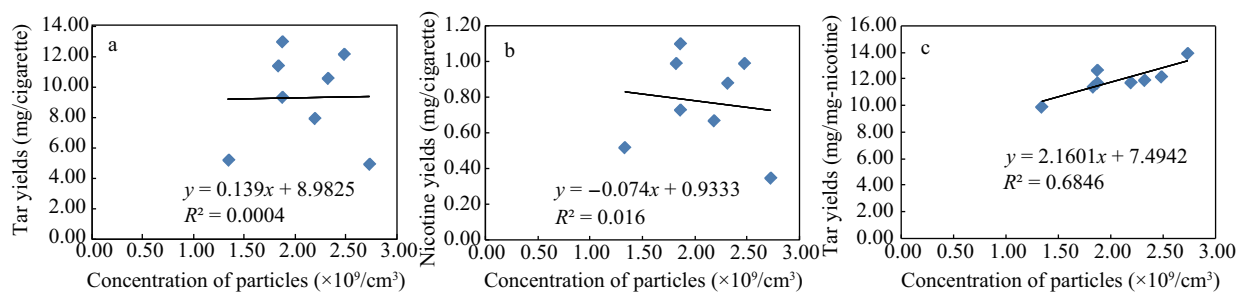


Fig. 6 Correlation between the concentration of particles and tar yields or nicotine yields. (a) correlation between the concentration of total particles and tar yields per cigarette; (b) correlation between the concentration of total particles and nicotine yields per cigarette; (c) correlation between the concentration of total particles and tar yield on a per-mg of nicotine basis. The concentration of particles as well as the values of tar or nicotine yields is the mean value for each brand of cigarettes. The correlation analysis was conducted using Microsoft Office Excel 2007.

test cigarettes. Particles smaller than 0.1 μm are labeled ultrafine particles, and particles between 0.1 and 2.5 μm are termed fine particles (Wichmann et al., 2000). Wichmann et al. (2000) concluded that both fine particles (represented by particle mass) and ultrafine particles (represented by particle number) showed independent effects on mortality at ambient concentrations. Epidemiological and toxicological studies show that inhalation of fine and ultrafine particles may cause adverse health effects, which might be related to factors including mass, surface area and number concentration of particles (Brouwer et al., 2004). The data obtained from this study showed that the smoke aerosol was composed of fine and ultrafine particles, and the particulate mass was dominated by fine particles and the contribution to particle number was similar for both fine particles and ultrafine particles.

The particulate matter in cigarette smoke carries a variety of chemical constituents, which form the tar, as well as nicotine and water. The study of tar has been generally focused on its toxicological effects, and nicotine is the addictive component of cigarette smoke. In the present study, we carried out a preliminary study on the correlation between the concentration of particles and tar yields or nicotine yields. There was no linear correlation between the concentration of total particles and tar yields per cigarette or with nicotine yields per cigarette. McCusker et al. (1983) previously reported that the number concentration of smoke particles from some “low” tar cigarettes was found to be similar to that of some “medium” tar cigarettes. The World Health Organization Study Group on Tobacco Product Regulation (TobReg) recommends that toxicant yields be normalized per milligram of nicotine for the regulation of tobacco products. The purpose of this normalization is to shift the interpretation of measurements away from the quantity of smoke generated per cigarette and the misleading use of the machine-measured yields as data of smoker exposure and risk (TobReg, 2008). Reporting results on a per nicotine basis represents theoretically a calculation to correct for a smoker’s nicotine intake based on the assumption that consumers smoke cigarettes to titrate their blood nicotine levels (Johnson et al., 2009). Hence, we normalized tar yields on a per-mg of nicotine basis, and found that the shifted tar yields showed an approximately linear increase with increasing concentration of total particles. The results suggest that decreasing the concentration of total particles in cigarette smoke might reduce the tar yields on a per-mg of nicotine basis. Certainly, the small number of test samples is a limitation for this result, so there needs to be further work with a large number of brands of cigarettes to confirm the above results in the future. In addition, we recommend further analysis of the chemical characteristics of smoke particulate matter so that the physicochemical properties of smoke aerosol can be explained explicitly.

4 Conclusions

The number concentrations for different size of particles in cigarette smoke generated by a smoking machine are on the order of 10^5 – 10^9 cm^{-3} , and there are large differences in the particulate mass concentration among different size particles. The particle number of the size category below 0.1 μm approximates that of the category of 0.1–2.0 μm . However, the particles in the size category of 0.1–2.0 μm contribute extremely heavily to total particulate mass. In addition, this study with small sample size indicates that the tar yields normalized on a per-mg of nicotine basis show an approximately linear increase with increasing concentration of total particles. In the present study, all particle size measurements were performed under the ISO machine-smoking regimen. It is well known that no machine-smoking regimen can represent all human smoking behaviors. However, machine-smoking testing is useful to characterize cigarette emissions for product design and regulatory purposes. Therefore, the data obtained from this work could provide a referenced insight into the physical properties of fresh cigarette smoke aerosol. The further study of chemical characteristics and biological responses of particles of different sizes associated with the physical properties of cigarette smoke will provide information for a comprehensive understanding of the mechanisms of smoking-related diseases.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (No. 21007094) to Xiang Li.

REFERENCES

- Adam, T., McAughey, J., McGrath, C., Mocker, C., Zimmermann, R., 2009. Simultaneous on-line size and chemical analysis of gas phase and particulate phase of cigarette mainstream smoke. *Analyt. Bioanal. Chem.* 394(4), 1193–1203.
- Alderman, S.L., Ingebrethsen, B.J., 2011. Characterization of mainstream cigarette smoke particle size distributions from commercial cigarettes using a DMS500 fast particulate spectrometer and smoking cycle simulator. *Aerosol Sci. Technol.* 45(12), 1409–1421.
- Ali, M., 2010. A novel method of characterizing medicinal drug aerosols generated from pulmonary drug delivery devices. *PDA J. Pharm. Sci. Technol.* 64(4), 364–372.
- Anderson, P.J., Wilson, J.D., Hiller, F.C., 1989. Particle size distribution of mainstream tobacco and marijuana smoke. Analysis using the electrical aerosol analyzer. *Am. Rev. Respir. Dis.* 140(1), 202–205.
- Becquemain, M.H., Bertholon, J.F., Attoui, M., Roy, F., Roy, M., Dautzenberg, B., 2009. Particle size in the smoke produced by six different types of cigarette. *Rev. Mal. Respir.* 24(7), 845–852.
- Bernstein, D., 2004. A review of the influence of particle size, puff volume, and inhalation pattern on the deposition of cigarette smoke

- particles in the respiratory tract. *Inhal. Toxicol.* 16(6), 675–689.
- Brouwer, D.H., Gijssbers, J.H., Lurvink, M.W., 2004. Personal exposure to ultrafine particles in the workplace: exploring sampling techniques and strategies. *Ann. Occup. Hyg.* 48(5), 439–453.
- FSPTCA, 2009. Public Law No: 111-31, H.R. 1256, 111th. Cong. Available at: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:h1256enr.txt.pdf. Accessed on May 20, 2013.
- Hinds, W.C., 1978. Size characteristics of cigarette smoke. *Amer. Ind. Hyg. Assoc. J.* 39(1), 48–54.
- IARC (International Agency for Research on Cancer), 2004. Tobacco smoke and involuntary smoking. In: *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, vol. 83. IARC Press, Lyon.
- IOM (Institute of Medicine), 2001. *Clearing the Smoke: Assessing the Science Base for Tobacco Harm Reduction*. National Academy Press, Washington, DC.
- ISO, 2000. ISO 4387: Cigarettes-Determination of Total and Nicotine-Free Dry Particulate Matter Using a Routine Analytical Smoking Machine, 3rd ed. International Organization for Standardization, Geneva.
- Johnson, M.D., Schilz, J., Djordjevic, M.V., Rice, J.R., Shields, P.G., 2009. Evaluation of *in vitro* assays for assessing the toxicity of cigarette smoke and smokeless tobacco. *Cancer Epidemiol. Biomarkers. Prevent.* 18(12), 3263–3304.
- Kane, D.B., Asgharian, B., Price, O.T., Rostami, A., Oldham, M.J., 2010. Effect of smoking parameters on the particle size distribution and predicted airway deposition of mainstream cigarette smoke. *Inhalat. Toxicol.* 22(3), 199–209.
- Keskinen, J., Pietarinen, K., Lehtimki, M., 1992. Electrical low pressure impactor. *J. Aerosol Sci.* 23(4), 353–360.
- Liu, Z., Ge, Y., Johnson, K.C., Shah, A.N., Tan, J., Wang, C. et al., 2011. Real-world operation conditions and on-road emissions of Beijing diesel buses measured by using portable emission measurement system and electric low-pressure impactor. *Sci. Total Environ.* 409(8), 1476–1480.
- McCusker, K., Hiller, F.C., Wilson, J.D., Mazumder, M.K., Bone, R., 1983. Aerodynamic sizing of tobacco smoke particulate from commercial cigarettes. *Arch. Environ. Health* 38(4), 215–218.
- Nussbaum, N.J., Zhu, D., Kuhns, H.D., Mazzoleni, C., Chang, M.C., Moosmiller, H. et al., 2009. The in-plume emission test stand: an instrument platform for the real-time characterization of fuel-based combustion emissions. *J. Air Waste Manag. Assoc.* 59(12), 1437–1445.
- Rodgman, A., Perfetti, T.A., 2008. *The Chemical Components of Tobacco and Tobacco Smoke*. USA: Taylor and Francis Ltd.
- Sangani, R.G., Ghio, A.J., 2011. Lung injury after cigarette smoking is particle related. *Inter. J. Chron. Obstruct. Pulmon. Dis.* 6, 191–198.
- Sherman, C.B., 1991. Health effects of cigarette smoking. *Clin. Chest Med.* 12(4), 643–658.
- Study Group on Tobacco Product Regulation (TobReg), W.H.O., 2008. *The Scientific Basis of Product Regulation: Second Report of a WHO Study Group*. WHO Press, Geneva.
- US DHHS (U.S. Department of Health and Human Services), 1989. *Reducing the health consequences of smoking, 25 years of progress. A report of the Surgeon General*, DHHS Publ. No. (CDC) 89–8411. Center for Chronic Disease Prevention and Health Promotion. Office on Smoking and Health, Rockville.
- Wayne, G.F., Connolly, G.N., Henningfield, J.E., Farone, W.A., 2008. Tobacco industry research and efforts to manipulate smoke particle size: implications for product regulation. *Nicot. Tobacco Res.* 10(4), 613–625.
- Wichmann, H.E., Spix, C., Tuch, T., Wlke, G., Peters, A., Heinrich, J. et al., 2000. Daily mortality and fine and ultrafine particles in Erfurt, Germany part I: role of particle number and particle mass. *Res. Rep.* (98), 5–86.
- Yoshida, T., Tuder, R.M., 2007. Pathobiology of cigarette smoke-induced chronic obstructive pulmonary disease. *Phys. Rev.* 87(3), 1047–1082.



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

Atmospheric 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

Jaе-Seong Lee

Sungkyunkwan 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)

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. 4 2014

Supervised by	Chinese Academy of Sciences	Published by	Science Press, Beijing, China
Sponsored by	Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences	Distributed by	Elsevier Limited, The Netherlands
Edited by	Editorial Office of Journal of Environmental Sciences P. O. Box 2871, Beijing 100085, China Tel: 86-10-62920553; http://www.jesc.ac.cn E-mail: jesc@263.net , jesc@rcees.ac.cn	Domestic	Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China Local Post Offices through China
Editor-in-chief	Hongxiao Tang	Foreign	Elsevier Limited http://www.elsevier.com/locate/jes
CN 11-2629/X	Domestic postcode: 2-580	Printed by	Beijing Beilin Printing House, 100083, China
		Domestic price per issue	RMB ¥ 110.00

ISSN 1001-0742

