Science of the Total Environment 476–477 (2014) 57–64

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Impacts of firecracker burning on aerosol chemical characteristics and human health risk levels during the Chinese New Year Celebration in Jinan, China

Lingxiao Yang [a,b,*], Xiaomei Gao [a,d], Xinfeng Wang [a], Wei Nie [a], Jing Wang [a], Rui Gao [a], Pengju Xu [a], Youping Shou [a], Qingzhu Zhang [a], Wenxing Wang [a,c]

[a] Environment Research Institute, Shandong University, Jinan 250100, China
[b] School of Environmental Science and Engineering, Shandong University, Jinan 250100, China
[c] Chinese Research Academy of Environmental Sciences, Beijing 100012, China
[d] School of Resources and Environment, University of Jinan, Jinan 250022, China

HIGHLIGHTS

- The effect of firecracker burning on aerosol characteristics and human health was assessed.
- The burning of firecrackers elevated the concentrations of particles and water-soluble ions.
- The burning of firecrackers varied the chemical composition of $PM_{2.5}$ and the number size distribution of particles.
- The burning of firecrackers did not alter the mass size distributions of the water-soluble ions.
- Pollutants emitted from the firecracker burning caused high non-carcinogenic risks to human health.

ARTICLE INFO

Article history:
Received 2 September 2013
Received in revised form 23 December 2013
Accepted 23 December 2013
Available online 21 January 2014

Keywords:
Chemical component
Risk assessment
Firecrackers
Chinese New Year
Jinan

ABSTRACT

Measurements for size distribution and chemical components (including water-soluble ions, OC/EC and trace elements) of particles were taken in Jinan, China, during the 2008 Chinese New Year (CNY) to assess the impacts of firecracker burning on aerosol chemical characteristics and human health risk levels. On the eve of the CNY, the widespread burning of firecrackers had a clear contribution to the number concentration of small accumulation mode particles (100–500 nm) and $PM_{2.5}$ mass concentration, with a maximum $PM_{2.5}$ concentration of 464.02 μg/m^3. The firecracker activities altered the number size distribution of particles, but had no influence on the mass size distribution of major water-soluble ions. The concentrations of aerosol and most ions peaked in the rush hour of firecracker burning, whereas the peaks of NO_3^- and NH_4^+ presented on the day following the burning of firecrackers. K^+, SO_4^{2-} and Cl^- composed approximately 62% of the $PM_{2.5}$ mass, and they existed as KCl and K_2SO_4 during the firecracker period. However, during the non-firecracker period, organic matter (OM), SO_4^{2-}, NO_3^- and NH_4^+ were the major chemical components of the $PM_{2.5}$, and major ions were primarily observed as $(NH_4)_2SO_4$ and NH_4NO_3. Estimates of non-carcinogenic risk levels to human health showed that the elemental risk levels during the firecracker period were substantially higher than those observed during the non-firecracker period. The total elemental risk levels in Jinan for the three groups (aged 2–6 years, 6–12 years and ≥70 years) were higher than 2 during the firecracker period, indicating that increased pollutant levels emitted from the burning of firecrackers over short periods of time may cause non-carcinogenic human health risks.

1. Introduction

Festivals worldwide, such as Independence Day in the US, France's Commemoration of the French Revolution, the Las Fallas in Spain, the Lantern Festival and Spring Festival in China, Diwali Festival during October/November in India, and New Year's Eve celebrations throughout the world, are often celebrated with the extensive burning of firecrackers. The burning of firecrackers is responsible for elevated levels of pollutants, including gaseous pollutants (e.g., SO_2, NO_x and O_3) (Attri et al., 2001; Ravindra et al., 2003; Moreno et al., 2007; Barman et al., 2008; Godri et al., 2010; Singh et al., 2010; Nishanth et al., 2012) and particles (e.g., TSP, PM_{10} and $PM_{2.5}$) with water-soluble ions and

* Corresponding author at: Environment Research Institute, Shandong University, Jinan 250100, China. Tel.: +86 531 88366072.
E-mail address: yanglingxiao@sdu.edu.cn (L. Yang).

0048-9697/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.12.110

trace metals (Kulshrestha et al., 2004; Drewnick et al., 2006; Moreno et al., 2007; Vecchi et al., 2008; Camilleri and Vella, 2010; Moreno et al., 2010; Perrino et al., 2011). In addition, the burning of firecrackers often causes degradation in air quality (Clark, 1997; Vecchi et al., 2008) and health hazards (e.g., chronic lung diseases, cancer, neurological and haematological diseases) (Becker et al., 2000; Kamp et al., 2005; Godri et al., 2010; Moreno et al., 2010). As a result, the pollution caused by the burning of firecrackers has recently received serious attention in the scientific community. However, most of the above studies were located abroad in areas with relatively low air pollutant levels, but data is still limited for China.

The Spring Festival and the Lantern Festival are two important celebrations with intensive burning of various firecrackers in China, a country that already has suffered serious air pollution. In China, several studies have been conducted to characterise the impacts of firecracker burning on air quality. These studies have indicated significant increases in the levels of $PM_{2.5}$ and PM_{10} with elements and water-soluble ions (Wang et al., 2007; Chang et al., 2011; Huang et al., 2012), and in the number concentration of particles in the size range of 100–500 nm (Zhang et al., 2010) due to the extensive burning of firecrackers. Li et al. (2013) also found that the emissions from the firecracker burning significantly changed the morphology and chemical composition of individual airborne particles and the transformation pathway from SO_2 to SO_4^{2-}. The above studies provided limited information regarding the aerosols, water-soluble ions and metal components emitted from the burning of firecrackers. However, the impacts of firecracker burning on aerosol chemical characteristics, especially for $PM_{2.5}$ and its chemical components, and human health risk levels have not been systematically studied in China.

To investigate the impacts of firecracker burning on aerosol chemical characteristics and human health risk levels, a campaign was conducted from February 3rd to 26th 2008 in Jinan, China, which spans the Chinese New Year. Jinan is the capital of Shandong Province, the hometown of Confucius, and is often the site of Chinese New Year celebrations that include the extensive burning of firecrackers. In addition, Jinan suffers from serious air pollution, especially particulate matter pollution (Baldasano et al., 2003; Yang et al., 2007, 2012; Gao et al., 2011). Therefore, it is important to understand whether the extensive burning of firecrackers has significant impacts on aerosol chemical characteristics and human health risk levels in this highly polluted region. In this manuscript, we discuss the impacts of firecracker burning on the mass size distribution of water-soluble ions, number concentration and size distribution of particles, and the chemical compositions of $PM_{2.5}$ during the firecracker period. And then we choose three highly sensitive groups, including children aged 2 to 6 years, children aged 6 to 12 years and older adults (≥70 years) to assess the potential health impact of $PM_{2.5}$ from the firecracker burning.

2. Methodology

2.1. Sampling site

The study was conducted at two urban sites in Jinan, the capital of Shandong Province (36°69′ N, 117°06′ E), from February 3rd to February 26th 2008. The filters for $PM_{2.5}$ and size-segregated aerosols were collected on the rooftop of a six-storied teaching building on the Centre Campus of Shandong University, approximately 20 m above ground level. Online instruments for particle number concentration and water-soluble ions in $PM_{2.5}$ were located at the rooftop (15 m above ground level) of public teaching building on the Hongjialou Campus of Shandong University, 1 km away from the Centre Campus. The inlets for aerosols were 1.5 m above the laboratory rooftop. These two sampling sites were surrounded by densely populated residential and commercial areas. The specific event of this study was the Chinese New Year and is characterised by the extensive burning of firecrackers from the night of February 6th to the morning of the following day when the city was shrouded in fume and smoke, particularly in the densely populated residential areas. In this study, we defined the day of February 6th as the firecracker period, while the other days as the non-firecracker period.

2.2. Instruments

2.2.1. Filter-based instruments

$PM_{2.5}$ samples were collected manually by using a Reference Ambient Air Sampler (Model RAAS 2.5–400, Thermo Andersen) with Teflon filters (Teflo™, 2 μm pore size and 47 mm diameter, Pall Inc.) at a flow rate of 16.7 L/min. Size-resolved aerosol samples were collected on aluminium substrates (MSP) by using the MOUDI (Micro-Orifice Uniform Deposit Impactor 110 with rotator, MSP) at a flow rate of 30 L/min. The MOUDI has eight stages with the size ranges of ≥18 μm, 10–18 μm, 5.6–10 μm, 3.2–5.6 μm, 1.8–3.2 μm, 1.0–1.8 μm, 0.56–1.0 μm, 0.32–0.56 μm and 0.18–0.32 μm. The sampling time for both $PM_{2.5}$ and size-resolved aerosol samples was approximately 24 h, normally from 9:00 a.m. to 8:45 a.m. the following day from February 3rd to February 26th 2008. A total of 20 samples for $PM_{2.5}$, and 13 sets of size-resolved aerosol samples with each set comprising of nine samples, were collected during the whole campaign. The flow rates of $PM_{2.5}$ sampler and MOUDI were calibrated before the field campaign, and field blanks were collected at the start and end of the field campaign. After sampling, all the filters were kept in plastic Petri dishes and then stored in a refrigerator at −4 °C for subsequent analysis in laboratory. In the laboratory, the concentrations of water-soluble ions were determined by ion chromatography (ICs, model Dionex 90) (Zhou et al., 2010), OC and EC in $PM_{2.5}$ were analysed by a semi-continuous OC/EC analyser (Sunset-DOSCOCEC, Sunset Lab, Portland, OR) (Wang et al., 2011), and trace metals in $PM_{2.5}$ were determined by using X-ray fluorescence (XRF) (Yang et al., 2013).

2.2.2. Real-time instruments

Particle number concentration at the range of 10 nm–10 μm was measured by a wide-range Particle Spectrometer™ (WPS model 1000XP, MSP Co., USA). This instrument combines the principles of differential mobility analysis (DMA), condensation particle counting (CPC), and laser light scattering (LPS). The detailed information for the principles of these parts can be found in Xu et al. (2011). The time of WPS measurements was from February 4th to February 9th 2008. Before and after the measurement, PSL spheres with sizes of (0.269 μm and 0.1007 μm mean diameter) and (0.701 μm, 1.36 μm, 1.6 μm, and 4.0 μm mean diameter) were used to calibrate DMA and LPS respectively. The DMA and CPC can measure particle number size distribution at the range of 10–500 nm in up to 96 channels. The LPS covers the 350–10,000 nm range in 24 additional channels. In this study we chose the sample mode with 60 channels in DMA and 24 channels in LPS. It took about 8 min for one complete scanning of the entire size range.

An ambient ion monitor (AIM; Model URG-9000B, URG Co.) was deployed to measure the hourly concentrations of water-soluble inorganic ions in $PM_{2.5}$. The AIM measurements started from February 3rd and ended on February 9th. Multi-point calibrations were performed every four days after changing the eluent solutions. The uncertainties were approximately 10%, and the estimated detection limits ranged from 0.010 to 0.084 $\mu g/m^3$ for all ions. The data from AIM had been compared to the filter samples, and they perfectly matched (Gao et al., 2011).

2.3. Elemental risk level calculations in $PM_{2.5}$

In this study, representative elemental components of $PM_{2.5}$ were applied to calculate elemental risk levels to assess the possible impacts on human health.