Atmospheric Environment 194 (2018) 7–13

Contents lists available at ScienceDirect

Atmospheric Environment

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

Emission rates of ultrafine and fine particles generated from human smoking of Chinese cigarettes

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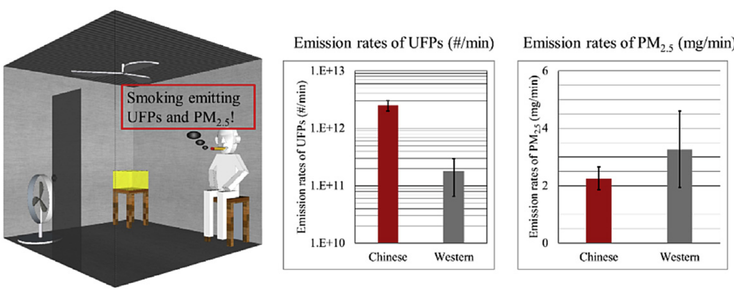
GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Particulate matter
Second hand smoke
Emission rate
Source strength

ABSTRACT

The household second hand smoke problem is still severe in China due to the large number of smokers and the prevalence of smoking at home. We selected ten Chinese cigarettes, including seven best-selling products of different brands and three types of products of the same popular brand, to measure the emission rates of ultrafine particles (UFPs: particulate matter with diameter less than 0.1 μm) and fine particles ($PM_{2.5}$: particulate matter with aerodynamic diameter less than 2.5 μm) with the help of two habitual smokers. The emission rate of UFPs generated from smoking popular Chinese cigarettes was $2.51 \pm 0.50 \times 10^{12}$ #/min or $1.98 \pm 0.30 \times 10^{13}$ #/cigarette, and the emission rate of $PM_{2.5}$ was 2.25 ± 0.39 mg/min or 17.63 ± 1.56 mg/cigarette. The emission rates of UFPs and $PM_{2.5}$ from Virginia-type cigarettes were higher than those from blended-type and exotic flavor-type cigarettes of the same brand. The emission rates of UFPs and $PM_{2.5}$ from Chinese cigarettes were higher than those from Western cigarettes. The measured UFPs and $PM_{2.5}$ emission rates from human smoking of Chinese cigarettes can be used to assess the population exposure and design control measures in residences.

1. Introduction

Currently, the second-hand smoke (SHS) problem is still severe in China. China contributes to over 30% of the smokers in the world and is the world's largest consumer and producer of tobacco (Asma et al., 2015; Drope et al., 2018; Reitsma et al., 2017; Yang et al., 2011). Strict bans on smoking in all public places have been enforced in over 30 cities in China since 2014 (ThinkTank Research Center for Health Development, 2018). However, these bans cannot prevent SHS in private indoor environments, especially residences, where people spend

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https://doi.org/10.1016/j.atmosenv.2018.09.014
Received 25 July 2018; Received in revised form 7 September 2018; Accepted 11 September 2018
Available online 13 September 2018

Table 1
Information about Chinese cigarette samples.

NO.	Type	Tar content (mg)	Nicotine content (mg)	Carbon monoxide content (mg)	Cigarette length (mm)	Filter length (mm)
I-1	Virginia-type	11	1.2	11	84	32
I-2	Virginia-type	11	1	11	84	32
I-3	Virginia-type	11	1	11	84	30
II-1	Virginia-type	11	1	11	84	30
III-1	Virginia-type	10	1.1	12	84	32
III-2	Virginia-type	10	1	11	84	32
III-3	Virginia-type	11	1.1	11	84	30
V	Virginia-type	11	1	12	84	30
B	blended-type	5	0.4	6	93	35
E	exotic flavor-type	8	0.6	9	84	30

the majority of their time (Khajehzadeh and Vale, 2017; Klepeis et al., 2001; Lee and Lee, 2017; Matz et al., 2014). Surveys show that roughly 60–70% of Chinese non-smokers, estimated as 717 million people, are exposed to household SHS (Asma et al., 2015; Yang et al., 2011, 2015). In outdoor smoking areas, high SHS levels have also been reported (Fleck et al., 2016; Ruprecht et al., 2016; Sureda et al., 2013), even though the ventilation may be much better than indoor environments. Moreover, these outdoor smoking areas affected adjacent smoke-free indoor areas and increased indoor SHS levels (Sureda et al., 2013). Thus, SHS is a prevalent and vital environmental problem for both indoor and outdoor environments in China, causing over two hundred thousand deaths annually (Gakidou et al., 2017).

Various hazardous air pollutants are generated from human smoking, especially a large amount of particulate matter (Dermentzoglou et al., 2003; Hollbacher et al., 2017; Klepeis et al., 2003; Liu et al., 2014; Lopez et al., 2012; Lu and Zhu, 2007; Pinto et al., 2017; Ruprecht et al., 2017; Saffari et al., 2014; Wang et al., 2012, 2018). Smoking is a prominent particulate matter source, including ultrafine particles (UFPs; particulate matter with diameter less than 0.1 μm) and fine particles ($PM_{2.5}$; particulate matter with an aerodynamic diameter less than 2.5 μm) (Afshari et al., 2005; Dacunto et al., 2013; Dermentzoglou et al., 2003; Gemenetzis et al., 2006; Glytsos et al., 2010; He et al., 2004; Hollbacher et al., 2017; Hussein et al., 2006; Leaderer et al., 1994; Wu et al., 2012), which have adverse health effects on people (Karlsson et al., 2009; Lanzinger et al., 2016a, 2016b; Li et al., 2016; Ostro et al., 2015; Stone et al., 2017). Non-smokers exposed to SHS at home inhale comparable quantities of PM to non-smokers living in smoke-free homes in heavily polluted cities, such as Beijing (Semple et al., 2015). Conventional cigarettes generate many more UFPs and $PM_{2.5}$ than cigars, tobacco pipes, electronic cigarettes, and heat-not-burn tobacco products (Klepeis et al., 2003; Leaderer et al., 1994; Protano et al., 2017; Ruprecht et al., 2017). Moreover, filter-tipped cigarettes emit significantly more $PM_{2.5}$ than the non-filter cigarettes (Schulz et al., 2016). Combined with the fact that filter-tipped conventional cigarettes are the most prevalent in China (State Tobacco Monopoly Administration, 2016a), the need for controls on the UFPs and $PM_{2.5}$ generated from human smoking has become extremely evident in China.

Most previous studies focused on concentrations of UFPs or $PM_{2.5}$ during smoking (Chao and Wong, 2002; Dermentzoglou et al., 2003; Gemenetzis et al., 2006; Hollbacher et al., 2017; Leaderer et al., 1994; Liu et al., 2014; Lopez et al., 2012; Na et al., 2004; Protano et al., 2017; Saffari et al., 2014; Schulz et al., 2016), however, the results varied over a large range and may have been influenced by the different smoking durations, room volumes, and ventilation conditions in these studies. Therefore, the emission rates of UFPs and $PM_{2.5}$ from human smoking are required for population exposure assessments and designing control measures in residences.

In this study, we determined the emission rates of UFPs and $PM_{2.5}$ from smoking the seven most popular commercially available Chinese cigarettes with the help of two habitual smokers. The emission rates of UFPs and $PM_{2.5}$ from smoking Virginia-type, blended-type, and exotic flavor-type cigarettes of the same popular brand are compared and discussed.

2. Experimental

2.1. Selection of respective Chinese cigarettes

Chinese cigarettes are classified as Class I, II, III, IV, and V based on their prices (State Tobacco Monopoly Administration, 2016a). According to survey results by the State Tobacco Monopoly Administration (2016b), the sales volume of Class I, II, and III cigarettes is over 75%, and their most popular products are listed in Table S1 (detailed results are shown in Supporting Information, Table S1). Over nine hundred thousand cases are sold per year of the seven most popular products (I-1, I-2, I-3, II-1, III-1, III-2, and III-3, shown in Table S1). Therefore, these seven most popular Chinese cigarettes were selected for the measurements in this study.

Chinese cigarettes are classified as Virginia-type, blended-type, exotic flavor-type, cigar-type, and new blended-type (with added Chinese herbs in the tobacco) based on the tobacco type (State Tobacco Monopoly Administration, 2002). The information listed on the packages of these seven cigarette types is shown in Table 1. All seven types are Virginia-type cigarettes. Virginia-type cigarettes account for 97.85% of Chinese cigarettes (State Tobacco Monopoly Administration, 2016a). Their tar, nicotine, and carbon monoxide contents are similar, with ranges of ranges of 10–11 mg, 1–1.2 mg, 11–13 mg, respectively. Their cigarette lengths are 84 mm. They are all filter-tipped, and their filter lengths are 30 or 32 mm.

Blended-type cigarettes account for 1.55% of Chinese cigarettes, exotic flavor-type cigarettes account for less than 0.61%, and the other two types are less popular in China (State Tobacco Monopoly Administration, 2016a). To further discuss the emission rates among different types, the most popular brand of Chinese blended-type cigarettes was selected (Qu et al., 2014). Virginia-type, blended-type, and exotic flavor-type cigarettes products of this brand were chosen for the measurements in this study. The information from the packages of these three cigarettes is also shown in Table 1. The tar, nicotine, and carbon monoxide contents of the selected blended-type and exotic flavor-type cigarettes are much lower than those of the Virginia-type cigarette. The cigarette and filter lengths of the selected blended-type cigarettes are different from the other two types.

2.2. Instrumentation and measurement

Measurements were performed in a stainless-steel environmental chamber with the dimensions of 2.0 m (length) × 2.0 m (width) × 2.0 m (height), as shown in Fig. 1. The average relative differences of the particle concentrations between different locations in the chamber was 12%, which indicates that indoor air was mixed well by the two fans used during the measurements. We determined the