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Characteristics of the pollutant emissions in a tunnel of Shanghai on a weekday

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ABSTRACT

Tunnel displays a typical semi-closed environment, and multitudes of the pollutants tend to accumulate. The samples of gaseous pollutants and particulate matter (PM) were collected from the Xiangyin tunnel at Shanghai to investigate the characteristics of the pollutant emissions. The results indicated that both gaseous pollutants and PM exhibited much higher concentrations during the rush hours in the morning and at night due to vehicle emission. Two peaks of the PM concentration were observed in the scope of 0.7–1.1 and 3.3–4.7 μm, accounting for 14.6% and 20.3% of the total concentrations, respectively. Organic matter (OM), EC, and many water-soluble ions were markedly higher at the rush hours in the morning than those at night, implicating comprehensive effects of vehicle types and traffic volume. The particle number concentrations exhibited two peaks at Aitken mode (25 nm and 100 nm) and accumulation mode (600 nm), while the particle volume concentration displayed high values at the accumulation mode (100–500 nm) and coarse mode (2.5–4.0 μm). The peak around 100 nm was detected in the morning rush hours, but it diminished with the decrease of the traffic volume. Individual-particle analysis revealed that main particles in the tunnel were Fe-rich particles, K-rich particles, mineral particles, Ca–S rich particles and Al–Si particles. The particles collected at the rush hours displayed marked different morphologies, element concentrations and particle sizes compared to the ones collected at the non-rush period. The data presented herein could shed a light on the feature of vehicle emissions.

Introduction

Aerosol particles play significant roles on climate by changing the energy transfer through the radiative forcing, and potentially cause adverse health effects as carriers of toxic chemicals (Li et al., 2008; Lin et al., 2005; Jacobson, 2001). Some aerosol particles probably absorb or scatter the solar radiation, thereby influencing the global climate (Anenberg et al., 2012; Liu et al., 2014). Health studies have proved that fine particulate ($PM_{2.5}$) showed close relationship to respiratory and cardiovascular disease, and even increased risk for cancer or death (Adar et al., 2007; Liu et al., 2015). Exposure to organic particles was

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associated with allergies and adverse respiratory effects, frequently expressed as asthma or chronic obstructive pulmonary disease (Lerner et al., 2012).

Vehicle emissions have been considered as a main source of atmospheric pollutants (Chiang and Huang, 2009). About 23% of NO_x, 17% of CO, and more than 50% of VOCs were released from vehicle emissions in East China (Fu et al., 2013; Chiang et al., 2007; Lee et al., 2002). Moreover, about 6.7 million tons and 8.3 million tons of $PM_{2.5}$ and PM_{10} were emitted by vehicles in Pearl River Delta in 2006, respectively (Cui et al., 2016). The occurrence of hazy days has been increasing since 2005, particularly in some megacities of China (Tong et al., 2007). Some gaseous pollutants (*e.g.*, NO_x and VOCs) were the key precursors of second species, such as ozone, in ambient air, which probably induced a severe fog-haze episode (Zhou et al., 2014). S. Guo et al. (2014), L. Guo et al. (2014) concluded that photochemical oxidation of NO_x and SO_2 emitted from traffic emissions was primarily responsible for urban haze in China. Hu et al. (2015) also reported that $Zn(NO_3)_2$ and $ZnSO_4$ displayed higher concentrations in the haze-fog episodes compared with the clear episodes. The number fractions of organic carbon principally derived from vehicle emissions reached to 30% in Shanghai (Hu et al., 2016). In recent years, the numbers of automobiles increased from 187 to 296 million between 2011 and 2015 in China, seriously deteriorating air quality (Cai et al., 2010). Thus, to address the feature of vehicle exhausts has become a crucial issue to understand the influence of vehicle emissions on air quality in China.

It is an arduous challenge to investigate the characteristics of vehicle emissions accurately to ambient air because these pollutants emitted from vehicles are inclined to mix with PM rapidly in the atmosphere. To date, many methods have been used to address vehicle emission features, including the engine dynamometer test (Na et al., 2015), remote sensing (Andrew, et al., 2003), and tunnel research (Liu et al., 2012). Dynamometer test is costly and its procedure is complex. Furthermore, the test condition of the dynamometer cannot absolutely simulate the realistic driving state. Remote sensing just measures emissions of individual vehicle as they drive by a roadside sensor, but not obtain fleet-average emission results. Moreover, the dynamometer test and remote sensing cannot distinguish the vehicle emissions from other sources effectively. In contrast, tunnel research not only reflects the real driving environment with less environmental interference, but also makes use of the fact that emissions from vehicles inside tunnels could be isolated from other sources easily. Additionally, there is an increased emissions in concentration and prolonged exposure to the pollutants emitted by the vehicles due to the confined space and inadequate ventilation (El-Fadel and Hashisho, 2001; Brito et al., 2013; Ho et al., 2004). Thus, the research on the tunnel has become a popular mean to study the characteristics of vehicle emissions.

A growing body of tunnel studies has been conducted in megacities on the world. Many tunnel studies focused on the characteristics of emissions including concentrations, components and emission factors of the pollutants. Ma et al. (2011) reported that the concentrations of CO, SO_2, and NO_x, reached to 12–39 ppm, 20–48 ppb, and 1.2–3.1 ppm, respectively, in the Hsueh-shan tunnel. Ho et al. (2009) reported that the VOC concentrations in Shing Mun tunnel were about 5–10 times higher than those in the ambient air of Hong Kong. It were generally considered that benzene, toluene, xylene and isoprene were the major species of VOCs, all of which generally exhibit higher concentrations in the tunnel due to high intensity emission of vehicle exhausts (Chiang et al., 2007). Carbonaceous compounds and water-soluble ions were primary components of PM collected from the tunnel (Pio et al., 2013). However, the components and concentrations of the pollutants varied significantly in the different tunnels probably due to the impacts of engine type, fuel consumption, vehicle characteristics and other uncertain factors (Alves et al., 2015). It was well documented that the number, speed, age, and type of vehicle showed remarkable effects on the concentrations and species of gaseous pollutants and atmospheric PM inside the tunnel (Shu et al., 2001). Vehicle number generally showed a significantly positive relevance with the pollutant concentration inside the tunnel (Zhou et al., 2014). Especially, the emission factors in the Wuzushan tunnel were higher than those in the Kuixinglou tunnel as the result of high proportion of diesel vehicle in the former (Cui et al., 2016). The NO_x emission increased with vehicle speed for uphill driving and possessed higher values for uphill driving than those for downhill driving (Andrew et al., 2003). However, few studies concerned about the morphology and mixing state of PM within the tunnel, which were also sensitive to the vehicle emissions. Knowledge of the morphology and mixing state of individual particles in the tunnel was crucial to understand the vehicle emission features (Li et al., 2016).

In the present study, the PM samples were collected and gaseous pollutants were on-line analyzed over a 24-hr period in the Xiangyin tunnel of Shanghai. The main objectives of this study are: (1) to investigate the diurnal variation of gaseous pollutants and PM inside the tunnel, (2) to determine the concentration and composition of PM, and (3) to decipher the number and volume concentrations, size distribution and morphology of PM at a single-particle level.

1. Experimental section

The samples were collected in the Xiangyin tunnel, which was located at the middle ring of Shanghai. This tunnel is a length of 2.6 km with the maximum speed limit of 80 km/hr. Diesel and gasoline vehicles were main vehicle types across the Xiangyin tunnel. The proportion of diesel vehicles through Xiangyin tunnel was high in the daytime, while they were relatively low at night because diesel vehicles were prohibited entering downtown area since the evening rush hours. The samples including aerosol particles and gaseous pollutants inside the tunnel were collected at the midpoint of the tunnel, and the ambient samples outside the tunnel were collected in the site about 50 m far from the exit of the tunnel. Ambient air samples in the tunnel were collected once each hour from 14:30 on April 24th to 14:30 on April 25th, 2013. The sampling period was a weekday, which could represent the pollution status in the tunnel in the weekdays. Ambient air was collected at a flow rate of 1 L/min. The samples were analyzed within one day after the sampling.

Particles inside the tunnel were collected in the eight size fractions: 0.4–0.7, 0,7–1.1, 1.1–2.1, 2.1–3.3, 3.3–4.7, 4.7–5.8, 5.8–9, and >9 μm, respectively. The sampling pump flow rate was set at 28.3 L/min. Before the sampling, the quartz filters were

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