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Compositional characteristics of black-carbon and nanoparticles in air-conditioner dust from an inhabitable industrial metropolis☆

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ABSTRACT

Atmospheric dust, especially air-conditioner dust in urban-industrial environments, can act as a significant sink for both black carbon and nanoparticles posing allied health risks to the air conditioner repairman as well as to local inhabitants. However, the chemical composition of black carbon/nanoparticles in air-conditioner dust and their association with potentially toxic elements remain uncertain. The present study investigate the black carbon and nanoparticles compositions of air-conditioner dust and their associated potentially toxic elements, as an indicator of indoor air-pollution. The black carbon and nanoparticles in air-conditioner dust, were comprehensively characterized using array-based techniques including Inductively Coupled Plasma-Mass Spectrometry, particle size distribution, Scanning Electron Microscopy, Transmission electron microscopy along with Energy-dispersive X-ray spectroscopy and selected area-(electron) diffraction, from metropolitan area of Hefei, China. Geo-accumulation index values of air-conditioner dust reveal Lead, Tin, Arsenic and Cadmium are under Geo-accumulation Classes V-VI level of contamination. The majority of the particles were found to be in the ultrafine nanoparticles range (<100 nm). A strong correlation was found between black carbon and total potential toxic elements content ($R^2 = 0.79$). The metallic nanoparticles (Iron, Copper and Lead) and black carbon were identified using Scanning Electron Microscopy/Transmission electron microscopy along with Energy-dispersive X-ray spectroscopy/selected area (electron) diffraction mode. Using array-based techniques seems to be a useful tool to study the black carbon and nanoparticles in air-conditioner dust. It is the first demonstration presenting evidence for the concept of air-conditioner dust as a sink for black carbon/nanoparticles bound potentially toxic elements in the urban-industrial environments, as an ultimate source of environmental pollutants.

1. Introduction

Air conditioning (AC) system is used worldwide to provide thermal comport as well as a healthy air quality in the indoor environment (Yu et al., 2009). The indoor air quality is deteriorated by a variety of factors including temperature, air circulation, humidity, particulate matter (PM) pollution, biological and gaseous pollutant (Graudenz et al., 2005). The origin of indoor particulate can be divided into two categories that are indoor and outdoor pollution sources. Particles released by indoor sources like smoking, cooking, heating, cooling, construction, furnishing and burning are mostly ultrafine which constitute 80% in terms of particle count (See et al., 2006). Particles released from the outdoor environment penetrate through doors, ventilation system, windows and AC filters for fresh air (Gramotnev and Ristovski, 2004). The air loaded with PM is filtered by AC in order to improve the indoor air quality

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which is widely used and economical method (Yu et al., 2009). Filters are the most important part of AC and it has been investigated that these filters can remove pollutants efficiently in a steady manner which get deposited on these filters (Bekö et al., 2006). Irrespective of the fact that air filtration by AC filters improve the air quality these filter can be a source of contamination as a lot of nanoparticles (NPs) along with organic and inorganic pollutants including organic carbon, trace elements, nitrate, sulfate and volatile organic compounds get deposited on these filters of AC (Verdenelli et al., 2003).

NPs having a diameter of 0.1 μm or less are of key importance because these can remain suspended in the air for a long time as compared to other coarse size PM and can be transported for a long distance (Yinon et al., 2010). One of the basic property of NPs is its large surface area to volume ratio which makes it capable of adsorbing a large amount of potential toxic elements (PTEs) and it is the most dominant particulate in the atmosphere (Lighty et al., 2000). A variety of sources contribute as a source of PTEs and black carbon (BC) NPs including outdoor and indoor activities (Isaxon et al., 2015; Wan et al., 2011). Elevated concentration of chromium (Cr), zinc (Zn), copper (Cu), manganese (Mn), lead (Pb) and cadmium (Cd) NPs are attributed to cigarette smoke, use of cosmetics, construction and demolition (Dundar and Altundag, 2002), paints, carpet materials and also vehicular emission in form of fine dust (Chen et al., 2010), while in indoor environment use of gasoline and lead containing paints play their role in Pb emission (Olujimi et al., 2015). Nickel (Ni) and iron (Fe) NPs originates as a result of coal combustion, fossil fuel (Ullah et al., 2017), waste products incineration, automobile emissions, decay of old engine, smelting process, and industries in outdoor environment while in indoor environment it mainly released from smoking, use of stainless steel utensils and low category jewelry (Cempel and Nikel, 2006). Use of lubricating oil (Patel et al., 2012) and fossil fuel increase the concentration of Aluminum (Al), Mn, magnesium (Mg) and Fe-NPs and other PTEs (Yousaf et al., 2017). Another NPs quite important due to its high magnitude toxicity and ultrafine size is soot (BC or elemental carbon) (Hussein et al., 2006). BC is released as result of incomplete combustion by a variety of sources including indoor and outdoor sources and weathering of graphite carbon in rocks (Zhang et al., 2015). The two main form of BC are char and soot, char is produced at low temperature than soot with a size range of 1–100 μm that is larger than soot (Zhan et al., 2016). Other than this it can be found in NPs form with a size range of <100 nm that is mostly released is a major part of diesel. Temperature is the key factor deciding the size and form of BC (Sahu et al., 2014). BC is of special importance because of its long range transport, climate change role and due to its large surface area it is involved in a variety of heterogeneous activates (Johnson et al., 2005). Large surface to volume ratio and large number of nanopores of BC-NPs are the main reason for its high sorption and its relation with other PTEs which are produced along with BC during combustion process (Glaser et al., 2005). Previous studies revealed that PTEs concentration (Niu et al., 2010), and BC concentration increase with a decrease in particle size (Gramsch et al., 2014). NPs are a potential health hazard due to its small size it can penetrate deep into the respiratory track and cause severe health problems (Ali et al., 2017b).

Up till now no detailed study has been conducted focusing the compositional and Nano characteristics of dust accumulated on AC filters. The current study aim to investigate the following objectives: (1) To evaluate the concentration and pollution characteristics of PTEs in AC dust collected from metropolitan area of Hefei, China (2) To comprehensively characterize BC and dominant NPs in AC dust using array-based techniques including Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), aerosolization and Scanning Electron Microscopy (SEM)/Transmission electron microscopy (TEM) along with Energy-dispersive X-ray spectroscopy (EDS)/selected area (electron) diffraction mode (SAED) (3) To find out relation between BC and ΣPTEs in AC dust in an urban environment.

2. Materials and methods

2.1. Site description and sample collection

The present study was conducted in Hefei capital of Anhui province with an area of 11,408 km^2 and population 4.6 million lying in upper limits of Yangtze delta. It is situated at 117° 11 to 117° 22 east longitude and 32° 48 to 31° 58 north latitude lies within the north subtropical climate zone. It is a prefecture level city of Hefei administrators with 9 county-level division including 4 districts namely Yaohi, Luyang, Shushan and Baohe district. In this study, houses were selected randomly from different areas of Hefei and the AC filters (split AC 1.5–3 tons) from selected locations were properly cleaned at the end of January in order to remove the preexisting dust and pollutants (Fig. 1). Sampling was done in June, and July because these are the hottest months with prevailing dry condition and the use of air conductions is at its peaks in these months. In this investigation, 71 samples were collected using a plastic brush, paper sheets and air tight polythene bags. To ensure proper collection of samples the dust from filters were collected in a closed room and the filters were tapped slowly in order to avoid the interference of air as the dust deposited on these filter was of very minute size that can resuspend with ease. The samples were then transferred to airtight polythene bags. These samples were further sieved at a mesh of 200 (particles size < 75 μm) and were air dried for 48 h in order to carry out further analysis.

2.2. ICP-MS analysis and geo-accumulation index (I_{geo})

AC dust samples were digested in the acid mixture using the method described by Yousaf et al. (2016). Agilent 7500cx Inductively Coupled Plasma Mass Spectrometer (ICP-MS, Agilent Technologies, and Santa Clara, CA, USA) was used to identify trace element concentrations in acid-digested AC dust samples. Instrument calibration is given in supplementary information. A total of 18 trace elements (barium (Ba), lithium (Li), Mg, Cd, tin (Sn), Pb, gallium (Ga), arsenic (As), strontium (Sr), Cu, Ni, Fe, Cr, Mn, vanadium (V), thallium (Ti) and Al) were identified in this study. BC concentration in AC dust sample was identified using thermal-optical reflectance method (TOR) according to Zhan et al. (2016).

To find the accumulation of trace elements, geo-accumulation index (Table 1) was used to find out a single element pollution status in the environment (Müller, 1979).

$$Igeo = log^2\left(\frac{C_{sample}}{1.5 \times C_{background}}\right) \quad (1)$$

Where, I_{geo} is the geo-accumulation index for different trace element. C_{sample} is the concentration of PTEs in sample and $C_{background}$ is the element background value. To avoid variation in background values a constant of 1.5 was added. These background fluctuations are basically due to lithogenic variation in the dust.

2.3. Aerosolization of AC dust

Samples selected on the bases of PTEs concentration and total mass were aerosolized using the dry dispersion (Disperser) method introduced by Tiwari et al. (2013) based on vacuum generator and