G Model
PARTIC-1067; No. of Pages 10

ARTICLE IN PRESS

Particuology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Particuology

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

Enhancement of filtration efficiency by electrical charges on nebulized particles

Hui Chen[a], Zhenyi Zhang[a], Zhenzhong Zhang[a,b,*], Feng Jiang[a], Ruiming Du[a]

[a] Environmental Technology Division, Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing 100084, China
[b] Institute of Nuclear and New Energy Technology, Collaborative Innovation Center of Advanced Nuclear Energy Technology, Key Laboratory of Advanced Reactor Engineering and Safety of Ministry of Education, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 23 July 2017
Received in revised form 28 July 2017
Accepted 31 July 2017
Available online xxx

Keywords:
Nebulization
Artificial aerosol
Electrical charges
Charge distribution
Electret HEPA filter
Penetration

ABSTRACT

There have been few investigations of effects of electrical charge, carried by lab-generated particles, on filtration efficiency testing. Here, we measured the elementary charge on particles and the fraction of particles carrying that charge with a combined electrometer, differential mobility analyzer, and scanning mobility particle sizer. A typical solid NaCl aerosol and liquid diethylhexyl sebacate (DEHS) aerosol were generated with Collison and Laskin nebulizers, respectively. Our experimental results showed that NaCl aerosols carried more charge after aerosol generation. The average net elementary charge per particle was approximately 0.07. The NaCl aerosol was overall positively charged but contained a mixture of neutral and charged particles. Individual particles could carry at most four elementary charges. According to constant theorem, we speculated that original NaCl aerosol contained 17% neutral, 45% positive-, and 38% negative-charged particles in the diameter range from 30 to 300 nm. A Kr-85 neutralizer was used to decrease the charge on the NaCl particles. Our results indicated that the DEHS aerosol was electrically neutral. The effects of electric charge on particle collection by electret and electroneutral high efficiency particulate air (HEPA) filters were analyzed. Theoretical calculations suggested that charges on original NaCl aerosol particles enhanced the filtration efficiency of HEPA filters.

Introduction

Airborne particulate matter exists widely both in- and outdoors. Long term exposure to particulate matter may contribute to health issues, such as, asthma, heart disease, and cancer (Andersen, 2012; Koskinen, Husman, Hyvärinen, Reponen, & Nevalainen, 1995). Particulate matter can also have adverse effects on human manufacturing activities, including bio-medicine and electronic and precision instrument manufacture (Zhang & Yu, 2014). To improve manufacturing conditions, air filters are widely used to eliminate airborne particulate matter. The mechanism of particle deposition on filter fibers is complicated. Existing research has shown that diffusion, impaction, interception, electrostatic precipitation, and gravity settlement are key factors affecting particle deposition processes (Finlay, 2001). The effects of electrostatic charging of particles to enhance collection by fibers have been extensively reported (Chernyakov, 2005; Emi, Kanaoka, Otani, & Ishiguro, 1987; Mccain, Kistler, Pontius, & Smith, 1984; Zebel, 1965). The effects of electrical charging of particles on their collection by fibers have also been widely reported in a number of experimental studies, which can be categorized into two types: (i) the use of various high-voltage devices to charge the particles and testing of different filter materials for the charged particle collection (Alonso & Alguacil, 1999; Choi et al., 2002; Kanaoka, Emi, Otani, & Iiyama, 1987; Kim, Nason, & Lawler, 2008); (ii) studies of the particle collection performance of electret filters (Ballard et al., 1985; Baumgartner, Loffler, & Umhauer, 1986; Fjeld & Owens, 1988; Li & Jo, 2010; Park et al., 2007). These studies have indicated that electrostatic forces enhance particle collection by fiber filters owing to non-electrostatic mechanisms involving diffusion, inertial impaction, and interception. The classification of high efficiency particulate air (HEPA) filters is strict and considers collection efficiency. Therefore, the charge state of particles and the filters may considerably influence filter classification results. However, there have been few studies of the effects of electrical charge carried by lab-generated particles on the results of filtration efficiency tests.

* Corresponding author at: Environmental Technology Division, Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing 100084, China.
E-mail address: zhangzz@mail.tsinghua.edu.cn (Z. Zhang).

https://doi.org/10.1016/j.partic.2017.07.008

Please cite this article in press as: Chen, H., et al. Enhancement of filtration efficiency by electrical charges on nebulized particles. *Particuology* (2017), https://doi.org/10.1016/j.partic.2017.07.008

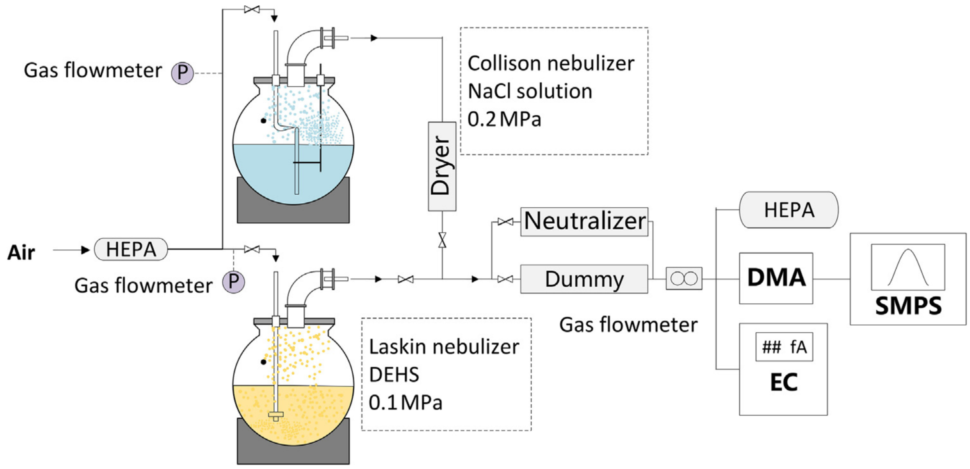

Fig. 1. Schematic of the experimental setup.

To evaluate the performance of filters, artificially generated aerosols are produced and applied to air filter performance testing system. Previous experiments have shown that most aerosolizing processes are likely to make particles electrostatically charged, particularly in the first few minutes after their dispersal. When particles carry extra electrical charge, their deposition on pneumatic pipes, filter media fibers, and other particle separation devices might be enhanced during the testing process, resulting in an increase in collection efficiency (Azhdarzadeh, Olfert, Vehring, & Finlay, 2014). However, there is limited data available to describe the charge state of particles in the workplace. Experimental studies (Mainelis et al., 2001) have shown that artificially generated aerosols have a bipolar electrical charge distribution. Mainelis et al. have investigated the charge state of particles in the range of 0.65 and 0.80 μm with a mean diameter of 0.73 μm. These results showed that NaCl particles carried a few hundred positive and negative elementary charges when aerosolized by a standard Collison nebulizer. However, the charge distribution was somewhat narrower when aerosolized by a bubbling aerosol generator. It has also been found that a large proportion of nebulized particles carry a small number of elementary charges. However, precise measurements of the electrical charge carried by nebulized aerosols at the most penetrating particle size (typically within the range of 0.1–0.3 μm for common filters) have not yet been performed.

Considering the effects of electrical charging of nebulized particles, neutralization or current elimination is required to obtain nebulized aerosols before application to evaluating filter performance (Forsyth, Liu, & Romay, 1998). All neutralizers (radioactive or non-radioactive) ionize the surrounding atmosphere by producing positive and negative ions. Particles carrying extra elementary charges will be discharged when they interact with air ions of the opposite polarity. When the charge state of an airborne particle reaches equilibrium, the neutralized aerosol will have a bipolar electrical charge distribution, as described by the Boltzmann equation (Cooper & Reist, 1973; Emets, Kascheev, & Poluektov, 1991; Keefe, Nolan, & Rich, 1959). However, particles may still carry some charge after neutralization. Current elimination is another effective method of discharging aerosols. Current elimination is based on a high-voltage electric field applied between two concentric electrodes. Particles carrying an electrical charge will deviate from their original trajectory and precipitate on electrode plates owing to the force induced by the electric field, thus causing a high loss rate of the aerosol concentration.

Our previous simple laboratory tests have focused on the net electrical capacity of nebulized aerosols and the effects on collection efficiency of HEPA filters. Experimental results have shown that the net electrical capacity of solid NaCl aerosols decreases to a low level after neutralization, and to an even lower level after passing through current elimination apparatus. The net electrical capacity of liquid diethylhexyl sebacate (DEHS) maintains a low level regardless of discharged or not. According to some standards (EN 1822-5, 2009; GB/T 6165, 2008; IEST-RP-CC034, 2009), two types of aerosol, namely, nebulized solid NaCl aerosol and liquid DEHS aerosol, are applied for evaluating the performance of HEPA filters. The standards do not require passage of the aerosol through a current elimination apparatus before the filter. Studies have shown that the penetration rate is slightly lower if the solid NaCl aerosol is not discharged. However, precise studies of the electrical charge on aerosols and the mechanisms causing increased filter efficiency have not yet been performed.

The main objective of this work is to precisely measure the electrical charge on nebulized particles and the fraction of particles carrying electrical charge in the most penetrating particle size range. On the basis of these measurements, we analyze and discuss the effects of nebulized particle electrical charge on collection efficiency of HEPA filters.

Materials and methods

Experimental setup

As shown in Fig. 1, the experimental setup consists of three steps: experimental aerosol generation, aerosol neutralization, and aerosol sampling. The experimental equipment and procedures are described as follows.

Aerosol generation

Aerosol was generated, then neutralized before passing to the sampling vessel. Air filtered by an HEPA filter was used as the carrier gas. In this study, we used two aerosol nebulizers to generate solid (i.e., NaCl) and liquid aerosols (i.e., DEHS) based on a custom-made Collison nebulizer and a standard Laskin nebulizer (TOPAS^{TM}, model ATM220), respectively. NaCl solution (0.1%) was sprayed by a standard Collison nebulizer at a pressure of 0.2 MPa. In a standard Collison nebulizer, high-pressure air is pushed through a nozzle in which air is compressed into a small space. The air pressure around the nozzle is lower than that of the air in the NaCl solution reservoir and the pressure difference draws fluid up a feed tube. The fluid is then driven through the nozzle as a dispersion of droplets with a wide size distribution. Our system featured an inner wall at the air nozzle outlet, which contained most of the larger droplets. The remaining droplets passed through the Collison nebulizer with