Aerosol Science 40 (2009) 285 – 294

Contents lists available at ScienceDirect

Aerosol Science

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

A novel bipolar charger for submicron aerosol particles using carbon fiber ionizers

Bangwoo Han[a,b], Neelakshi Hudda[a], Zhi Ning[a], Hak-Joon Kim[b], Yong-Jin Kim[b,*], Constantinos Sioutas[a,*]

[a] Department of Civil and Environmental Engineering, University of Southern California, Los Angeles, CA 90089, USA
[b] Eco-Machniery Research Division, Korea Institute of Machinery and Materials, Daejeon 305-343, South Korea

ARTICLE INFO

Article history:
Received 13 June 2008
Received in revised form
17 November 2008
Accepted 17 November 2008

Keywords:
Carbon fiber
Bipolar charging
Submicron
Aerosol
Ozone

ABSTRACT

A simple and novel bipolar charging device using carbon fiber ionizers was developed to neutralize submicron aerosol particles without the generation of ozone. The ion currents of the positive and negative ions generated by carbon fiber ionizers were so chosen as to optimize particle neutralization. The particle penetration, charging probability and charge distribution resulting from the charger were investigated and compared to those from a Kr-85 radioactive neutralizer for the particles in the size range of 20–120 nm. Size distributions for various laboratory-generated aerosols (sodium chloride, ammonium nitrate, ammonium sulfate and glutaric acid) neutralized by the charger were also investigated and compared to those obtained without neutralization. Particle penetration in the charger was over 90% for particles larger than 20 nm. Charging probability and charge distribution for the charger were in good agreement with those from Kr-85 neutralizer and with theoretical estimations. Size distributions observed for the charger and Kr-85 neutralizer were also in good agreement for particles of different concentrations and various chemical compositions. The newly developed bipolar carbon fiber charger can neutralize submicron particles, at least as effectively as currently available radioactive neutralizers and with negligible ozone generation which is its major advantage.

1. Introduction

Charging of aerosol particles has become one of the most important tools to control the behavior of particles in aerosol generation, transport and measurement processes. Bipolar charging (i.e. charge neutralization) has been particularly important in aerosol sizing and measurement systems, such as a differential mobility analyzer (DMA; Knutson & Whitby, 1975; Kousaka, Okuyama, & Adachi, 1985) and particle beam mass spectrometers (Ziemann, 1998). Charge neutralization is essential in decreasing the initial electrical charges on the particles produced by aerosol generators and thus reducing the particle deposition in tubes or valves during transport.

Radioactive materials have been commercially used for particle neutralization. Radioactive sources such as Am-241, Kr-85 and Po-210 have been used for the production of stable and equal number of positive and negative ions by means of radioactive decay. However, legal restrictions limit their broader use because of the possibility of radioactive leaks.

* Corresponding authors. Tel.: +82 42 868 7475, fax: +82 42 868 7284 (Yong-Jin Kim); tel.: +1 213 740 6134, fax: +1 213 744 1426 (Constantinos Sioutas).
E-mail addresses: yjkim@kimm.re.kr (Y.-J. Kim), sioutas@usc.edu (C. Sioutas).

0021-8502/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jaerosci.2008.11.005

Corona discharge has also been explored as a means to neutralize particles, since this technique can easily generate a high number concentration of positive and negative ions and thus neutralize aerosols at higher flow rates and concentrations (Adachi, Pui, & Liu, 1993; Romay, Liu, & Pui, 1994). Nonetheless, these chargers showed some problems such as imbalance of positive and negative ion concentrations, particle generation by sputtering of the electrodes or by chemical reaction as well as ozone emission during corona discharging (Murray & Gross, 1989; Romay et al., 1994; Sakata, Inaba, Yoshida, & Okada, 1991). Ozone generated in the corona discharger is of particular concern, as it may alter the chemical and microphysical properties of the charged particles by means of chemical reactions involving particle-bound organic components, such as polycyclic aromatic hydrocarbons and alkanes (Eliason, Aloisio, Donaldson, Cziczo, & Vaida, 2003; Katrib et al., 2004).

As an alternative to radioactive sources and corona discharge, soft X-ray has been attempted as a particle neutralization device (Shimada, Han, Okuyama, & Otani, 2002). The soft X-ray charger can generate a high number of stable ions and thus bring particles into the stationary charge states in shorter charging time than the radioactive chargers. However, they utilize an expensive and complicated soft X-ray generator and controller. A novel corona discharger for charging submicron particles using high frequency AC voltage with a capacitor was recently developed (Stommel & Riebel, 2004). This discharger proved to be an attractive alternative to radioactive source with low particles losses. However, it resulted in generating 100–1200 ppb ozone concentration under typical operation conditions, a range that exceeds the National Ambient Air Quality Standards (NAAQS) of US for ozone (80 ppb). More recently, a surface-discharge microplasma aerosol charger (SMAC) was developed for neutralizing aerosol particles (Kwon, Sakurai, Seto, & Kim, 2006). The SMAC had minimum particle losses and showed good potential for replacing traditional radioactive sources. However, the surface-discharge plasma neutralizer still generated ozone in the range of about 100 ppb.

Carbon fiber ionizers can be simply and inexpensively developed by applying a few kV to a bundle of carbon fibers to generate positive or negative ions. They can produce stable ions with sufficiently high concentrations, without generating ozone and thus, they have been used in indoor air purifiers to generate negative ions as an alternative to corona discharge (Chen, Huang, Lin, Chen, & Hsu, 2006). We have found that carbon fiber ionizers can charge fine and ultra-fine particles with low particle losses and as effectively as existing corona chargers, while generating negligible ozone and other particles (Han, Kim, Kim, & Sioutas, 2008). This technique can be also easily applied to generate high number concentrations of stable bipolar ions for neutralizing aerosols. To the best of our knowledge, no previous attempts were made to study bipolar charging of submicron aerosol particles using these carbon fiber ionizers.

In the present work, we describe the development of a novel bipolar charging device using carbon fiber ionizers and discuss its performance characteristics, including particle penetration, charging probability, charge distribution and size distribution. Charging probability and charge distribution resulting from the bipolar charger were compared to those obtained from a radioactive neutralizer as well as theoretical predictions based on diffusion charging theory.

2. Experimental setup

Fig. 1 shows the carbon fiber bipolar charger developed in this study which consists of two carbon fiber ionizers and a charging chamber. Each carbon fiber ionizer consists of a carbon fiber electrode placed inside a grounded stainless steel (SS) cylinder. The carbon fiber electrode is a bundle of approximately 300 carbon fibers, each about 5–10 μm in diameter and 5 mm in length; this is the same type of carbon fiber electrodes used in indoor air purifiers. The bundle of carbon fibers is connected to a 1/8″ SS rod with a crimp socket connector and then covered with a heat shrinkable tube. The SS rod is covered with a silicon tube inside a SS cylinder for electrical insulation. Compressed filtered air is introduced at 4–6 l/min into the SS cylinder via a 1/4″ SS tube to drive the ions generated in the ionizer into the charging chamber. The end of the SS tube is placed near the tip of carbon fiber to create a jet that flushes out the generated ions to the charging chamber, thus minimizing the loss of ions in the SS cylinder where a high electric field is formed. Two ion streams of positive and negative ions created by the carbon fiber ionizers operating at positive and negative DC voltage of 2.0–4.0 kV, respectively, are introduced into the charging chamber. The aerosol stream is introduced into the charging chamber at 1.5 l/min and mixed with the incoming ion streams. The residence time of the particles is about 1.0 s in the chamber, which has a volume of 188 cm^3.

Fig. 2 shows the experimental setup for measuring the charge probability, charge distribution and size distribution of particles in the bipolar charger. Sodium chloride (NaCl) aerosol particles within the size range of 10–500 nm were generated by nebulizing NaCl solutions with a nebulizer (VORTRAN Medical Technology, Inc., Sacramento, CA) and mixed with particle-free filtered air and then passed through a dilution chamber to reduce the particle concentration to within the operating range of measurement devices, such as DMA and condensation particle counter (CPC). Total number concentration of the particles was monitored by a CPC (Model 3022A, TSI Inc., St Paul, MN) at the exit from the dilution chamber. Particles were then passed through a Kr-85 neutralizer (Model 3012, TSI Inc. St. Paul, MN) at a rate of 1.5 l/min before being introduced into a DMA (1st DMA; Model 3071, TSI Inc., St. Paul, MN) with a sheath flow of 15 l/min. The particles exiting the 1st DMA, at a given voltage, were introduced into another Kr-85 neutralizer, followed by a parallel plate electrostatic precipitator (1st ESP) to which a DC high voltage of about 10 kV is applied. The particles exiting the 1st ESP can be considered as nearly non-charged monodisperse particles. The fraction of multiply charged larger particles was reduced to about or less than 10% by carefully adjusting the size distribution of the test aerosol, as we have discussed in our paper, Han et al. (2008). The number concentration of the generated monodisperse particles was 7.1×10^2, 7.6×10^3, 1.1×10^4, 7.5×10^3, 6.1×10^3 and $4.1\times10^3/cm^3$ for 20, 40, 60, 80, 100 and 120 nm, respectively. The