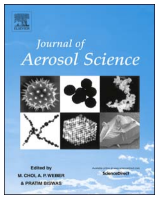
Journal of Aerosol Science 102 (2016) 41–54

Contents lists available at ScienceDirect

Journal of Aerosol Science

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



Experimental and theoretical study of a novel electrostatic enhanced air filter (EEAF) for fine particles

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ARTICLE INFO

Article history:
Received 26 March 2016
Received in revised form
8 June 2016
Accepted 1 August 2016

Keywords:
Particle
Filtration
Corona discharge
Voltage–current characteristic
Efficiency

ABSTRACT

This study proposed a novel electrostatic enhanced air filter (EEAF) system which could improve the filtration efficiency of fibrous filter for fine particles without increasing the pressure drop. The system had a pin-filter medium-grounded conductive plate structure. The pin was connected to a high voltage source. The corona discharge field would be generated in the spaces among pin, filter medium and conductive plate when high voltage was applied. Both the particles and the filter medium were charged when the gas went through. The filtration efficiency could be improved due to electrostatic field effect. An experimental system was constructed to study the influences of many factors on the filtration efficiency, including filter medium type, applied voltage, pin-filter distance, and dust loading. The ozone emission rate was also measured. Besides, two theoretical models for the voltage–current characteristics and the filtration efficiency of the EEAF were developed and validated by the experimental data. The results proved that the EEAF system could increase the filtration efficiency of filter medium obviously without increasing the pressure drop and with low ozone generation.

1. Introduction

In recent years, increasing pollution of ambient fine particles ($PM_{2.5}$) has drawn worldwide attention. Exposure to fine aerosol particles of biological and non-biological origin in indoor environments has seriously negative effect on human health (Lelieveld, Evans, Fnais, Giannadaki, & Pozzer, 2015). Public concerns regarding air quality have necessitated the development of efficient and economical particle filtration techniques (Mangili & Gendreau, 2005; Delfino, Sioutas, & Malik, 2005).

The fibrous filters are widely used in residential and industrial buildings. It captures the particulate matter by the inertia, impact and diffusion mechanisms (Thomas, Penicot, Contal, Leclerc, & Vendel, 2001). The fibrous filter could reach ultrahigh efficiency for the fine particles, such as the high efficient particulate air filter (HEPA). But it also has relatively high pressure drop which increases with the dust loading. Its life span is restricted by the pressure drop. The effective way to increase the life span of HEPA is to use pre-filters before HEPA. The better choice is to improve the ability of the pre-filters economically which usually has low efficiency and low pressure drop. If the efficiency of the modified pre-filter is high enough, it could

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http://dx.doi.org/10.1016/j.jaerosci.2016.08.012
0021-8502/

replace the HEPA. There are two methods to improve the pre-filter. One is to use the advanced electrostatic precipitator (ESP) which removes the particulate matter by electrostatic force (Kim, Han, Kim, & Yo, 2010). The ESP has very low pressure drop but it is usually difficult to obtain ultrahigh efficiency for the fine particles. And its efficiency decreases with the dust loading. Besides, the ESP has usually high ozone production (Kim, Han, Kim, Oda, & Won, 2013; Li et al., 2015). Thus, the ESP could not replace the fibrous filter completely though some new ESPs have been proposed (Li et al., 2015). The second one is to combine the electrostatic effect with the fibrous filter, including the electret, the ions and external electrostatic field. The electret is a type of fiber containing electrostatic charge (Rashmi, Dipayan, & Apurba, 2013). The electret filter could achieve high efficiency but it is still has high pressure drop. The efficiency of electret filter also decreases in the dust loading process due to the charge decay (Shi & Ekberg, 2015). Thirdly, many researches had studied the ionizer-assisted air filters (Shi & Ekberg, 2015; Park, Yoon, & Hwang, 2011; Park, Yoon, Noh, Byeon, & Hwang, 2010; Noh et al., 2011; Shi, Ekberg, Truuschel & Gusteen, 2012; Agranovski, Huang, Pyankov, Altman, & Grinshpun, 2006). The main reason why the efficiency could be improved is that some incoming charged particles upstream of the filter may be shielded out due to repelling forces caused by unipolar ions captured by the fibers (Agranovski et al., 2006). Their results indicated that the ion could only improve the efficiency of small particle efficiently and the electrostatic efficiency increase of large particle (>0.4 μm) was not obvious (Shi et al., 2012; Park et al., 2011). For particle with diameter larger than 0.4 um, the efficiency enhancement was below 10% (Shi et al., 2012). The filtration velocity (0.04–0.15 m/s) in previous study was similar to our paper (Shi et al., 2012). The external electrostatic field without discharge could polarize the filter fiber and thus would increase the filtration efficiency (Lee et al., 2001). But its improvement is also not very high (from 70% to 82% for poly-disperse particle with median diameter of 2 μm) as the fiber polarization is relative weak. Thus, all these methods have limited effects. For the first solution with ESP, its advantages include the strong electric filed and high ion concentration, which result from the corona discharge. Its disadvantages are the high ozone production due to the strong corona discharge and efficiency decrease during the lifetime. For the second solution, its advantage is low ozone production. Its disadvantage is low efficiency improvement due to the weak electrostatic effect. A better solution is to combine the advantages of the both methods and overcome their disadvantages.

This study proposed a novel electrostatic enhanced air filter (EEAF) system in which the filtration efficiency of the fibrous filter could be improved obviously with low ozone production. The EEAF had a pin-filter medium-conductive plate structure, in which a weak corona discharge field was created. The influence factors on the filtration efficiency were studied, including filter medium type, applied voltage, pin-filter distance and dust loading. The ozone production was also investigated. Besides, two theoretical models for the voltage-current characteristics and the filtration efficiency of the EEAF were developed and validated by the experimental data.

2. Experimental system

Fig. 1(a) illustrates the schematic diagram of the experimental system. The cross section of the duct is square with 200 mm side length and the total duct length is 3 m. The face filtration velocity is fixed at 0.1 m/s, which is usually used in the filtration system. The air temperature is 20 °C and the relative humidity (RH) in the test duct is below 10% in this study.

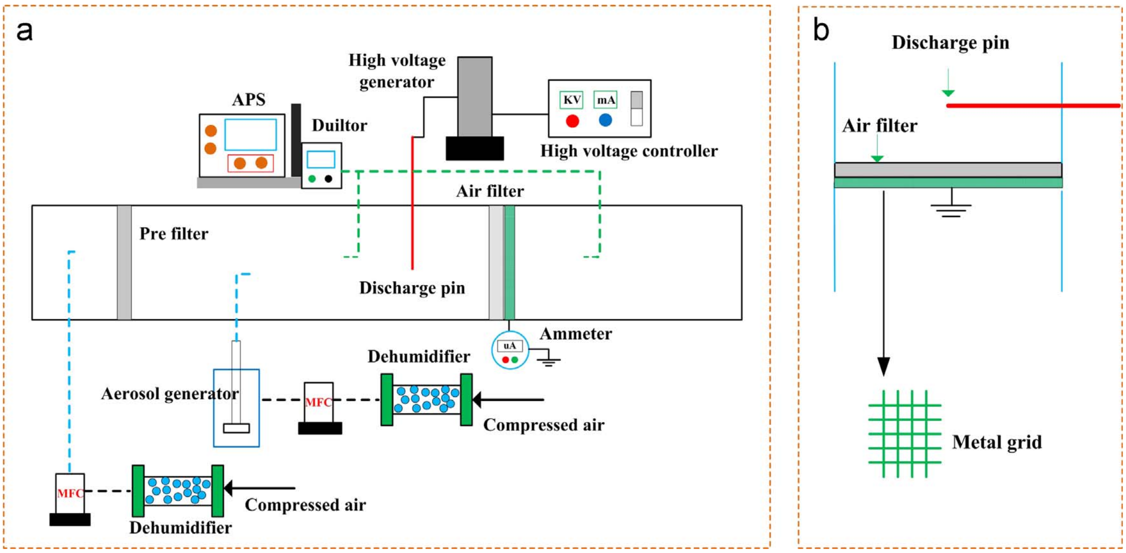

Fig. 1. Experimental system for the measurement of electrostatic filter efficiency.