Journal of Hazardous Materials 351 (2018) 29–37

Contents lists available at ScienceDirect

Journal of Hazardous Materials

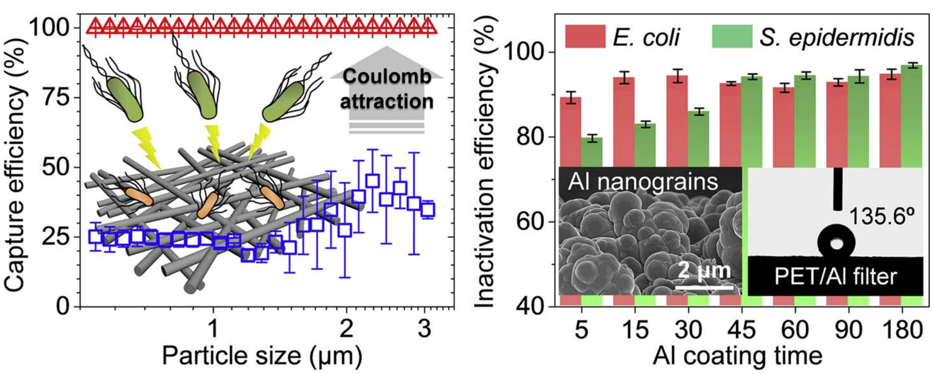
journal homepage: www.elsevier.com/locate/jhazmat

Washable antimicrobial polyester/aluminum air filter with a high capture efficiency and low pressure drop

Dong Yun Choi[a,1], Ki Joon Heo[b,c,1], Juhee Kang[b], Eun Jeong An[a], Soo-Ho Jung[a], Byung Uk Lee[c], Hye Moon Lee[a,d,**], Jae Hee Jung[b,e,f,*]

[a] Powder and Ceramics Division, Korea Institute of Materials and Science, Changwondaero 797, Seongsan-gu, Changwon, 51508, Republic of Korea
[b] Center for Environment, Health, and Welfare Research, Korea Institute of Science and Technology (KIST), Hwarang-ro 14-gil 5, Seongbuk-gu, Seoul, 02792, Republic of Korea
[c] Aerosol and Bioengineering Laboratory, Department of Engineering, Konkuk University, Neungdong-ro 120, Gwangjin-gu, Seoul, 05029, Republic of Korea
[d] Alink Co. Ltd., Chanwondaero 797, Seongsan-gu, Changwon, 51508, Republic of Korea
[e] Green School, Korea University, Anam-ro 145, Seongbuk-gu, Seoul, 02841, Republic of Korea
[f] Division of Energy & Environment Technology, KIST School, Korea University of Science and Technology, Hwarang-ro 14-gil 5, Seongbuk-gu, Seoul, 02792, Republic of Korea

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Air filter
Antimicrobial filter
Bioaerosol
Conductive fiber
Particulate matter

ABSTRACT

Here, we introduce a reusable bifunctional polyester/aluminum (PET/Al) air filter for the high efficiency simultaneous capture and inactivation of airborne microorganisms. Both bacteria of *Escherichia coli* and *Staphylococcus epidermidis* were collected on the PET/Al filter with a high efficiency rate (~99.99%) via the electrostatic interactions between the charged bacteria and fibers without sacrificing pressure drop. The PET/Al filter experienced a pressure drop approximately 10 times lower per thickness compared with a commercial high-efficiency particulate air filter. As the Al nanograins grew on the fibers, the antimicrobial activity against airborne *E. coli* and *S. epidermidis* improved to ~94.8% and ~96.9%, respectively, due to the reinforced hydrophobicity and surface roughness of the filter. Moreover, the capture and antimicrobial performances were

* Corresponding author at: Center for Environment, Health, and Welfare Research, Korea Institute of Science and Technology (KIST), Hwarang-ro 14-gil 5, Seongbuk-gu, Seoul, 02792, Republic of Korea.
** Corresponding author at: Powder and Ceramics Division, Korea Institute of Materials and Science, Changwondaero 797, Seongsan-gu, Changwon, 51508, Republic of Korea.
E-mail addresses: hyelee@kims.re.kr (H.M. Lee), jaehee@kist.re.kr (J.H. Jung).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.jhazmat.2018.02.043
Received 13 October 2017; Received in revised form 8 February 2018; Accepted 22 February 2018
Available online 24 February 2018
0304-3894/

stably maintained during a cyclic washing test of the PET/Al filter, indicative of its reusability. The PET/Al filter shows great potential for use in energy-efficient bioaerosol control systems suitable for indoor environments.

1. Introduction

Bioaerosols are classified as airborne biological particulate matter (PM), including microorganisms (e.g., viruses, bacteria, and fungi), biological particulate fragments, and toxins. Individual bioaerosols range in size from submicroscopic particles (< 0.01 μm) to particles larger than 100 μm, which are readily transmitted by wind and can float for a long time in the atmosphere [1–3]. Because they can be inhaled or attach to humans in their airborne state, they are an etiological agent for respiratory and infectious human diseases [4]. Thus, the control of microorganisms suspended in air is currently an active research field driven by the increasing demand for occupational and public health safety [5–7].

Fibrous filters are used widely as a method for removing hazardous bioaerosols due to their fascinating features, such as a light weight, cost-effectiveness, easy of fabrication, and universal applicability [1,8–10]. However, microorganisms that are captured in such filter media can remain viable, and some can even grow and propagate by absorbing air moisture and nutrients in dust. These organisms can become resuspended in the air upon the deterioration of the filters or accidental physical impact during maintenance [11]. In addition, volatile organic compounds, an indoor air carcinogen produced by microbial metabolism, can be emitted [12]. Hence, many efforts have been made to inactivate biological PM by depositing antimicrobial components onto filter fibers, such as inorganic materials (e.g., Ag, Cu, and TiO_2 nanoparticles (NPs)) and organic materials (e.g., *Sophora flavescens*, *Euscaphis japonica*, and *tea tree oil* NPs) [13–20]. However, because antimicrobial NPs physically adhere to the fiber surfaces, these filters show poor durability against washing treatments for reuse. Moreover, the antimicrobial activity of the filters progressively diminishes due to the accumulation of dust covering the functional particles [21,22].

Modern air-cleaning devices are composed of multiple filters with different functions that support high-efficiency PM capture, antimicrobial activity, and adsorption of gaseous pollutants. However, multiple layers of filters result in high pressure drops along with long airflow pathways, and require more energy consumption and frequent filter replacement [23]. Therefore, considerable attention is being devoted to the development of multifunctional air filters that integrate at least two layers with different functions into a single layer [24,25].

To enable high-efficiency PM capture, fibrous filters should be thicker or be composed of densely packed nanofibers. Such filter structures inevitably increase airflow resistance, consequently leading to greater energy consumption [26,27]. However, if electrostatic forces between the particles and fibers are established, the capture efficiency can be improved substantially without an increase in filter pressure drop [28]. Recently, our group reported a conductive polyester/aluminum (PET/Al) fibrous filter showing high-efficiency electrostatic PM removal (~99.99% for 30–400 nm particles) with a low pressure drop [29]. Because the PET/Al filter is electrically conductive, strong electric fields can be created around the filter by directly introducing electric potential, and the charged PM is effectively deposited onto the fibers via Coulomb forces. There have been several reports of the mild antimicrobial activity of alumina (Al_2O_3) particles against microorganisms [30–32]. In addition, thin oxide layers (3–10 nm) form on the Al nanostructures of the PET/Al filter, which could confer antimicrobial activity. Improving the antimicrobial properties of the PET/Al filter via the structural control of the Al layers would be of great significance to support its potential as a bifunctional filter for total air quality treatment.

In this study, we demonstrate the bifunctionality of the PET/Al filter regarding its high effective capture and inactivation of airborne bacteria. This filter showed a pressure drop 10 times lower per thickness compared with a commercial high-efficiency particulate air (HEPA) filter. Both *Escherichia coli* and *Staphylococcus epidermidis* were captured on the PET/Al filter with a high efficiency of ~99.99% via electrostatic forces. The antimicrobial activity of the filter itself for each species was increased to ~94.8% and ~96.9%, respectively, due to the enhanced

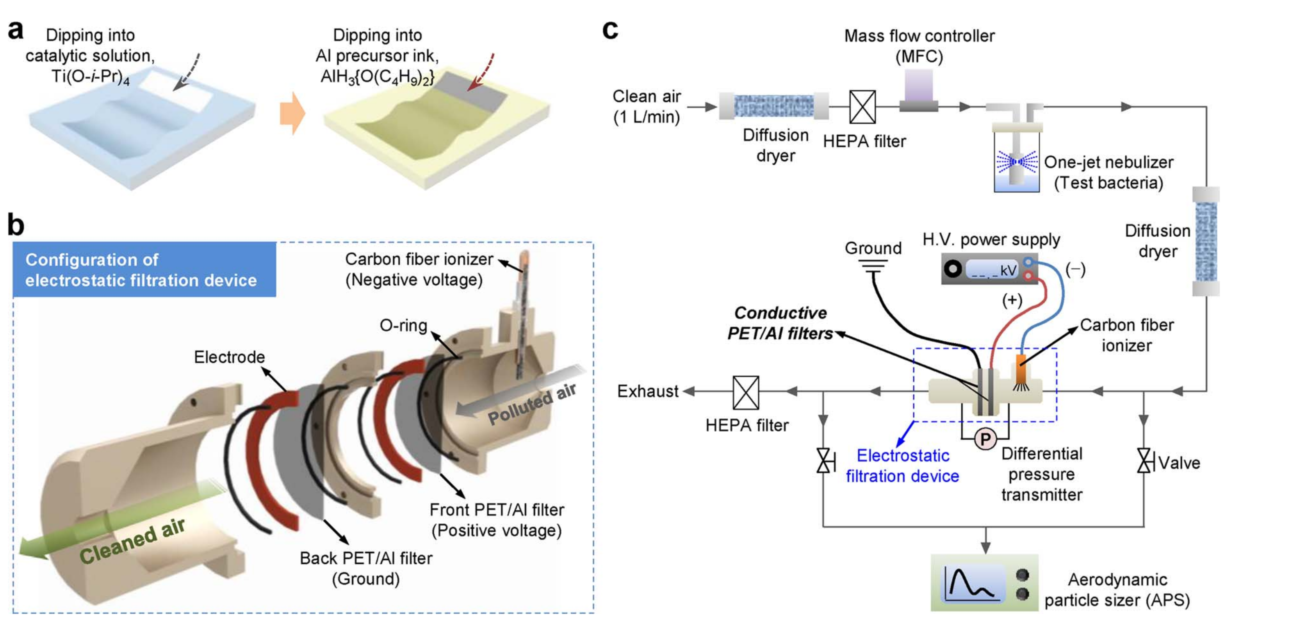


Fig. 1. (a) Diagram of the chemical solution process for conductive polyester/aluminum (PET/Al) filter fabrication. (b) Configuration of the electrostatic filtration device composed of a carbon fiber ionizer and two PET/Al filters. Electric fields are formed between the front filter and the ionizer as well as the back filter and the front filter. Inflowing particles are negatively charged by the ionizer, and are captured by Coulomb forces towards the front PET/Al filter. (c) Schematic diagram of the experimental setup used in the filtration tests. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).