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Atmospheric Environment 39 (2005) 3675–3685
ATMOSPHERIC ENVIRONMENT
www.elsevier.com/locate/atmosenv

Size-dependent collection of micrometer-sized particles using nylon mesh

Naomichi Yamamoto[a,*], Kazukiyo Kumagai[a], Minoru Fujii[b], Derek G. Shendell[c], Osamu Endo[d], Yukio Yanagisawa[a]

[a]*Department of Environmental System, Institute of Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan*
[b]*National Institute for Environmental Studies, Onogawa 16-2, Tsukuba-shi, Ibaraki 305-8506, Japan*
[c]*Community Action to Fight Asthma (California State Coordinating Office), 1515 Clay Street, Suite 1700, Oakland, CA 94612, USA*
[d]*National Institute of Public Health, Shirokanedai 4-6-1, Minato-ku, Tokyo 108-8638, Japan*

Received 13 September 2004; received in revised form 21 February 2005; accepted 4 March 2005

Abstract

Our study explored the size-dependent collection characteristics for micron-sized particles using several kinds of commercially available woven nylon net filters. The particle concentrations with and without the filter were compared to determine the filtration characteristics. The theoretical efficiencies based on a single-fiber theory and a hole model were also computed. Although the theoretical efficiencies were generally consistent with the experimental results, the non-uniformity of air velocity profile within a mesh hole, and a particle's detachment from or bounce off the filters, should be further investigated in future research. Overall, the present study revealed the size-fractionation capability of the nylon wire mesh filters for micron-sized particles from experimental and theoretical points of view. Unlike impactors, the size-fractionation characteristics of the nylon wire mesh filter were determined by particle size, mesh fiber diameter, and a combination of different particle collection mechanisms including impaction, interception, and gravitational settling. Each mechanical process appears interdependently governed in part by the filter dimensions such as filter mesh size (diameter of opening) as well as related variables such as packing density and fiber diameter.

Keywords: Coarse particles; Filtration; Size distribution; Woven net filter; Mesh size

1. Introduction

The nylon net filter is a type of wire-mesh screen filter composed of woven nylon nets with known sizes (diameters) of mesh openings. Filtration using this type of filter is achieved by means of mechanical particle collection processes including impaction, interception, and Brownian diffusion. While impaction occurs when the particle crosses the abruptly changing streamlines near the filter fiber and hits the fiber because of its inertia, interception occurs when the center of a particle passes within a distance equal to the particle radius from the rim of the filter fibers. Brownian diffusion is an irregular wiggling motion of particles caused by the persistent collision by gas molecules. As a result, the particle collides with a fiber while traveling through it on a non-intercepting streamline (Hinds, 1999). Although

*Corresponding author. Tel.: +81 3 5841 7335; fax: +81 3 5841 8583.
E-mail address: naomichi.yamamoto@yy.t.u-tokyo.ac.jp (N. Yamamoto).

1352-2310/$ - see front matter
doi:10.1016/j.atmosenv.2005.03.001

interception and impaction are generally important mechanisms to collect supermicron particles with a filter, diffusion is the predominant mechanism for submicron particles. Therefore, when filtration sampling is conducted, particles of two different size ranges are collected with similar efficiency although the collection mechanisms differ.

Even though the collection efficiency of a filter is not uniquely related to the size of the particles to be collected, the size-fractionation technique using a nylon wire-mesh screen filter may be useful for large airborne particulate species such as of biological origin, like allergenic house dust generally in the coarse size range (e.g., 10–40 μm diameter dust mite fecal particles, a major type of house dust allergens) (Tovey et al., 1981). In particular, uniform collection of culturable biological particles, such as airborne fungi, on a filter is of interest because the conventional cascade impactors for the purpose of particle size fractionation may result in the overload of culturable organisms underneath the impaction nozzle, causing a single colony to grow from multiple depositions of organisms (McCartney et al., 1997). Since airborne fungal particles are in the range of 0.5 to 30 μm in size (Hinds, 1999), a size range for which diffusion can be neglected, the aforementioned complexity of size-fractionation measurement may be ignored for these particulate species.

The goal of the present study is to explore the possibility of a size-fractionation technique for micron-sized particles using several kinds of the commercially available woven nylon net filters. Although the particle collection mechanism with fine wire-mesh screen filters as diffusional batteries has been extensively studied to characterize fine particle removal (Sinclair and Hoopes, 1975; Cheng and Yeh, 1980; Yeh et al., 1982; Cheng et al., 1985), few studies have been conducted to establish a size-fractionation technique for measuring supermicron airborne particles of biological or chemical (combustion) origin. To determine the size-fractionation characteristics, ratios of the airborne particle concentrations with filtration to without filtration, measured by light-scattering particle counters, were calculated to obtain filtration efficiencies. The theoretical efficiencies calculated based on a single-fiber theory and a hole model were then compared with the experimental results.

2. Experimental

2.1. Filters

Nylon net filters with 11, 20, 60, 100 and 160 μm mesh sizes (Millipore Corp., Tokyo, Japan; 47 mm diameter, nylon 6,6 (Millipore, 2002)) were used. The filters consisted of woven nylon nets with opening area fractions of 6, 14, 42, 44 and 53% on a filter surface for the 11, 20, 60, 100 and 160 μm mesh filter sizes, respectively; filter thicknesses were 65, 55, 50, 80 and 100 μm, respectively. The packing density, α, was calculated by the following equation given by Cheng and Yeh (1980):

$$\alpha = \frac{\text{volume of solid}}{\text{total volume}} = \frac{4m_s}{\pi d_s^2 h \rho_s}, \qquad (1)$$

where m_s is mass of filter, d_s is filter diameter, h is filter thickness, and ρ_s is density of the filter material ($= 1.14\,\mathrm{g\,cm^{-1}}$ for nylon 6,6). The filter mass was determined using a microbalance (Model AG204, Mettler Toledo Inc., USA). The fraction of a filter's surface area with mesh openings, ε, was equal to the projected area ratio of a mesh opening to a double-cross of axes of proximate nylon net fibers. Therefore, the diameter of a nylon fiber, d_f, is given by

$$d_f = \left(\frac{l^2}{\varepsilon}\right)^{0.5} - l, \qquad (2)$$

where l is filter mesh size. The dimensions of the filters are also summarized in Table 1.

Table 1
Dimensions of the woven nylon net filters

Mesh size[a] l (μm)	Mesh opening[a] ε (%)	Thickness[a] h (μm)	Filter mass m_s (SD, in mg)[b]	Packing density[c] α	Fiber diameter[d] d_f (μm)
11	6	65	71.4 (0.3)	0.56	34
20	14	55	60.3 (0.5)	0.55	33
60	42	50	31.9 (0.5)	0.32	33
100	44	80	45.5 (0.2)	0.29	51
160	53	100	52.8 (0.1)	0.27	60

[a]Information values.
[b]Weighed by a microbalance ($n = 3$); SD = standard deviation.
[c]Calculated by Eq. (1).
[d]Calculated by Eq. (2).