Journal of Aerosol Science 114 (2017) 250–262

Contents lists available at ScienceDirect

Journal of Aerosol Science

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

Screen collection efficiency of airborne fibers with monodisperse length

Bon Ki Ku[*], Gregory Deye, Leonid A. Turkevich

Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health (NIOSH), Division of Applied Research and Technology (DART), 1090 Tusculum Ave, MS-R7, Cincinnati, OH 45226, USA

ARTICLE INFO

Keywords:
Glass fiber
Fiber length
Nylon mesh screens
Collection efficiency

ABSTRACT

Fiber length is believed to be an important variable in determining various toxicological responses to asbestos and other elongate mineral particles. In this study we investigated screen collection characteristics using monodisperse-length glass fibers (i.e., 11, 15, 25, and 53 µm in length), to better understand the collection of fibers with different lengths on screens with different mesh sizes. A well-dispersed aerosol of glass fibers (geometric mean length ~ 20 µm), generated by vortex shaking, was fed directly into the Baron Fiber Length Classifier, in order to produce monodisperse length fibers. With nylon mesh screens (10, 20, 30, 41 and 60 µm mesh sizes), the screen collection efficiency was measured using an aerodynamic particle sizer. As the screen mesh size decreases from 60 µm to 10 µm, the screen collection efficiency for 53 µm fibers increases (from 0.3 to 0.9) while 11 µm fibers exhibited a collection efficiency independent of screen mesh size. The collection efficiency for the longest fibers was found to be nearly constant for aerodynamic diameters 1–4 µm for screens 20 and 30 µm, but to rise significantly at aerodynamic diameters larger than 4 µm. For the 20 µm screen, the collection efficiency for fibers with lengths > 20 µm is a factor of two to five larger than that for spherical particles with the same aerodynamic diameter. We believe that fibers are collected on the screen primarily by interception below 4 µm in aerodynamic diameter, and by impaction above 4 µm. This study represents a fundamental advance in the understanding of the interaction of screens with a fibrous aerosol.

1. Introduction

Understanding fiber deposition in the respiratory system is of great interest to elucidate the adverse health effects of inhaled fibrous particles (Baron, 2001; Hesterberg & Hart, 2001; Spurny, Stober, Opiela, & Weiss, 1979). In addition, NIOSH has advocated comprehensive research on airborne fibers, such as asbestos and elongated mineral particles (EMPs), in order to isolate the particular parameters of toxicity of these materials (NIOSH, 2011). Because fiber length has long been suspected as being a crucial parameter in determining various toxicological endpoints of asbestos and similar materials (Stanton et al., 1981), efforts have been made to study the deposition of airborne fibers in the respiratory system and in the filtration media as a function of fiber dimension (especially length). Related studies have been conducted on the deposition of fibrous particles in the human nasal/oral airways (Su & Cheng, 2005, 2006, 2009; Su, Wu, & Cheng, 2008) and on filtration media (Gentry & Spurny, 1978; Gentry, Spurny, Opiela, & Weiss, 1980; Gentry, Spurny, & Schoermann, 1989) in the submicrometer and micrometer size range for both asbestos and man-made fibers. Understanding the subtleties associated with the deposition of these materials on filter media is equally important for a proper

---

[*] Corresponding author.
E-mail address: bku@cdc.gov (B.K. Ku).

http://dx.doi.org/10.1016/j.jaerosci.2017.09.006
Received 17 January 2017; Received in revised form 3 May 2017; Accepted 5 September 2017

0021-8502/ Published by Elsevier Ltd.

interpretation of air sampling.

Gentry and colleagues studied the collection efficiency of asbestos fibers using optical light scattering (Gentry & Spurny, 1978) and electron microscopy (Gentry et al., 1989). They reported a number of difficulties in measuring the collection efficiency of fibers on filters compared to isometric particles: (1) fiber samples typically have a wide range of lengths and diameters; (2) well-dispersed fibers are not easy to aerosolize from the bulk fiber samples, and the generated aerosol typically contains many agglomerates; (3) the collection efficiency on a substrate depends on fiber orientation. Interpretation of the optical scattering by fibers is complicated by the fiber orientational degree of freedom, so it is not straightforward to deconvolute fiber length from the scattering signal. Using electron microscopy to get fiber length and diameter distributions is time-consuming.

Ku and colleagues demonstrated a vortex shaking method to produce well-dispersed fibers from glass fiber powders (Ku, Deye, & Turkevich, 2013). A recent study has shown that screens with different apertures can remove longer fibers in the micrometer size range (Ku, Deye, & Turkevich, 2014); these authors suggest that screens can serve as a means to separate fibers by length. Myojo (1999) proposed a method for determining the length distribution of fibrous aerosol using an array of wire mesh screens. Chen, Wang, Bahk, Fissan, and Pui (2014) studied penetration of carbon nanotube (CNT) particles of mobility diameter 20–500 nm and their alignment through fibrous and electret filter media. Bahk, Buha, and Wang (2013) developed a method to determine CNT lengths by combination of mobility measurement and filtration model calculation. However, there is still little information available about how fiber length may influence screen collection efficiency. Thus, it is desirable to measure collection efficiency of screens in removing airborne fibers as a function of length and to characterize the aerodynamic behavior of the fibers during this process.

In this study we investigated screen collection efficiency of airborne glass fibers (a surrogate of asbestos) with monodisperse length. There were several aims to this study: 1) to determine the relation between screen collection efficiency and fiber length for given different mesh screens; and 2) to better understand the collection characteristics of fibers. To achieve this, monodisperse length fibers were prepared (in real time) by a dielectrophoresis-based Baron fiber length classifier (Baron, Deye, & Fernback, 1994; Deye, Gao, Baron, & Fernback, 1999). The length-selected fibers were used to obtain collection efficiency of screens with different mesh sizes by measuring upstream and downstream concentrations of the fibers using an aerodynamic particle sizer. The collection efficiency for fibers was compared to that of spherical particles for one screen.

2. Experimental methods

Glass fiber powder, supplied by Japan Fibrous Material Research Association (Kohyama, Tanaka, Tomita, Kudo, & Shinohara, 1997), was aerosolized (with geometric mean length of 20 µm, and, correspondingly, a mean length of 30.1 µm) by a vortex shaking method (Ku et al., 2013) and was provided, at 1.5 lpm, through a neutralizer (Po-210, 2 µCi), to the fiber length classifier (FLC). Characterization of the vortex generator system is described in detail in our recent study (Ku et al., 2013). The principle and operation of the FLC are described in the previous studies (Baron et al., 1994; Deye et al., 1999). Briefly, this classifier A (Fig. 1) isolates fibers of a chosen length through the process of dielectrophoretic mobility. Due to the electric field magnitude gradient, a neutral fiber experiences a net force in the annular region of the FLC (between the inner electrode and the outer tube). A 50-Hz A.C. potential of 0–10 kV peak-to-peak (square wave) is applied between the inner and outer electrodes to make fiber separation. In this alternating field, charged fibers oscillate about the trajectory predicted for dielectrophoretic motion. If the fibers would not be highly charged (the fibers are neutralized before the FLC), the oscillation would be sufficiently small that additional deposition and hence significant broadening of the classified fiber distribution would not occur, as shown in the previous studies. In practice, the product of the fiber length and the FLC voltage is roughly constant. Operated in the differential mode, the shortest fibers transit the length of the instrument and exit via the dump slot; the longer fibers are deposited on the inner electrode (rod); only a narrow range of intermediate length fibers are collected at the output of the instrument. For conductive long fibers, the dielectrophoretic velocity is proportional to the square of the fiber length (Lipowicz & Yeh, 1989). Aerosol and sheath flows are provided at 50% relative humidity (RH) to ensure conductivity of the glass fibers; this conductivity enables polarization and alignment of the fibers in the electric field (Wang et al., 2005).

The FLC-selected samples are sampled by the arrangement at C (Fig. 1). The filters may be changed by this arrangement without disturbing the classifier flow. The fiber samples were collected on a mixed cellulose ester (MCE – pore size 0.8 µm, SKC) filter and imaged (off-line) with phase contrast microscopy (PCM) to measure fiber length distributions. The aerodynamic diameter is also measured by a TSI 3321 Aerosol Particle Sizer (APS) at B. The APS is modified to return the filtered exhaust to a sheath supply within the APS unit while pulling 1.0 lpm from the return. This limits the APS intake to 1.0 lpm with a dilution ratio of 1:1.

Nylon net screens (Millipore Corp., Billerica, MA) with different nominal screen mesh sizes (10, 20, 30, 41, and 60 µm) are loaded in one of the laminar flow chambers indicated at D (Fig. 1) while the other remains empty. The test chambers are conducting tubes and their nominal diameter is 2.5 cm (measured inner diameter 2.2 cm) and total length is 23 cm. Physical properties for nylon net screens used in the study are summarized in Table 1. Screen collection efficiency, η, was obtained from

$$\eta = 1 - \frac{C_{down}}{C_{up}} \tag{1}$$

where C_{up} and C_{down} are the fiber number concentrations of the chamber without and with a screen, respectively. The mean collection efficiency for each fiber length was calculated based on three replicate concentration measurements. Measurement uncertainties are quoted as one standard deviation. Two identical tube chambers (one chamber with a screen and the other without a screen) were used to measure screen collection efficiency. Because identical aerosol paths through the chambers are employed, this approach avoids systematic errors due to particle losses that occur in the chambers to measure particle concentrations with/without a