Characterization of Screen-Penetrating Aerosol Fibers and Their Alignment in an Electric Field

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ABSTRACT

Length classification of airborne fibers, including carbon nanotubes/nanofibers, is a fundamental technology important for toxicology studies of these materials. Fiber toxicity appears to depend on fiber concentration, dimensions (diameter and length) and durability in the lungs. Recently, the National Institute for Occupational Safety and Health (NIOSH) has published a Roadmap for research of asbestos fibers and other elongate mineral particles (EMPs) (NIOSH, 2011). An underlying theme is that, in order to better understand the toxicity of fibers, it is necessary to develop methods for classifying fibers by length so as to enable toxicology studies to directly test length as a salient parameter. In this study, we explored the use of screens as a length separation method of airborne fibers in the micrometer size range. Fiber alignment in an electric field was also investigated as a way to improve screen collection.

Keywords: glass fiber length, aerosol, mesh screens, alignment, electric field

1 INTRODUCTION

Length classification of airborne fibers, including carbon nanotubes/nanofibers, is a fundamental technology important for toxicology studies of these materials. Fiber length has long been suspected (Stanton et al., 1981) as being a crucial parameter which determines various toxicological responses (fibrosis, lung cancer, mesothelioma) to the presence of asbestos in the lung. Direct toxicological testing has been hampered by the inability to prepare significant quantities of length-classified asbestos samples. Our recent work at the National Institute for Occupational Safety and Health (NIOSH) has focused on developing techniques to separate mineral fibers by length in order to prepare asbestos samples of well-defined length for subsequent toxicological study. Various techniques are under investigation to prepare fibers longer or shorter than the size of a typical alveolar macrophage ($L_{macro\phi}$ ~ 20 μm). The preparation of control samples, containing only shorter fibers (i.e., L < 20 μm), is of equal importance to the preparation of samples of the presumably potent long fibers. The work reported here attempts to address this challenging problem. Recently, Ku et al. have used screens with different pore sizes to obtain short fibers by removing longer fibers by interception mechanism (Ku et al., 2014). They demonstrated that using the screen with the blockage on its center could give a relatively sharp cut-off of fiber length because the centrally blocked screen configuration distorts the flow and possibly aligns the fibers parallel to the plane of the screen. In this study, we explored the use of screens (housed in asbestos sampling cassettes) as a length separation method of airborne fibers in the micrometer size range. In addition, fiber alignment in an electric field was also investigated as a way to improve screen collection.

2 EXPERIMENTAL METHODS

A well-dispersed aerosol of glass fibers (a surrogate for asbestos) was generated (Fig. 1) by vortex shaking (Ku et al., 2013b) a Japan Fibrous Material Research Association (JFMRA) glass fiber powder (Kohyama et al., 1997). Fibers were collected on a mixed cellulose ester (MCE) filter, imaged with phase contrast microscopy (PCM), and lengths were measured. Nylon net screens (Millipore Corp., Billerica, MA) ,with different screen mesh sizes (60, 20, and 10 μm; models NY60, NY20, and NY10), were used to examine the effect of screen pore size on the length distribution of fibers penetrating though each screen. We also investigated with double screen and centrally blocked screen configurations. The two duplicates of the fiber samples were collected for length distribution measurement to ensure the effect of screen pore size on the length distribution of fibers penetrating through each screen. To investigate fibler alignment in an electrical field, two electrodes, i.e., circular and parallel configurations, were designed. The alignment of fibers was observed under different electric field, charge state of the fibers (e.g., naturally charged or neutralized), and humidity (e.g., dry air or humid air), using phase contrast microscopy (PCM).

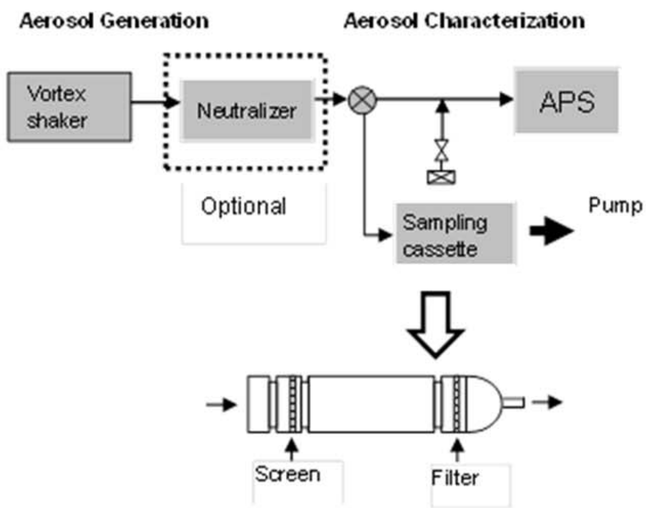


Figure 1: Experimental setup for length measurement of fibers (top); configuration of a sampling cassette with a screen and a filter (bottom). APS: aerodynmaic particle sizer. Adapted from Ku et al. (2014).

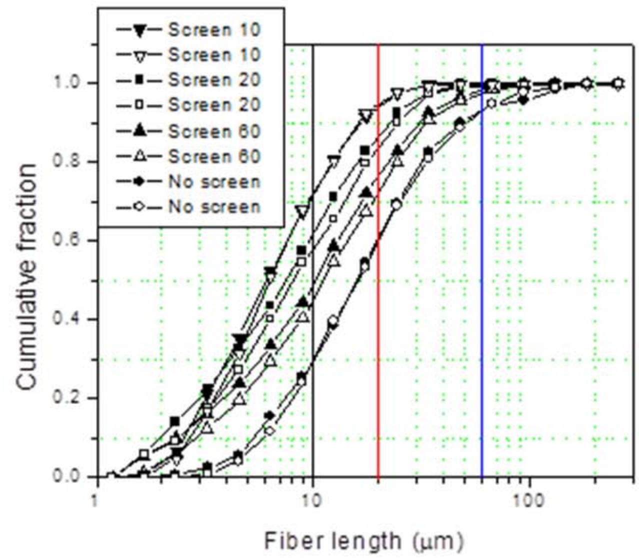


Figure 2: Cumulative fractions of glass fibers penetrated through a screen and collected on MCE filter for different screen mesh sizes. The vertical lines at 10, 20 and 60 µm are included as indicators of the relevant screen apertures.

3 RESULTS AND DISCUSSION

3.1 Length distributions of glass fibers penetrated through a screen

Figure 2 shows cumulative fractions of glass fibers penetrated through a screen as a function of fiber length for different screen sizes. For each screen, shown are two independent runs to illustrate our level of consistency—the fiber length distributions are all constructed from PCM images at 40 X magnification. For comparison, the control for the case of no screen is also included, for the two independent runs. While not identical, the two distributions are very similar, with count median lengths L_{50} ~ 18.4 µm (run1) and L_{50} ~ 18.3 µm (run 2). With no screen, the length distribution of the fibers is similar to that reported for the powder (Kohyama et al., 1997). As soon as the screens are introduced, the median length, L_{50}, of the length distribution is substantially reduced, although this is not simply related to the aperture size: L_{50} ~ 10 µm (60 µm screen), L_{50} ~ 7.7 µm (20 µm screen), L_{50} ~ 6.2 µm (10 µm screen). For all screens, these median lengths are smaller than the nominal aperture size. For clarity, we have indicated, with colored vertical lines, the nominal aperture size L_{mesh} ~ 10 µm (black), 20 µm (red), 60 µm (blue). Again, the major effect with the introduction of any of the screens is to shift the entire distribution to shorter lengths.

3.2 Length distributions using screens with different configuations

We also investigated two additional screen configurations. The first *double screen* configuration consists of two screens positioned back to back (at random azimuthal alignment). The second *centrally blocked* configuration introduces a blocking disk at the center of the screen (Figure 3 inset). Figure 3 shows cumulative fractions of fibers collected under these three conditions: single screen, double screen and centrally blocked screen for 60 µm screens. Using either the double screen or centrally blocked screen configuration tends to sharpen the length distribution of the penetrating fibers (i.e., it reduces both the long and short fiber “tails”); this effect is more pronounced for the smaller aperture screens (not shown here). There appears to be minimal effect on the midpoint of the length distributions for these alternative configurations (double screen or centrally blocked screen), as compared with the corresponding single screen. The centrally blocked screen configuration yielded samples substantially free of the long fibers (Fig. 3): the fraction of fibers longer than a typical macrophage (L ~ 20 µm) is 0.18 (60 µm screen) (Fig. 3), 0.06 (20 µm screen) and 0.06 (10 µm screen). This latter value would be quite acceptable to be used for a short fiber control in a toxicology experiment.

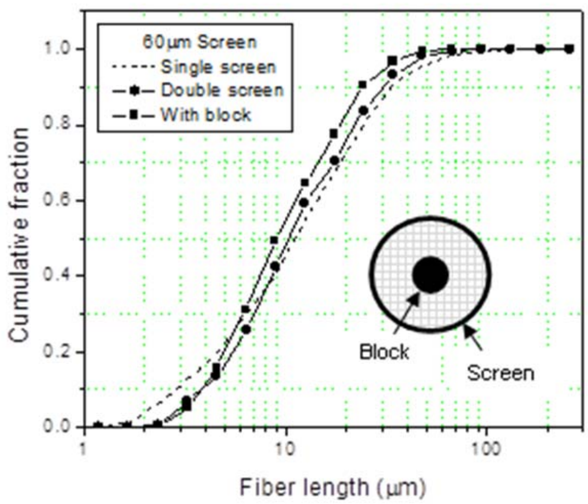


Figure 3: Cumulative fractions of fibers penetrated through 60 µm screen with different configurations and collected on a 25 mm MCE filter.

3.3 Visualization of aerosol fiber alignment in an electric field

We also investigated the degree of fiber alignment in two electrical field configurations: one is with cylindrical electrodes and the other is with parallel electrodes. Figure 4 shows an optical image for fibers collected on MCE filter downstream (immediately after) cylindrical electrodes with an applied DC voltage of 8.1 kV in dry air and naturally charged fibers. The airborne fibers of all lengths are aligned parallel to the applied DC electrical field (see the direction of electric field line shown on the top left of the image). Figure 5 shows the case of parallel plate electrodes. Figure 5b illustrates fiber orientation by a field E = 7.3 kV/cm (fibers are collected on a filter downstream from the electric field), as compared to the random fiber orientation for the case with no electric field (Fig. 5a).

The orientational degree of freedom of a fiber reduces the collection efficiency of screens. A strong electric field may be used to orient the fibers parallel to the screen and thereby increase the screen efficiency in removing the long fibers from the air stream. Figure 6 (open triangles) shows the collection efficiency of 20 µm pore size screen right after electric field (EF) – shown is the change in collection due to the applied electric field (relative to the applied electric field). Also, shown (closed squares) is the collection efficiency of the screen without an applied electric field – shown is the collection due to the presence of the screen (relative to the unobstructed aerosol stream). As a control, we also measured (closed triangles) the effect of the electric field without a screen – shown is the depletion of the aerosol stream due to the presence of the electric field (relative to the aerosol stream with no electric field). Taken together, these results demonstrate the synergetic effect of electric field and screen, with an increase in collection efficiency presumably due to fiber alignment.

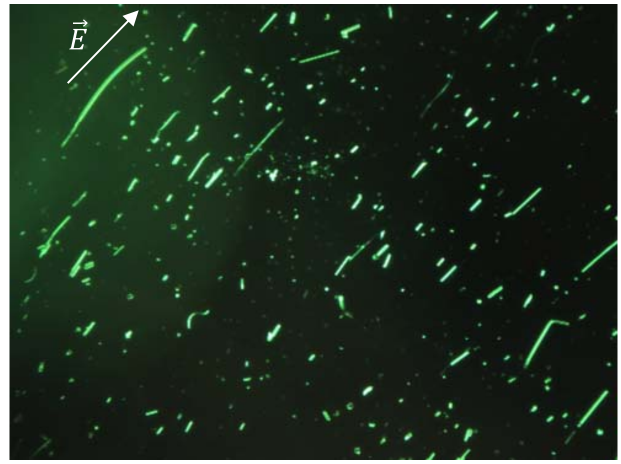
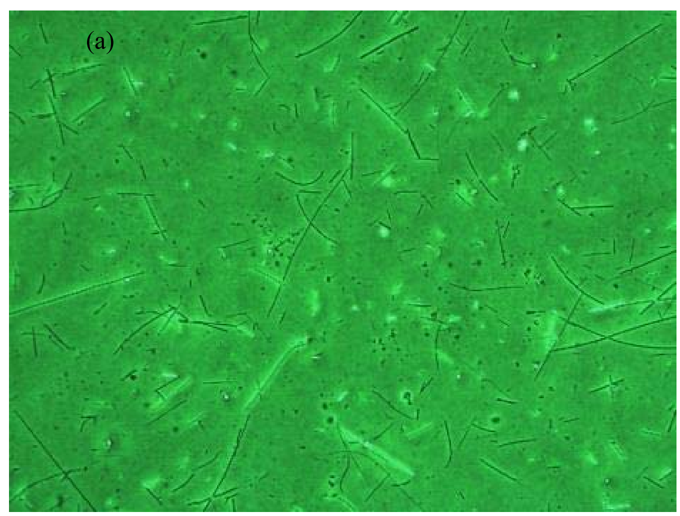


Figure 4: Optical image for fibers collected on MCE filter downstream right after cylindrical electrodes applied by different high DC voltage of 8.1 kV, in dry and naturally charged condition and at aerosol flow rate of 1.5 lpm.



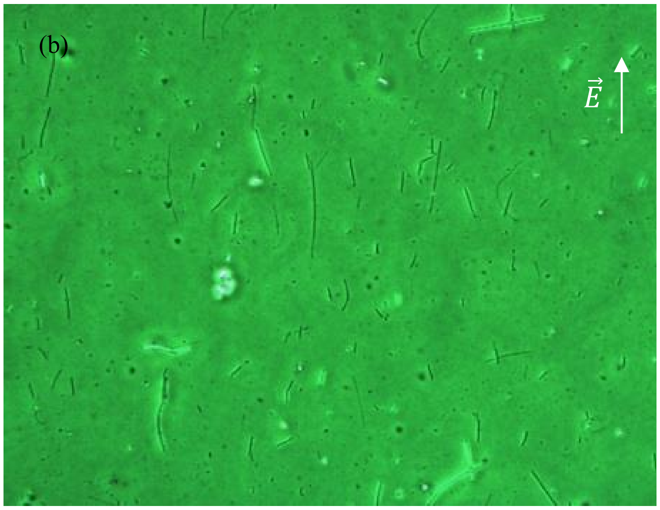


Figure 5: Visualization of fiber alignment: (a) No electric field, (b) 7.3 kV/cm, parallel plates, in dry and naturally charged condition.

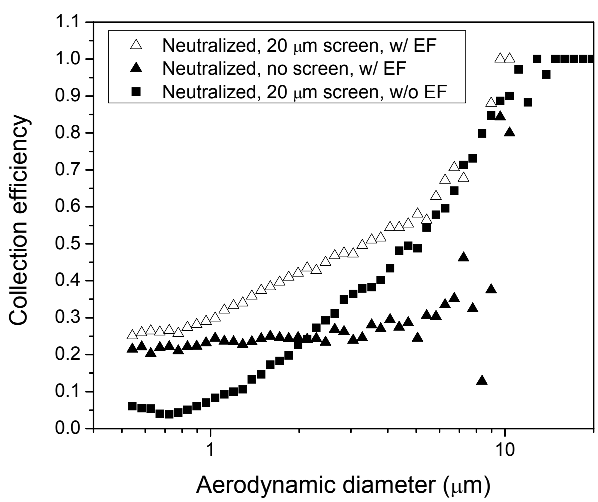


Figure 6: Collection efficiency for 20 μm pore size screen right after electric field (EF)

4 CONCLUSIONS

In this study, filtration of airborne fibers by screens was investigated as a means to prepare toxicology samples free of long fibers. Three different screen mesh sizes were used to classify glass fibers, and their 50% cut-off length, geometric mean length, and geometric standard deviation were obtained, based on a phase contrast microscopy. The fibers were aerosolized by a simple vortex shaker. This work has demonstrated the selectivity of a variety of screen configurations to deplete long fibers from an aerosol stream, and that fibers can be aligned by an applied electrical field. The combimation of electric field and screen improves collection of fibers on the screen. The effect of electric field on fiber alignment has not been quantitatively investigated in this study and needs to be investigated by measuring the angle of fiber relative to electric field direction.

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