Ann. occup. Hyg., Vol. 46, Supplement 1, pp. 215–218, 2002
Published by Oxford University Press
DOI: 10.1093/annhyg/mef673

Development of a Filter Assembly to Match the Deposition of Ultrafine Aerosol in the Lung: A Pilot Study with Beryllium

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A new criterion has previously been proposed for assessing inhalation risk from ultrafine aerosols. This deposited submicrometer particulate (DSP) criterion matches the lung deposition curve for aerosols with a size of <1 μm. A method for matching the DSP criterion using rack-etched polycarbonate filters has been described in the literature, but the sampling results must be adjusted by a correction factor to match the DSP curve. A new design that matches the criterion without the need for any correction factors and has been used with a real-time particle counter to measure processes in the beryllium industry where data suggest that the ultrafine (<0.1 μm) fraction of beryllium might be an important metric for predicting disease.

Keywords: ultrafine particles; beryllium; lung deposition

INTRODUCTION

Recent interest in the ultrafine size portion of beryllium aerosol (McCawley *et al.*, 2001) has led to the development of an assembly of three filters that allow size-selective collection of that material. This assembly was designed to try to meet a newly proposed criterion for deposited submicrometer particulate (DSP) (McCawley, 1999). A DSP filter assembly consisting of track-etched polycarbonate filters has previously been described (Hornsby-Myers, 2000) for use as a size-selective device to match the lung deposition curve for ultrafine aerosol. A drawback of the previously published design was the need for a correction factor to allow a better match with the deposition curve. A different design has now been conceived, not using the correction factor.

MATERIALS AND METHODS

A TSI 8160 CertiTest™ was used to determine the penetration and, by subtracting the penetration efficiency from 100%, the collection efficiency of the filters that were used in these tests. The TSI 8160, using dioctyl phthalate, generated nine different aerosol sizes in the range 0.03–0.4 μm for these tests with a geometric standard deviation (GSD) of ≤1.3.

For the loading tests, sodium chloride was generated using a TSI Model 8130 Automated Filter Tester. The impactor generator (Model 8118A) in the Model 8130 produced an aerosol with a mass median diameter of 0.26 μm (count median diameter 0.075 μm) with a GSD of ≤1.75.

In the field, an impactor was used as a preselector to eliminate particles >0.5 μm and to try to minimize overloading. The filter assembly used in the field was used with a wide mesh wire screen pad in the impactor. The millimeter openings in the screen were not felt to be small enough to cause diffusional losses and compromise the sampling efficiency. The count median diameter of the aerosol being sampled in the field was known to be <0.1 μm (McCawley *et al.*, 2001), so it was felt that the impactor preselection would not unduly influence the sampling results.

A flow rate of 2.5 l/min was used with the 5.0 μm pore size filter assembly. The flow rate was determined using a calibration cowl attached to the impactor, which was placed in-line between a pump and a BIOS Dry-Cal electronic bubble meter. Flows were set within 1% and maintained within 5% of

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the specified rate. The impactor was not used in the laboratory testing since particle sizes generated were all less than the cut-point. While there was concern that an impactor might change the pressure differential in the filter assembly and affect collection efficiency, testing of the effect of pressure differentials is only at a preliminary stage.

RESULTS

The previous design (Hornsby-Myers, 2000) used three 3.0 µm pore size track-etched polycarbonate filters sandwiched together, without spacing, at 2.2 l/min to achieve a result as close to the desired deposition curve as possible. A correction factor was then used to move the collection efficiency curve downwards to match the deposition curve (Fig. 1). Several pore sizes were tried in an attempt to refine the results better and to dispense with the correction factor.

Because there is no theory that adequately addresses the desired arrangement (filters sandwiched together with no spacers), a trial-and-error technique was used to determine the most appropriate parameters. Trials included a range of flow rates from 1.75 to 10.0 l/min for between one and four layers of filters. Ultimately it was found that an optimal flow rate was 2.5 l/min for three 5.0 µm pore size track-etched polycarbonate filters (Fig. 2). As with the previous filter assembly, there is a concern about overloading the filters and changing the collection efficiency characteristics of the filter assembly. The

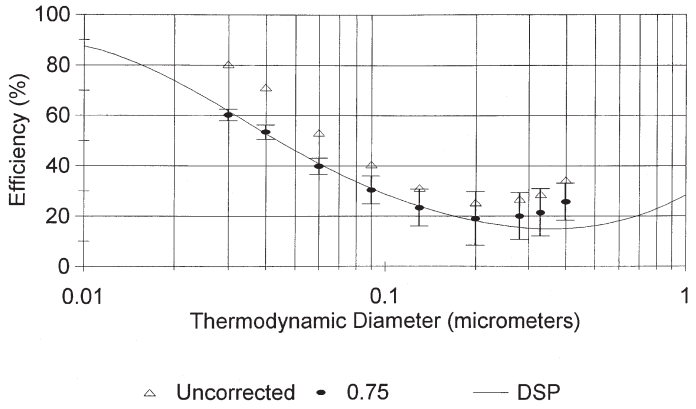

Fig. 1. The solid line is the DSP criterion. The open triangles are the data representing the average efficiency for a three layer, 3.0 µm pore size, track-etched polycarbonate filter assembly operated at 2.2 l/min. These data must be corrected by a factor in order to better match the DSP criterion. A correction value of 0.75 (the solid circles) allows the minimum bias between the filter assembly and the criterion it is attempting to match. The bars around the corrected values are the 95% confidence intervals for an average of seven sets of data using a different filter set each time.

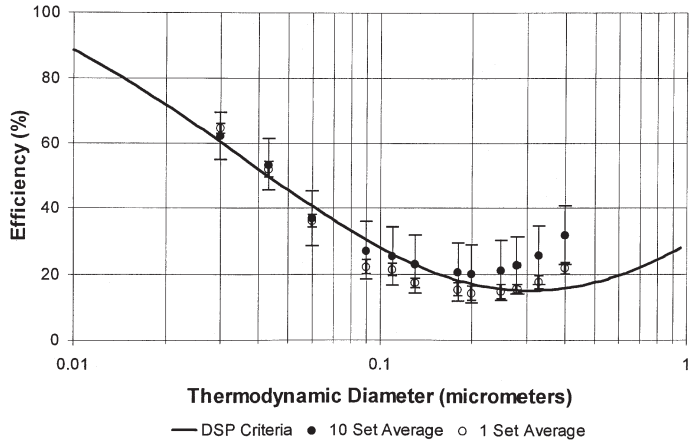

Fig. 2. The solid line is the DSP criterion. The data points are for 10 repetitions and also for 10 consecutive sets of the three layer, 5.0 µm pore size, track-etched polycarbonate filter assemblies operated at 2.5 l/min, with no correction factor. The bars around the data points are the 95% confidence intervals.

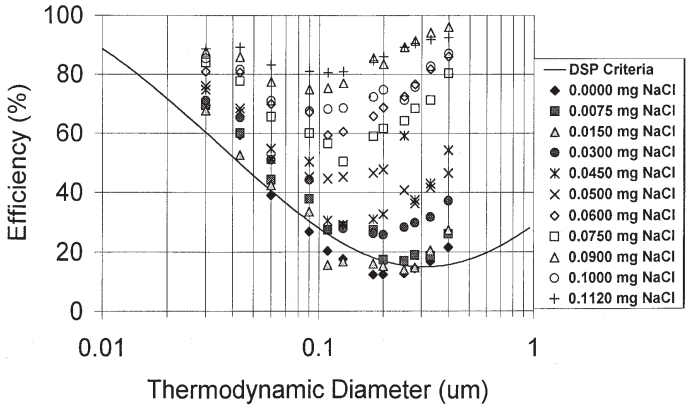

Fig. 3. The results of loading the three layer, 5 µm pore size, track-etched polycarbonate filters operated at 2.5 l/min. The solid filled points are acceptable loading levels, not exceeding the 95% confidence intervals around the average sampling efficiency for the unloaded assembly.

sampling characteristics change noticeably between loadings of 30 and 50 µg of loading with the sodium chloride challenge aerosol (Fig. 3). This is a much lower critical loading level than the 100 µg that was observed with the 3.0 µm pore size used at 2.2 l/min**.**

The utility of the filter assembly used with the impactor can be seen (Fig. 4) when it is used preceding a condensation particle counter to determine the DSP fraction of an aerosol generated while copper beryllium was being poured into molds. As the flow of molten metal increased with time, the particle count increased. At the midpoint in the pour the particle concentration decreased as the flow began to decrease. This allowed real-time monitoring and insight into engineering control modifications.

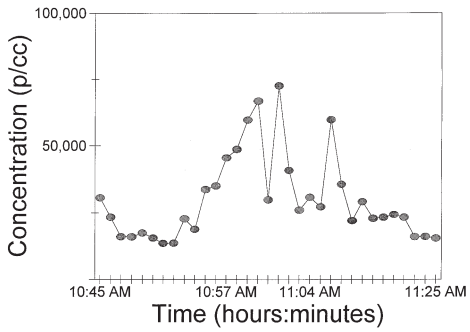

Fig. 4. Data obtained during a pour of molten beryllium copper during normal casting operations at a beryllium facility. A TSI P-Trak was used for particle counting with the three layer, 5.0 µm pore size, track-etched polycarbonate filter device, with a 0.5 µm pre-separation impactor preceding the filter device attached. The data plotted here are the result of a differential measurement. The total particle concentration was measured for 1 min, then the impactor with the filter assembly was attached and a second measurement made for 1 min. The difference between the two in what would have been collected is noted as the DSP concentration. This differential measurement was repeated multiple times during the entire pour and the results are plotted here. By observation, it was noted that the greater the perceived flow from the ladle, the higher the particle count.

DISCUSSION

The traditional approach to size-selective aerosol sampling has been to match the penetration characteristics of particles in the lung. This approach has been used successfully to measure and control dusts from substances such as silica or coal that produce pneumoconiosis. Controversy, nevertheless, has still surrounded the appropriateness of this technique for other situations (Soderholm and McCawley, 1991). The argument is that for a particle to contribute to the dose in the lung it must first deposit in the lung. Penetration is not deposition. Not all particles that penetrate into the lung will deposit. Therefore, measuring penetration is not the same as measuring dose. In the case of silica dust and the dust in coal mines, fortune favored penetration measurements, with the estimated dose correlating to what, in theory, was being measured. The underlying reason for this agreement is that the mass median particle size of this type of mechanically generated dust is >1.0 µm.

In a break with the traditional approach of using particle penetration into the lung to define the size-selective sampling curve, the American Conference of Governmental Industrial Hygienists (McCawley, 1999) offered a proposal for the DSP criterion, defined in terms of lung deposition. The DSP sampling curve follows the pattern for total deposition in the lung and therefore is expressed in terms of a spherical particle with a density of 1 g/cc. (Density is specified because the deposition of particles >0.4 µm is influenced by density, whereas those that are smaller have deposition efficiencies independent of density.) The DSP criterion can also be used to set something akin to respirable or thoracic criteria exposure limits for submicrometer aerosol since there is a relatively constant proportion be-

tween DSP and the deposition of aerosol in the thoracic or total lung region.

The data presented here for the 5.0 μm filter assembly matched the characteristics of the DSP criterion in laboratory testing. This may allow a more appropriate and more accurate assessment of lung dose than penetration measurements. Because of the particle overload that the filter assembly experiences at relatively low concentrations, a direct reading instrument, used for a brief time, is probably the most appropriate means of collecting data. Because the filters retain the particles that would deposit in the lung, the direct measurement would have to be made differentially first with the filter assembly attached and then with it unattached to give the measurement. Alternatively, the 3.0 μm pore size version of the filter assembly could be used for a longer sampling period but would have to have a correction applied to its reading.

The arrangement used in the field, with an impactor preceding the filter assembly, needs further evaluation. Data should be collected on side-by-side samples with that arrangement, using both the 3 μm and the 5 μm filter assemblies, to better demonstrate their precision and accuracy. Further investigation into the overloading effect should be done with a variety of aerosol sizes. Whether a drop in pressure causes the observed changes in performance is being investigated, since this may also affect the use of the filter assembly in other devices such as the impactor or as a mass sampler with a filter pad following it. Applicability of any of the arrangements of the trilayer filter assemblies for other metal fumes and diesel exhaust, while apparent, still needs to be demonstrated and a higher flow arrangement for ambient sampling would be useful.

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