FINAL PERFORMANCE REPORT

Asbestos Fiber Collection by NIOSH - Approved Respirators

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SIGNIFICANT FINDINGS

The research was conducted in three phases. First, the size-specific collection efficiencies of ten manufacturer's dust/mist respirator filters were assessed using monodisperse latex spheres. Second, the overall collection efficiencies of three manufacturer's respirators were evaluated using silica and asbestos aerosols under steady and cyclic flow conditions. Third, the relationships between these empirical results and the predictions of both physically-based (i.e., the single fiber model) and semi-empirical models were examined.

Latex Sphere Test Results

We found that dust/mist respirator filters exhibit high efficiencies -- typically greater than 99.5% -- for collecting particles with aerodynamic diameters greater than 1 um. These filters are less efficient at collecting smaller particles. We observed a minimum collection efficiency of about 90% for particles with aerodynamic diameters of 0.1 um.

Although there was some variability in the performance of the ten manufacturer's filters, most of the filters exhibited very similar particle collection characteristics. One manufacturer's filters consistently performed worse than the others at all particle sizes tested. The three respirators chosen for the silica and asbestos tests were selected from the remaining nine manufacturers.

Silica and Asbestos Test Results

When the dust/mist respirators were challenged with a silica test aerosol -- CMD of 0.5 um, GSD of 2.3 -- under steady flow conditions, their overall mass collection efficiencies were centered on 99.5%. When these same respirators were tested with silica under cyclic flow conditions -- characteristic of human breathing patterns during "medium work" -- their performance was worse. Overall silica penetration was approximately 50% greater under cyclic flow than under steady flow.

In tests using amosite asbestos -- count median length of 4.5 um (GSD = 2.5) and aspect ratio of 9 -- under steady flow the dust/mist respirators exhibited overall count collection efficiencies between 99.9% and 99.99%. When the asbestos tests were repeated under conditions of cyclic flow, valve failure occurred in one of the respirators, leading to substantially degraded performance -- typically around 99.5% with some replications worse than 98%. For the other two respirators asbestos collection under cyclic flow was similar to, or perhaps somewhat better than, that observed under steady flow.

Finally, it is worth noting that in these experiments we were not able to demonstrate a strong relationship between the performance of a respirator in the silica test and its performance in the asbestos test. The steady flow data shown below illustrate this point.

Manufacturer	Typical Penetration (%)	
	Silica (mass)	Asbestos (count)
A	0.071	0.0012
B	0.11	0.033
C	0.44	0.0081

However this statement is made quite tentatively in view of the large within manufacturer variability observed in these experiments. The GSD of the ten replicates for silica was on the order of 2-3 and for asbestos the GSD was between 2 and 7.

Modelling Respirator Performance

The single fiber efficiency model has the potential to predict the size-specific (and overall) collection efficiency of a respirator on the basis of characteristics of the filter media, the aerosol, and the conditions of flow.

It is relatively easy to measure the properties governing impaction, interception and diffusion. According to the single fiber model, taken together, these mechanisms account for collection efficiency of 30 to 40% for particles with aerodynamic diameters between 0.1 and 0.5 um and 70% or more for particles with aerodynamic diameters 2 um or larger. The observed collection efficiencies, between 90% and 99.5%, are much greater -- presumably because of the electrostatic forces operating in dust/mist filters.

Although one variant of the single-fiber model -- the Kanaoka model -- permits analysis of electrostatic effects, it requires information on both the charge density on the filter and the distribution of charge on the aerosol. Because the aerosols in our experiments were passed through a charge neutralizer, it is reasonable to assume that they carried a Boltzmann charge distribution. Unfortunately, we were unable to determine the charge density on the filters. Respirator manufacturers were unwilling to divulge this information and we were not able to develop a method for reliably measuring filter charge density. Until such information becomes readily available, the single fiber model will be of little value for predicting the collection efficiency of dust/mist respirators.

An alternative approach for estimating the collection effiency than can be expected when a respirator is challenged with a specific aerosol was developed. This semi-empirical approach assumes that overall collection efficiency may be estimated by multiplying the size-specific collection efficiency -- determined by latex sphere tests -- by the fraction of the aerosol in each size range and summing over all particle sizes. Because only a limited number of sizes can be tested, it is necessary to estimate the collection effiency expected at intermediate sizes by interpolation. In the examples that follow, a two parameter Weibull model provided the basis for interpolation.

The predictions of overall silica collection efficiency (mass) -- under steady flow conditions -- for the three manufacturer's filters were between 99.92 and 99.95%. The observed collection efficiencies for these respirators were 99%, 99.8% and 99.9%. Note that the respirator with the poorest performance is the same respirator that experienced valve failure in the asbestos tests. These data indicate: (i) that the semi-empirical approach may give reasonable estimates of the overall efficiency of respirator filters, and (ii) that actual respirator performance may be somewhat worse than predicted because of the contributions of other mechanisms -- such as valve leakage -- to overall performance.

Application of this approach to estimate the (count) collection of asbestos is complicated by the need to estimate the size-specific collection of fibers of various lengths and diameters on the basis of the observed collection of latex spheres. If the primary mechanism of collection in dust/mist filters were impaction, it would be appropriate to assign collection efficiencies to asbestos fibers on the basis of their aerodynamic diameters. However, it is much less clear what index of the size of an asbestos fiber should be used to characterize its potential for collection by electrostatic forces.

Conclusions and Recommendations

If possible, NIOSH should test respirators under conditions similar to those under which they will be used -- e.g., cyclic flow, fiberous aerosols. In addition, respirator test protocols must include elements that assess the life cycle performance of all components critical to a respirator's performance -- e.g., exhalation valves.

If the filter to filter variability seen in these experiments is not atypical, large numbers of replications may be needed to adequately assess the performance of a respirator.

Size-specific particle collection data would be useful to many respirator users in that it would permit them to assess the likely performance of a respirator challenged with a specific aerosol of concern.

Research aimed at better understanding the behaviour of fiberous aerosols in electrostatically-charged filters would be extremely valuable as would efforts to develop a method for measuring the charge density on respirator filters.

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16. Abstract (Limit: 200 words)

The first phase of this project involved assessing the size specific collection efficiencies of ten manufacturer's dust/mist respirator filters using monodisperse latex spheres. The second phase involved the evaluation of the overall collection efficiencies of three manufacturer's respirators using silica (14808607) and asbestos (1332214) aerosols under steady and cyclic flow conditions. The final phase involved an examination of the relationship between these empirical results and the predictions of both physically based and semi empirical models. Using latex spheres a high degree of efficiency, typically greater than 99.5 percent, was demonstrated by the dust/mist respirator filters for collecting particles with aerodynamic diameters greater than 1 micrometer. A minimum collection efficiency was noted of about 90 percent for particles with aerodynamic diameters of 0.1 micrometers. When the dust/mist respirators were challenged with a silica test aerosol, the overall mass collection efficiencies centered on 99.5 percent at steady flow conditions. Under cyclic flow conditions the silica penetration was about 50 percent greater than under steady flow. In tests with amosite (12172735) asbestos, an overall efficiency of 99.9 to 99.99 percent was achieved at steady flow. Under cyclic flow conditions, the corresponding figure ranged from 98 to 99.5 percent. The authors recommended that NIOSH test its respirators as much as possible under conditions similar to those in actual use at the job site.

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