Laboratory Evaluation of Pressure Differential Based Respirable Dust Detector Tube

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ABSTRACT

A new type of respirable dust sampler was developed and compared side by side to personal gravimetric samplers in the laboratory. The new sampler correlates filter back pressure with mass accumulation to provide mid-shift and end-of-shift determinations of cumulative exposure. The sampler uses a small low flow rate pump to draw dust through a small detector tube that contains a porous urethane foam respirable classification section and glass fiber filter that collects respirable dust. Six different coal dusts were aerosolized in a laboratory dust chamber and a total of 118 triplicate observations were obtained. For individual coal types, the correlation coefficients were between 0.87 and 0.97. The precision of the two methods was similar with the percent relative standard deviation of the personal samplers of 11.83% and the new detector method of 13.96%. For all coal types tested the data were best described by a power function where $\Delta P = 1.43 mass^{0.85}$, with a correlation coefficient of 0.73. Assessment of the method under field conditions is currently in progress.

INTRODUCTION

Sampling dust levels in mining presents unique challenges because of the variable composition of the dusts and in the constantly moving workplace (Hearl and Hewett, 1993). Monitoring of personal respirable dust exposure is an important step in eliminating many dust related occupational illness and diseases Currently, dust levels in mining are measured either gravimetrically, using filters and the accumulated dust mass in a given quantity of air (Raymond, Tomb, and Parobeck, 1987), or through the use of instantaneous electronic dust monitors (Cantrell, Williams, *et al.*, 1993). The filter method takes several weeks to process before results are reported to the mine. This time delay, coupled with the constant change and movement created by the mining process makes the filter measurement useful only as an historical data point. The results do not provide timely feedback to detect or correct excessively dusty conditions. Electronic dust measurement methods that do provide immediate feedback include photometers, beta gauge and piezobalances. These electronic devices have helped to understand dust generation patterns in mines and have been very useful research tools. Their use for routine personal monitoring, however, is limited due to their accuracy, complexity, size, and expense.

The objective of eliminating occupational dust diseases by reducing worker dust exposures can be accomplished using a number of strategies. Obviously the establishment of permissible dust exposure limits is a first step. Adoption of these permissible levels into law and enforcing compliance of these levels has been a mainstay of reducing occupational exposures. Good business practices have also led progressive companies to prevent worker illnesses through worker education and adoption of best available engineering control technologies (Taylor and Thakur, 1993). Effective monitoring with immediate feedback of exposure results to workers is another method that has shown benefits at reducing exposures in other occupational settings (Zohar, Cohen, *et al.*, 1980).

In the Report of the Secretary of Labor's Advisory committee on the Elimination of Pneumoconiosis Among Coal Mine Workers (U.S. Department of Labor, 1996), several recommendations deal with the development of continuous respirable dust monitors to help protect workers health. In addition, the NIOSH Criteria Document lists improved sampling devices as a research need pertinent to coal miner respiratory health and prevention of disease. Several approaches are being taken to address these needs. These studies include, but are not limited to a Machine Mounted Respirable Dust Monitor (Cantrell and Williams, *et al.*, 1997), light scattering dust monitor response (Lehocky and Williams, 1996); (Tsao and Lin, 1996), pressure drop evaluation of filter medias (Dobroski, Tuchman, *et al.*, 1995) and other novel techniques. One of the principle goals of each of these efforts has been to identify or develop an instrument that will give short term or real time measurements of worker dust exposure.

The dust detector tube was developed to provide an inexpensive, short term measurement of the cumulative personal dust exposure of a worker during a shift. The dust detector tube is modeled after the concept of a radiation dosimeter or more precisely, after the sorbent detector tubes used to measure exposure to various gases. The disposable single use tube contains a respirable size classifier and the pressure drop filter media.

The correlation between filter back pressure and mass is not new (Hamilton and Knight, 1957). Recent work by Dobroski *et al.*, demonstrated a linear pressure versus mass response for a specific filter media (Dobroski and Tuchman, *et al.*, 1995). Concurrent work on the use of porous foam as a respirable dust classification media (Aitken and Vincent, *et al.*, 1993) lent itself to the disposable detector tube idea. Combining these elements in an appropriately designed tube can detect respirable mass through the pressure increase across the filter. An inexpensive commercially available low flow pump with integral pressure transducer, pulls dust through the device and onto the filter. These devices are economical and could be worn daily to estimate dust exposure.

DESCRIPTION OF DEVICE

The dust dosimeter is analogous to a conventional gas detector tube in that a small, low flowrate pump is used to pull a sample into a small diameter tube where the dust is sized and deposited onto a filter. A uniform dust mass loading results in a proportional pressure increase across the filter. Any pressure transducer or one integral with the pump can be used to correlate with filter mass. After the detector tube has been used to make a measurement, the tube can be discarded, and a fresh tube used for the next measurement. Figure 1 shows the comparison of the dust dosimeter system with a personal sampler.

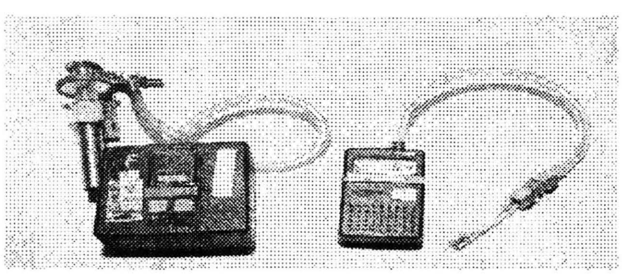

Figure 1. Comparison of dust dosimeter on right with personal sampler on left.

Dust enters the inlet of the detector tube, illustrated in Figure 2, through a 6.3 mm diameter by 8 mm length of polyurethane open cell foam (Type S, Filtercrest™ from PCF foam, Corp., Hamilton, OH) with a density of 50 pores per inch. This segment filters out oversized non-respirable particulate and protects the main classifier from plugging with over size material. The tube narrows to a 4.0 mm diameter section that contains a 25 mm length of 90 pore per inch open cell urethane foam that collects the non-respirable dust and passes the respirable fraction of the dust.

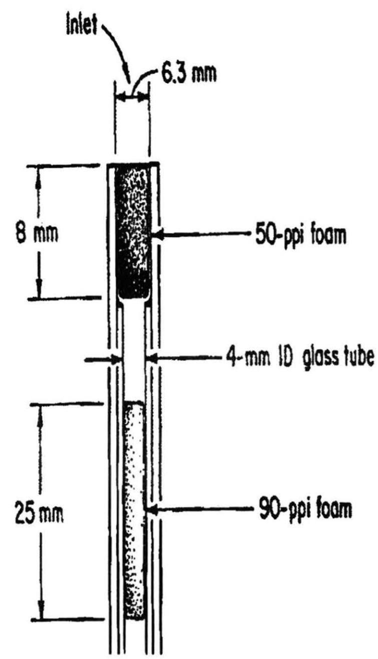

Figure 2. Dust detector tube.

The respirable dust deposits onto an 8 mm diameter Pallflex Fiberfilm[1] T60A20 fluorocarbon coated glass fiber filter supported by a porous cellulose fiber backup pad. The filter holder was constructed from a compression tube fitting that was bored to 9.53 mm, the same outside diameter as the glass tube. Figure 2 shows the glass tube to filter interface held in place with a flanged, barbed nylon tube fitting compressed onto the backup pad. A commercially available low flowrate air sampling pump with integral pressure transducer was used to monitor the pressure increase with mass loading.

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[1]References to commercial products are for informational purposes and does not imply endorsement by CDC.

METHODS

A direct comparison between dust concentrations determined by personal gravimetric samplers and the pressure increase of the dust dosimeter was made in a laboratory dust chamber by comparing the means of triplicate measurements of each type of sampling device. The relative standard deviation of each triplicate grouping was also determined. These measurements were then plotted and least squares regression analysis used to determine the correlation equations.

Personal Gravimetric Samplers

Flow controlled personal sampling pumps operated at a flow rate of 1.7 lpm were used to sample coal dust aerosols from the laboratory aerosol chamber. Dust was classified using 10 mm nylon Dorr-Oliver cyclones and deposited onto standard coal mine sampling cassette filters. Filters were pre and post weighed at the Pittsburgh Research Laboratory (PRL) under controlled atmosphere conditions. Filters were prepared without the tamper resistant backflow valve or the inner stainless steel support wheel. Pump flows were checked weekly with a Gilian Bubble Flow Meter, a primary standard flow measurement device. A total of nine personal samplers were arrayed for each test in groups of three so that each grouping was evenly spaced about the central portion of the chamber at about the same elevation.

Dosimeters

Flow controlled sampling pumps manufactured by SKC Inc. (Pocket Pump™) were operated at a flow rate of 0.265 lpm to draw coal dust aerosols into the dust detector tubes. Clean dust detector tubes were prepared with the size selective foam classifiers and new collection filters. A total of six dust detector tubes were used for each test and divided into groups of three that were arrayed in the test apparatus in an alternating pattern around the central portion of the chamber and at a similar elevation to the personal samplers.

The pump pressure transducer measures the pressure of the entire detector tube, including the two porous foam sections. The contribution to the total pressure from the foams was determined by measuring the pressure restriction of the combined foam sections before and after testing during heavy dust loading conditions. A slant tube manometer was used to measure the pressure at 0.265 lpm. Pressure drop through the interconnecting tubing at this low flow rate was negligible.

Test Aerosols

Six different coal dust aerosols from various sources were used in the study. Coal from the Pittsburgh, Illinois #6, Upper Freeport, Pocahontas, and Beckley A seam, were ground to minus 325 mesh size. One of the Beckley A seam coal samples was doped with a 10% by mass Minu-Sil[2] ground silica. Dusts were aerosolized using a TSI fluid bed generator and disbursed in a 1 m^3 aerosol chamber. The aerodynamic size of each coal aerosol was measured with an Anderson 298 Personal Impactor
operated at a flow rate of 2 LPM for time periods between 0.75 and 2 hours to obtain optimal stage loadings. Impactor substrates were coated with Dow Corning 316 Silicone Release Spray 24 hours prior to preweighing. Substrate weights were measured using procedures similar to the filter weighing. Size distributions were calculated and reported as the mass median aerodynamic diameter (MMAD) and geometric standard deviation(GSD).

Test Procedure

All sampling inlets were arrayed in the central portion of the test chamber facing toward a central point in the chamber. Previous studies of the chamber showed little spatial variability (less than 5%) within the central portion of the chamber. Sampling heads were connected to their respective pumps through short sections of flexible plastic tubing that passed through a bulkhead manifold.

The fluidized bed dust generator was loaded with the coal to be tested and run for a minimum of 1 hour or until a light scattering photometer inside the chamber indicated that an equilibrium concentration had been reached. All personal sampling pumps and dosimeter pumps were then started. Initial back pressures from the dosimeter pumps were recorded. At 10 minute intervals the dosimeter pump pressures were recorded and the light scattering concentration was recorded.

At one hour intervals, groups of 3 personal sampling pumps were switched off. The mass loadings for each grouping of three personal samplers were averaged and the mean and standard deviation reported. Each test lasted for a total of three hours. The pressure readings of the dosimeter pumps were recorded and the initial pressure subtracted to determine the cumulative pressure increase caused by the dust loading for each time interval. Each group of three dosimeter pumps were averaged for each hour interval and the mean and standard deviation reported.

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[2]U. S. Silica Corporation, Berkley Springs, WV

Each three hour test yielded 6 results (two groups of three dosimeters times three gravimetric sampling intervals). This test sequence was repeated three times for each of the six coal types tested for a total of 108 observations. An additional 10 observations were made with the Beckley A seam coal to obtain heavier dust loadings by sampling for 8 hours. During one test within each coal type, a personal impactor sample was taken after the first hour of the test to determine the MMAD of the aerosol in the chamber.

Analysis

Preliminary data analysis was made by comparing the cumulative dust concentrations as determined by the light scattering photometer with the cumulative pressures recorded by the dosimeter pumps. The photometer readings were corrected for each test at 10 minute intervals by using the average mass from the 3 hour personal gravimetric samplers as the correct cumulative mass for that test. This analysis compares the cumulative performance between individual detector tubes. Detailed data analysis calculated the average increase in detector tube pressure of 3 dosimeters and calculated the average personal gravimetric personal sampler mass at hourly intervals. The respective relative standard deviations (RSD) were also calculated. Regression analysis used Excel™ calculation functions to compute power and linear analysis of the dosimeter pressure vs personal gravimetric sampler mass. Error bars were computed based on 1 standard deviation from the mean.

RESULTS AND DISCUSSION

This testing covered a range of concentration equivalents from about 0.1 to 2 times the MSHA permissible exposure limit (PEL) of 2 mg/m^3 (Hearl and Hewett, 1993). Dust mass loadings for the testing covered a range from 0.23 to 3.42 mg. This is equivalent to an 8 hour concentration range from 0.28 to 4.19 mg/m^3. Not all coal types covered the entire range.

For each test sequence, the cumulative pressure from the dosimeters and the cumulative mass, determined from the gravimetrically corrected light scattering measurements, were plotted versus time. A typical test result is show in Figure 3 where the three dosimeters can be seen to follow similar trends. When cumulative pressure is plotted as a polynomial expression, the regression coefficients are better than 0.99. The step like function in the pressure accumulation in the figure is an artifact of the low precision output from the pump pressure digital transducer. A more precise pressure transducer should help to improve the accuracy and precision. The drift in dust feed to the chamber can also be seen in the non-linear cumulative mass data. The comparison between the personal sampling method and the dosimeter method was determined for each coal type. The average mass, measured by personal sampling pumps for 1, 2, and 3 hour intervals was plotted against the corresponding average dosimeter pressure increase.

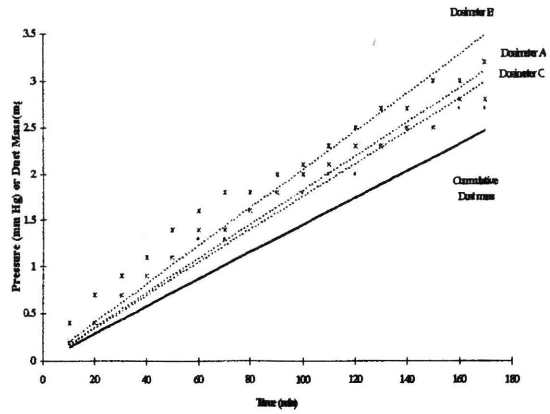

Figure 3. Result from individual test.

Results from each individual coal type consisted of 18 pairs of differential pressure versus dust mass data. Figure 4 contains the data for each coal type, and includes best fit power function and correlation coefficient. For each coal type, the correlation coefficient was better than 0.87. The relative standard error for the triplicate personal samplers varied between 9.7 and 16.4 and for the triplicate differential pressure measurements varied measurements varied between 9.0 and 24.8 with averages of 11.83 and 13.96 respectively. The MMAD of the coal dusts used was quite constant and varied between 3.6 and 5.6 micrometers with a GSD between 2.15 and 2.38.

The high correlation coefficient for individual coal types suggests that the dust dosimeter may be capable of determining respirable dust levels as well as the personal sampler. However, when data from all coal types is combined, the correlation coefficient decreases to 0.73. Figure 5 shows all of the laboratory results along with the +/- 50% error limits of the function. European standards for scanning type instrumentation use the 50% criteria. So, in the laboratory, for well defined conditions the dust dosimeter gives results that are about equivalent to that of the personal sampler, and over all, the dust dosimeter might be useful as scanning type dust instrument.

Many questions remain to answered about the utility of the dust dosimeter. Additional research from underground mines needs to be conducted before the final accuracy of the dust dosimeter can be determined. These tests would include the effect of variable size distributions of dust encountered underground, considerations as to the sensitivity of the device to water sprays, and pump characteristics in the underground environment.

The question of accuracy versus cost is pertinent to an overall evaluation of any new respirable dust assessment technique. The low cost approach of the dosimeter lends itself to an increased number and frequency of samples that can be taken. Furthermore, the cumulative shift personal dust exposure will be immediately available to workers. This can enable quick corrections to procedures or dust controls to immediately reduce dust exposures. Direct availability of the data to the workers may also help to reduce tampering with exposure data. The reduced size, weight and noise level of the new pumps may also encourage better worker acceptance of the new technique. While more accurate methods may be possible, and indeed beneficial for certain applications, that level of accuracy may not be required for routine monitoring of many workplace environments. Improved accuracy may be of less importance when all other benefits are considered.

CONCLUSION

A new respirable dust sampling device has been developed based on the principle of the correlation of pressure restriction of a filter with increasing mass loading. The laboratory comparison of this technique with conventional personal gravimetric sampling showed good correlation for individual coal types and good correlation at higher mass loadings for all coal types. The advantages of this new approach to dust sampling include the immediate availability of the cumulative shift dust exposure, a significant reduction in size of the instrumentation that a person must carry to evaluate their respirable dust exposure, and lower cost per sample.

Protection of workers respiratory health depends on many factors. Dust assessment tools for engineering control development and compliance determination are available. Another potentially powerful tool to help improve workers health may be the empowerment of the worker and management with the timely knowledge of what current dust exposures are routinely occurring. The inexpensive dust detector tube may provide that knowledge that helps workers protect their respiratory health.

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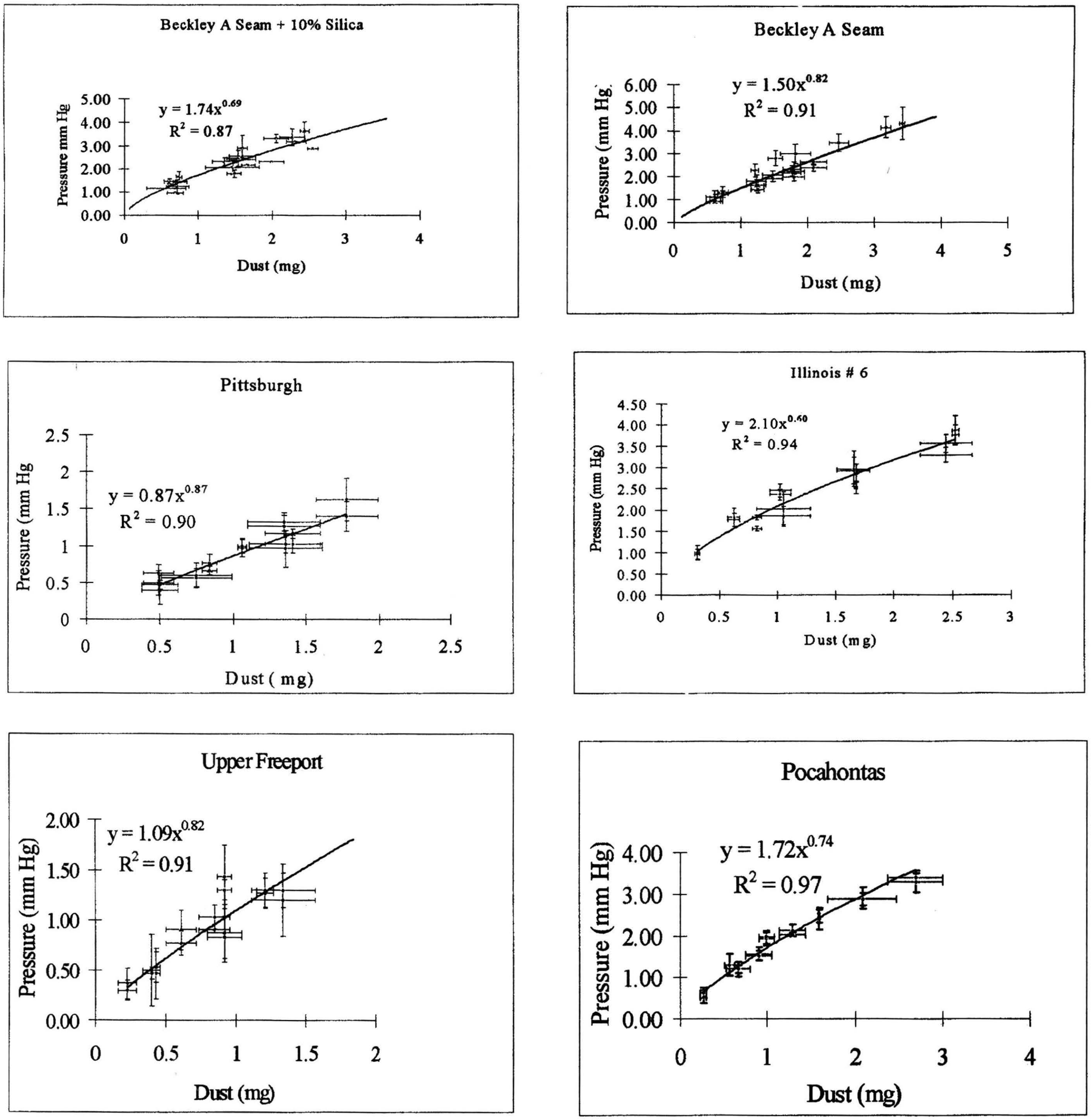

Figure 4. Differential pressure increase with dust mass for each of the 6 coal types tested.

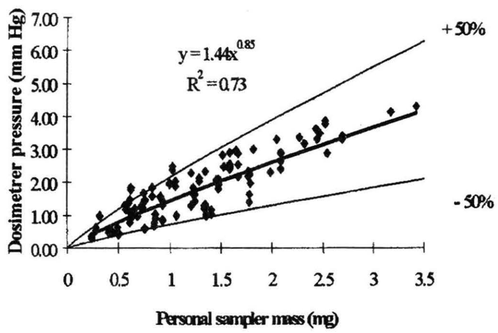

Figure 5. Correlation of all laboratory data of pressure with mass.