UPDATE ON THE DEVELOPMENT OF PERSON-WEARABLE DUST MONITORS

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ABSTRACT

The compliance sampling method for coal mine dust has not changed appreciably in the last 30 years. A call for more frequent sampling with immediately available results is leading to new instruments that may supplement or replace the existing sampler. This report discusses two such instruments that provide immediate results of dust levels. The first, called the Dust Dosimeter, is designed to supplement the existing compliance sampler. It uses the pressure drop across a filter to provide an inexpensive screening type of measurement. The Dust Dosimeter has been tested in the laboratory and a limited number of coal mines. Side by side testing has compared the Dust Dosimeters performance with personal coal mine samplers in triplicate area sample measurements. For all coal types tested the data were best described by a power function where $\Delta P = 1.43 \text{ mass}^{0.85}$, with a correlation coefficient of 0.73. Individual coal types have correlation coefficients greater than 0.91. Preliminary area sampling in non-diesel mines shows agreement with the laboratory data. The correlation in mines with diesel equipment was 10 to 20 times the response to coal particulate.

Another sampler in the early stages of development is called the Personal Dust Monitor (PDM). Designed to give compliance quality accuracy, the PDM uses the frequency change of a vibrating element to measure dust and give immediate feedback of results. The technical components of the device are available and work is in progress to package the components into a person-wearable unit.

INTRODUCTION

The sampling of coal mine dust has remained virtually unchanged in the last 30 years since the passage of the 1969 Coal Mine Health and Safety Act legislated a full shift dust exposure limit of 2 mg/m^3. The device used to determine compliance with this standard has been the personal sampler[1] that is worn by the miner and consists of a size classification device, a filter, and an air pump. Minor improvements to pump and filter cassette design have occurred but the basic design is the same. The lack of change has been, in part, because of the simplicity of design, the reasonable accuracy, and the direct measurement of mass that enables easy interpretation of the results. However there are drawbacks. Sampling is conducted at infrequent intervals. Also, the results are not provided soon enough for timely correction of overexposure.

In the Report of the Secretary of Labor's Advisory Committee on the Elimination of Pneumoconiosis Among Coal Mine Workers,[2] several recommendations deal with the development of continuous respirable dust monitors to help protect workers' health. In addition, the NIOSH Criteria Document[3] 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 include, but are not limited to a Machine Mounted Respirable Dust Monitor,[4] light scattering dust monitors,[5,6] the Dust Dosimeter,[7] and the Personal Dust Monitor. The principal goals of each of these efforts has been to develop an instrument that will give short term and real time measurements of worker dust exposure.

In this report, we discuss the development status of two new types of personal dust sampling devices. The first, called the Dust Dosimeter, uses the pressure drop across a filter to provide low-cost screening measurements with immediate feedback of results. The Dust Dosimeter has been tested in the laboratory and is currently being tested in mines. The second, called a Personal Dust Monitor, is a vibrating tube microbalance that gives continuous mass-based measurements along with immediate feedback of results. The Personal Dust Monitor is in early stages of development by a contract to Rupert and Patashnick Co. in Albany, New York.

WHY PERSONAL MONITORING

Two decades ago, NIOSH[8] concluded that area monitoring was an inadequate way to measure employee exposure to contaminants. When contaminant sources are nearby, the workplace has contaminant concentration gradients that make personal monitoring the only reliable way to assess employee exposure. The same is true for mining workplaces; however, it is not appreciated what a big difference it can make to move the sampler a foot or two away from the employee.

In 1977, Bituminous Coal Research, Inc. (BCR)[9] conducted a comprehensive dust gradient study in six mines to assess the impact of moving the sampler away from a continuous miner operator. They compared the dust concentration measured at the operator's lapel to the dust concentration at a fixed location elsewhere on the mining machine. In four of the mines, they placed samplers on the rear post of the canopy that covered the operator cab. These were the closest samplers, and were not more than 2 ft from the operator sampler on his lapel.

If we consider the concentration ratio between the two locations, the average ratio fixed location concentration / operator concentration (F/O), mine to mine varied from 0.67 to 1.07. This dispelled any notion that a simple correction factor for all mines could be used. BCR also found a wide shift-to-shift variation in the same mine, as follows in Table 1:

Table 1

Mine	Fixed-location (F)	# of shifts	Mean ratio(F/O)	Std Dev	RSD
C	right rear post	12	0.666	0.257	39%
C	left rear post	12	0.806	0.264	33%
D	rear cab	10	0.690	0.259	38%
E	left rear post	8	0.934	0.556	60%
E	right rear post	8	1.07	0.619	58%
F	rear cab	8	0.956	0.263	28%

Table 1 gives the mean concentration ratio for each mine, the shift-to-shift standard deviation in the concentration ratio, and the standard deviation / mean, or relative standard deviation (RSD). We may compare these RSD values with some commonly used accuracy criteria. Two that can be used are the NIOSH instrumentation accuracy criterion[10] and the European Community (EC) standard for "screening measurements."[11] The NIOSH criterion specifies that the instrument reading must be within 25% of the true value 95% of the time, corresponding to a RSD of 12.7%. The EC screening standard requires a reading within 50% of the true value 95% of the time, corresponding to a RSD of 25%.

The RSD values from the BCR testing averaged 43%, and fail to meet either criterion by a wide margin. It is a surprising result considering that the samplers were only a few feet apart, and it clearly illustrates why it is necessary to conduct personal, rather than area, sampling.

DUST DOSIMETER

The Dust Dosimeter was devised to provide an inexpensive estimate of a miner's dust exposure at any point during the shift. It works using the change in filter pressure as an indication of filter mass. As filters load with dust, increased air pressure is needed to pull the same amount of air through the filter. The British used pressure drop in 1957 to monitor the dustiness of coal dusts in a laboratory setting for very high loadings of total dust.[12] The Dust Dosimeter employs new microprocessor technology to adapt the same principle to a mine-worthy device. Figure 1 shows the Dust Dosimeter's two main parts, the detector tube, and pump with integral pressure transducer. The detector tube contains a course porous foam to trap large particulate and water drops, and a fine porous foam that removes non-respirable dust. The size-penetration curve of the foam is similar to that of the 10-mm Dorr-Oliver cyclone. The respirable dust deposits on a glass fiber filter.

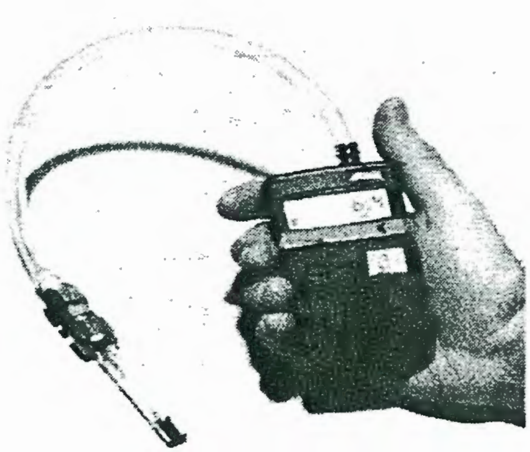

Figure 1: Dust Dosimeter

The Dust Dosimeter has limitations. For example, fine dust will increase the pressure restriction of a filter at a faster rate than an equivalent mass of coarse dust. However, since coarse dust can be eliminated by size classification devices such as cyclones, error caused by large particles can be eliminated. Most respirable mine size particulate of significant mass is between 0.5 and 7.0 micrometers. Normally, in non-diesel mines, there is not significant mass below about 1.0 micrometer in size and the differential pressure method of measurement results in good correlation with mass in the respirable size range.

Laboratory results of the correlation between personal samplers mass and the Dust Dosimeter pressure showed good agreement for individual coal types and quite reasonable agreement for all coals tested.[13] Six different coal dusts were aerosolized in a laboratory dust chamber and a total of 119 triplicate sets of observations were obtained. For individual coal types, the correlation coefficients were between 0.91 and 0.97. The precision of the two methods was similar, with the relative standard deviation of the personal samplers at 11.83% and the dosimeter at 13.96%. For all coal types tested the data were best described by a power function where $\Delta P = 1.43\ \text{mass}^{0.85}$, with a correlation coefficient of 0.73. Figure 2 shows the results for all laboratory data. The method becomes more accurate at higher dust loadings such that all laboratory data with mass loadings greater than an equivalent concentration of about 2.0 mg/m^3 fall within +/- 25% of the power function.

Testing of the Dust Dosimeter in mines is underway. This study is comparing personal sampler mass and Dust Dosimeter pressure at outby locations in coal mines. As in the laboratory studies, triplicate measurements of both mass and pressure change are being made and the correlation between the two methods reported. Locations with low, medium and high dust concentrations are being selected. Preliminary analysis of the data show that for mines with no diesel equipment the correlation between mass and pressure follows the

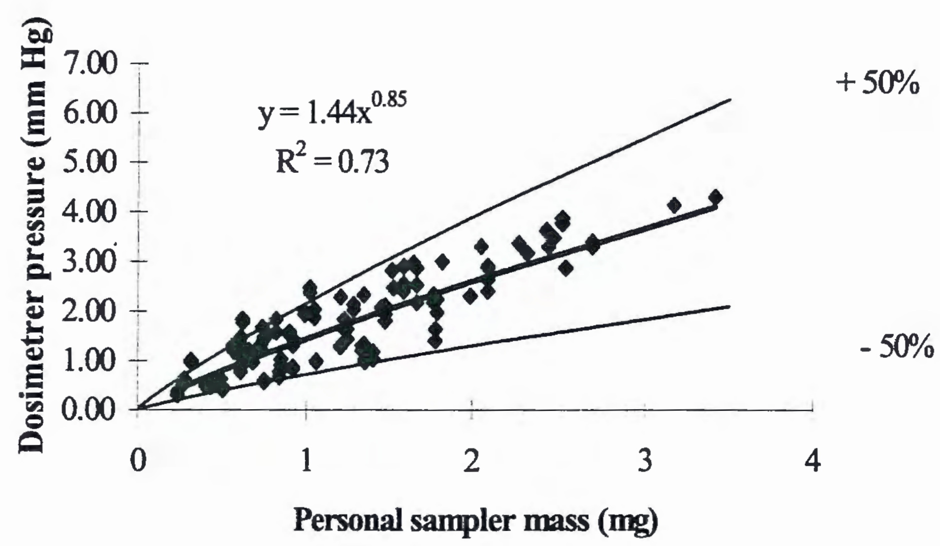

Figure 2: All Laboratory Data

laboratory data for all coals sampled (see Figure 3). Both longwall and continuous mining data from the Pittsburgh coal seam show that correlation does not depend on mining method. Data from the Kittanning seam is limited by the lack of mass data beyond 0.5 mg. There is also a parallel research contract with Penn State University and the University of Minnesota to evaluate the performance of the Dust Dosimeter.

When the Dust Dosimeter was used in coal mines with face diesel haulage or in mines with outby diesel usage, the correlation with laboratory results was poor compared to the non-diesel mines. In fact, the response was 10 to 20 times more sensitive to diesel particulate mass than to coal particulate mass in areas of heavy diesel use. What was surprising was that very low levels of diesel particulate have a significant impact on the correlation between pressure and mass in mines with low levels of outby diesel use. This prevents the dust dosimeter in its present form from effectively estimating coal dust mass because of the overwhelming response to small amounts of diesel particulate. This data is being confirmed with further laboratory and field studies. Additional research is in progress to see how the diesel effect may be handled.

Through a Cooperative Research and Development agreement with SKC Inc., Eighty Four, Pennsylvania, dust detector tubes are being produced in conductive plastic for additional laboratory and mine testing. In addition, the pump computer program is being altered to display in dust units rather than pressure. At this point the disposable detector tubes are estimated to sell for $7 and the modified pocket pump should cost about $600 each. The overall cost is lower than the personal sampler because the expense of weighing and shipping the samples is eliminated.

PERSONAL DUST MONITOR

The Personal Dust Monitor measures dust with a tapered element oscillating microbalance. The oscillating tapered element is the heart of a commercially available dust monitor, sold by Rupprecht and Patashnick Co., Inc.(R&P), in Albany New York. This monitor is used around the world to assess combustion particulate and ambient air quality levels.

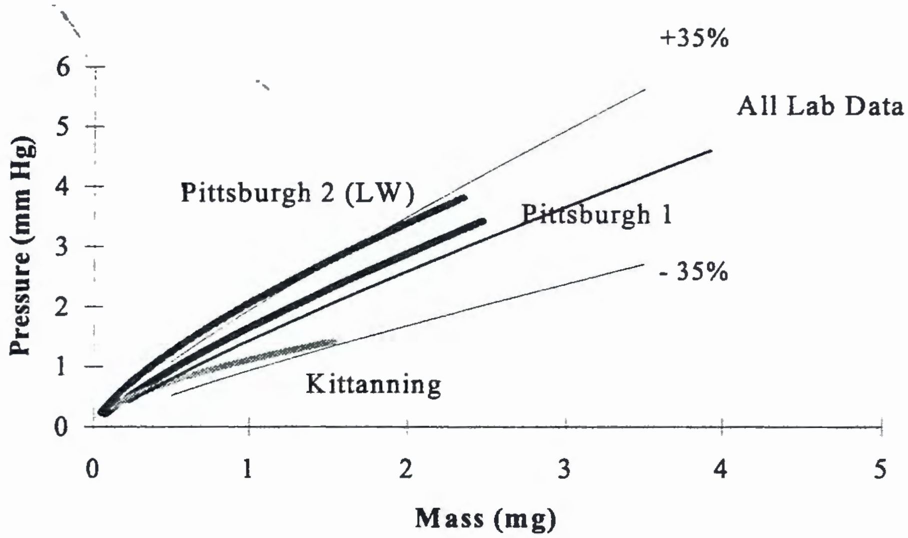

Figure 3: All Non-Diesel Coal Mine Data

The operating principle uses a replaceable filter cartridge mounted on the narrow end of a hollow tapered tube. The wide end of the tube is fixed. Air passes through the filter and down through the tube to a pump. The tapered tube with the filter on the end is maintained in oscillation in a clamped-free mode. The oscillation frequency depends on the characteristics of the tube and the filter mass at its end. As dust collects on the filter, the mass change is sensed as a frequency change in the oscillation of the tube. The mass of dust collecting on the filter is then determined directly. Since frequency can be measured accurately, the method can measure very small mass changes.

NIOSH has awarded a contract to R&P to develop a person-wearable dust monitor using the tapered element operating principle. The required accuracy is ±25% of the current sampling method, and the size and weight are expected to be reasonable for a miner to wear. There is no specified accuracy for periods less than 8 hours, but the instrument has the potential for measuring the dust level with reasonable accuracy for periods as short as an hour or so.

The future success of the personal dust monitor as a commercially viable product will be determined by many factors, including whether MSHA will require its use. The expected cost of the person-wearable dust monitor is between $5000 and $10,000 when purchased in minimum quantities of 500. A strong point for the technology is that the reliability and accuracy of the method have been proven in air monitoring applications world wide. A weak point is the difficulty of getting complex electro-mechanical equipment working in coal mines, as any witness to the automation of longwall roof supports would verify. The first models will be available for field testing at the end of the year 2000.

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