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Differential Pressure as a Means of Estimating Respirable Dust Mass on Collection Filters

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Researchers have studied various types of respirable dust sampling filters to determine if the differential pressure across them at a constant air flow rate can be used to estimate the accumulated dust mass. Results suggest that glass fiber depth filters that allow the dust particles to penetrate well into the filter material have considerable merit. The correlation between the increase in differential pressure (ΔP) and dust mass (M) when using 37-mm glass fiber filters is linear, provided they are not loaded with more than approximately 5 mg of dust. Under these conditions, the relationship between differential pressure and dust mass can be described by the equation [$\Delta P(\text{cm H}_2\text{O}) = 0.25 M(\text{mg})$]. Most of the data fall within ± 25 percent of a best-fit regression line and have a correlation coefficient (R^2) of 0.88. These results were obtained using coal dusts from Pittsburgh, Upper Freeport, and Pocahontas seams mixed with various percentages (0 to 100%) of rock dust. The density of these dusts varies from approximately 1.3 to 2.5 g/cc. Particle size effects were studied using cyclones to load different filters at three different flow rates, providing three different particle size distributions from the common dust environments. The resulting differential pressures were then measured at a flow rate of 2 L/min. Limited testing using surface collecting filters made of polyvinylchloride or nylon showed poor differential pressure versus mass correlation compared with the glass fiber filters. DOBROSKI, JR., H.; TUCHMAN, D.P.; VINSON, R.P.: DIFFERENTIAL PRESSURE AS A MEANS OF ESTIMATING RESPIRABLE DUST MASS ON COLLECTION FILTERS. APPL. OCCUP. ENVIRON. HYG. 12(12):1047-1051; 1997. © 1997 AIH.

As the nation's mining industry moves into the 21st century, occupational health concerns for miners still have great significance. Long-term health hazards seriously compromise the well-being of workers and escalate healthcare costs. Innovative solutions that reduce these problems are priority items for industry, labor, and the Mine Safety and Health Administration (MSHA). High on the priority list are instruments that can continuously measure the level of respirable dust in mining environments. With such instruments, control strategies could be quickly adjusted to reduce dust concentrations that are out of compliance.

The accurate, real-time measurement of respirable mine dust is difficult because it consists of both coal and mineral particles that may have different sizes, shapes, densities, and other properties. They may also be intermixed with water aerosols. These complex properties frustrate most real-time dust measuring instruments, requiring them to be specifically

calibrated for the dust they are intended to measure. For the mining environment, calibration is impractical because the nature of the dust changes continuously. Current regulations require mine personnel to collect dust samples on filter cassettes using sampling pumps and send them to an MSHA laboratory for gravimetric analysis to determine compliance with standards. This method delays the discovery of out-of-compliance conditions until the gravimetric analysis is complete, often several days later.

MSHA's Respirable Dust Task Group has recommended that research be conducted to develop dust monitors "that will provide continuous information to the miner and mine operator on the status of dust resulting from the mining process as well as information on the status of compliance with respect to the applicable respirable dust standard [emphasis added]." (1) To this end, much research has been directed toward candidate dust detection techniques such as nephelometry, beta attenuation, and resonant frequency decrementing. Research with these and alternative approaches must continue to eventually produce practical in-mine solutions to dust monitoring needs.

This article discusses a different approach to the problem, based on measuring the differential pressure increase (ΔP) that develops across collection filters loaded with dust mass (M). Discrete ΔP versus M data were obtained from individual filters, and the combined data from all the filters are representative of continuous ΔP versus M response. Each incremental increase in dust mass corresponds to an incremental increase in differential pressure. Although this concept is straightforward, there is little relevant literature (2-7) that addresses how filters respond to respirable mine dusts, or how the concept might be applied to a dust measuring instrument.

General Laboratory Procedures

All research was conducted under laboratory conditions, making it possible to control the test parameters. First, candidate filters were selected, weighed, mounted, and sealed in cassettes using cellulose support pads. Next, the clean differential pressure of each cassette was measured on a laboratory differential pressure apparatus (Figure 1) at a reference flow rate of 2 L/min. The cassettes were then connected to constant air flow pumps downstream of 10-mm nylon cyclones and installed into either of two test chambers. The larger chamber (2.7 m³) generated dust using a fluidized bed dust generator. Dust concentration was monitored using a tapered element oscillating microbalance (TEOM®) aerosol monitor interfaced to a personal computer. The smaller chamber (0.1 m³) used a mechanical dust mill to generate dust. The concentration in

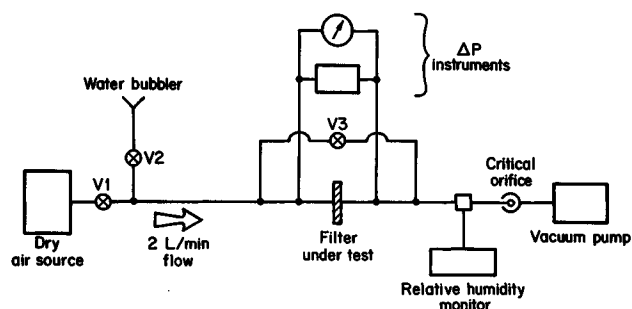


FIGURE 1. The laboratory differential pressure measuring apparatus.

this chamber was monitored using a real-time aerosol dust monitor (RAM-1).

The filters were then loaded with dust at flow rates of 1, 2, or 3 L/min for various lengths of time. The different flow rates altered the particle sizing performance of the cyclones. At a flow rate of 2 L/min, these cyclones pass only dust particles smaller than 10 μm aerodynamic diameter. At 1 L/min, they are less efficient and pass larger particles. At 3 L/min, they are more efficient and pass only smaller particles. Therefore, by using three sampling rates, dust particles of three relative size distributions could be deposited on different filters from common dust environments.

After dust loading, the differential pressure increase (ΔP) of each cassette was measured again on the laboratory differential pressure apparatus at a reference flow rate of 2 L/min. The filters were removed from the cassettes and weighed without being desiccated, but were equilibrated to ambient laboratory conditions of approximately 50 percent relative humidity (RH) at 25°C. Although this approach does not correct for moisture on the filters which contributes to the mass, it does provide a consistent environment under which all the filters were weighed, with errors from moisture changes unlikely to occur. A software program was then used to calculate regression equations and correlation coefficients and plot the results.

Dusts

Coal dusts from Pittsburgh, Pocahontas-4, and Upper Freeport seams were used in this research. Each of these coal dusts has a density of approximately 1.3 g/cc. When any of these coal dusts were mixed with 25 percent (limestone) rock dust by volume, the density of the mixture was approximately 1.6 g/cc. When mixed with 50 percent rock dust by volume, the density of the mixture was approximately 1.9 g/cc. The density of the pure rock dust was approximately 2.5 g/cc. These values were measured in the laboratory, but are in general

TABLE 1. Coal/Rock Dust Mixtures

Coal Dust (%) (Density, 1.3 g/cc)	Rock Dust (%) (Density, 2.5 g/cc)	Density of the Mixture (g/cc)
100	0	1.3
75	25	1.6
50	50	1.9
0	100	2.5

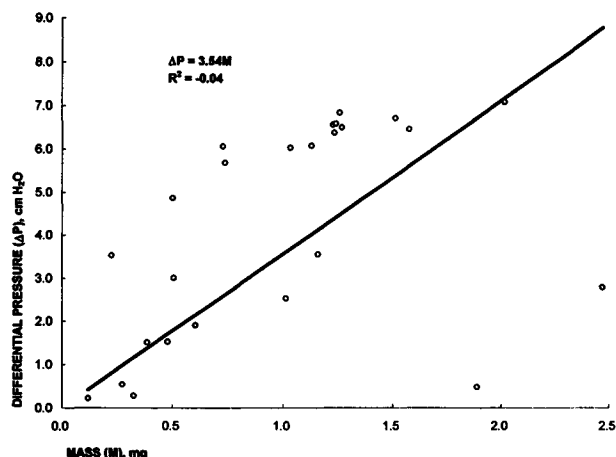


FIGURE 2. The differential pressure versus mass response of compliance cassettes.

agreement with known values of these materials. This information is summarized in Table 1.

A total of ten different dust mixtures were involved in this research: three different 100 percent coal dusts, three different 75–25 percent coal–rock dust mixtures, three different 50–50 percent coal–rock dust mixtures, and 100 percent rock dust.

Research Results

Polyvinylchloride Surface Collecting Filters

The first tests were conducted using commercially available sampling cassettes. These cassettes are used for coal mine dust standard compliance verification using the gravimetric method. Each cassette consists of a 37-mm diameter polyvinylchloride (PVC) filter, thin filter backing, aluminum mask, aluminum cone, and check valve, mounted in a sealed plastic enclosure. PVC is primarily a surface collecting material, so dust accumulates mostly on the surface as a cake, without appreciable penetration into the material. The mask and check valve are intended to make the cassettes tamper resistant.

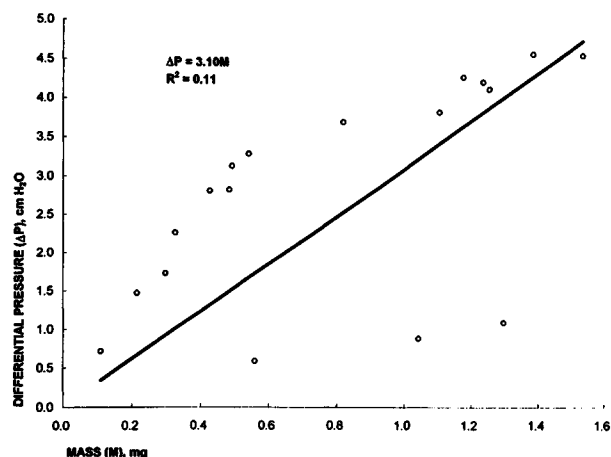


FIGURE 3. The differential pressure versus mass response of PVC filters.

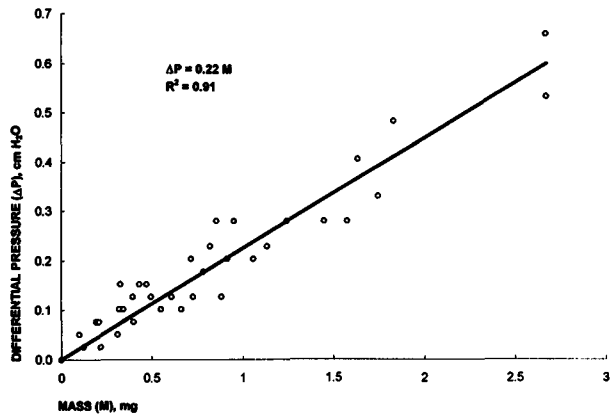


FIGURE 4. The differential pressure versus mass response of glass fiber filters (Pittsburgh coal dust with various amounts of rock dust).

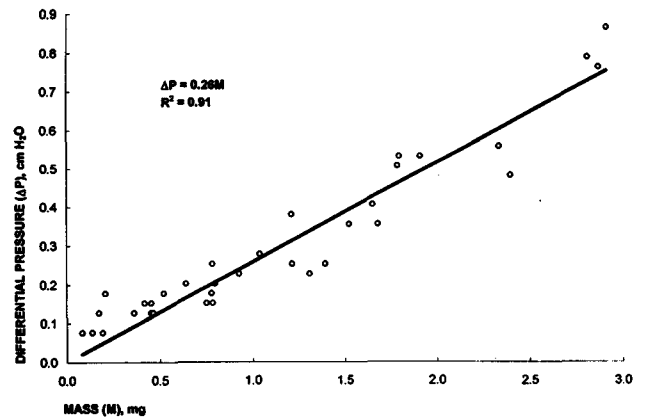


FIGURE 6. The differential pressure versus mass response of glass fiber filters (Upper Freeport coal dust with various amounts of rock dust).

The cassettes were loaded through cyclones with only one dust, at a flow rate of 2 L/min, to briefly study their general performance. Only if this performance seemed favorable would the more complicated multidust, three-flow tests be conducted. Results showed that these cassettes exhibited poor ΔP versus dust mass performance (see Figure 2). The mask does not allow the dust to deposit evenly on the PVC. Sometimes dust deposited beneath the mask, sometimes not. This variability in dust deposition area caused the ΔP response to be less predictable. The check valves introduced additional variations in ΔP that differed from cassette to cassette. While these devices did not exhibit a reliable ΔP versus dust mass relationship, it was still possible that PVC alone could have merit. Additional research indicated that this was not the case.

When PVC filter material was installed only with back-up pads in simple three-piece polystyrene cassettes, ΔP versus dust mass performance improved considerably over that of the compliance cassettes. Still, there were cases of outlier data points that were always lower, but never higher, than the correct values (see Figure 3). The reason for these anomalies was not determined, but no other filter material exhibited similar problems.

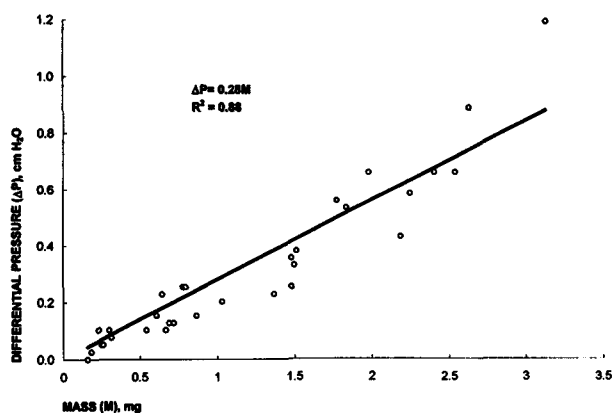


FIGURE 5. The differential pressure versus mass response of glass fiber filters (Pocahontas-4 coal dust with various amounts of rock dust).

Glass Fiber Depth Filters

These 37-mm diameter filters are made of glass fiber without binders or reinforcing backing. Figure 4 shows the differential pressure versus dust mass response when challenged with four different mixtures of Pittsburgh coal and rock dust. One quarter of the data points involve 100 percent Pittsburgh coal dust, one quarter involve 75 percent Pittsburgh coal dust mixed with 25 percent rock dust, one quarter involve 50 percent Pittsburgh coal dust mixed with 50 percent rock dust, and one quarter involve 100 percent rock dust. Each dust or mixture was loaded using the three flow rates described above. The response is linear, and the correlation coefficient associated with the data points is 0.91. This is relatively good performance considering the variety in dust compositions. Figures 5 and 6 show corresponding results when Pocahontas-4 and Upper Freeport coal dusts and rock dust mixtures were used. Figure 7 shows the response to 100 percent rock dust, an extreme but possible condition in any coal mine.

Figures 4 through 7 are, therefore, possible indications of how these filters would respond if loaded in the Pittsburgh, Pocahontas-4, and Upper Freeport coal seams. Figure 8 shows the filter response when all data are integrated. In every case, the filter performance is similar.

Up to 5 mg collected dust mass, the response of the filters

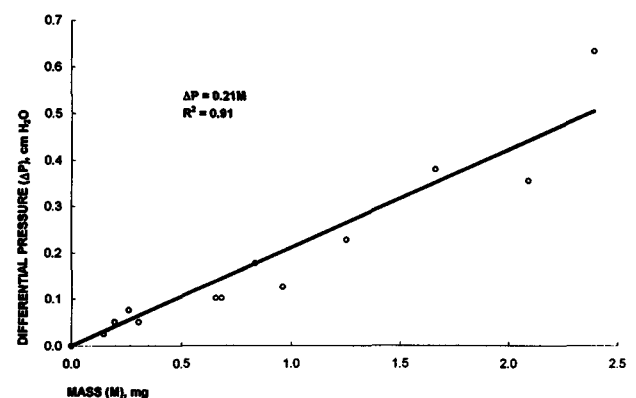


FIGURE 7. The differential pressure versus mass response of glass fiber filters (100% rock dust).

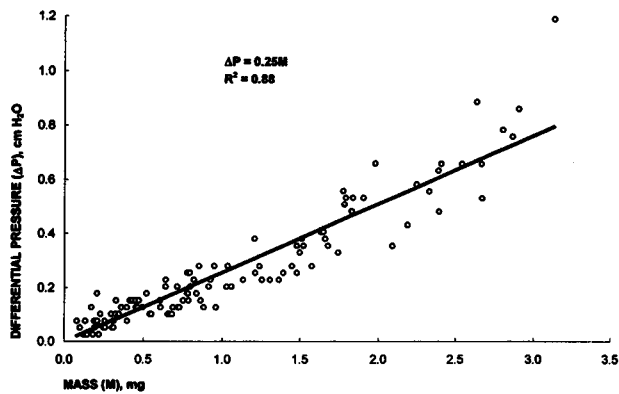


FIGURE 8. The composite differential pressure versus mass response of glass fiber filters. (This figure is the integration of all data from Figures 4 through 7).

TABLE 3. K and R² Values for Pocahontas-4 Coal Dust and Rock Dust Mixtures

Dust Mixtures	%	K	R ²
Coal	100	0.28	0.90
Rock	0		
Coal	75	0.30	0.91
Rock	25		
Coal	50	0.24	0.93
Rock	50		
Coal	0	0.21	0.91
Rock	100		
Combined data		0.28	0.88

can be mathematically expressed by the equation $\Delta P = KM$, where ΔP is the increase in differential pressure (centimeters H₂O) that results from dust mass M (milligrams) at a flow rate of 2 L/min. Table 2 summarizes the different values of K, and the corresponding correlation coefficients, for Pittsburgh coal dust and rock dust mixtures. For example, when the filters were challenged with a 75–25 percent Pittsburgh coal–rock dust mixture, the response was $\Delta P = 0.22M$, with a correlation coefficient of 0.87. The final entry in the table represents the integration of all the Pittsburgh coal and rock dust data.

Tables 3 and 4 are corresponding tables for Pocahontas-4 and Upper Freeport coal dust–rock dust mixtures. It can be seen from Tables 2 through 4 that the equation $\Delta P = 0.21M$ describes the filter's response to 100 percent rock dust. These tables also show that the value of K varied from 0.21 to 0.30, and the value of R² varied from 0.86 to 0.95.

Table 5 summarizes the overall response of the filters. Row 1 of Table 5 concerns the overall response to all the Pittsburgh coal dust–rock dust combinations, and is taken from the last entry found in Table 2. Rows 2 and 3 of Table 5 show corresponding information for Pocahontas-4 and Upper Freeport coal dust–rock dust combinations, and are taken from the

last entries found in Tables 3 and 4, respectively. Row 4 in Table 5 concerns the response to 100 percent rock dust. Row 5 concerns the overall response when every data point in the research is included.

For ideal filter performance, every regression line equation would have the same coefficient (K), because ΔP would be the same function of mass for any kind of dust. In addition, every correlation coefficient would numerically equal 1.0, because every data point would fall precisely on the regression lines. Therefore, a quantitative measure of actual filter performance is the degree to which they deviate from these ideals. Tables 2 through 5 show that filter performance is relatively close to the desired criteria.

Nylon Membrane Surface Collection Filters

Experiments were conducted using 37-mm, 1- μ m pore, nylon membrane, surface collection filters to compare their performance with the glass fiber filters. Pocahontas-4 coal dust mixed with 0, 25, 50, and 100 percent rock dust was used in a series of four tests. The results are shown in Figure 9. The performance of these filters was similar to that of the PVC surface

TABLE 2. K and R² Values for Pittsburgh Coal Dust and Rock Dust Mixtures

Dust Mixtures	%	K	R ²
Coal	100	0.26	0.86
Rock	0		
Coal	75	0.22	0.87
Rock	25		
Coal	50	0.22	0.91
Rock	50		
Coal	0	0.21	0.91
Rock	100		
Combined data		0.22	0.91

TABLE 4. K and R² Values for Upper Freeport Coal Dust and Rock Dust Mixtures

Dust Mixtures	%	K	R ²
Coal	100	0.26	0.92
Rock	0		
Coal	75	0.28	0.95
Rock	25		
Coal	50	0.24	0.93
Rock	50		
Coal	0	0.21	0.91
Rock	100		
Combined data		0.26	0.91

TABLE 5. Differential Pressure Summary of Dusts and Mixtures

Dust Mixture	Equation of the Regression Line*	Correlation Coefficient (R ²)
Pittsburgh/coal and rock dust	$\Delta P = 0.22M$	0.91
Pocahontas-4/coal and rock dust	$\Delta P = 0.28M$	0.88
Upper Freeport/coal and rock dust	$\Delta P = 0.26M$	0.91
Rock dust	$\Delta P = 0.21M$	0.91
All dust data combined	$\Delta P = 0.25M$	0.88

* ΔP is in centimeters H₂O; M is in milligrams.

collection filters. Neither of these nylon or PVC polymer filters could compare with the glass fiber filters in preliminary testing. Data scatter was severe.

Summary and Conclusions

Differential pressure experiments were conducted using PVC and nylon membrane surface collecting filters and glass fiber depth filters. The objective was to study the relationship between the differential pressure increase (ΔP) and dust mass (M) when the filters were challenged with different coal-rock dust mixtures having densities ranging from approximately 1.3 to 2.5 g/cc. The dusts were collected on filters at three different flow rates through cyclones, making it possible to study the effects of particle size distributions from common dust environments. The differential pressure increases of the dust-laden filters were then measured at a reference flow rate of 2 L/min and plotted versus dust mass.

The glass fiber depth filters gave the best results, and the overall response can be approximated by the equation [ΔP (cm H₂O) = 0.25M (mg)], with a correlation coefficient (R²) of 0.88. These results are favorable, considering the many dust variables involved and the high probability that these filters are not optimal. There are probably better filters yet to be identified. Because all tests were conducted under laboratory conditions, it cannot be concluded that the filter response would be the same if they were loaded in mine.

Compliance cassettes, PVC, and nylon surface collecting filters were not tested as extensively as the glass fiber filters because they did not exhibit good ΔP versus mass correlation during initial pilot testing. As a result, they did not merit multidust, multiframe tests, as did the glass fiber.

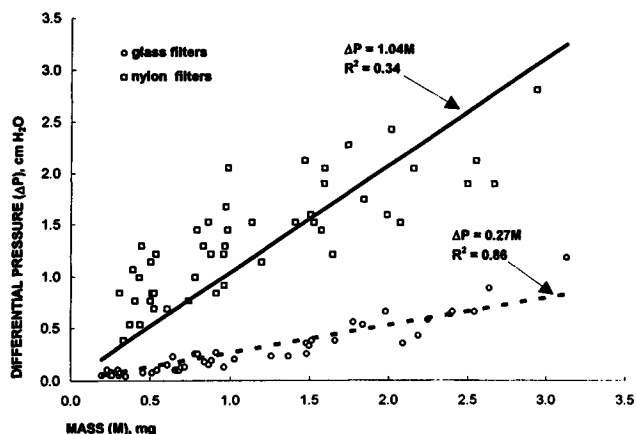


FIGURE 9. Comparison of the differential pressure versus mass response of nylon surface collection filters and glass fiber filters (Upper Freeport coal dust with various amounts of rock dust).

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