Implementing a New Personal Dust Monitor as an Engineering Tool

A new personal respirable dust monitor developed by Rupprecht & Patashnick Co., Inc. in a multi-year project funded by the National Institute for Occupational Safety and Health (NIOSH) generated promising results in underground coal mine testing performed by NIOSH and industry representatives during the summer of 2003. The mine data showed that the personal dust monitor (PDM) performed similarly to co-located manual reference samplers for full-shift samples at all four underground coal mines at which the evaluation took place.

The technology that forms the heart of the PDM, called the tapered element oscillating microbalance (TEOM system), is unique in its ability to collect suspended particles on a filter while simultaneously determining the accumulated mass with National Institute of Standards and Technology traceability. Because the monitor measures the true particle mass collected on its filter, its results do not exhibit the same sensitivity to water spray as do optically based measurement approaches. The technique achieves microgram-level mass resolution even in the hostile mine environment, and reports dust loading data on a continuous basis. Using the device, miners and mine operators have the ability to view both the cumulative and projected end-of-shift mass concentration values, as well as a short-term 15- or 30-minute running average.

During underground mine trials in the summer of 2003, technical personnel used the readings from the PDM to identify and correct several abnormal dust generating scenarios. These events demonstrated the potential of the PDM to be used as an engineering tool to evaluate the effectiveness of various dust control strategies. In a separate evaluation performed by CONSOL Energy, Inc., the mine operator evaluated the benefit of a proposed new water spray-based dust control system. Engineers measured the dust concentration upstream and downstream of a production location under different dust control scenarios using two PDM units. By evaluating the change in the dust loading between the upstream and downstream monitoring sites, the company was able to determine in a few hours which hardware configuration would yield the greatest benefit to the workplace environment.

BACKGROUND

Measuring underground coal mine dust concentrations is an essential part of protecting miners' health. The U.S. Secretary of Labor and the Federal Advisory Committee on the Elimination of Pneumoconiosis among Coal Mine Workers has recommended that better monitoring of coal miner dust exposures be used as a method to improve miner health. In consultation with labor, industry, and government, NIOSH issued a contract to Rupprecht & Patashnick Co., Inc. (R&P), Albany, N.Y., to develop a one-piece PDM.

The object was to miniaturize TEOM technology into a form suitable for a person-wearable monitor that would enable accurate end-of-shift dust exposure information to be available to miners. Furthermore, any person-wearable dust monitor should minimize the burden to the wearer by incorporating the monitor into the mine worker's cap lamp battery, with exposure data continually displayed during the shift to enable workers and management to react to changes in dust exposure.

In the summer of 2003, NIOSH conducted extensive testing of the PDM to determine its laboratory and in mine performance. In addition, anecdotal information collected in the mines showed several occasions where miners were able to identify situations that produced high levels of respirable coal mine dust.

The PDM's response to unplanned changes resulted in action being taken to keep dust exposures as low as possible. In another case that demonstrated the PDM's versatility, a mine was seeking to find a better dust control solution on its longwall headgate stageloader. In this instance, the PDM was used as a diagnostic tool by the miners to quickly evaluate the control technology.

HOW DOES THE PDM WORK?

The PDM is configured to provide accurate respirable dust personal exposure information in a form that is as convenient to wear as a normal cap lamp (See Figure 1). Respirable dust exposure data displayed by the device has two main objectives: providing the miner and mine operator with timely values to avoid overexposure to dust, allowing them to make any necessary changes during the course of a work shift; and computing an accurate end-of-shift statistic for a miner's average respirable dust exposure.

The mass sensor embedded in the PDM, holds the key to the accurate, time-resolved dust concentration measurements. The inertial, gravimetric-equivalent, mass measurement technique used in the device typically provides a limit of detection on par with that of the most sensitive laboratory-based microbalances.

Similar to the integrated sampling method, the PDM contains a sampling system that collects particles on a filter located downstream of a respirable cyclone. In contrast to the reference method, however, the PDM mass measurement is performed continuously during a working shift in a mine, instead of being delayed by the days or weeks required for a laboratory analysis.

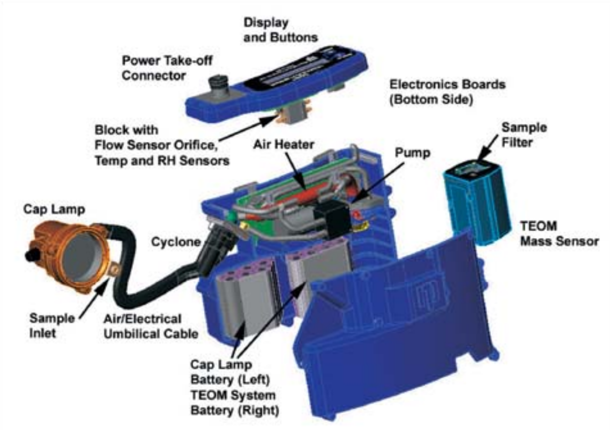

Figure 2-Major components of the PDM.

The PDM is a respirable dust sampler and a gravimetric-equivalent analysis instrument that is part of a belt-worn mine cap lamp battery. The main components of the device include a cap lamp and sample inlet located on the end of an umbilical cable, and a belt-mounted enclosure containing the respirable dust cyclone, mass measurement system, and a charging and communication module used to transmit data between the monitor and a PC while charging its lithium ion batteries for the next shift. The PDM is also designed to withstand the harsh conditions found in the mine environment, with the system designed to meet MSHA intrinsic safety type approval requirements.

A 2.2 liter per minute (l/min) flow of particle-laden air from the mine atmosphere enters an inlet mounted on the bill of the miner's hard hat, then passes through conductive tubing before reaching the Higgins and Dewell (HD) cyclone at the entrance of the PDM. The sample stream with respirable particles that exits from the cyclone is then conditioned in a heated section of tubing to remove excess moisture. As the air stream subsequently passes through the mass sensor, an exchangeable filter cartridge collects the respirable particles. The mass sensor can be removed from the PDM by a mine's dust technician who changes its particle collection filter and cleans the unit after the end of each work shift (See Figure 3).


Figure 3-Installing a sample filter in the mass sensor.

Downstream of the mass sensor, the filtered air sample flows through an orifice used in conjunction with a differential pressure measurement to determine the volumetric flow rate. The system computer uses this information to maintain a constant volumetric sample flow by varying the speed of a DC pump.

At the heart of the TEOM mass sensor is a hollow tube called the tapered element clamped at its base and free to oscillate at its narrow end. The exchangeable filter cartridge mounted on its narrow end collects the respirable particles contained in the air stream that pass from the entrance of the mass sensor through the tapered element. Electronic components positioned around the tapered element cause the tube to oscillate at its natural (or resonant) frequency. As additional mass collects on the sample filter, the natural oscillating frequency decreases as a direct result. This approach uses first principles of physics to determine the mass change of the filter, and is not subject to uncertainties related to particle size, color, shape, or composition.

Built-in sample conditioning to remove excess moisture minimizes the PDM's response to airborne water droplets. The PDM determines the mass concentration of respirable dust in the mine environment by dividing the mass (as determined by the frequency change) collected on its filter over a given period of time by the volume of the air sample that passed through the system during the same time frame.

The two battery packs inside the PDM provide power to the miner's cap lamp and the particle sampling and analysis system. Laboratory and in-mine testing conducted to date indicates a battery lifetime of 12 hours or more for both the cap lamp and mass monitor batteries.

The PDM internally stores the readings from its built-in environmental sensors and mass sensor for latter downloading, and provides summary information on a continuous basis to the miner through the display located on top of the battery case. The display continuously shows the latest values for the cumulative mass concentration, the current dust concentration, and the miner's end-of-shift projected exposure. Through this interface, miners can gauge their current dust exposure, as well as the effectiveness of actions taken to reduce the in-mine dust concentration.

The PDM also allows miners and management to initiate secondary dust loading measurements for specific monitoring objectives without affecting the shift-based statistics. The averaging time used for these readings is user-selectable prior to the start of the work shift, and can be set to a time base as short as 15 minutes for maximum instrument responsiveness. This capability enables the monitor to be a powerful engineering tool to gauge the effectiveness of various dust or ventilation engineering control techniques.

METHODS USED UNDERGROUND TESTING

Underground testing was conducted in four coal mines using five to six PDMs for a period of five days. Typically three miners would wear a PDM and a reference sampler and conduct their daily jobs. Two NIOSH employees, wearing PDMs and additional samplers, would shadow the miners wearing the PDM. A sixth unit was available at three of the four mines and was used as a guest unit without association with a reference sampler. The details of this study were previously reported in a NIOSH publication. During the course of this testing various observations were recorded where the near-real-time dust levels were associated with certain events.

In these tests, one way in which the PDM was used to as an engineering tool was in the form of an ABA comparison. From a dust control research viewpoint, an ABA type of test has been used to determine differences in dust levels associated with some change in the machinery or environment. The A portion of the test time takes place with a system operating normally, while the B period with a new dust control system turned on, and this is immediately followed by a return to another A time period where the system is operated normally.

ABA comparison logic was applied to this testing in a reciprocal fashion. The B portion of the analysis was a time period of unusually high dust concentration that resulted from some event. In practice, with this PDM testing, some typical level of dust concentration was observed on the PDM readout (later verified on the data file) and was to be considered an "A" condition. At some point in the testing an elevated dust level was seen that was not associated with routine conditions; this was considered to be the "B" portion of the test. Upon investigation by the miners, an engineering control breakdown which caused elevated dust levels was discovered and corrected. A follow-up reading with the PDM showed that dust concentrations returned to the typical levels or back to an "A" condition.

A second way in which the PDM was used as an engineering tool was a more formalized study using an upstream, down stream method. In this type of evaluation, two PDM units were used. One was placed in the intake air of a longwall stage loader and the second was placed about 15 meters down stream from the stage loader.

A new water powered dust collector was studied to determine if it was equal to or more effective than the water spray system already in use. In this evaluation, the water spray system and scrubber operating simultaneously were monitored for 15 minutes. The water sprays were then turned off and 15 more minutes of observations were recorded. Finally, the scrubber was switched off and only the water sprays were operated for an additional 15 minutes. Mining was continuous during this testing.

This testing used an engineering feature of the PDM that allows a secondary interval test to be conducted by pressing a combination of buttons on the PDM. This initiates a new zero reading of the instrument and the read out displays the cumulative concentration from that point in time until the unit is read and another series begins. The readings of both intake and down stream PDM's were hand recorded 15 minutes later and results reported.

ABA TYPE OBSERVATIONS

Results from the first ABA type of test observations occurred on a combination continuous miner/bolter machine that was ventilated with a fan-powered exhaust tubing system. In this configuration, a ventilation curtain is used to seal the fan exhaust into the return airway. If this curtain is improperly set or becomes dislodged, the high pressure created by the local fan discharge may overpower the main mine ventilation system and lead to air and dust recirculation back into the working areas.

During this phase of mine testing, a PDM, worn by a guest, was being observed while remaining in the dinner hole. Normal intake dust levels at this location were less than 0.1 mg/m^3. The PDM data file in Figure 4 showed that an increase in dust at this location occurred around 10:00 am. The guest left the dinner hole with the mine safety engineer and walked around the section to see where the dust was coming from. The improperly set curtain was discovered and fixed, the guest returned to the dinner hole, and dust concentrations returned to normal levels. The remainder of the file shows the guest visiting other parts of the section.

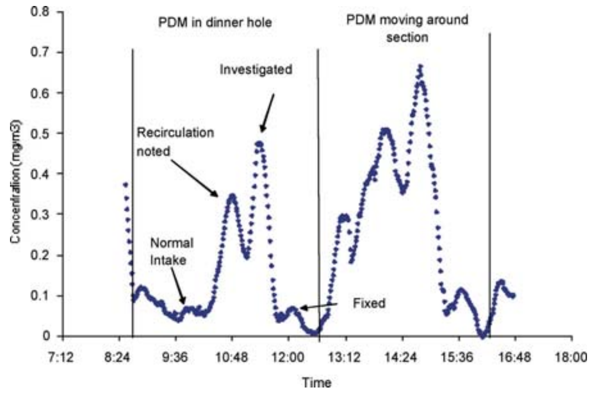

Figure 4-A problem with dust recirculation discovered, investigated, and fixed.

Results from a second ABA type test are from a longwall section. This testing discovered a faulty dust collector discharge on a roof-bolt drill that began intake entry roof bolting work during the middle of the shift. The interpretation of the data file is somewhat more complex in that there are actually two initial "A" type periods. Only one final "A" period of data was collected for this example.

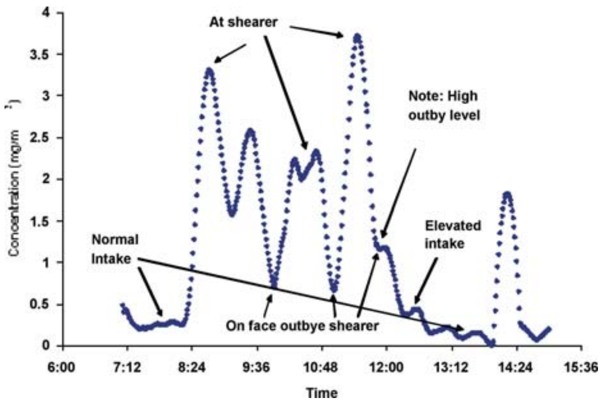

Figure 5-Detection of excessive intake dust levels while on a longwall face.

Figure 5 shows the PDM results from a NIOSH researcher moving from the intake to the face and following the shearer work cycle. The first "A" period observation was of normal intake levels, and the second "A" period was of normal face dust levels outby the shearer. This dust level is a result of the intake and crusher/stage loader dust sources. In the third outby shearer dust observation, an increase in the PDM display reading was noted. It was originally thought that this increase was due to fog; however, the PDM was designed not to measure water mist. Upon investigation it was discovered that roof bolting had begun in the intake and that the automatic dust collector discharge was contaminating the intake. The mine fixed the dust collector discharge, and intake levels returned to normal. The PDM output was actually used to "fine tune" the roof bolter discharge as seen by the two diminishing humps after the elevated intake observation. In this example, time did not permit a second follow-up "A" measurement of the on face outby shearer dust levels.

An unusual situation was discovered at one mine that used a portable enclosed steel skid mounted lunch room. Because of the cold temperatures at that mine, the doorways of the lunch room were normally closed with brattice. A heater in the center of the lunch room was used to warm the miners' lunches, make toast, and heat the room. Wire mesh suspended under the heat lamp held the food. When the miners wearing the PDM took breaks in the lunch room the PDM displays indicated dust levels between 0.7 and 1.1 mg/m³ while units outside the lunch enclosure were simultaneously measuring 0.2 to 0.4 mg/m³.

To explain these numbers, it must be remembered that all dust mass collected on a filter in a coal mine is considered to be coal mine dust regardless of the source. This mass may come from coal dust, rock dust, diesel particulate matter, silica dust, welding fumes, burnt toast, or burnt cooking oil. While no particulate matter was apparent in the lunch room, we must remember that respirable-sized aerosols are not visible to the unaided eye and that low levels of oil or toast smoke would be detected by samplers but not the eye.

The short-term PDM data for periods inside and outside the lunch room showed that levels inside climbed. To confirm that some other factor associated with the PDM was not causing the elevated levels, an extra personal sampler was run in the lunch room the following day, where it measured 0.69 mg/m³, confirming the earlier PDM data.

UPSTREAM DOWN STREAM MEASUREMENTS

This test was designed to determine the effectiveness of two dust control techniques on a longwall stage loader. The mining company was interested in reducing water usage of the existing water spray system and had heard that a water-powered dust scrubbing system that was effectively being used in other mines might be equally effective in controlling dust. The new scrubber system was installed in parallel to the existing water spray system such that a simple switching of valves could enable the spray system, the scrubber system, and both systems simultaneously.

Dust levels near the stage loader were typically low and the potential for unknown intake contamination of the testing dictated that the intake air dust levels be continuously monitored during the same intervals when the dust control systems were being evaluated. Therefore, one PDM dust monitor was positioned in the intake, and a second monitor was located on the crusher immediately downstream from the stage loader.

On-the-spot results from the testing are shown in Table 1. In general, the use of the scrubber showed some improvement in the downstream dust concentrations over the use of the water sprays alone. More testing would need to be conducted in this manner to determine if the observed differences were significant. However, over the course of the hour that it took to conduct the testing, it was concluded that the scrubber was at least as effective as the water spray systems alone. A similar attempt to measure the effectiveness of the control systems with a short-term-light scattering monitor were inconclusive due to the presence of water.

CONCLUSION

A unique method to collect and measure respirable coal mine dust using the tapered element oscillating microbalance has demonstrated potential use as an effective engineering tool to help dust control. The true mass measuring capabilities of the instrument and the heater to remove water from the mass sensor enabled accurate dust measurements to be made. The sensitivity of the device to detect small changes in dust over short time intervals was especially useful in understanding dust sources.

Table 1-PDM screen results from upstream / down stream sampling.

Test Description	Start Time	Stop Time	Upstream Conc. (mg/m³)	Downstream Conc. (mg/m³)	Down-Up Conc. (mg/m³)
Scrubber with water	10:56	11:11	0.070	0.367	0.297
Scrubber with no water	11:15	11:30	0.083	0.321	0.238
Water only	111:3	11:48	0.075	0.529	0.453

The PDM demonstrated its potential use as a engineering tool to locate and assess various sources of dust during normal mining operations. These observations and follow up actions were taken by experienced engineers and research personnel. The principles and concepts used to identify and fix some of the higher dust levels were common sense and would be easy for most users to readily understand. However, to make the most effective use of this information, training and experience in using this type of technology will be very important. Experience with the data from the unit will help workers gain confidence to use the information to maintain proper dust levels during mining.

As this technology is commercialized, further applications of the PDM data can be developed to better protect mine workers' health. Overall successes documented in this work have led to an early commercial version that will meet the Mine Safety and Health Administration commercial criteria for approval as underground cap lamps. Further in-mine trials will determine the long term durability, stability and maintenance requirements for this new dust monitor.

REFERENCES

1 Work-Related Lung Disease Surveillance Report, 1999, U.S. Dept of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, No. 2000-105, p. 34.

2 U.S. Department of Labor. 1996. Report of the Secretary of Labor(s Advisory Committee on the Elimination of Pneumoconiosis Among Coal Mine Workers; recommendations 8 and 17.

3 Patashnick, H. and Rupprecht, E. 1991. J. Air & Waste Manage. Assoc., 41: 1079.

4 Volkwein, Jon C., Robert P. Vinson, Linda J. McWilliams, Donald P. Tuchman, and Steve Mischler. Performance Of A New Personal Respirable Dust Monitor For Mine Use, NIOSH RI 9663. May 2004, http://www.cdc.gov/niosh/mining/pubs/pdfs/poinp.pdf

5 Dust Control Handbook For Minerals Processing, Bureau of Mines, Chapter 9, Contract J0235005, Martin Marietta Corporation Martin Marietta Laboratories, 1450 South Rolling Road, Baltimore, Md 21227-3898. February 1987 206 pp. available at http://www.oshaslc.gov/SLTC/silicacrystalline/dust/dust_control_handbook.html

AUTHOR INFORMATION

Volkwein (Tel: 412-386-6689 or E-mail: jvolkwein@cdc.gov)and Thimons work with NIOSH at the Pittsburgh Research Laboratory. Yanak works for CONSOL Energy, and Dunham, Patashnick, and Rupprecht work with Rupprecht & Patashnick Co., located in Albany, N.Y.