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EDITED BY:

Michael Karmis
Department of Mining and
Minerals Engineering
Virginia Polytechnic Institute
and State University

William H. Sutherland
Mine Safety and Health
Administration
U.S. Department of Labor

David R. Forshey
Bureau of Mines
U.S. Department of the Interior

J. Richard Lucas
Department of Mining and
Minerals Engineering
Virginia Polytechnic Institute
and State University

Gavin J. Faulkner
Department of Mining and
Minerals Engineering
Virginia Polytechnic Institute
and State University

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INSTRUMENTS AND PROCEDURES FOR MONITORING RESPIRABLE COAL MINE DUST CONCENTRATIONS

Kenneth L. Williams

Pittsburgh Research Center
Bureau of Mines
U.S. Department of Interior
Pittsburgh, PA 15236

ABSTRACT

The Bureau of Mines, U.S. Department of the Interior, conducts research to improve instruments and methods for measuring respirable dust levels in mines. This presentation includes new information on the performance of the coal mine dust personal sampling unit (CMDPSU), a brief description of some recently developed dust monitors, a summary of the most recent test results, and suggestions on how to best use respirable dust monitors, both new and old, in the mining environment.

Recently developed monitors include the real-time aerosol monitor (RAM-1), the MINIRAM, the continuous respirable dust monitoring system (CRDMS), and the tapered-element oscillating microbalance (TEOM). The RAM-1, a commercially available nephelometer, has been extensively tested and widely used by Bureau of Mines research personnel. The MINIRAM, also a commercially available nephelometer, is currently being field evaluated by the National Institute for Occupational Safety and Health (NIOSH), U. S. Department of Health and Human Services, and the Bureau of Mines. The CRDMS, a prototype nephelometer, is not commercially available and is being tested in the laboratory. The TEOM is an experimental prototype. It relates the frequency of oscillation of a special tapered element-filter combination to the mass of dust collected on the filter.

INTRODUCTION

Measurements of respirable dust are made regularly in coal mines to determine worker exposure, to evaluate dust control systems, to provide feedback for control purposes, to satisfy regulations, and to gather epidemiological data. Instruments and procedures for measuring respirable dust are as varied today as the reasons for making the measurements.

Which instrument or procedure is the best? The answer is that NO instrument or procedure for measuring respirable dust is appropriate in and of itself. The value of an instrument or procedure must be measured based on its intended application. Why do you want to measure the dust levels? What type of information do you need? Do you need shift averages or short-term measurements? What degree of accuracy is necessary? Only after you have answered these questions can you evaluate a particular instrument or procedure for measuring respirable dust.

This paper will provide an overview of the instruments and procedures that can be used today and in the foreseeable future in the coal mine environment and discuss some of the advantages of each. Topics will include gravimetric, light scattering, and oscillating microbalance techniques.

GRAVIMETRIC TECHNIQUES

The reference instrument for making mass concentration measurements in coal mines is the Mining Research Establishment (MRE) horizontal elutriator manufactured in Great Britain. In the United States, the mining community generally uses a cyclone-filter cassette-sampling pump system, commonly called the CMDPSU (fig. 1), and expresses measured respirable dust concentrations in terms of an MRE equivalent (14).* The CMDPSU is smaller, less sensitive to orientation, and can be worn by the worker to obtain a personal exposure measurement. The gravimetric technique, by its definition, measures the mass of the collected aerosol and does so without regard to other dust characteristics such as refractive index, shape, or size. Careful conditioning of filters before weighing removes moisture so that only the mass of collected dust is obtained.

Performance

Although much has been written about the performance of the CMDPSU, studies continue. A recent theoretical analysis by NIOSH suggests that operating the CMDPSU at the recommended 2 L/min flow rate and multiplying the result by the accepted factor of 1.38 to obtain an MRE equivalent value could lead to biases of up to 40 pct when sampling certain particle size distributions (2). The NIOSH study reports that operating the CMDPSU at 1.2 L/min and using a conversion factor of 0.91 would greatly lower the potential for biased results. Note that 40 pct biases are predicted to occur only when sampling particle size distributions that are at the extremes of the range of size distributions considered in the NIOSH analysis. It is not certain how often such size distributions are encountered in day-to-day mining operations.

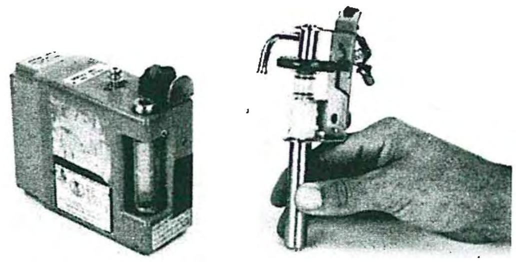

FIGURE 1. - Typical CMDPSU

The Mine Safety and Health Administration (MSHA), U.S. Department of Labor, performed a followup experimental evaluation of the NIOSH theoretical study (15). Measurements made by CMDPSU's operated at 2 L/min and 1.2 L/min were compared to MRE measurements for different size distributions of coal and limestone dust, both in the laboratory and at various typical underground coal mine sites. Based on the results of their study, MSHA concluded that "....there is no significant change in the variability

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* Numbers underscored in parentheses are references at the end of this paper.

associated with the factor derived to convert respirable dust measurements obtained with approved respirable CMDS [coal mine dust samplers] to equivalent MRE measurements when the flow rate of the CMDS is reduced from 2.0 to 1.2 L/min and that the variability associated with between-sampler measurements will be less for CMDS units operated at a flowrate of 2.0 L/min opposed to 1.2 L/min)." (Words in brackets added.)

A different study, conducted by the Bureau at the Pittsburgh Research Center, and also at the University of Minnesota, indicates that both high wind velocity (above 300 ft/min) and orientation of the cyclone inlet with respect to the wind direction can introduce inlet bias (5). For example, the sampling efficiency of a cyclone with its inlet oriented 90° to the wind direction, sampling 2.5 µm particles in a 1,770-ft/min wind, is 39 pct when compared to a cyclone with its inlet oriented directly into the wind. Placing a shield or collar around the cyclone in front of the inlet reduces measurement sensitivity to wind velocity and cyclone orientation, but more work needs to be done to optimize the design of such a shield. Note that high wind velocities (exceeding 1,000 ft/min) are encountered only at a limited number of mining situations.

Finally, a recent Bureau study of dust measurements made by multiple CMDPSU's worn by workers concluded that wearing of the samplers by someone moving about in a mine does not contribute significantly to the variation in measurements made with these instruments (3). In other words, dust samplers worn by personnel are just as precise as fixed-point samplers for measuring respirable coal dust.

Recent Improvements

The CMDPSU's that are most widely used today use a small, battery-operated sampling pump to draw air through the size-selective cyclone and filter. The airflow rate through these pumps must be periodically checked during a shift and manually adjusted to compensate for flow rate changes caused by battery voltage drop and by increased backpressure resulting from filter loading.

A new generation of sampling pumps has been developed that automatically control the airflow rate, usually to within ±5 pct the setpoint (13). Some examples of these pumps are the DuPont P-2500,* DuPont P-4000, DuPont Alpha 1, Gilian HFS 113, Mine Safety Appliances (MSA) Fixt-Flo, Bendix BDX 60, and Spectrex PAS 3000. Most of these pumps have been approved by MSHA for use in explosive methane-air mixtures under Title 30 of the Code of Federal Regulations (30CFR), Part 18. However, many do not satisfy 30CFR, Part 74, which requires sampling pumps to have a "visual indicator of flow rate (e.g., a flowmeter).... as an integral part of the pump unit or of the sampling head assembly." Some of the pump manufacturers elected not to include an external flow meter since the flow rate is automatically controlled. In some models, a warning light is lit if flow control has not been maintained. MSHA and NIOSH are considering the revision of these certification regulations.

Applications

The primary application of the CMDPSU is for compliance sampling. Decisions regarding compliance with the 2-mg/m^3 respirable coal mine dust standard are based on the average of several shift-long mass concentration measurements. The CMDPSU gravimetric approach is well suited to making such measurements. Since the CMDPSU is designed to be worn by the worker, it is also well suited for collecting exposure data for epidemiological studies.

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* Use of company or trade names is for identification purposes only and does not imply endorsement by the Bureau of Mines.

The time required to collect a weighable sample and the delayed, remote analysis characteristic of a gravimetric approach, however, usually eliminate the CMDPSU from consideration for control feedback measurements. The delay in obtaining dust level information usually makes it too difficult to relate dust levels to conditions that existed in the mine at the time the measurement was made.

Bureau researchers have been successful in using the CMDPSU for a second application. Several CMDPSU's are used for repeated short-term measurements to help isolate dust sources and to evaluate the performance of dust control techniques (10). One group of samplers is operated only during a particular segment of a mining operation (e.g., a head-to-tail pass of a longwall shearer) or while a particular control technique is in operation. A second group of samplers is operated during a different segment of a mining operation (e.g., a tail-to-head cleanup pass of a longwall shearer) or while a particular control technique is not operating. This alternating pattern is repeated until sufficient mass is collected on the CMDPSU filters for weighing. After weighing the filters from both groups of samplers and comparing the average measurement from each group, the researcher can determine which mining segment was dustier or how effectively the particular dust control technique reduced dust levels.

A third application also makes use of several CMDPSU's. Occasionally, the researcher may wish to collect a dust sample at a fixed distance from a moving piece of machinery. One feasible method is to mount samplers on a person who walks along at a fixed distance from the machine. Bureau researchers have successfully used a fishing vest with four large pockets (fig. 2). The sampling pumps are carried in the pockets and the sampling head assemblies are hung across the front of the vest. This arrangement equally distributes the weight of the samplers and permits the free use of both hands. Often, the researcher also carries a small, intrinsically safe tape recorder to make note of times or mining activities that may significantly affect sampling results.

FIGURE 2. - Sample vest

LIGHT SCATTERING TECHNIQUES

The delay in obtaining dust level information that is characteristic of the gravimetric approach prompted the Bureau to investigate light-scattering techniques to measure dust levels. A prototype RAM-1 (fig. 3) was designed and fabricated for the Bureau in 1978 under contract H0377092, "Improved Light Scattering Dust Monitor" (7). The instrument is now being manufactured by GCA Corp. Technology Div., Bedford, MA.

The RAM-1 is a portable, fully self-contained nephelometer that measures and displays instantaneous respirable dust levels in the air. Dusty air is drawn through a 10-mm-diameter Dorr-Oliver nylon cyclone. Only respirable aerosols (1) pass through the cyclone and enter the light-scattering

FIGURE 3. - The RAM-1

chamber. Here, the aerosols pass through a collimated light beam produced by a pulsed GaAs light-emitting diode (LED) that has a peak emission wavelength at 940 nm (infrared). The instrument detects light that is scattered by the dust particles at an angle of 70° ±25°. The detector converts that light into an electrical signal proportional to the amount of dust present in the airstream. A liquid crystal display shows the respirable dust concentration in mg/m^3. The RAM-1 can be connected to a chart recorder or data logger to record the output signal.

Random signals produced by stray scattered light are kept to a minimum by a system of light traps, optically black paint on the scattering chamber walls, synchronous detection of the pulsed source light, and a clean air sheath that keeps dust from depositing on the collimating lenses.

The battery-operated RAM-1 is designed to operate 6 to 7 hours on a single charge, weighs about 4 kg, and can be carried with one hand or on a shoulder strap. Three range scales (0-2, 0-20, 0-200 mg/m^3) can be used in varying dust concentrations. A fourth position on the range dial is a battery voltage check. Calibration and zero adjustments are included. Zero checks and adjustments are accomplished by drawing sampled air through an on-board filter before passing it into the sensing chamber. The output is then adjusted to zero while the instrument measures the dust-free air. Field calibration checks are accomplished by using the internal reference scattering rod, which scatters the same amount of light each time it is inserted into the beam. The value displayed during this calibration check should agree with the value displayed when the rod was inserted into the beam while the instrument was known to be calibrated properly. If the value displayed does not agree, the instrument has drifted out of calibration and can be corrected by adjusting the amplifier gain (calibration knob) until the display reading agrees with the proper value. The rate of sampling airflow can be adjusted with a screwdriver. A jack is provided for connections to a battery charger.

Although the RAM-1 is portable, its size (21 cm x 21 cm x 21 cm) and weight (4 kg) can be somewhat inconvenient in some underground operations. Furthermore, with only a digital display and an analog output, its data handling capabilities are limited.

A new-generation device, called the MINIRAM (fig. 4), was designed and fabricated for the Bureau in 1983 under contract H0308132, "Personal Dust Exposure Monitor--Light Scattering" (8). The contract was awarded under an interagency agreement between the Bureau and NIOSH, who cofunded the development. The instrument is now being manufactured by GCA Corp. Technology Div.

FIGURE 4. - The MINIRAM

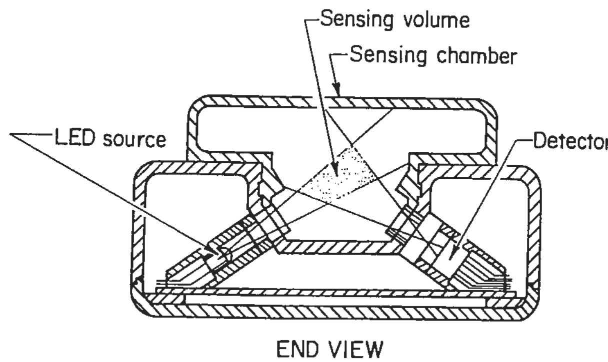

FIGURE 5.- Cutaway view of the MINIRAM

The MINIRAM is a very small, battery-operated, light-scattering dust monitor designed to operate 9 hrs on a single charge. Like its predecessor, the RAM-1, the MINIRAM uses light scattered from airborne dust particles to measure dust concentrations; however, no air pump or cyclone size selector is necessary to sample the respirable fraction of the dust. Instead, natural convection currents move airborne dust into an open-ended sensing chamber where collimated infrared light from GaAlAs LED with a peak wavelength of 880 nm is scattered from the particles (fig. 5). The intensity of infrared light scattered by respirable-size particles of coal mine dust is greatest at about 45° to 90°; therefore, infrared light detected between those angles represents the concentration of respirable dust (4).

The MINIRAM, like the RAM-1, keeps random signals produced by stray scattered light to a minimum by a system of light traps and baffles, optically black paint on the scattering chamber walls, and synchronous detection of the pulsed source light. However, no clean air sheaths are used to prevent dust from depositing on the optical surfaces; instead, the sensing cham-chamber is designed to be periodically removed and cleaned.

The MINIRAM, being about 10 cm x 10 cm x 5 cm and weighing only 0.63 kg, can be worn on a belt or shoulder strap. It automatically selects a measurement range of either 0-10 mg/m^3 to 0.01 mg/m^3 or 0-100 mg/m^3 to 0.1 mg/m^3, depending on dust concentrations being measured. Zeroing is controlled by the microprocessor by subtracting the value of an initial zero reading made in a clean air environment from subsequent dust-level readings.

The MINIRAM can display the current dust level reading, a time-weighted average, an 8-hour equivalent shift average, or the sampling time. It also stores up to seven average dust level readings for playback over the display or for digital output to a printer or computer. It has an analog output connection for recording the current dust level on a strip chart recorder and thus can be used for unattended recording of dust levels in fixed locations.

Both the RAM-1 and the MINIRAM are commercially available and have been approved by MSHA for use in explosive methane-air atmospheres.

The Bureau has produced a third light scattering dust monitor called the Continuous Respirable Dust Monitoring System (CRDMS) (9). The CRDMS (fig. 6) was designed and fabricated for the Bureau in 1983 under contract H0100110. The device is still an experimental prototype and as of yet is not approved for use in methane-air atmospheres.

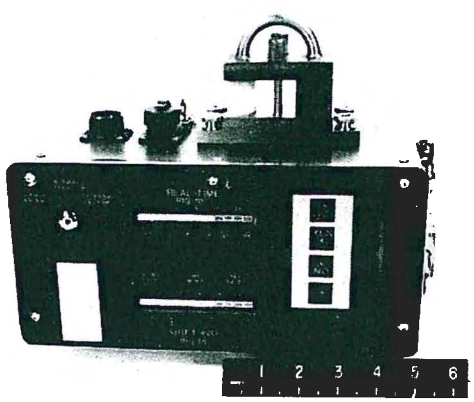

FIGURE 6. - The CRDMS

The optical system in the CRDMS is nearly identical to that in the RAM-1 except that it is much smaller in size. The CRDMS sensor display unit (SDU) was originally designed for vehicle-mounted applications and thus is very robust. The 3.2-mm thick stainless steel housing is 21 cm x 28 cm x 13 cm. The SDU weighs 9.9 kg and thus cannot conveniently be carried about the working area; rather, it is better suited to being transported to a fixed location for long-term, unattended operation. The SDU can be operated from a battery or from machine power.

The data display and handling features of the CRDMS make it one of the most sophisticated respirable dust monitors designed for use in coal mines today. An LED alphanumeric display shows the current dust level, total time in minutes that sampling has been conducted, and the present shift-average value. This same LED display is used to depict various diagnostic messages such as "cyclone blocked," "internal leakage," etc. Both current dust levels and shift-average dust levels are also graphically depicted by a linear series of LED segments. The segments are labeled and color-coded. As the dust level value increases, more segments are lighted, appearing much like the mercury of a thermometer as the temperature increases.

Data are available from the SDU as an analog signal for a chart recorder or as digital information consisting of 10-sec averages that can be transmitted to a printer or computer. In addition, data can be stored in memory in two modes. In one mode, up to 975 shift-average values can be stored with ancillary information (ID numbers, time of sampling, etc.). In the other mode, an arbitrary averaging interval can be selected and average dust level values for those time intervals can be stored up to the capacity of the memory. For example, the SDU can store 11 hours of 10-sec averages or 66 hours of 1-min averages. The stored data can then be played back one value at a time on the alphanumeric display, or transmitted to a portable, battery operated data retrieval unit (DRU).

The DRU (fig. 7) can collect data from up to six SDU's and then be carried to a different location to transmit that data to a printer or computer. Thus, the DRU can allow the SDU to remain at a fixed sampling location for extended periods of time.

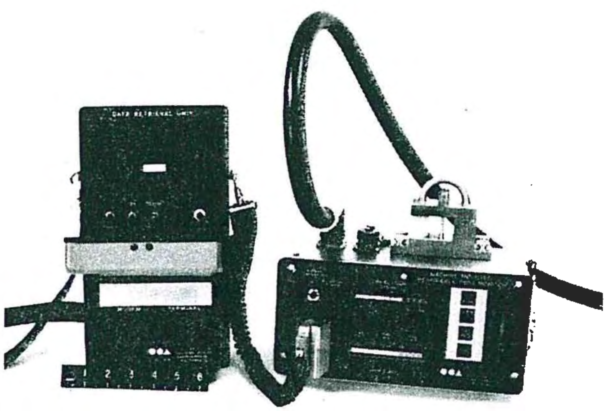

FIGURE 7. - The DRU connected to CRDMS

Performance

Since all three of these light scattering dust monitors use essentially the same optics, performance of all three are expected to be very much alike. Test results on the RAM-1 and the MINIRAM do indeed show similar behavior; performance tests on the CRDMS are not yet completed.

The response of light scattering dust monitors depends on particle characteristics other than mass such as size, index of refraction, and shape. In one series of tests, the RAM-1 response to one sample of coal dust differed by a factor of 2 from its response to a different sample of coal dust (18). The particle size distributions of the dusts were nearly the same; however, the surfaces of one sample of dust were much more reflective than those of the other. In general, if the monitors are to indicate true mass concentration, each must be calibrated with that particular dust or at the site where subsequent measurements will take place.

Once calibrated, the response of the monitors is linear with mass concentration, at least up to about 10 mg/m^3. The reproducibility of the measurements when averaged over several hours is good, probably on the order of currently used gravimetric devices.

Aerosolized water, perhaps from water sprays used for dust control, will cause light-scattering monitors to respond if the droplets are the proper size and if they are permitted to enter the sensing chamber of the instrument. However, tests with the RAM-1 in the return airway of a full-scale model mine entry showed that the cyclone precollector removed most of the droplets created by sprays typical of those used on continuous mining machines. RAM-1 readings were only 0.14 mg/m^3 in the worst case.

The MINIRAM was not tested with water droplets. However, a Tyndallometer TM-Digital (4), a light-scattering device similar to the MINIRAM in that dust enters an open-ended sensing chamber by convection, responded as high as 25.2 mg/m^3 in the full scale model tests described. The MINIRAM, operated in its open cell configuration, is also expected to respond to water droplets.

Recent Improvements

The RAM-1 and MINIRAM have no built-in facility for recording a time-resolved history of the data. A few chart recorders are battery operated and portable, but usually must be operated outby the last open crosscut.

The long cables and bulky size of these recorders make them inconvenient for underground recording of the monitor output. However, the Bureau has obtained experimental permits to use small data loggers (Metrosonics dl 331) with the RAM-1 and MINIRAMS. The data loggers are battery operated, weigh about 0.37 kg, and are 7.6 cm x 13 cm x 2.2 cm. If set to collect data at 10-sec intervals, the memory capacity of the data loggers will allow data collection over a 5-hour period. Once the data are stored in the data logger, they can be extracted by special readers and presented in a readable format. Software packages are available to manipulate and display the data in a variety of ways.

As mentioned earlier, the MINIRAM can be expected to respond to water droplets that may be present near water sprays used for dust control. To deal with that problem, an adapter is available (fig. 8) whereby a sampling pump draws dusty air through a cyclone before it enters the sensing chamber of the MINIRAM. The results from the full-scale model tests with the RAM-1 indicate that the adapter should remove most of the droplets that would normally be present before they can enter the sensing chamber. Note that the cyclone would also remove some particles along with the droplets. The MINIRAM would then have to be recalibrated with the adapter in place if the user wished to measure true respirable mass concentrations.

Finally, if no water is present and the MINIRAM is used in its open-cell configuration, light from the sun or from a miner's cap lamp can cause the photodetector in the instrument to temporarily overload. The manufacturer can supply a "sun shield" (fig. 9) that prevents light from such sources from inadvertently entering the sensing chamber.

FIGURE 8. - MINIRAM with sampling adapter (sampling pump not shown)

FIGURE 9. - MINIRAM with sun shield

Applications

The rapid response of light-scattering dust monitors make them attractive dust-measuring tools in three areas: dust control engineering, feedback for control, and screening for enforcement purposes.

To date, the RAM-1 has been most widely used as a dust control engineering tool; that is, to locate dust sources or to measure the performance of dust control techniques (12). To be useful for locating dust sources, the RAM-1 does not need to be extremely accurate, but its response must be proportional to changing dust levels. If the RAM-1 reading increases as you approach the dust source (where dust concentrations are highest), dust sources can be identified.

When measuring the performance of dust control techniques, the dust-measuring instrument does not need to accurately measure dust levels, but the instrument response to dust must be linear. Consider, for example, when the ratio of RAM-1 readings to the mass concentration of respirable dust is 1.5, as in the example in figure 10. If the mass concentration upstream of the dust control device is 2 mg/m^3, the RAM-1 would indicate 3 mg/m^3. If the mass concentration downstream of the dust control device is 1 mg/m^3, the RAM-1 would indicate 1.5 mg/m^3. The reduction of the mass concentration from 2 to 1 mg/m^3 indicates a 50 pct efficiency for the control device just as the change in RAM-1 readings from 3 to 1.5 mg/m^3 indicated--

$$\frac{2-1}{2\text{(grav.)}} = \frac{3-1.5}{3\text{ (RAM-1)}} = 0.50.$$

RAM-1 tests show that the instrument response to mass concentrations of dust is linear as long as the properties of the dust do not change appreciably. However, the RAM-1 response to dust will change slightly if

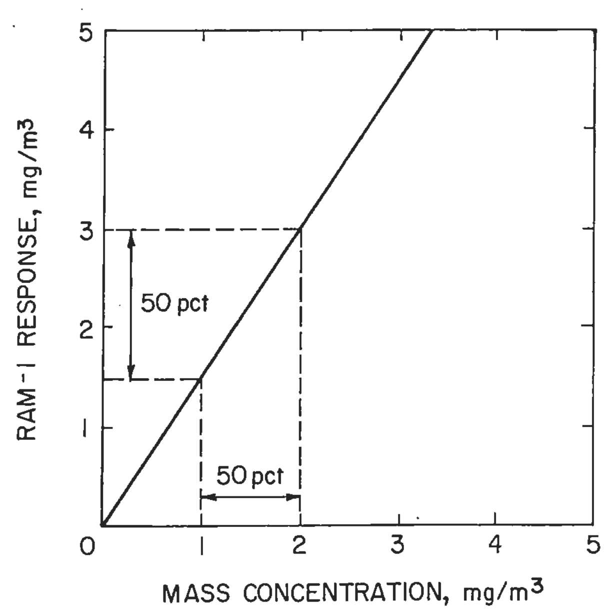

FIGURE 10. - Dust control efficiency when RAM-1 response is linear and does not change with particle characteristics

the size distribution of the dust changes. In most test cases, the ratio of RAM-1 readings to mass concentration increased as the mass median aerodynamic diameter (MMAD) decreased.

Many dust control techniques remove larger particles more efficiently than smaller ones. The downstream dust cloud would thus be made up of smaller particles than the upstream cloud. If a RAM-1 was used to measure the removal efficiency of the dust control technique by measuring and comparing upstream and downstream mass concentrations, the result could be biased.

To demonstrate this idea, consider the artificial data in fig. 11. The solid line could represent the response of the RAM-1 to a dust cloud upstream of a dust control device. The broken line could represent the response of the RAM-1 to a dust cloud of smaller particles that passed through the dust control device. If the control device reduced the mass concentration from 4 mg/m^3 to 2 mg/m^3, the reduction efficiency of the control device would be 50 pct. However, if we compared the RAM-1 readings upstream and downstream using the proper response functions, the indicated reduction efficiency would be only 12.5 pct. Note that the RAM-1 response change shown in fig. 11 is exaggerated to demonstrate the principle; however, test data to date do not show such large changes in instrument response because of changes in size distribution. Until more is known about the effect of particle size on the RAM-1 response and the typical degree of change in particle size distribution as a result of dust control devices, the amount of bias introduced into control device reduction efficiency measurements will be unknown. Since a shift to smaller particles downstream causes an increase in the RAM-1 response, reduction efficiency of the control device indicated by the RAM-1 will be underestimated as in fig. 11. Therefore, even though the AMOUNT of error in the estimate of dust reduction efficiency is unknown, the estimate will, in most cases, be conservative.

Light scattering technology is probably best suited for the second area of application, that is, feedback for control. Here, knowing the exact mass concentration of dust is not as important as being able to quickly recognize changes in dust levels. Sudden or large changes in dust levels that are immediately made known to mine personnel give them the opportunity to relate dust levels to improper or undesirable mining activities or conditions and to take appropriate corrective action. The rapid response characteristic of light scattering dust monitors is ideal for such feedback, but the potential measurement bias caused by particle size or type is not significant.

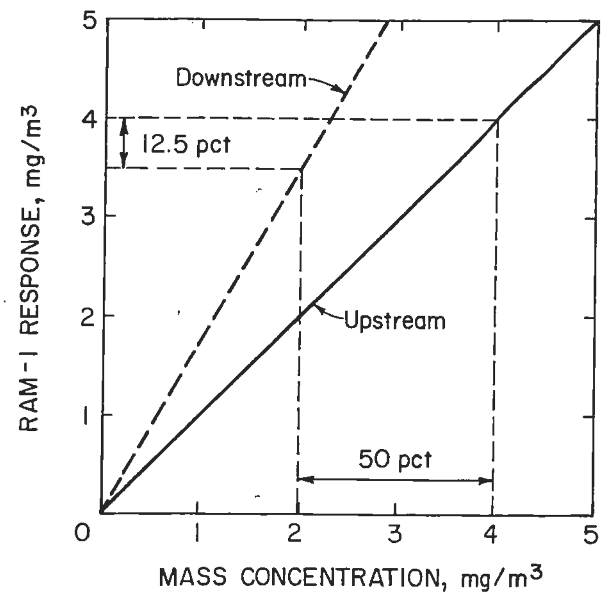

FIGURE 11. - Dust control efficiency when RAM-1 response is linear, changes with particle size distribution

Finally, MSHA has expressed an interest in using a light scattering device, in particular the MINIRAM because of its size and data-averaging capabilities, as a screening tool to more quickly identify dusty areas that should be sampled. MSHA would like to use more efficiently its inspectors to focus primary attention on the problem areas by having them make a few short dust measurements at numerous locations that would enable them to decide whether full-shift gravimetric sampling is warranted to insure a healthy workplace.

Since these brief surveys will probably be conducted at a wide variety of locations in mines, the monitor response will be susceptible to changes because of varying size distributions. Even particle types could vary because of rock bands in different seams or rock dusting operations. MSHA must decide how much bias or error is tolerable for such measurements and also develop a sampling strategy that would insure that the short-term results are representative of the dust levels at that site over a working shift. Either the RAM-1 or the MINIRAM could be used in these applications since both performed similarly in the lab tests. The MINIRAM might be attractive because of its lower cost, smaller size and weight, and its data averaging and storage feature. However, when used in the open cell configuration, the MINIRAM is more susceptible to zero drift because of dust deposition on the optics, photodetector overload from extraneous light sources, and measurement error because of water droplets entering the sensing volume.

OSCILLATING MICROBALANCE TECHNIQUES

In 1982, a prototype device called the tapered element oscillating microbalance (TEOM) was delivered to the Bureau. The instrument was designed and fabricated under contract H0308106, "Personal Dust Exposure Monitor--TEOM" (11). The contract also was awarded under an interagency agreement between the Bureau and NIOSH. The device as delivered to the Bureau is not commercially available, but other devices using the TEOM dust-sensing technique have been manufactured for other applications (6,16,17).

The active element of a TEOM system is a specially tapered, hollow tube constructed of an elastic, glasslike material. This tube is firmly mounted at the wide end; the other end supports a replaceable filter and is permitted to vibrate. The tapered tube with the filter at the free (narrow) end forms an oscillating system whose natural frequency will change in relation to the mass of the filter and the dust it has collected. As the air is drawn through the tube and its filter by a pump connected by a hose to the base of the hollow element, particulate matter collected by the filter increases its mass, reducing the oscillation frequency of the element. By measuring the change in frequency, one can calculate the increase in mass on the filter. The sensitivity and the frequency of the element can be chosen by proper dimensioning of the tapered element and filter mass.

To detect the frequency of oscillation, an LED-phototransistor pair is aligned perpendicular to the plane of oscillation of the tapered element as depicted in fig. 12. The output signal of the phototransistor is modulated by the light-blocking effect of the vibrating element and then amplified.

Part of the amplified signal is applied to a conductive coating on the outside of the tapered element. Since the element is between two plates of opposite electrical polarity (fig. 12), the electrical forces created by the oscillating voltage on the element

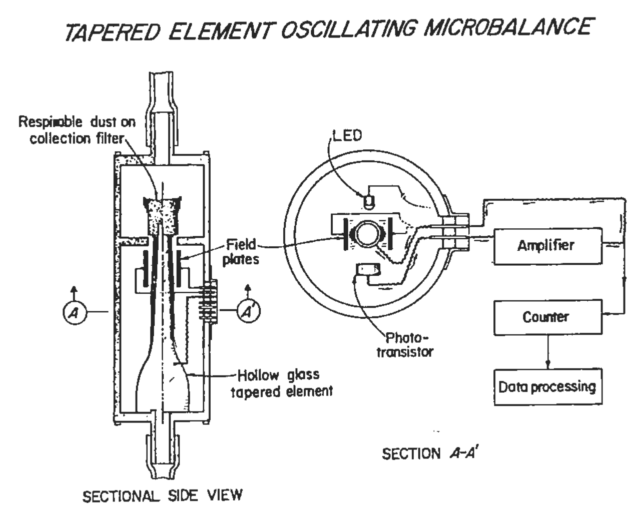

FIGURE 12. - TEOM operation--sample analysis

create enough force to sustain oscillation of the element. The other part of the amplified signal from the LED-phototransistor pair is sent to a counter and data processing stage. Here, the frequency of oscillation of the tapered element is calculated and stored in memory.

The TEOM is housed in a 8.9-cm-long, 3.2-cm-diameter aluminum canister fitted with hose connections at each end and an electrical connector on the side (figs. 12 and 13).

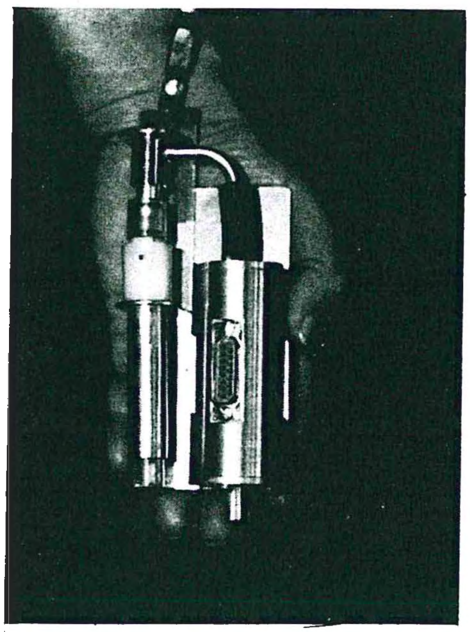

FIGURE 13. - TEOM connected to cyclone

During sampling, the canister replaces the filter cassette normally used in the personal samplers (fig. 14). Prior to sampling, the initial frequency of the TEOM is measured and recorded using the readout system designed for this purpose (fig. 15). During sampling, the TEOM is not active, but the filter collects the dust from the air being drawn through it. After sampling, the TEOM canister once again is placed in the readout system, and the frequency is measured after the filter is conditioned to remove excess water. The mass difference is computed and recorded into the system memory against the identification number of the canister. The final frequency reading can serve as the initial reading for the next measurement. The filter capacity permits the use of the same canister for several full-shift samples before the filter has to be replaced.

FIGURE 14. - TEOM canister being worn in place of filter cassette

Performance

The TEOM measures mass regardless of particle characteristics such as shape, size, or index of refraction. Laboratory tests comparing TEOM dust mass measurements to gravimetric dust mass measurements showed that the two methods agree to within 10 pct. However, because the TEOM measures mass without regard to the medium, the mass of any moisture present on the collection filter will be incorrectly measured as dust mass.

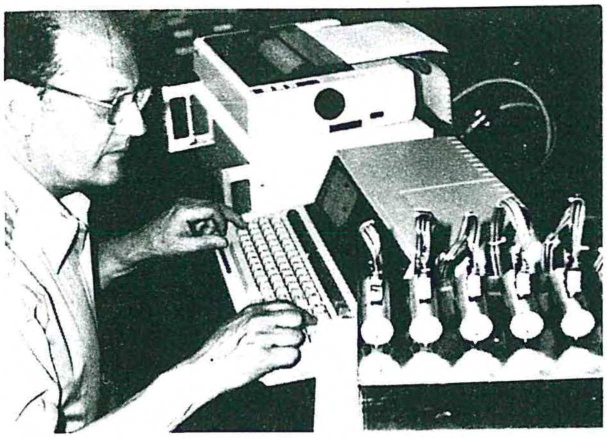

FIGURE 15. - TEOM readout system

Recent Improvements

The TEOM system is still a prototype, so not many changes will be made until testing of the present system identifies whatever problems may exist. However, the contractor has supplied the Bureau with filters that are much less hygroscopic than the filters originally supplied with the system. Further tests will be conducted with the new filters.

Applications

Since measurement performance tests on the prototype are not completed, the optimum application of the TEOM cannot be identified. It measures mass regardless of particle size or type, and the moisture problem can be avoided with proper conditioning of the filter. Thus, the present "end-of-shift," remote-analysis configuration seems to be best suited for collecting epidemiological data or for making compliance measurements. It would not be appropriate for providing feedback for control.

If measurement performance tests suggest that the TEOM dust measurement technique is sufficiently sensitive, a future modification could conceivably provide short-term dust level measurements (on the order of 30 secs) at the mine site. In that case, the TEOM could also be used for control feedback, etc. If the moisture problem can be corrected, the TEOM could be the ideal instrument; that is, an accurate, portable dust monitor that rapidly measures the mass concentration of dust without respect to the size or type of dust. Such a device could find nearly universal application.

SUMMARY

There are various technologies available today to measure concentrations of coal mine dust, and each can be judged only with respect to a given application. The CMDPSU is normally used for compliance measurements or to collect exposure data for epidemiological studies because it can be worn by the worker and it measures the mass of the sampled dust without respect to other particle characteristics. The delayed analysis usually rules out using the CMDPSU for control feedback monitoring, but some success has been achieved in using repeated short-term gravimetric measurements to evaluate the dust reduction efficiency of dust control techniques.

The rapid response of light scattering dust monitors make them very valuable tools for feedback monitoring, locating dust sources, evaluating dust control techniques, and perhaps as a screening tool for compliance. Since the response of these monitors depends on particle characteristics other than mass (such as size, shape, and refractive index), they are not usually considered for compliance monitoring. However, if the monitors are properly calibrated for the dust to be measured, and if particle characteristics remain somewhat constant, light-scattering dust monitors may be capable of reasonably estimating the true mass concentration of respirable dust.

The TEOM is still undergoing study, but it promises to be a significant advancement in the field of aerosol measurement. If the TEOM, with proper modifications, can control the moisture problem and provide accurate short-term dust mass measurements, it would find almost universal application.

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