MEETING DUST ASSESSMENT NEEDS OF AN AUTOMATED MINING INDUSTRY

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INTRODUCTION

The Bureau of Mines is vigorously conducting research to automate mining processes in an effort to keep U.S. coal mining competitive in the world market. However, just as the industrial revolution and its aggressive push for productivity exposed increased numbers of workers to serious injury, will "high-tech" mining also mean high-risk mining? The answer is "no," or at least "not necessarily." In fact, one potential benefit of automation is to remove humans from the most hazardous underground tasks. This concept is certainly not new. Tethered or radio-operated remote control miners signaled the very beginnings of automation. Miner operators could now work under well-supported roof, away from potential methane ignitions and high dust levels in the face area.

The Bureau is now conducting the next logical step in automation research. A continuous miner has already been outfitted with a suite of sensors and a computer to interpret sensor data and control movement of the machine. With the push of a button, the mining machine can execute a complete sump-shear-load cycle with the machine head position controlled to within 1 cm. Navigation research is well underway, so eventually the miner will be able to mine coal within the seam with very little human intervention. Several schemes to detect the interface between the coal and surrounding strata are being researched. Sophisticated laser, acoustic, inertial, and magnetic guidance systems will soon become feasible. The ultimate goal, of course, is completely automated operation that requires no human involvement.

Does this mean that our worries about pneumoconiosis, silicosis, and related dust-induced diseases are over? Not for many years. While the objectives of automation and robotics are admirable, humans will still be going underground well into the next century. Individual exposure to dust may be reduced in many cases, but certainly not eliminated. For the foreseeable future, robotic miners will require human supervision; and like today's technologically advanced automobiles, tomorrow's mining systems will still require maintenance. Maintenance will be a service that highly trained humans will continue to provide, and those humans will be exposed to dust. Machines designed to mine more coal will likely liberate more dust, unless dust control research keeps pace. In addition to health concerns, increased dust levels may pose problems for optical or laser guidance systems and other types of sensors, as well as increase the requirement for rock dusting to prevent dust explosions.

A critical element of any control system is monitoring. Information about the contaminant must be gathered so control efforts can be assessed and adjusted as required. This paper provides a brief overview of a Bureau project that addresses improved monitoring and analysis of hazardous coal mine dusts. Since the project is a recent initiative, the intent of the paper is not to provide extensive technical detail, but only to introduce the reader to the work being conducted.

REAL-TIME DUST LEVEL ASSESSMENT

Since the respirable coal mine dust exposure standard in the United States is expressed as a mass concentration (2 mg/m^3), gravimetric dust sampling techniques are appropriate and acceptable for compliance monitoring if conducted properly. The Bureau recognized several years ago, however, that a real-time method for assessing dust levels was needed to locate dust sources and evaluate dust control systems efficiently. The long sampling time required to collect filter samples and the delay involved in weighing the filter make gravimetric techniques too time-consuming and labor-intensive for such purposes. This realization brought about the development of several light-scattering dust monitors, including the widely used RAM-I[1] and the more recent MINIRAM. Other private sector instruments were developed without Bureau sponsorship. The advantages of these devices are almost instantaneous indication of dust levels, portability made possible by small size and battery-powered operation, and relative mechanical simplicity.

Many researchers have evaluated the performance of these and other light-scattering dust monitors. The conclusion common to almost all of these works is that the response of photometers is *not* directly related to the mass concentration of the dust. Particle characteristics such as size, index of refraction, and shape all affect the response. A special concern when sampling near water sprays used for dust abatement is that water droplets entering the instrument sensing chamber can scatter light and cause falsely high readings. The water droplet problem is minimized with instruments like the RAM-1 that use a cyclone preseparator. In that case, the cyclone captures most droplets larger than a few micrometers. In passive, open-chamber instruments like the MINIRAM, however, the problem can be severe unless a cyclone adaptor is used. Such uncertainty in light-scattering measurements makes them unsuitable for compliance measurements, but is generally acceptable for relative "before-and-after" measurements associated with evaluation of control systems. Even here, however, results can be very misleading if the size distribution of the dust cloud is dramatically altered by the dust control system.

The Bureau is conducting basic research to develop a light-scattering dust monitor that accurately measures the mass concentration of dust, even in the presence of water droplets. The Mie theory of scattering of electromagnetic radiation is often applicable to the scattering of light by respirable dust particles. The detailed mathematics are quite complex, but in general, the intensity of light scattered by a particle is a function of detection angle, intensity and wavelength of the source light, and particle size, index of refraction, shape, and surface properties. The Bureau is using computer models of Mie scattering to study the implications of varying instrument configurations and particle characteristics. The theory and computer models deal with ideal spherical particles. Although particle irregularity will introduce unknown changes into the model predictions, the model can still provide general guidance regarding the selection of important instrument parameters.

As an example, Figure 1 shows a two-dimensional diagram of the intensity of light scattered by a spherical particle as a function of angle for a given set of conditions. The value α, called the particle size parameter, is the ratio of the particle diameter to the source light wavelength. Figure 2 shows an intensity diagram for a somewhat larger particle, all other parameters remaining the same. This analysis indicates that each particle will have a scattering signature that may be unique to its physical characteristics. A novel experimental apparatus, called DAWN-A, has been obtained by the Bureau's Pittsburgh Research Center that will allow direct three-dimensional measurement of the intensity of light scattered by a particle as a function of angle. As shown in Figure 3, the device consists of a sphere upon which are mounted several photodetectors. As a particle passes through the sphere, laser light is scattered to the detectors in a pattern associated with that particle. Intensity information is processed by a computer. Research during the remainder of the project will examine the scattering signatures for a wide variety of particles likely to be found in coal mines. Once these signatures are known, a photometer may be designed that uses only those parts of the scattering signature needed to discriminate between liquid and solid particles, and to compensate for particle size, shape, and index of refraction effects. The eventual design might need to include more than one source and detector in order to gather enough information to complete the analysis. Long-term research might even lead to limited dust component analysis using the scattered-light signature.

The anticipated result of the research will be a dust monitor that can continuously and accurately measure the real-time mass concentration of dust particles in a coal mine. A monitor with such capabilities will find applications in dust control research, and perhaps even in compliance monitoring. The real value of such a device, however, lies in automated dust

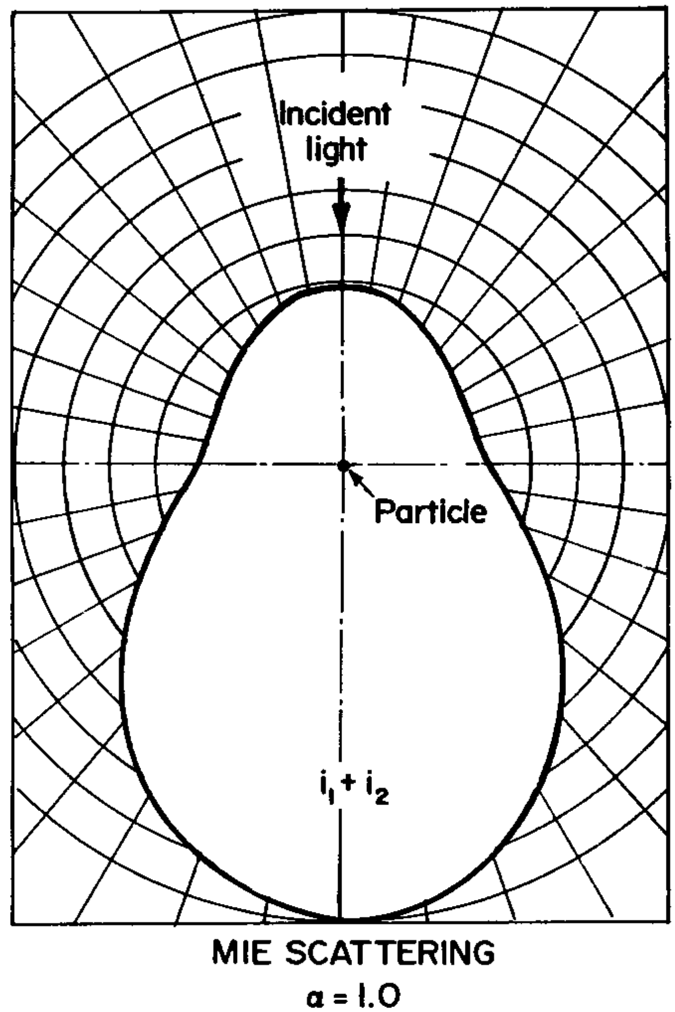

Figure 1. Scattered light intensity as a function of angle α = 1.

control systems. Dust control research has identified many viable methods to control respirable dust, but operating parameters must often be adjusted to fit the situation at hand. Water spray pressure or ventilation rate may need to be changed, for example. To automate the adjustment of dust control parameters requires that information about dust levels be fed back to a control unit that can decide what change to make in the operating parameters. The improved photometer could serve as that critical feedback mechanism.

Requiring worker presence to adjust dust control system operating parameters manually would largely defeat one purpose of automated mining, that is, to remove personnel from hazardous areas. Automated dust controls would greatly reduce the need for human presence.

In addition, they would address the other main reason for automated mining, competitiveness. Controlling dust is not free. Power for fans, scrubbers, and water pumps is an expense that must ultimately be reflected in the cost of coal. Along with reducing labor costs to monitor and adjust dust

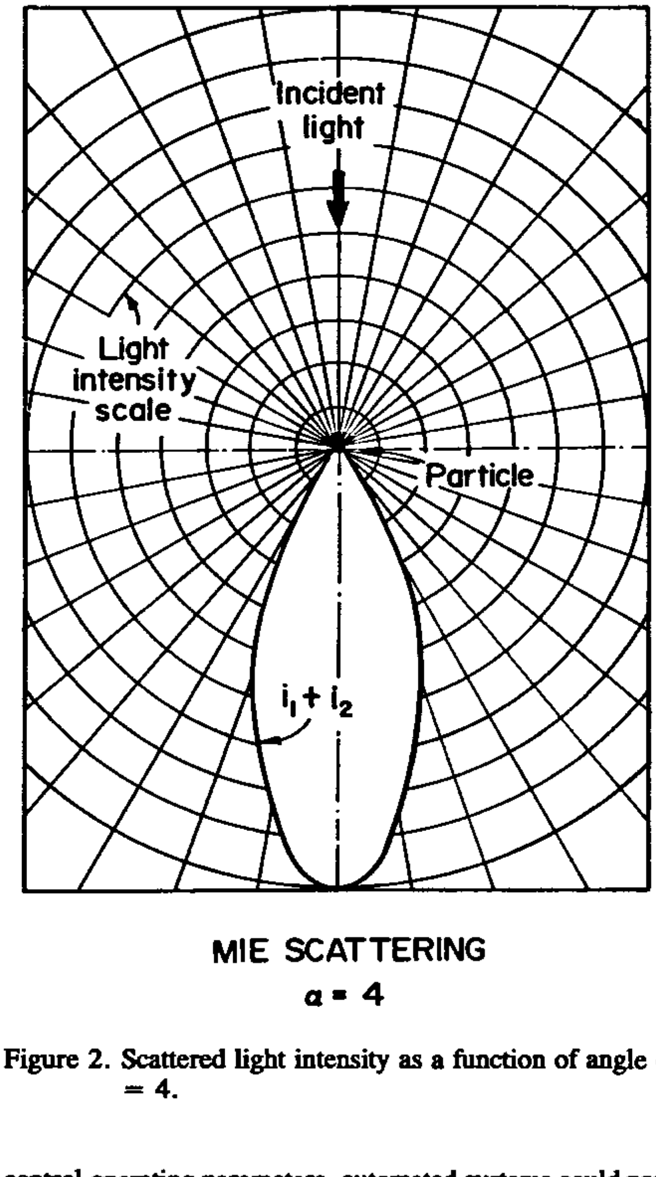

Figure 2. Scattered light intensity as a function of angle $\alpha = 4$.

control operating parameters, automated systems could prevent unnecessary costs incurred by using overly restrictive dust control methods.

DUST COMPONENT ANALYSIS

While real-time knowledge of airborne mass concentrations of respirable coal mine dust is important for control purposes, health specialists know that lung diseases, especially silicosis, are not correlated simply to levels of coal mine dust. The individual components of the dust have an important bearing on the likelihood of contracting disease. This realization is reflected in the practice of reducing exposure standards in coal mines when quartz levels exceed 5 pct. Some European data suggest that silicosis is not directly related to the percentage of quartz alone. Other minerals such as kaolin and mica have some fibrogenic capacity of their own. On the other hand, minerals such as feldspar, calcite, calcium sulphate, siderite, hematite, pyrites, etc., exist in high quantities in coal mine dust samples and may reduce the toxicity of the quartz present. All of this research points to the importance of being able to determine the amount of quartz and other components in respirable coal mine dust samples accurately.

Real-time, in situ component analysis of airborne coal mine dust remains a researcher's dream, but significant progress has been made in spectroscopic analysis techniques. The Bureau has purchased a Fourier transform infrared (FTIR) spectrometer to assess its capabilities. Already, the instrument has demonstrated an order of magnitude greater sensitivity to quartz than dispersive infrared techniques. These results were obtained by the manufacturer during courtesy analyses of Bureau-prepared filter samples.

Dispersive infrared spectroscopy has served as a mainstay analysis technique for quartz for many years. It has a working measurement range of 25 to 250 µg of quartz with a precision of 13 to 22 pct. Figure 4 is a diagram depicting the operation of a typical dispersive infrared spectrometer. By a system of mirrors and lenses, the source beam is split and follows two separate paths to the detector. Synchronized beam choppers (C_1 and C_2) allow the beams to alternately pass through a sample and a reference cell to the detector. The reference cell measurement allows compensation for such things as variation in source light intensity, temperature, pressure, etc. Infrared light from the source is viewed in discrete wavelength intervals throughout the range of interest, and the transmitted intensity is measured at the detector at each wavelength interval. These wavelength intervals can be referred to as "resolution elements." According to Skoog and West,[1] "The quality of the spectrum—that is, the amount of spectral detail—increases as the number of resolution elements become larger or as the frequency intervals between measurements become smaller." For dispersive infrared spectroscopy, then, increased spectral quality involves two costs. The first is the increased time required to measure transmittance at a greater number of resolution elements. The second is diminished sensitivity. This results because as the resolution interval gets smaller, the signal available to the detector is smaller.

Figure 5 is a diagram of a typical FTIR spectrometer. Here as well, the beam is split, but there are no choppers to alternate beam paths. Half the beam is reflected from a fixed mirror, through the sample to the detector. The other half of the beam is reflected from a mirror that moves at a well-defined rate, changing the path length of half the beam. The recombination of the two beams results in an optical interference that strengthens or diminishes the signal at the detector. In fact, the rate of change of signal strength is directly proportional to the movement of the oscillating mirror. By applying a mathematical Fourier transform to the function that describes the detected signal intensity as a function of mirror position in time, a function describing the intensity as a function of wavelength, that is, the absorption spectrum, can be obtained. The advantage of the FTIR is that all resolution elements for a spectrum are measured simultaneously. Separate measurements need not be taken for each wavelength as is the case in the dispersive infrared system.

Since quartz is recognized as a major health hazard and receives special emphasis under the respirable coal mine dust

Figure 3. DAWN-A

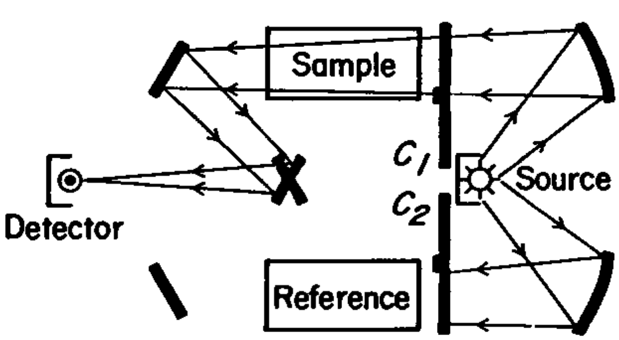

Figure 4. Typical dispersive infrared spectrometer.

exposure standard, the project is directing substantial effort to improving the analysis methods for quartz. The Mine Safety and Health Administration (MSHA) is already considering the use of an FTIR in its Method P7 for routine coal mine dust sample analysis. Although users will enjoy the benefits of improved sensitivity, they must conduct the somewhat laborious sample preparation required by Method P7. Preparations include low-temperature ashing and sample redeposition. One objective of the Bureau project is to develop a valid, convenient method for direct on-filter FTIR analysis for quartz.

As discussed above, other minerals appear to either enhance or diminish the toxicity of quartz, or even cause damage

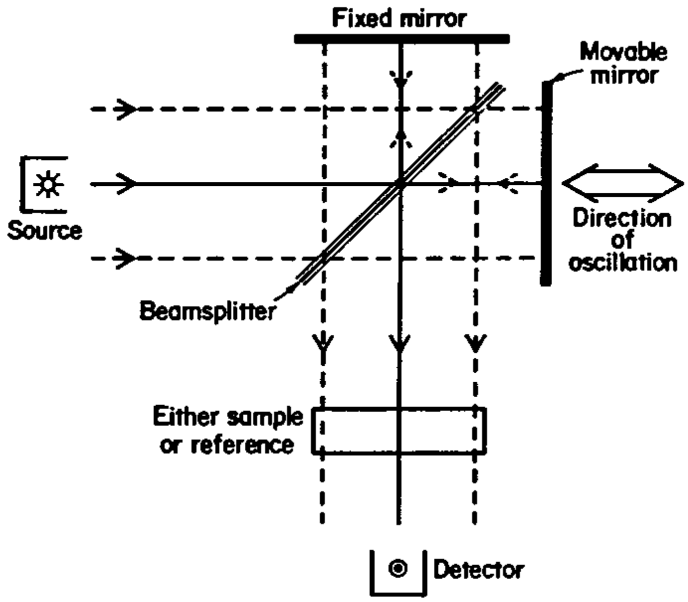

Figure 5. Typical FTIR spectrometer.

on their own. Thus, to understand completely occupationally related lung diseases, the capability of measuring the other components in the dust sample will be essential. Multicomponent analysis of dust samples is, therefore, another of the many long-range objectives of the project.

SUMMARY

The project reviewed in this report has two primary goals. The first is to provide accurate real-time measurement of the mass concentration of airborne respirable coal mine dust. Such capability is needed to provide feedback regarding dust levels to future automated dust control systems. The DAWN-A, a unique experimental apparatus for studying light scattered by dust particles, will be used to design an improved photometer. The second goal is to provide improved capabilities for respirable dust sample component analysis. Such information will be needed to understand occupational lung disease and to better assess the hazards of workplaces. Fourier transform infrared spectroscopy has been selected as a promising technique to accomplish that goal. Just as the Bureau of Mines is applying high technology solutions to problems of production and competitiveness in the international mineral industry market, it is also applying state-of-the-art technology to the measurement and analysis of respirable dust. The project tasks are in their early stages, but initial work points to an exciting and fruitful future.

REFERENCES

1. Skoog, D. A., and D. M. West. Saunders College. *Principles of Instrumental Analysis*. p. 241. (1980).

[1] Use of trade names is for identification only and does not imply endorsement by the Bureau of Mines.

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