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Historical perspective of personal dust sampling in coal mines

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ABSTRACT: Proper measurement of dust particle concentration is a critical step toward the elimination of dust-related occupational disease. This paper examines the development of dust sampling methods in U.S. coal mines, with emphasis on the benefits of personal sampling and on recent developments that permit real-time assessment of dust exposure.

1 INTRODUCTION

Historically, a wide variety of dust sampling instruments have existed, and they used several different techniques to measure dust (ILO, 1965). Some depended on dust settlement, while others operated by measuring the scattering of a light beam caused by dust in the beam, by impingement of a dust-laden air jet onto a collecting surface, by filtration of dust, or by electrical and thermal precipitation of dust. For the most part, these instruments gave dust concentrations in terms of a particle count, usually stated in millions of particles per cubic foot.

For years in the U.S., the most common dust sampling device was the midget impinger, developed in 1937 by the U.S. Bureau of Mines (Littlefield et al., 1937) (Figure 1).

Air was drawn through the impinger by a hand-cranked pump. Inside the device, the air emerged from a small orifice at high velocity and impinged on the bottom of a liquid filled container. Dust particles over a micrometer in size were trapped in the liquid, and then could be counted.

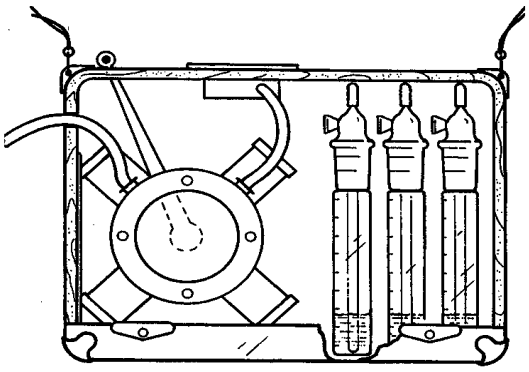

Figure 1. Midget impinger.

However, in the 1960s, two new insights about dust diseases (Orenstein, 1959) triggered major changes in how dust sampling was done. The first was the realization that the progression of disease correlates with the mass of the dust, not the particle count. The second was the recognition that dust particles under about 7 micrometers in size are the ones that enter the inner lungs. This led to the development of sampling devices that measured the mass of dust particles under 7 micrometers in size.

First in line for mining use was the Mining Research Establishment (MRE) gravimetric sampler, developed in the United Kingdom in 1964 (Dunmore et al., 1964). In operation, this device first removed non-respirable dust particles by passing the air through a stack of closely spaced horizontal plates, called an elutriator, where the larger dust particles settled out (Figure 2).

The smaller respirable dust particles that can enter the inner lung pass through the elutriator and are collected on a filter for subsequent weighing.

In operation, the MRE was placed at a fixed location in the return air stream just downwind of working faces. Although compactly designed, it was far too heavy to be worn all day by a worker. Also, for the elutriator to work correctly, the device had to be held in a steady horizontal position, and not tilted.

In the U.S., a smaller and lighter "personal sampler" was developed for mining use (Jacobson and Lamonica, 1969). Previous research by the U.S. Atomic Energy Commission (Lippman and Harris, 1962) had found that dust particles over 7 micrometers in size could be removed by a commercially

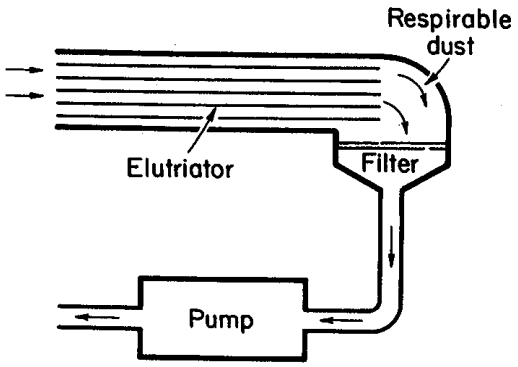

Figure 2. MRE gravimetric sampler.

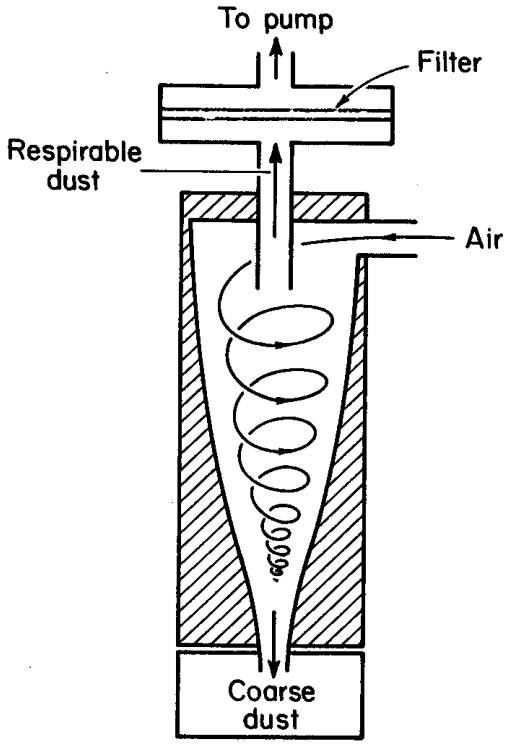

Figure 3. Cyclone-filter assembly.

available 10-mm nylon cyclone, a small funnel-shaped device in which the larger dust particles are removed by spinning the air stream (Figure 3).

The cyclone was attached to a filter that collected the respirable dust, and the cyclone-filter assembly, weighing just a few ounces, could be pinned to the lapel of a mine worker. From the filter, a short hose extended to an air pump mounted on the worker's belt.

The operating principle of the personal sampler was the same as the MRE device, with the cyclone in place of the elutriator. Smaller size and less sensitivity to orientation permitted the personal sampler to be worn by a miner. However, the size range of dust that is separated by the cyclone is slightly different than the size range of dust separated by the elutriator. In order to correlate dust exposure with health effects data, it was necessary that the personal sampler give the same dust concentration value as the MRE device. When the cyclone was operated at 2.0 liters/minute and the dust mass collected multiplied by a correction factor, determined through experimentation to be on average 1.38, the dust concentration results of the personal sampler mimicked the MRE device.

Thirty years later, the personal sampler is still in use, a testimony to the quality of its design.

2 ALTERNATIVES TO GRAVIMETRIC SAMPLING

The alternative to the personal gravimetric sampler most often used in mining is light scattering instruments. These use a light source and a light sensor to measure the light scattered by dust particles, which provides a rough indication of dust concentration. Several of these instruments have been characterized in the laboratory for different dusts. The relationship of scattered light to dust concentration depends on particle size, particle composition, and instrument design, thereby requiring a calibration for each type of dust measured (Williams and Timko, 1984). The big advantage of light scattering instruments is that they provide an instantaneous readout of the dust concentration. Still, in underground use, a calibrated instrument of this type can deviate from a personal sampler reading by as much as a factor of two (Page and Jankowski, 1984). This discrepancy has limited light scattering instruments to dust source identification and control technology evaluation, and has precluded their use for monitoring compliance with dust standards in U.S. mines.

3 ADVANTAGES OF PERSONAL SAMPLING

For measurement of the exposure of workers to mine dust, personal sampling has enjoyed two big advantages over fixed location sampling (also called area sampling). First, personal sampling measures the dust that the worker actually breathes. Most at-risk workers in mines are located close to where coal is broken and dust is generated. When dust sources are close to workers, inevitably there are sharp dust concentration gradients around the worker. For example, many coal mine studies have shown that dust levels can double or drop by half within just a few feet from the operator of a mining machine. Under such conditions, a fixed location (area) sampler has no hope of accurately measuring a worker's dust ex-

posure. For this reason, NIOSH concluded (Leidel et al., 1977) that area sampling is unsuitable for measuring air contaminant exposures in the workplace. This proscription referred to all work places, not just coal mines.

Second, when dust standards are based on personal sampling, the dust control engineer has added incentive to use every possible tool to lower the amount of dust breathed by workers. Dust control at longwall mines is an example. At longwalls, there are four tools for dust control (Shirey et al., 1985):

1. Reduce the amount of dust that is generated and escapes into the air. This is mostly accomplished by wetting the coal.
2. Remove the dust from the air by using water sprays or a dust collector.
3. Dilute the dust by providing more air.
4. Isolate the dust from the workers by moving the dust cloud away from the workers or the workers away from the dust cloud. For example, remote control of longwall shearers can lower the exposure of shearer operators by moving them upwind of shearer dust sources.

Dust control is a difficult engineering and administrative challenge, and every possible tool is needed. Of these four tools, isolating the dust from the workers is one of the most effective, and a compliance scheme based on personal sampling provides additional incentive for using isolation as much as possible.

On continuous miner sections, a compliance scheme based on personal sampling provides additional incentive to use remote control and take advantage of its benefits. For example, on sections with exhaust ventilation, the use of remote control has enabled machine operators to step back out of the dust cloud by 10 to 15 ft, producing huge decreases in dust exposure (Divers et al., 1982). On sections with blowing ventilation, remote control enables the operators to stand in front of the line curtain and breathe dust-free intake air a high proportion of the time (Jayaraman et al., 1987).

In summary, a compliance scheme based on personal sampling provides a strong incentive to reduce the dust breathed by workers. When compliance is based on fixed-point monitoring, the incentive to achieve compliance is to lower dust levels at the fixed-point location, which does not necessarily benefit the worker.

4 CONCERNS ABOUT THE EXISTING PERSONAL SAMPLING DEVICE

Among mining industry stakeholders in recent years, the personal sampler has been found lacking, for several reasons:

1. The cost and inconvenience associated with personal sampler measurements has precluded more frequent use. In coal mines, the mine operator is required to take samples every other month. Inspectors take samples four times a year.
2. Delays associated with mailing the filter, weighing the sample, and getting the feedback to mine operators total about two weeks, preventing the timely correction of high dust exposures. This delay is viewed as a fault of the technology.
3. The results can be biased, either by intent or accidentally. The sampler can be placed in a less dusty location or the inlet can be covered.
4. The personal sampler is difficult to use from the standpoint of control technology assessment, which often requires short-term measurements. When the sample collection time is short, there is not enough dust collected on the filter for an accurate measurement.

Because, in the U.S., dust regulations are written to specify the existing device (MSHA, 2001) rather than any device that meets a set of performance criteria, a change in the sampling device may not be a simple matter.

5 TWO NEW PERSONAL SAMPLING TECHNOLOGIES – THE TEOM-BASED PERSONAL DUST MONITOR AND THE DOSIMETER

Two dust measurement technologies, evolved in recent years, have potential for better personal sampling of mine dust. They offer the ability to read out the dust level at the end of the shift so that excessive dust exposures may be corrected immediately. Both can also make more frequent measurements. These technologies are the tapered element oscillating microbalance (TEOM) and the dosimeter. The TEOM is a portable microbalance that continuously weighs a filter as dust is deposited on it. The dosimeter is a low cost screening device that depends on filter pressure drop to measure dust.

5.1 *TEOM-based monitors*

TEOM-based ambient particulate monitors are used around the world to measure combustion particulate and ambient air quality levels (Patashnick and Rupprecht, 1991). The TEOM operating principle uses a replaceable filter cartridge mounted on the narrow end of a hollow tapered tube. The wide end of the tube is fixed. Air passes through the filter and down through the tube to a pump. The tapered tube with the filter on the end is maintained in oscillation. The oscillation frequency is controlled by the characteristics of the tube and the filter mass at its end. As dust collects on the filter, the mass change is measured as a frequency change in the oscillation of the tube. The exact mass of dust collecting on the filter is then determined directly.

Since frequency can be measured accurately, the method can measure very small mass changes.

In recent years, TEOM-based devices have been scaled down in size and adapted for mine use (Cantrell et al., 1997). The first such TEOM-based device used in a coal mine was the Machine-Mounted Continuous Respirable Dust Monitor. This device contained all of the workings to measure dust in a 4 cubic foot box weighing 160 pounds. Mounted in a fixed location in the face area, it offered the ability to measure dust continuously day after day. However, it suffered from lack of reliability and relied on area sampling measurements that yielded little information about personal exposure.

Very recently, the TEOM has been scaled down enough in size and weight so that it could be worn by workers as a personal sampling device. This scaled-down TEOM, called a personal dust monitor (Volkwein and Kissell, 1999), (Figure 4) is now being evaluated by NIOSH. Preliminary results from this evaluation will be presented later in this session of the conference.

5.2 *The dosimeter*

The dosimeter, which acts as a screening tool, is the second device that may find a meaningful role for personal sampling in mines (Figure 5).

The concept behind the dust dosimeter is to trade off a bit of accuracy to achieve convenience and low cost (Volkwein and Kissell, 1999). The dosimeter operates by pumping 0.25 liters of mine air a minute through a 4-mm diameter filter. As respirable dust builds up on the filter, the air pressure drop across the filter increases, serving as an indication of the accumulated mass.

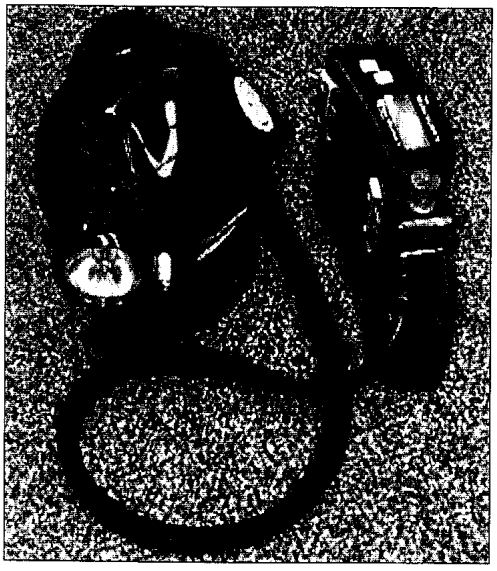

Figure 4. TEOM-based personal dust monitor.

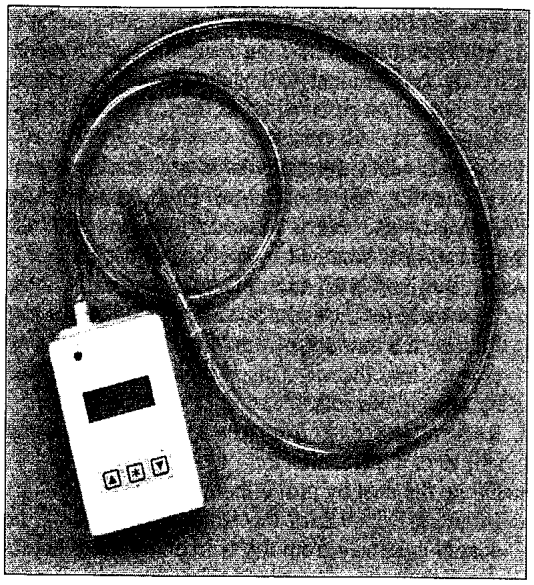

Figure 5. Dust dosimeter.

Several evaluations of the dosimeter have been completed (Volkwein et al., 2000) (Ramani et al., 2001). When a single calibration is used for all types of coal, the dosimeter is less accurate than the personal sampler. However, when calibrated and used for a single type of coal, its accuracy is equivalent to the personal sampler. A disadvantage of the dosimeter is that it cannot be used to measure mine dust in the presence of diesel particulate. Diesel particulate produces a much greater pressure drop than mineral dust for a given mass of material on the filter.

6 CONCLUSIONS

The personal gravimetric sampler was devised in the 1960s to take advantage of new knowledge about dust disease and to provide accurate measurements of dust in the breathing zone of workers. In our quest to improve the respiratory health of the mine worker, it was one of the most significant technological developments. Over the past 20 years, many dust-measuring technologies have been evaluated as candidates to replace the personal gravimetric sampler. Most have been found inadequate because of low accuracy, excessive size and weight, and/or high cost. As a technology, the personal sampler may not meet the needs of every segment of the mining industry, but its combination of light-weight design, ruggedness, accuracy, and low cost have been difficult to beat. Also, changes in the personal sampler may be hindered because in the U.S. dust regulations are written to specify the existing device rather than any device that meets a certain set of performance criteria.

Evaluations of light-scattering instruments show them to deviate from the personal sampler, precluding their use for compliance measurements in U.S. mines. They can be used effectively for dust source identification and control technology evaluation. However, the TEOM-based personal dust monitor and the dosimeter both offer completely new approaches to dust sampling. The cost and the accuracy of these instruments are under continuing evaluation by NIOSH.

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