Evaluating the Use of Isokinetic Probes and Aerosol Monitors To Measure DPM in Real Time

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Objective

To develop a system for accurately measuring diesel particulate matter (DPM) concentrations from inside flexible ventilation ducts (vent bags) and develop a monitoring strategy that allows production and maintenance personnel to measure diesel particulate matter in an underground mine environment in real time.

Background

NIOSH has identified DPM as being a Apotential occupational carcinogen.@ Therefore, occupational health and safety researchers have been challenged to find ways of controlling exposures to DPM. In response, NIOSH has been evaluating the effectiveness of various applied control technology strategies designed to reduce DPM concentrations in the workplace.

One strategy for assessing DPM reduction is to use the NIOSH 5040 method to ascertain the contribution of various pieces of mining equipment to ambient DPM levels. This can be done by isolating a piece of equipment in a stope or other work area and measuring the quality of incoming and outgoing air. Measuring incoming air is important because it may contain an unknown quantity of DPM generated by diesel equipment working upstream. Prior attempts to measure incoming DPM concentrations near the supply fan were hampered by plumes of Acontaminated@ air re-circulating into the fan inlet. Therefore, to obtain accurate DPM samples of the air supplied to the stope, a sampling probe was needed that can be inserted directly and easily into a flexible ventilation duct without irreparably damaging the duct or inhibiting mine production.

A limitation of the NIOSH 5040 method is its lack of timeliness. That is , while the NIOSH 5040 method is the most appropriate method for measuring DPM, results may not be available for as many as 2 to 3 weeks. Therefore, it becomes desirable to have a surrogate analytical method that allows DPM concentrations to be estimated in real time so that a hazardous condition can be detected and abated without delay.

This work is still in progress and is intended to describe methodology and preliminary data. Additional data have been obtained, and they are currently being analyzed. Future surveys are also planned using these techniques.

Approach

When obtaining representative samples of airborne particulates in rapidly moving air, samples must be obtained isokinetically. To achieve isokinetic conditions, it is critical that the air is sampled in such a way that a disproportionate number of particles of the same size are not selected preferentially. Therefore, the particle-size distribution of the sample must be exactly the same as the particle-size distribution in ambient conditions. Air entering and traveling through the inlet of the sampling probe must have the same velocity as the air in the ventilation duct.

The design requirements for an effective isokinetic probe are that it beC

$ Constructed from rugged, rust-proof material,
$ Easy to install from outside the bag while air is moving inside,
$ Capable of reaching the center of the duct air flow to prevent duct wall effects,
$ Easy to orient directly parallel to the airflow,
$ Sized for use with a personal-dust-type pump,
$ Fitted with an inlet orifice that permits the velocity between the bag and the probe tip to be matched, and
$ Accurate, i.e., the sample collected from the vent bag must be representative.

However, since the ventilation flow rate varies inside the ventilation bag, it will not always be possible to achieve isokinetic sampling. The study design allowed for near-isokinetic sampling conditions supposing that larger particles would be removed selectively by size from the sample downstream in the sampling train and that smaller particles would not be significantly affected by the difference in flow rate.

Methods

The prototype isokinetic probe manufactured by EDCO Manufacturing[1] of Rathdrum, ID, is made from aluminum tubing bent into an S shape (see figure). The set collar can be adjusted so that the probe protrudes about 10 to 30 cm (4 to 12 in) into a duct. A rubber washer seals the inside, and a foam-backed, aluminum contour washer seals the outside.

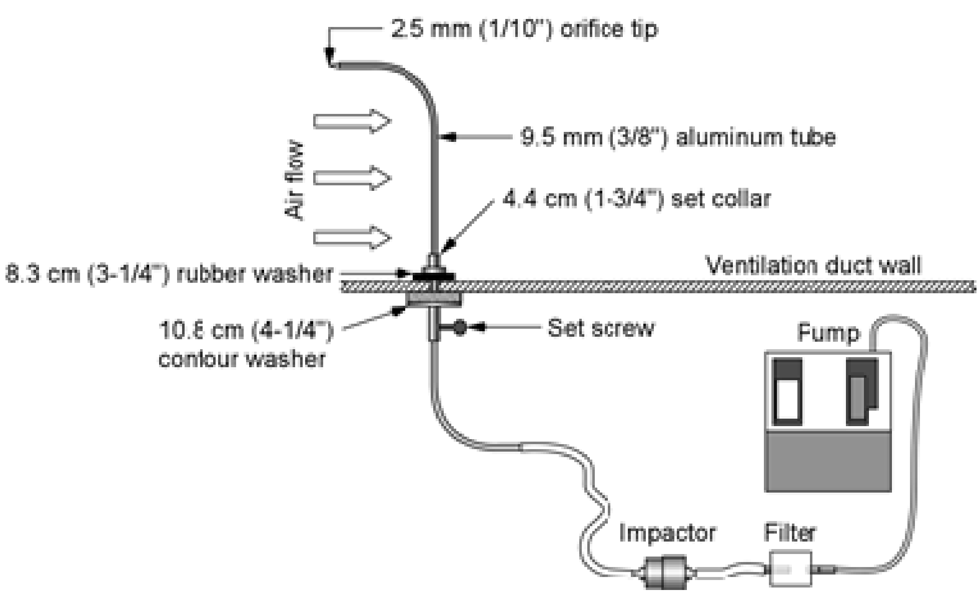
The diameter of the inlet orifice is the key to proper functioning of the isokinetic probe. The velocity of the air in the orifice should be as close to the velocity in the ventilation duct as possible. Using flow calculations based on the use of personal dust pumps calibrated to 1.7 L/min (0.48 ft^3/min), an optimum inlet orifice size of about 2.5 mm (0.1 in) is suggested for typical mine vent bags, i.e., for 76 cm (30 in) in diameter vent ducts carrying 4,200 L/sec (10,000 ft^3/min) of air and 107 cm (42 in) in diameter vent bags carrying 9,400 L/sec (20,000 ft^3/min) of air.

1 Mention of specific products or manufacturers does not imply endorsement by the National Institute for Occupational Safety and Health.

The balance of the sampling train consists of a modification described in NIOSH method 5040. All sampling trains were connected using flexible plastic tubing and included a personal dust pump calibrated to conditions, a 37-mm (1.5-in) quartz filter cassette, and a submicrometer impactor. All samples were collected at 1.7 L/min (0.48 ft^3/min) so that an aerodynamic diameter cut (d_{ae50}) of 50% collection efficiency in 0.9 μm was achieved. Samples were collected for approximately 50 min, after which the filter cassette was sent to an analytical laboratory for analysis.

The test instrument chosen for this direct reading instrument study was the MIE, Inc., Personal DataRAM Model pDR-1200 B a light-scattering, aerosol monitor in an active sampling configuration when using an air sampling pump. This instrument has a concentration measurement range of 0.001 to 400 mg/m^3 and a particle-size detection range of 0.1 to 10 μm. However, when a size-selecting impactor is integrated into the sampling train, a submicrometer cut of 0.9 μm can be achieved. The DataRAM does not analyze DPM specifically, nor does it detect the entire particle size range of DPM. Instead, this approach relies on the DataRAM analyzing the larger end the range of particle sizes (typically between 0.01 and 1.00 μm), which contribute more to overall DPM mass concentration than do smaller particles. Other attractive features of this instrument are that it is easy to operate, it can be worn as a personal sampling device, and it costs approximately $5000.

NIOSH 5040 submicrometer samples and DataRAM samples were collected side-by-side in two different sampling arrays simultaneously. Each array consisted of three NIOSH 5040 submicrometer samplers and one DataRAM sample. One of the arrays was positioned at a central location in the stope, while the other array was utilized a series of isokinetic probes inserted into a flexible mine ventilation duct. Thus, the same air was being sampled, but at different places in the ventilation pattern. The sample location and ventilation patterns are illustrated in figure 1. A cross section of the isokinetic probe is illustrated in figure 2.



Field Performance

Results (table 1) from a western underground mine showed good agreement among the triplicate NIOSH 5040 samples for total carbon between the two sampling arrays. Of particular interest was the apparent correlation of the total carbon between geometric mean concentrations and DataRAM time-weighted average concentrations, approximately 35%. These data support the use of direct-reading, light-scattering, particle analyzers as a surrogate measurement strategy for DPM exposures .

Table 1. Sampling Results

	In-duct samples		In-stope samples	
	GM	GSD	GM	GSD
NIOSH 5040, total carbon (g/m^3) (n = 3)	268.41	1.11	251.57	1.15
DataRAM, time-weighted average (g/m^3)	171		165	
DataRAM/NIOSH 5040, GM (% difference)	36.3		34.4	

GM = Geometric mean. GSD = Geometric standard deviation.

Limitations

In addition to accepting near-isokinetic sampling conditions, it should be noted that the DataRAM data are presumed to be dependent on particle-size distribution. Therefore, this simple procedure must be performed every time conditions likely to affect particle-size distribution change. Operating parameters that may affect conditions include a change in fuel, DPM emission-control technology, or a change in diesel engine. Future sampling events are planned to further validate this sampling strategy and to measure the effects of various particle sizes.

Discussion

These data were obtained in an empty, well-ventilated, ventilation-isolated stope with no equipment operating in it. Therefore, conditions were optimum for testing the technique. Incomplete data analysis of samples obtained from subsequent surveys in a different mine where control technologies were being applied have shown that adequate ventilation is critical. Good ventilation contributes to adequate mixing, which is a basic premise for the technique. Another basic premise is that there be no thermal stratification. Our studies have shown that well-ventilated stopes that do not exceed 4.6 m (15 ft) high do not have measurable stratification effects.

One other difference between subsequent data and the data presented here is that the samplers were distributed across the entire cross section. While every attempt was made to keep the samplers more than 0.3 m (1 ft) away from any rib or back, it was not always possible. Interlocation analysis showed that geometric standard deviations were larger among those samplers that were not positioned across the stope cross section.

While preliminary geometric statistical analysis has revealed promising correlations among all samplers (GSD < 2), it appears that the technique was not sensitive enough to demonstrate significant reductions from baseline, nonengineering-controlled conditions. Future surveys are planned in other mines, and closer attention will be paid to ventilation rates and sampler locations.

For More Information

For information on the design and/or use of the isokinetic sampler, please call (509) 354-8000 and ask for Patrick Hintz, Dave Denton, or Art Miller or e-mail us at Phintz@cdc.gov, Ddenton@cdc.gov, or Amiller@cdc.gov.