THE DIESEL FRACTION OF RESPIRABLE DUST IN UNDERGROUND DIESEL COAL MINES

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INTRODUCTION

The particulate output from diesel equipment can be a major component of the respirable dust in coal mines. Based on measurements of diesel engine output in underground coal mines, Francart and Stoltz estimated the concentration of diesel particulate in respirable coal mine dust to range from 0.7 to 1.6 mg/m^3 (1). Measurements, made as part of this study of face area diesel concentration from sampling in nine diesel mines, ranged to 1.28 mg/m^3.* These levels can be significant when compared to the respirable coal mine dust standard of 2.0 mg/m^3.

This article summarizes the results from sampling undertaken as part of a joint National Institute for Occupational Safety and Health (NIOSH)-Bureau of Mines (BOM) project to develop a simple, inexpensive method for estimating the diesel fraction of respirable dust in coal mines.

Aerosols are defined as solid or liquid particles suspended in a gas (2). Two categories of aerosol, that differ in aerodynamic size and can be found in underground diesel coal mines, are dusts and fumes. Because of their differing aerodynamic properties, dusts and fumes can be separated by size in cascade impactors.

Dusts are aerosols that are formed by mechanical means. Examples include the crushing and grinding of rock and coal. In general, dusts have aerodynamic diameters larger than 1 micrometer (supermicrometer) (2). In an all-electric underground coal mine sampled by Cantrell, over 90% of the respirable aerosol mass was supermicrometer (3). Burkhart reported similar aerosol size-distribution results for intake, face, haulageway, shuttlecar, and feeder breaker areas of continuous mining sections (4).

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* All diesel mines sampled as part of this study used diesel equipment to transport coal from the face. The levels of diesel particulate reported in this paper will not be representative of levels found in diesel mines where coal is transported from the face by electric means.

Fumes are produced by the condensation of gaseous combustion products. Diesel fumes generally have aerodynamic diameters of less than 1 micrometer (submicrometer). Khatri and Johnson reported that 90% of diesel particulate mass measured to be smaller than 1 micrometer (submicrometer) (5). Cantrell, through source apportionment analyses at two diesel coal mines, reported similar results (3).

Using Burkhart's data, the upper 95% confidence limit of the submicrometer mass of non-diesel coal mine dust was less than 0.1 mg/sample (6). Because the diesel mass is predominantly submicrometer, the mass sampled in excess of 0.1 mg/sample in underground diesel coal mines can be presumed to be from diesel sources.

METHODS

Method I (Cyclone-Impactor)

A 1-stage, single-jet impactor was inserted into a respirable coal mine dust sampling train (cyclone followed by an impactor followed by a filter). The effective cut-off diameter (ECD) for the impactor was an approximately 1.0 micrometer aerodynamic diameter. The impactor insert was designed by Jones, et. al. (7), and is based on impactor theory developed by Dr. Virgil Marple of the University of Minnesota's Particle Technology Laboratory. The impactor insert consists of three parts (see Figure 1). The first part is a standard 37-mm sampling cassette top with a modified orifice (opening). The second is a spacer (the middle piece of a 3-piece sampling cassette). The third is a greased aluminum foil impaction plate with holes through which the airstream passes. The orifice can be constructed by filling in the opening of a standard 37-mm 3-piece cassette with epoxy cement and redrilling it to a 0.1 cm diameter. The hole size should be checked using a caliper, and the hole's longitudinal axis should be perpendicular to the impaction plate. The spacer is a standard centerpiece for a 3-piece sampling cassette. The impaction plate consists of a pre-weighed 37-mm slide with four holes of 0.64 cm (0.25 inch) in diameter located 90 degrees apart and 1.14 cm from the plate's center. Aluminum foil is used for the substrate.

A permissible sampling pump calibrated to a flowrate of 2.0 liters per minute (lpm) pulls air through the cyclone, impactor, and filter. In the cyclone, larger particulate is removed from the airstream. Respirable dusts then penetrate the cyclone and accelerate through the orifice of the impactor. Supermicrometer particulate is unable to remain in the deflected airstream, and impacts on the greased plate. The non-diesel respirable mass can be approximated as the weight change of the impaction plate. Submicrometer aerosol (diesel fume) remains entrained in the deflected airstream and is deposited on a Polyvinyl Chloride (PVC) filter. The diesel mass can be approximated as the weight change of the filter. Both the diesel and non-diesel mass can be converted to United Kingdom Mining Research Establishment (MRE) sampling instrument units for compliance sample comparisons by multipying by 1.38 (8).

When impactors become overloaded, particle bounce can result in sampling errors. This occurs when dust paticles that would normally be deposited on the impaction plate land on other particles, bounce, and become reentrained in the airstream and are deposited on the final filter. To avoid overloading, samples should not be taken in areas of extreme concentration such as are found in some returns or downstream of rockdusters. In addition, sampling time should be adjusted so that no more than 2-3 mg is collected on the impaction plate.

Method II (Personal Impactor)

The mass of diesel fume in respirable coal mine dust can also be approximated using an Anderson Model 298 Personal Impactor (Figure 2). The personal impactor is an 8-stage cascade impactor with cut points of 21.3, 14.8, 9.8, 6.0 3.5, 1.55, 0.93, and 0.52 micrometers in aerodynamic diameter (9). A cut point is the diameter where 50% of the particulate will deposit on a given stage, and 50% of the particles will pass on to the next stage. Pre-weighed, weight-stable Apiezon H grease-coated mylar slides were used for impaction substrates. A back-up PVC filter collected the particulate that passed through the impactors. After sampling, the substrates and the back-up filter were reweighed to determine the change in mass. Samples with a weight change of over 3.0 mg were dropped from consideration to minimize the effect of particle bounce on sample results. The average weight change for blank samples was added or subtracted, as appropriate, from the weight change for each sample.

To approximate the diesel contribution to respirable coal mine dust from personal impactor samples, both the submicrometer and respirable concentrations must be known. The submicrometer (diesel) mass is the mass collected on the eighth stage and final filter of the personal impactor.

To approximate MRE respirable dust from personal impactor samples first entailed the assignment of an average aerodynamic diameter to the particulate collected on each impactor stage. A good approximation of an average diameter for a stage is the geometric mean between the cutpoint for a particular stage and that of the stage above it (10). The geometric mean between cutpoints can be calculated using the equation:

$$GMC = EXP\ ((Log\ ECD_i + Log\ ECD_{i+1})/2)$$

Where GMC is the geometric mean between cutpoints and ECD_i is the 50% cutpoint for stage i. The next step is to estimate the fraction of particulate on each stage that penetrates the 10 mm nylon cyclone when operated at 2.0 lpm. This was accomplished using equations developed by Caplan, Doemeny, and Sorenson that relate aerodynamic diameter to cyclone penetration (11). The fractional penetration for the average diameter (GMC) for each stage was determined using these equations. They are 0.0 (stages 1-4), 0.13 (stage 5), 0.98 (stage 6), 1.0 (stage 7), 0.99 (stage 8) and 1.0 (final filter). Cyclone equivalent mass is the summation of the mass collected on each stage, multiplied by the fractional penetration for each stage. MRE respirable mass is cyclone-equivalent mass multiplied by the 1.38 conversion factor.

AVERAGE CONCENTRATION FOR DIESEL/NON-DIESEL SAMPLES

Based on personal impactor area sample results, the average submicrometer concentration was higher for the nine diesel mines than for the four non-diesel mines sampled (Figure 3). The differences were significant at the 95% confidence level. The diesel concentration was approximated as the submicrometer concentration from diesel mines*. Results showed average diesel concentration to range from 0.77 mg/m^3 (1.06 mg/m^3 MRE) on shuttlecars to 0.62 mg/m^3 (0.86 mg/m^3 MRE) at the face to 0.19 mg/m^3 (0.26 mg/m^3 MRE) in intake airways. If projected over an 8-hour shift, average diesel concentrations represent 43% of the 2.0 mg/m^3 MRE respirable coal mine dust standard for face areas and 53% on shuttlecars. In contrast, the MRE adjusted submicrometer concentration for all-electric mines projected over an 8-hour shift would represent 12% of the respirable coal mine dust standard for face areas and 6% on shuttlecars. From a control standpoint the diesel estimates are significant.

Submicrometer particulate estimates from personal impactor inserts were compared to those made from 2 lpm cyclone 1-stage impactor inserts. Figure 4 shows a linear regression of the two sets of estimates. The correlation coefficient was 0.95. The results indicate that the cyclone insert provides a reasonable estimate of personal impactor submicrometer concentration.

Respirable dust estimates from personal impactor samples were also compared to those made from cyclones. Figure 5 shows the results of a linear regression of 43 paired samples taken in four diesel mines. The cyclone mass was 1.1 times the personal impactor mass. The correlation coefficient was 0.98. The hypothesis that the two sets of data are equal cannot be rejected at the 95% confidence interval. Results indicate that personal impactor estimates were reasonable predictors of cyclone mass.

Figure 6 shows the results of personal impactor sampling. It contains the average MRE respirable dust, submicrometer, and MRE submicrometer particulate concentrations for face areas of the mines sampled. The MRE adjusted submicrometer contribution to MRE respirable dust is 1.38 times larger than this average. For face areas of the diesel mines in Figure 6, the median respirable dust concentration was 1.90 mg/m^3. The median submicrometer particulate concentration was 0.77 mg/m^3. The median submicrometer concentration constituted 41% (56% MRE adjusted) of the respirable mass. The highest diesel concentration (Figure 6), of 1.28 mg/m^3 (1.77 mg/m^3 MRE), was from an area of Mine D2 with an 18-20% grade. Higher particulate emissions were expected for that mine because of the additional load the steep grade places on diesel equipment. Since diesel particulate was the major constituent of face area MRE respirable dust (mine average 2.30 mg/m^3), dust control strategies for this mine should target diesel controls.

The lowest diesel concentrations were reported in Mines D3 and D9. Mine D3 had no intake diesel activity, and correspondingly low submicrometer concentrations. It also used blowing ventilation that tapped the clean source of intake air and kept diesel particulate emitted by tramcars away

*Approximately 10% of the non-diesel respirable mass is in the submicrometer range. The increased submicrometer mass is offset by the presence of approximately 10% of the diesel mass in the supermicrometer size range.

from the face. The reason for the low levels in Mine D9 are not as apparent.

DISCUSSION

The measurement of the submicrometer fraction of respirable coal mine dust can be of benefit to the engineer in the formulation of dust control strategies for diesel mines. It enables the engineer to approximate the diesel concentration in intake air, the diesel concentration at the face, and the non-diesel concentration at the face. With this information he can target specific areas to control. As an example, if submicrometer (diesel) particulate is the major component of respirable dust at the face, then scrubbers mounted on the continuous miner may not be the most effective control (with respect to amount of dust reduction per unit of cost). In this case, the controls such as engine modifications, maintenance, improved ventilation, or the rerouting of equipment with respect to ventilation may be more effective.

Because of the variability of mining conditions inherent to the mining procedure, more than one sample should be taken at each location. Locations sampled should include the last open crosscut (intake air), the face, and on Board equipment itself.

Miners are often exposed to high concentrations of rock dust for short periods of time when handling contaminated ventilation tubing, etc. Rock dust in high concentrations can penetrate the samplers and show up in the submicrometer size range. This may result from particle bounce, sampler movement, or both. For this reason, area samples are preferable to personal samples. Area samples should not be taken downstream of the rockduster.

Another consideration is the effect of biases on sample weight change. The weight change of these samples is often in the 0.1-0.3 mg range. The use of a balance with a sensitivity in the 0.01 mg range is preferred. Both laboratory blanks and field blanks should be used to check results. Experience has shown a 0.02-0.03 mg correction is often required because of changes in humidity, etc. Letting the filters and substrates equilibrate in a controlled environment for over 24 hours minimizes these biases. Equilibration is recommended for both pre- and post-weighings of filters and substrates.

Because of differences in concentration at the face and intake, the problem of over-and underloading of impactors must be addressed. In areas of high concentration, it is often necessary to collect partial-period consecutive samples, combining mass and sampling times, as if the consecutive samples were collected as one sample.

There are many problems that must be addressed when using these methods. With proper care, the methods will be effective in the approximation of the diesel fraction of respirable coal mine dust.

SUMMARY

1. Both the personal impactor and a 1-stage single jet impactor insert to a cyclone sampling unit were used to approximate the diesel component of respirable coal mine dust.

2. The 1-stage impactor insert to a 10 mm nylon cyclone sampling unit provided a good estimator of personal impactor submicrometer concentration.

3. Personal impactor estimates were reasonable predictors of cyclone mass.

4. The median diesel concentration estimates reported by mine average for 9 mines sampled would represent 43% and 53% contributions to the respirable coal mine dust standard for face areas and shuttle cars respectively.

5. The highest submicrometer (diesel) aerosol levels were found in a mine with an 18-20% grade. The lowest levels were found in a mine with non-diesel intakes and blowing face ventilation.

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