TEST REPORT ON THE MACHINE-MOUNTED CONTINUOUS RESPIRABLE DUST MONITOR

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ABSTRACT

The machine-mounted continuous respirable dust monitor (MMCRDM) is a fixed-location area sampling device developed for possible use at the working face of an underground coal mine. This device, based on proprietary technology known as the tapered element oscillating microbalance, has evolved over the past eight years through a cooperative effort of the former Bureau of Mines, MSHA, and the Rupprecht & Patashnick Company in Albany, NY. The capability to measure respirable coal mine dust levels on a continuous basis, rather than depending solely on periodic samples obtained from the traditional coal mine dust samplers, has been a goal in the mining industry for nearly two decades. Recently, an extensive series of laboratory and underground tests was conducted by NIOSH with the cooperation of MSHA and coal operators to test the performance of the MMCRDM.

In preliminary laboratory testing, the MMCRDM seemed to work well. However, in every underground test, when compared to reference samplers placed close to the inlet, the MMCRDM failed to meet the 25% accuracy criterion specified in the contract under which it was developed. Two reasons explain this failure: First, in most tests the bias (the relative discrepancy between the average MMCRDM concentration and the average reference sampler concentration) was too great. Second, the variability of the samplers used for reference comparison was too large.

Finally, the underground testing of the MMCRDMs showed that they are quite unreliable at this stage of development. In the majority of mine tests, no more than 10 shifts of data were taken before the MMCRDM failed to function properly. Major breakdowns, requiring the return of the MMCRDM to the factory for repairs, occurred on average every 28 days. To be considered mine-worthy, MMCRDM reliability must be substantially improved.

KEYWORDS

Dust, coal dust, dust instrumentation, dust sampling, dust monitoring, black lung, pneumoconiosis

INTRODUCTION

The machine-mounted continuous respirable dust monitor (MMCRDM) measures dust with a tapered element oscillating microbalance (TEOM)(Cantrell et al., 1997). TEOM ambient particulate monitors are proprietary instruments sold by the Rupprecht and Patashnick Company, Inc. (R&P), in Albany, NY. TEOM-based monitors are used around the world to measure combustion particulate and ambient air quality levels (Patashnick and Rupprecht, 1991). From the U.S. EPA, TEOM instrumentation has received regulatory certifications for measuring PM-10 concentration; from the German EPA this instrumentation has received regulatory certifications for monitoring TSP concentration.

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.

For this study, the MMCRDM dust particle preselector was specifically designed to match the size penetration curve of the sampler currently used for coal mine respirable dust compliance measurements. This compliance sampler uses a 10-mm Dorr Oliver cyclone operated at a flow rate of 2 l/min. The

MMCRDM dust particle preselector consists of three components. Sample air enters an omni-directional inlet cap, then passes through a central tube to an elutriator, which removes particles larger than about 15 μm in size, and finally enters a virtual impactor, which passes only respirable size particles to the tapered element filter.

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LABORATORY TESTS

In laboratory experiments, the dust level indicated by the MMCRDM was compared to that measured by the traditional coal mine dust compliance samplers. A humidified dust chamber (Marple and Rubow, 1984), designed for instrument testing, was used. The design of the chamber permits the experimenter to set humidity and dust levels that are uniform throughout the chamber, so as to allow direct comparison of one instrument with another. The dust size distribution was selected to match that found in underground coal mines (Rubow et al., 1990). In initial laboratory measurements using coal dusts (8 μm mmd, 2.0 σ_g), the MMCRDM indicated a dust concentration that was 20% less than the concentration from the dust compliance samplers. To ensure that the MMCRDM gave a similar dust reading during the field tests, the cut-point of the virtual impactor was adjusted by changing the nozzle orifice diameter until the difference in concentrations was less than 5%.

After the impactor orifice size was adjusted, the MMCRDM was compared to three co-located dust compliance samplers under several different test conditions. The results for all of the test conditions are shown in Figure 1, where the accumulated mass on the MMCRDM filter is compared to the average mass collected on the three compliance sampler filters.These tests included two types of coal (Pittsburgh and Pocahontas #3), three relative humidity levels (40%, 60%, and 80%), and four respirable dust levels that might be encountered underground (0.4 mg/m^3, 0.8 mg/m^3, 1.2 mg/m^3, and 1.6 mg/m^3). Each test was conducted for a six hour period. The trend line in Figure 1 is the best fit to the points. The calculated R_2 correlation value is quite high, indicating a very good correlation.

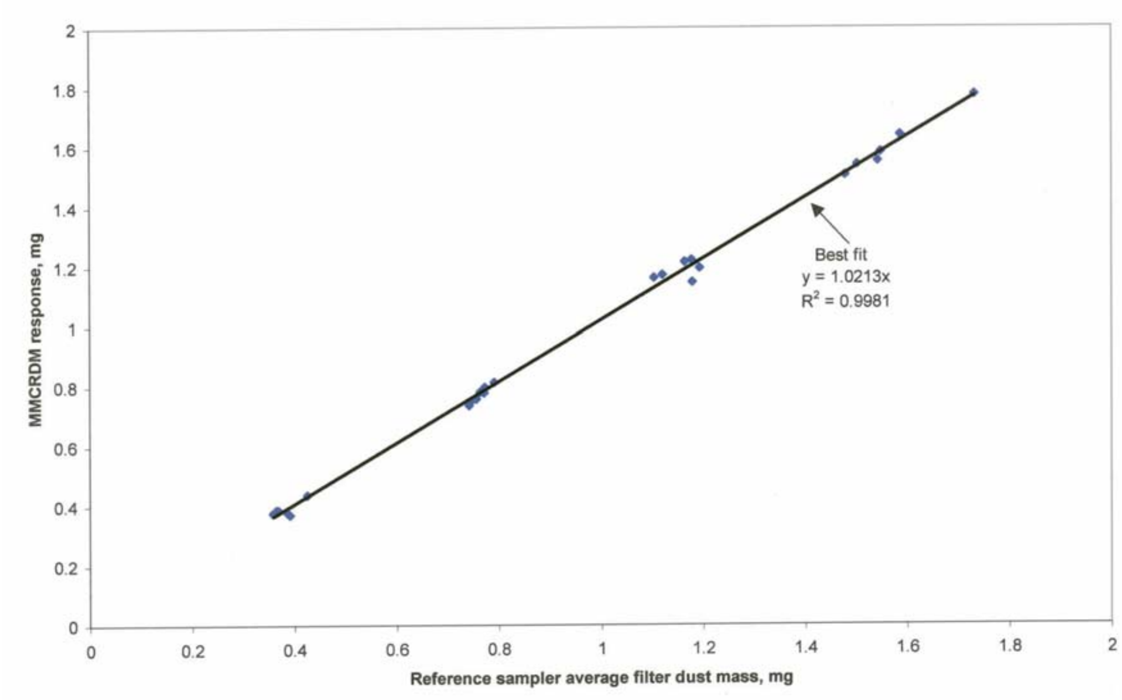

Figure 1. MMCRDM - Reference testing in lab

FIELD TESTS

NIOSH and the Mine Safety and Health Administration (MSHA) planned and conducted these field studies according to an agreed-upon partnership. To determine the field accuracy of the MMCRDM, we used as a reference the traditional coal mine dust compliance samplers, the same type of sampler that had been used in the laboratory study. These reference samplers were always placed in close proximity to the MMCRDM inlet. Sampling was conducted on-section for the entire shift, with the exception of the time it took the MMCRDM to warm up.

Test data were excluded from the analysis only for clearly defined anomalies related to data collection. These included instances where the reference sampler pump shut down during the shift, where the reference filter cassette was severely damaged, or where the MMCRDM failed to operate, mostly because the filter changer jammed. Operating failures of the MMCRDM were confirmed by examining a monitor diagnostic printout available at the end of each shift. In a few shifts, the compliance samplers were turned on too early; where the operating times of the compliance samplers exceeded that of the MMCRDM by more than 30 minutes, those shifts were also excluded.

Dust concentrations measured by the MMCRDM were automatically calculated by the monitor. For the reference samples, MSHA pre- and post-weighed the filters to a precision of 11 μg in its automated sample weighing facility. One filter blank was established for each shift of samples, and filter post-weights were corrected for weight changes in the blank. The pumps used were the Mine Safety Appliances Co. Elf-Escort flow controlled pump. Pump calibration was checked before each sampling shift using a Gillibrator calibrator and a filter load.

In the first mine (Garmeada), the research team conducted a 16-shift test in a continuous miner section that had a mobile bridge conveyor, a situation representative of a small percentage of continuous miner sections. The MMCRDM was located on the first bridge conveyor section, and two reference samplers were placed within 15 cm of the MMCRDM inlet.

The second mine (Baker) was a homotropal longwall in which the airflow across the face moved from tailgate to headgate. The MMCRDM and the two adjacent reference samplers were placed at the headgate, downwind of the shearer. The two reference samplers were about 45 cm from the MMCRDM inlet. Data were obtained for 10 shifts.

In the third mine (Shoemaker), the researchers conducted an 8 shift test in a continuous miner section, with the MMCRDM placed on the mining machine in front of the operator's cab. Two reference samplers were placed within 15 cm of the inlet.

In the fourth mine (Federal #2) the research team placed the MMCRDM and four reference samplers on a continuous mining machine. They were located on the conveyor housing at the left-hand side and toward the front of the operator's cab. The reference samplers were placed within 15 cm of the MMCRDM inlet. Data were obtained for 38 shifts.

In the fifth mine (Marrowbone), the MMCRDM and four reference samplers were placed in the return. The reference samplers were 15 to 23 cm from the MMCRDM inlet. Data were obtained for 9 shifts.

In the sixth mine (Shamrock), the MMCRDM was located on a longwall shearer in a spot where it was saturated by mist from the water sprays on the shearer. It failed due to collected moisture near the end of the first shift; therefore, none of the data could be used.

FIELD TEST RESULTS AND DISCUSSION

Figures 2 through 6 give the results for the five successful field tests. Each plotted point represents data for one shift, and the MMCRDM reading for that shift is plotted against the average value for the reference samplers that were operated during the same shift. The line in each of these figures represents the equation Y=X, and if the MMCRDM had no bias, the plotted points would fall equally on either side of this line. Bias is the relative discrepancy between the average instrument reading and the true value, the true value being the average of the reference samplers. For some of the mine tests (Baker-Figure 3, Federal #2-Figure 5, and Marrowbone-Figure 6), the plotted points indicate a considerable MMCRDM bias. Also, all of the data are considerably more scattered than the laboratory results.

The contract under which the MMCRDM was developed had a +/-25% accuracy criterion, meaning within +/-25% of the true value 95% of the time. So, we examined the field test results using criteria specified by Kennedy *et. al*. (1995) for determining whether a prospective air sampling instrument is sufficiently accurate. This accuracy test requires that readings from a prospective instrument be compared to a standard. Multiple readings are taken and the precision of these readings is calculated. Also, the bias is calculated. Kennedy et al. give a nomogram for conveniently obtaining the accuracy based on measured input values of precision and uncorrectable bias.

For each mine test, we calculated a concentration ratio for each shift. The concentration ratio was the MMCRDM reading for that shift divided by the average value for the reference samplers operating during that shift. These concentration ratios were then averaged over all shifts in the mine test, and the standard deviation calculated. The precision for each mine test was then obtained by dividing the standard deviation by the mean concentration ratio. Also, the concentration ratio was used to calculate the bias value for each mine test. (The bias is equal to the mean concentration ratio minus 1.) The input values and the accuracy results from the Kennedy nomogram were as follows:

		Concentration Ratio			
Figure #	Mine	Mean	Precision	Bias	Accuracy results
2	Garmeada	1.052	0.130	+0.052	29%
3	Baker	1.93	0.641	+0.93	
4	Shoemaker	0.951	0.226	–0.049	40% (estimate)
5	Federal #2	0.888	0.159	–0.112	34%
6	Marrowbone	1.40	0.110	+0.40	
---	Shamrock	------------- test failed due to water spray ----------------			

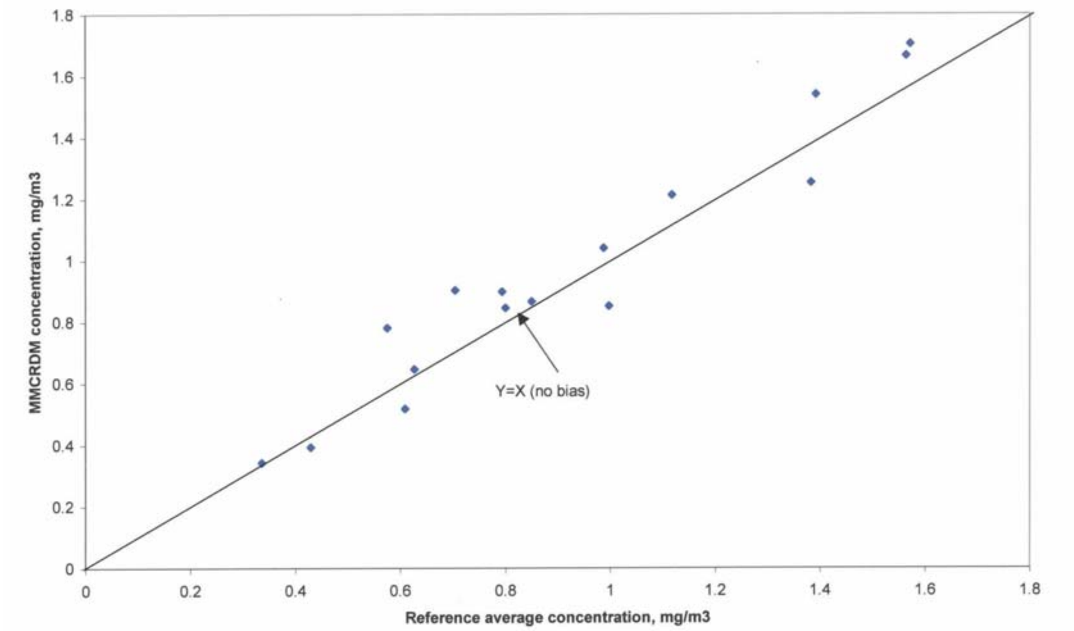

Figure 2. MMCRDM - Reference testing in Garmeada

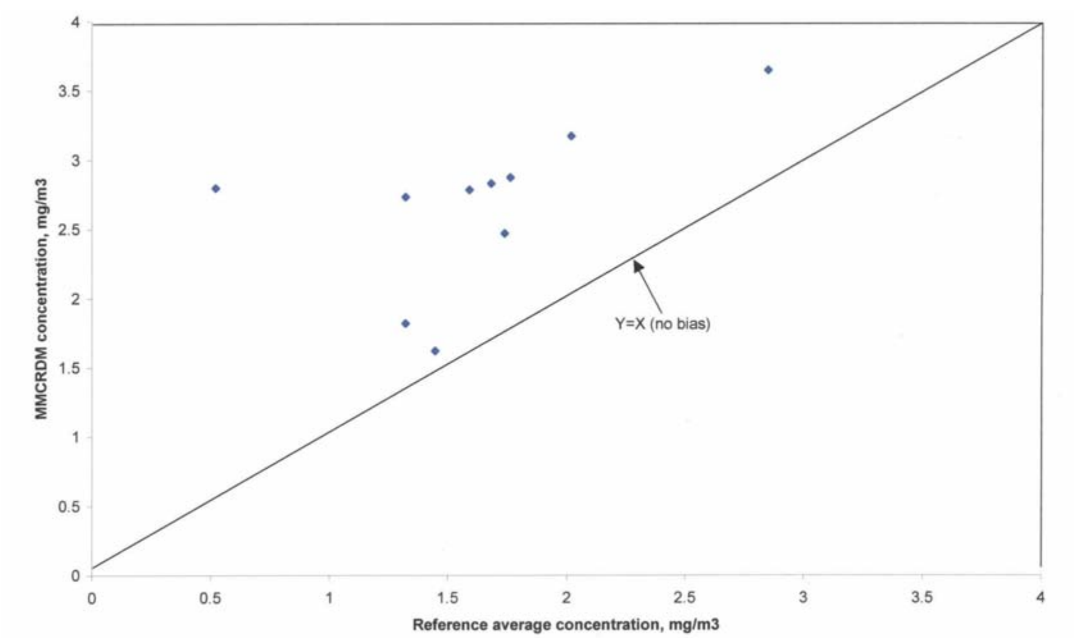

Figure 3. MMCRDM - Reference testing in Baker

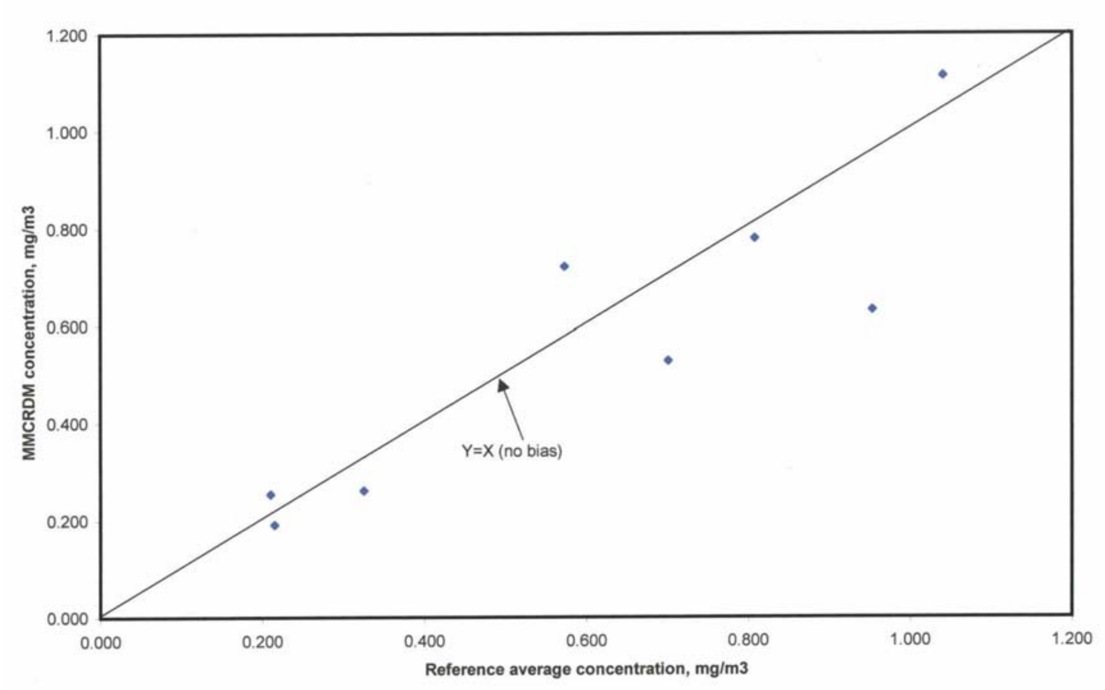

Figure 4. MMCRDM - Reference testing in Shoemaker

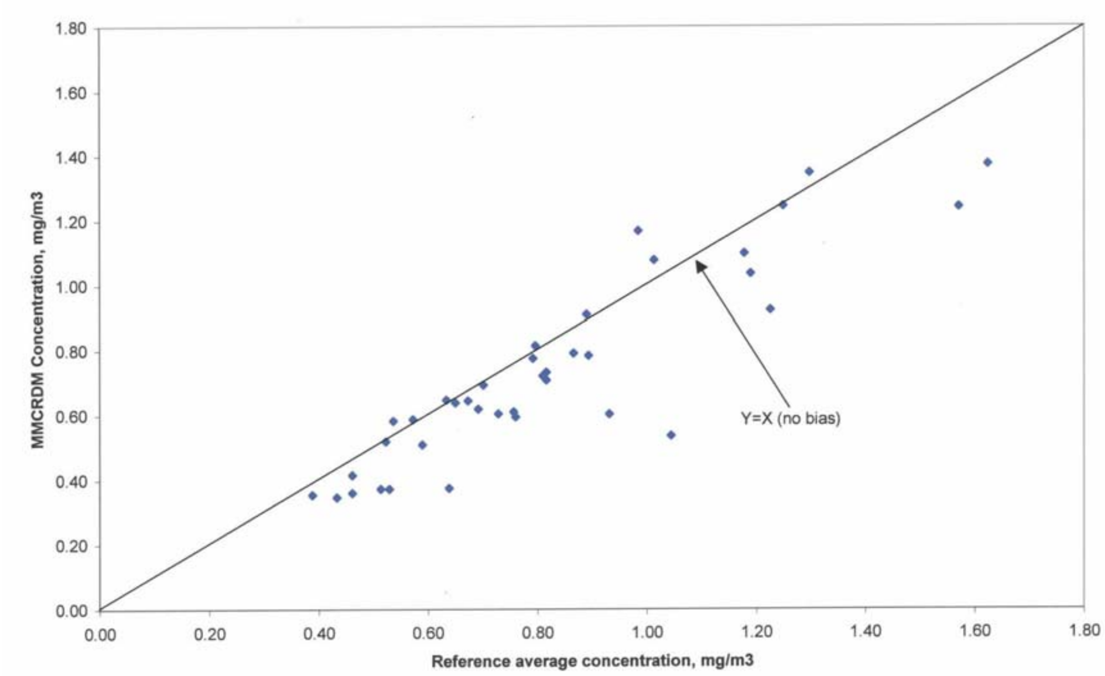

Figure 5. MMCRDM - Reference testing in Federal #2

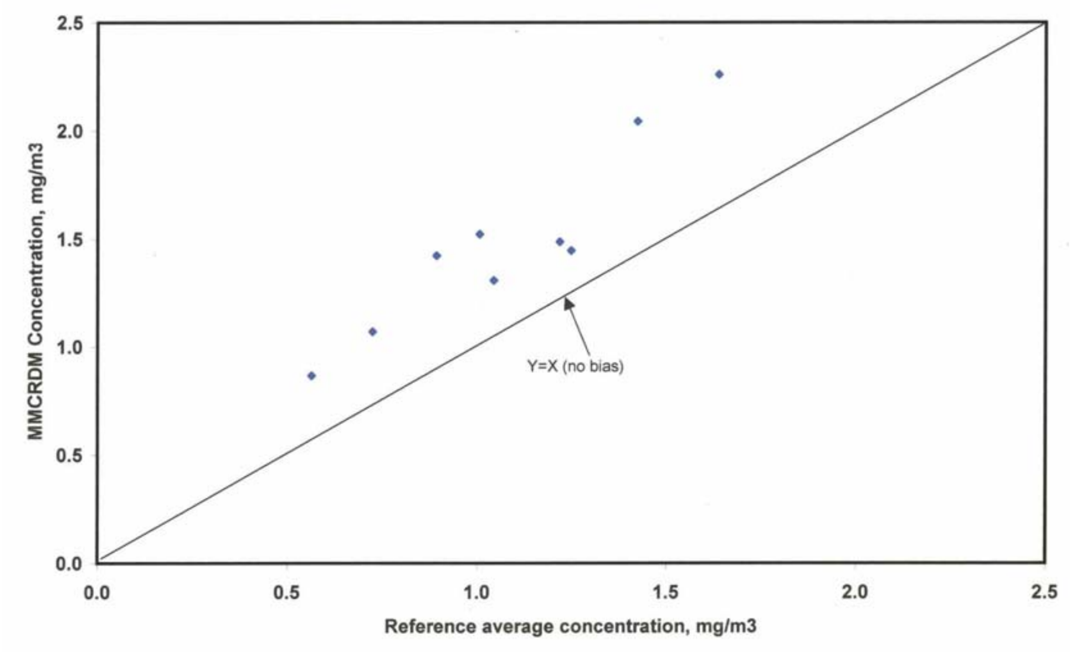

Figure 6. MMCRDM - Reference testing in Marrowbone

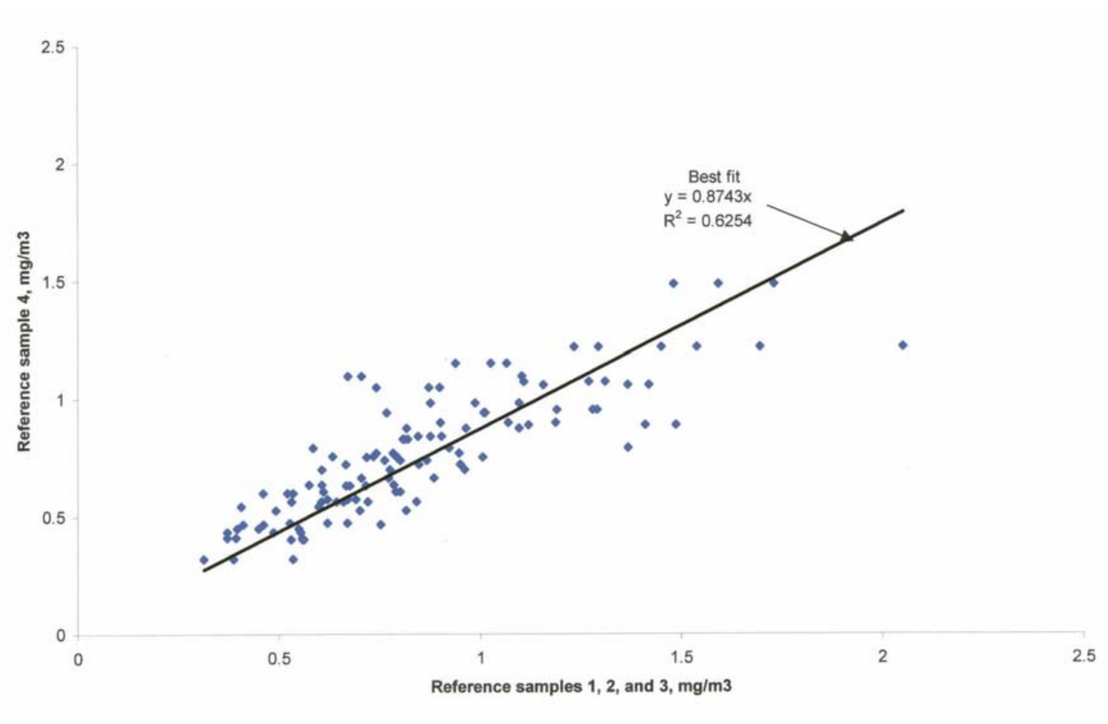

Figure 7. Federal #2 - Reference sample 4 versus 1,2 and 3

As an example, for Garmeada, data were taken for 16 shifts, resulting in 16 concentration ratio values. The mean of these 16 values was 1.052 and the standard deviation was 0.137. The precision was 0.137/ 1.052 = 0.130. The bias was 1.052 – 1.0 = 0.052. From the Kennedy nomogram, a precision of 0.130 and a bias of 0.052 yielded an accuracy of 29%.

Accuracy values are not provided for Baker or Marrowbone because the bias values of 0.93 and 0.40 were so high as to not warrant inclusion on the Kennedy nomogram (in other words, off the chart). The 40% accuracy reported for Shoemaker is an estimate because the precision value of 0.226 is also off the chart.

Not a single mine test met the 25% criterion because either the precision and/or the bias values were too high. A possible reason for the high precision values (in other words, poor precision) is that the concentration ratios reflect variance in the reference samplers as well as variance in the MMCRDM. For example, in Figure 7, the four reference samplers from the Federal #2 study are only plotted against each other, and they show considerable scatter as well as bias. The average reference sampler-to-reference sampler precision value for this mine test was 0.155. This value of 0.155 does not meet the 25% criterion.

Because the Kennedy method provides no allowance for variance in the reference, it is not surprising that the concentration ratio precision values are high. Thus, it is clear that the failure to meet the 25% criterion is due in some part to variability in the reference samplers.

Three of the five mines had bias values above 10%. Kennedy et al. state that acceptable methods must have an absolute bias no greater than 10%. These high bias values are difficult to explain, particularly since they vary so much from one mine to another. One possible explanation is that the preselector on the MMCRDM failed to completely mimic the Dorr-Oliver cyclone, and so when the dust particulate size distribution changed from laboratory to mine and from mine to mine, the bias also changed. Also, in the laboratory tests the dusty air surrounding the MMCRDM and the reference samplers was essentially quiescent, whereas in the mine tests the air was always moving. This change could have resulted in differences in flow field and particle path adjacent to the inlets, which in turn contributed to the discrepancy in results between laboratory and field.

MMCRDM OPERATIONAL SHORTCOMINGS

During the field testing, we found that the MMCRDM had many operational shortcomings. These were long warm-up times, rock dust interference, failure due to moisture, and particularly a lack of reliability.

Long warm-up times

To ensure that the MMCRDM measures only the mass of the coal dust and not any moisture on the filter, the measuring chamber that contains the filter and tapered element is heated to 50 degrees C. However, thermal gradients in the measuring chamber cause a lessening of accuracy. Hence, in those field tests where the power was removed between shifts an average of 59 minutes was needed for thermal equilibrium to be reached and for the first dust value to be computed. This means that no recording of dust data took place in the first hour.

Rock dust interference

Rock dusting caused large spikes in the MMCRDM reading. This may have added to the shift average.

Moisture

The only information we have about the impact of moisture is from the Shamrock Mine test, where exposure to a water spray caused the MMCRDM to fail after just one shift. The other mine locations were not as wet.

Reliability

Failure of the monitors pervaded the testing. In the majority of mine tests, no more than 10 shifts of data were taken before the MMCRDM failed to function properly. The average interval between breakdowns serious enough to require a return of the unit to the factory was 28 days. Most breakdowns were failures of a filter changer mechanism that had been designed and built specifically for the MMCRDM. Breakdowns repaired in the field were not recorded, but were many times as frequent.

MMCRDM - AREA SAMPLING INACCURACY

It should be noted that this report only compares the MMCRDM with reference samplers located adjacent to the MMCRDM inlet. The question as to whether such a device, even if accurate, correctly measures what nearby workers are breathing is a completely different issue. The practice of general air monitoring for measuring employee exposure, as the MMCRDM does, is called area sampling. Modern industrial hygiene practice has been to avoid area sampling and to sample airborne contaminants using "personal sampling" equipment worn by workers. It is well-known (Leidel *et. al*., 1977) that if the contaminant source is nearby, personal samples are more accurate than area samples, simply because the sampler is in the workers breathing zone rather than several feet away. We will address this area sampling inaccuracy issue in a separate report, to be published.

SUMMARY

In preliminary laboratory testing, the MMCRDM seemed to work well. However, in every underground test, when compared to reference samplers, the

MMCRDM failed to meet the 25% accuracy criterion specified in the contract under which it was developed. Two reasons explain this failure: First, the variability (the precision value) of the compliance samplers used for reference comparison was too large. Second, in three of the five successful mine tests the bias values were too great. Had the reference sampler variability been less, the accuracy criterion would still not have been met due to the large bias values obtained at the Baker, Federal #2, and Marrowbone mines.

Finally, the underground testing of the MMCRDMs showed that they are quite unreliable at this stage of development. In the majority of mine tests, no more than 10 shifts of data were taken before the MMCRDM failed. Major breakdowns, requiring return of the unit to the factory for repairs, occurred on average every 28 days. Electronic devices often suffer reliability problems when put into underground coal mines. Given the complexity of the MMCRDM, an extended shakedown period should have been expected.

The results lead to two conclusions. First, the MMCRDM cannot be used to represent worker exposure levels to respirable dust. Second, the reliability of the MMCRDM must be vastly improved for the monitors to be considered mine worthy.

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