PERFORMANCE OF RESPIRABLE DUST SAMPLING SYSTEMS IN UNDERGROUND COAL MINES

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ABSTRACT

Our long-term research on respirable coal mine dust emphasizes the suppression of dust sources for the prevention of coal workers' pneumoconiosis. As part of this research, concentration measurements were made by using various samplers in 2 Canadian underground coal mines. The dust sampling in longwalls and development headings included fixed position and personal sampling. The airflow rates of sampling pumps deviated on average 1.4% from initially calibrated values. The weight of a 37 mm diameter membrane filter changed as much as 0.05 mg due to humidity.

The relationships specific to mine site and mining method, between concentrations measured by fixed position sampling using different samplers and those determined by Casella gravimetric samplers (CGS-113A) are described. Respirable dust concentrations determined by samplers consisting of DuPont (2500A) or Gilian (HFS) pumps with Casella cyclones approached that by the CGS. The samplers made of MSA (F-F) pumps with Dorr-Oliver cyclones measured respirable values on an average at 45.5% for Mine A and 58.5% for Mine B of the values determined by the CGS. The respirable dust concentration ratio of Anderson eight-stage cascade impactors to the CGS markedly varies as a non-linear function of dust level. The shift-length average concentrations determined by a light-scattering system SIMSLIN II were lower than those by the CGS. A Hund's dust monitor TM-DATA measured the concentrations nearly equal to that by the SIMSLIN II. The differences in instantaneous dust level between the 2 systems are presented for coal cutting time.

Precision and practical aspects of coal mine dust measurements and implications of assessing the miner's health risk due to prolonged dust exposure are discussed.

INTRODUCTION

The etiology of coal workers' pneumoconiosis has not yet been fully understood. The prevention of this occupational disease thus depends upon elimination of airborne coal mine dust to which miners are exposed. The objectives of the Canada Centre for Mineral and Energy Technology (CANMET) respirable dust research program are directed to the suppression of the respirable dust in coal mine environments.

Numerous dust sampling systems or dust monitors are available and have been used for dust measurement by the mining industry. For long-term evaluation of dust exposure and for assessment of effectiveness of a dust suppression measure, it is essential that the measurements made by different samplers be reproducible and comparable. This paper describes part of CANMET's dust research program which evaluated the performance of various types of dust sampling systems tested in two Canadian underground coal mines covering three periods of time, i.e. December 1984–March 1985; December 1985–June 1986; and January–February 1987.

INSTRUMENTS AND METHODOLOGY

Gravimetric Samplers

A Casella Gravimetric Sampler (CGS) Type 113A employs a horizontal elutriator to remove non-respirable sized particles by gravitational settlement. A personal sampling system (which can also be used as a fixed position sampler) consists of an electronically flow-controlled pump and a cyclone that selects dust particles by centrifugal action. A cascade impactor is another particle size selector used in a sampler based on inertial impaction. The Anderson (Marple) Cascade Impactor Model 298 has eight stages of dust collection.

Light-Scattering Real-Time Dust Monitors

Two real-time dust monitors were used: a SIMSLIN II and a Hund's TM-DATA. The SIMSLIN II employs a horizontal elutriator as a dust particle size selector. Its laser light source has a wavelength of 0.904 μm and the scattered light by dust particles is detected between 12–20 degrees to the forward direction. The TM-DATA has, as its light source, an infrared light beam with a wavelength of 0.950 μm. This

instrument measures the light scattered by dust particles at an angle of 70 degrees to the direction of the beam. Although it does not employ a horizontal elutriator the use of this scattering angle and the specific wavelength permits the measurement of respirable dust concentration. Both the SIMSLIN II and the TM-DATA are portable and thus useful in evaluating real-time dust levels for various coal winning activities. Their output signals may be fed to a computer for analysis, comparison, and graphical presentation.

Field Dust Sampling and Performance Tests

Both fixed position and personal sampling were used in CANMET's dust sampling program. Personal dust sampling, either face-time or portal-to-portal, directly provides information on individual dust exposure. For the fixed position sampling, specific locations were chosen for shift-length sampling in longwall sections and development headings of two underground coal mines (Figure 1). Station D, which is in the tailgate 70 m from the faceline, is a statutory dust control point of an advancing or a retreating longwall. It was this location where various samplers or dust monitors were tested side-by-side at breathing zone height. Similar tests were also carried out at Station Q which is 100 m from a development heading (Figure 1). The results of performance test work which will be described in this paper were obtained by fixed position sampling in five longwall sections of Mine A, in two longwall sections of Mine B, and in one deep development heading of Mine B during the three periods of time as indicated previously.

RESULTS

Sampling Airflow Rates

The pump of each sampler used with a specific type of filter was calibrated at CANMET's Cape Breton Coal Research Laboratory prior to sampling. Following a shift-length survey, the flow rate of this pump was again determined. The absolute differences or deviations between the initial and final flow rates were calculated and expressed as percentages of the initial flow rates. The mean deviations determined in various mine sites appeared different for each pump type used with the samplers. With DuPont pumps in the walls of both mines, the mean deviation varied from 0.7 to 1.0%, while with Gilian pumps in Mine B the mean deviation varied from 1.2 to 1.4%. The mean deviation of CGS was higher (2.1%) in Mine A as compared with those evaluated in Mine B for wall sections (0.9%) and for a development heading (1.0%). The individual deviation in the flow rate ranged from 0 to 6.2% in the two mines for CGS; for all the personal gravimetric samplers, the deviation ranged from 0 to 7.1% in the mines.

Filters as Dust Collection Media

Membrane filters react by weight change in various environmental conditions. Millipore membrane filters (made of mixed cellulose acetate and nitrate) gain weight when the surrounding humidity increases. The enclosed weighing chamber of an electro-microbalance (CAHN C-29) can be a different environment for a membrane filter as compared to the laboratory environment. Therefore the time during which a filter is kept in the chamber before a reading is made, becomes an important factor when weighing filters. We make use of an air conditioner and blanks to overcome this problem. Other filters such as Nuclepore polycarbonate and glass fibre filters showed negligible weight loss. An ionizing unit (Staticmaster) was also used to eliminate static charges on all the filters before weighing.

Variability of Concentration Measurement made by Casella Gravimetric Samplers Type 113A

Two to three sets of the Casella Gravimetric Samplers (CGS) were used for each dust survey. The standard deviation and percent variation expressed as a percentage of the average of concentrations measured by the CGS, were evaluated for each sampling shift and are shown in Figure 2, in which the abscissa represents the concentration values normalized to the maximum average concentration determined during a specific shift. This variation in standard deviation (Figure 2a) from 0.01 mg/m^3 to 0.34 mg/m^3 appears to be fixed regardless of the normalized concentration and thus indicates a systematic error of measurement as high as 0.34 mg/m^3. The percent variation (Figure 2b) varies from 0.1% at the normalized concentration of 0.61 to 10.3% at 0.23. For Mine A, this variation appears to decrease with increasing concentration but for Mine B, it increases slightly as the concentration increases.

Relative Respirable Dust Concentrations Determined by Personal Gravimetric Samplers

At the dust control points of the wall sections of Mine A and Mine B, three to five sets of personal gravimetric samplers (one set with the Dorr-Oliver cyclone and the others with Casella or Rotheroe/Mitchell cyclones) were installed side-by-side with CGS. The standard deviation and percent variation obtained for the samplers using the Casella cyclones are shown in Figure 3. For comparison purposes those evaluated in a dust chamber by using 12 sets of the personal samplers are also included. The variation in standard deviation (Figure 3a) from 0.03 mg/m^3 to 0.45 mg/m^3 in the two mines appears to be fixed regardless of the normalized CGS concentration. The result of testing in the dust chamber (Figure 3a) has shown a systematic error of measurement as high as 0.44 mg/m^3 in the normalized concentration range of 0.24 to 0.65. A high standard deviation value (0.56 mg/m^3) has been observed in the dust chamber beyond the concentration range of interest. Regardless of the mine type, the percent variation decreases from 9.2% to 1.1% in the concentration range of 0.2 to 1.0 (Figure 3b). Similar to the variations of CGS, the percent variations of the personal samplers in Mine B are less than those determined in Mine A. The overall decreasing trend of the percent variation observed in the two mines has been verified by the results obtained in the dust chamber. Regardless of mine dust concentration, the average of percent variations (1.9%) evaluated in Mine B was less than the average (5.3%) in Mine A.

For each individual sampling system, the ratio of respirable dust concentration measured by this sampler during a sampling shift to the average of concentrations determined by CGS in the same shift was calculated. The ratios were grouped by sampler type for the two mines in Table I. On the longwalls

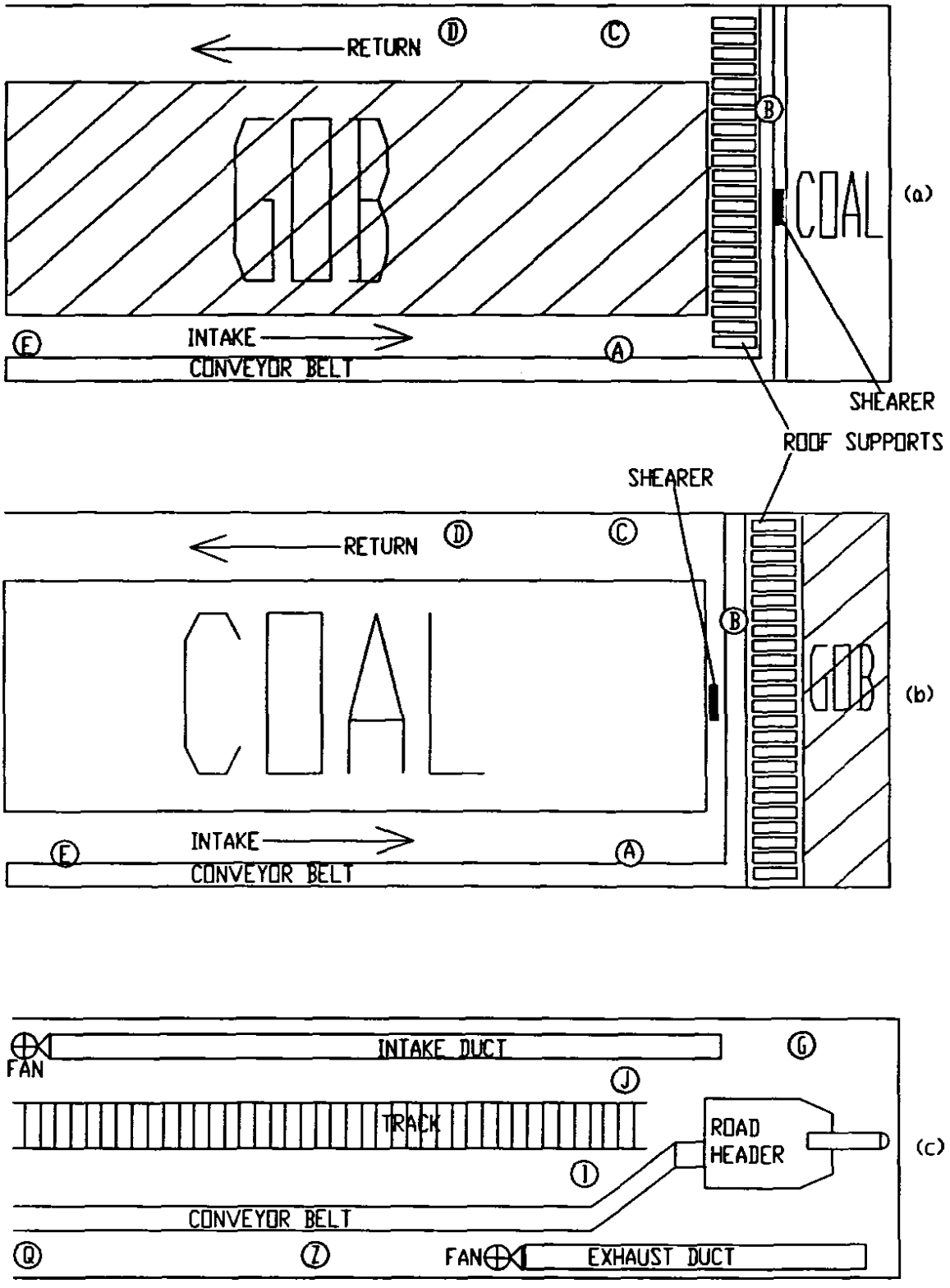


Figure 1. Fixed position sampling locations in (a) an advancing longwall section, in (b) a retreating longwall section and (c) a development heading.

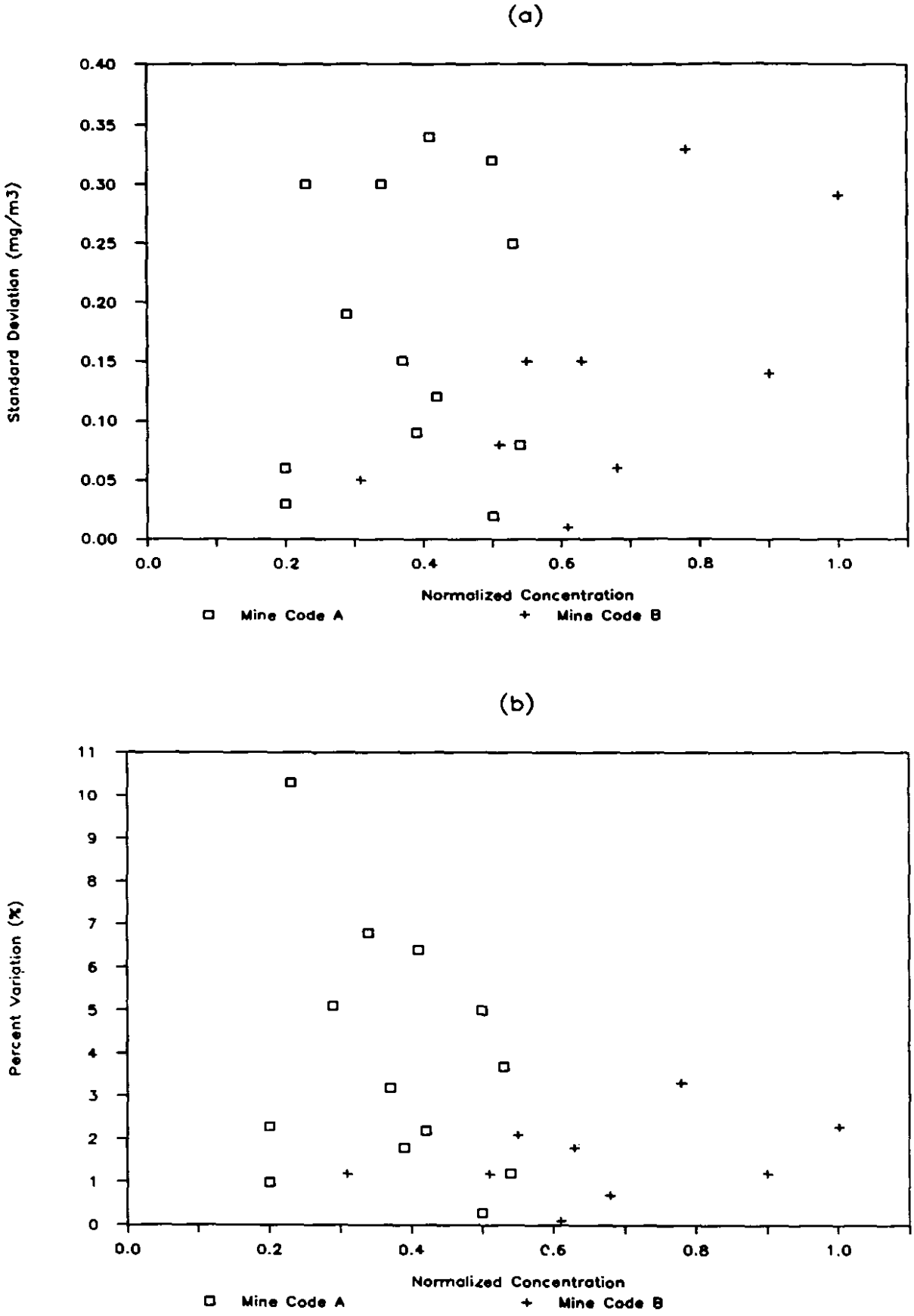


Figure 2. (a) standard deviation and (b) percent variation of concentrations measured at longwalls by Casella Gravimetric Samplers 113A for each field test in Mine A and Mine B.

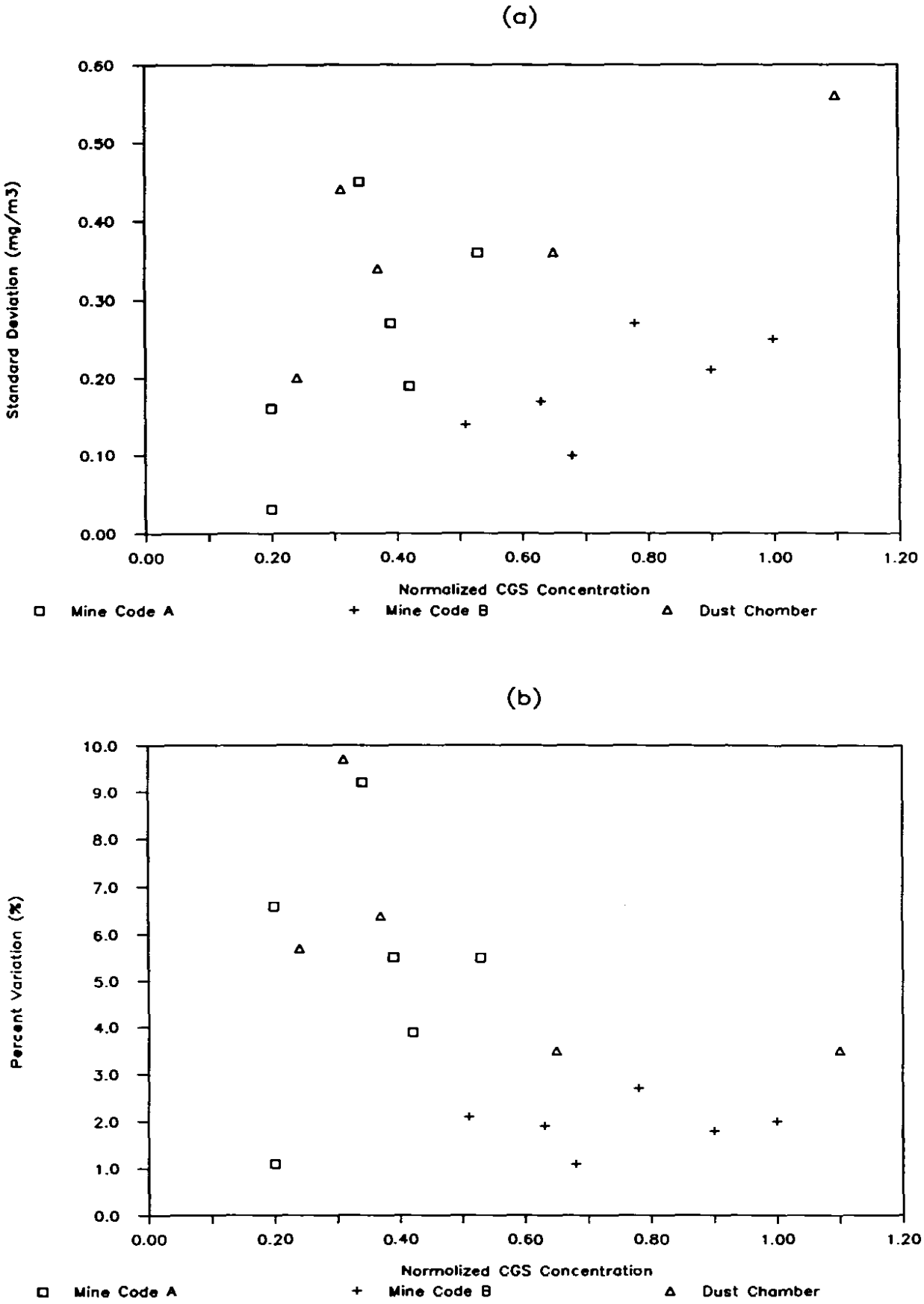


Figure 3. (a) standard deviation and (b) percent variation of Personal Gravimetric Samplers with Casella cyclones tested in Mine A, in Mine B and in a dust chamber.

Table I

Average of Ratios of Concentration Measured by a Personal Sampling System to the Averaged Concentration Determined by the Casella Gravimetric Samples (CGS) 113A

Sampling System	Mine A (5 Walls)		Mine B (2 Walls)		Mine B (1 Development Heading)	
	Average Ratio	Standard Deviation	Average Ratio	Standard Deviation	Average Ratio	Standard Deviation
DCM[1]	0.89 (12)[+]	0.11	1.01 (5)	0.03	1.09 (2)	0.15
DCG[2]	0.89 (8)	0.08	1.01 (7)	0.04	1.11 (2)	0.06
GCM[3]	0.99 (4)	0.06	1.05 (4)	0.04	-	-
GCG[4]	0.96 (4)	0.04	1.04 (6)	0.04	1.11 (2)	0.01
DCN[5]	0.92 (4)	0.06	1.05 (4)	0.04	-	-
MCM[6]	0.94 (5)	0.12	-	-	-	-
MCG[7]	0.89 (2)	0.13	-	-	-	-
MNP[8]	0.45 (9)	0.03	0.58 (6)	0.04	0.60 (2)	0.09

[1]DCM = DuPont Pump + Casella Cyclone (or Rotheroe/Mitchell Cyclone) + Millipore (MP) Mixed Cellulose Acetate and Nitrate Membrane Filter (37 mm dia., 0.8 μm pore).
[2]DCG = DuPont Pump + Casella Cyclone + Glass Fibre (GF) Filter (37 mm dia., 1.5 μm pore).
[3]GCM = Gilian Pump + Casella Cyclone + MP Membrane Filter.
[4]GCG = Gilian Pump + Casella Cyclone + GF Filter.
[5]DCN = DuPont Pump + Casella Cyclone + Nuclepore Polycarbonate Membrane Filter (37 mm dia., 0.8 μm pore).
[6]MCM = MSA Pump + Casella Cyclone + MP Membrane Filter.
[7]MCG = MSA Pump + Casella Cyclone + GF Filter.
[8]MNP = MSA Pump + Nylon Cyclone + PVC Filter (37 mm dia., 0.8 μm pore).

[+]Number of ratios averaged for each sampler type is shown in parentheses.

of the two mines, the averaged ratio appeared to be different from one sampler type to the other. The ratios evaluated for Mine A were less than those determined for Mine B. The average ratio obtained in the development heading of Mine B had greater values than the two walls of this mine had for four types of sampler. The average ratios determined by the samplers with the nylon cyclones had approximately one-half the values of those evaluated by the samplers with the Casella cyclones both in Mine A and in Mine B.

Measurement of Respirable Dust Concentration and Particle Size Distribution by Marple Personal Cascade Impactors Model 298

Two Marple (Anderson) cascade impactors, M1 and M2, were employed in two wall sections of Mine A and in one wall section and a development heading of Mine B. To evaluate respirable dust concentration, the mass determined for Stages No. 5 through No. 8 and for the backup filter were summed as the respirable portion which represented particles less than 6 μm in aerodynamic equivalent diameter. The relative respirable dust concentrations determined in the wall sections of the two mines by the impactors are plotted in Figure 4, versus the average CGS concentration normalized to the maximum CGS concentration value. The relative concentration ranged from 0.81 to 1.24 as determined by the impactor M1, and ranged from 0.69 to 1.18 as determined by the impactor M2 in the normalized CGS concentration range of 0.26 to 1.0. The relative concentrations appear to decrease non-linearly with increasing mine dust levels determined by CGS. For M1 and M2, the size distributions (expressed as percent by mass) obtained from four tests in the wall sections of Mine A, six tests in the wall section of Mine B, and two tests in the development heading of Mine B were averaged and shown in Figure 5. There are larger proportions of particles with sizes greater than 6 μm (expressed in geometric mean diameter, G.M.D.) in Mine A as compared with the distributions obtained in Mine B. The size distributions obtained in the development heading had a greater proportion of particles with size less than 6 μm as compared to those obtained in the wall section of Mine B or the wall sections of Mine A. It must be noted that in calculating a size distribution, the dust collected on the substrate of the first stage (with a G.M.D. of 32 μm) and the backup filter was not used.

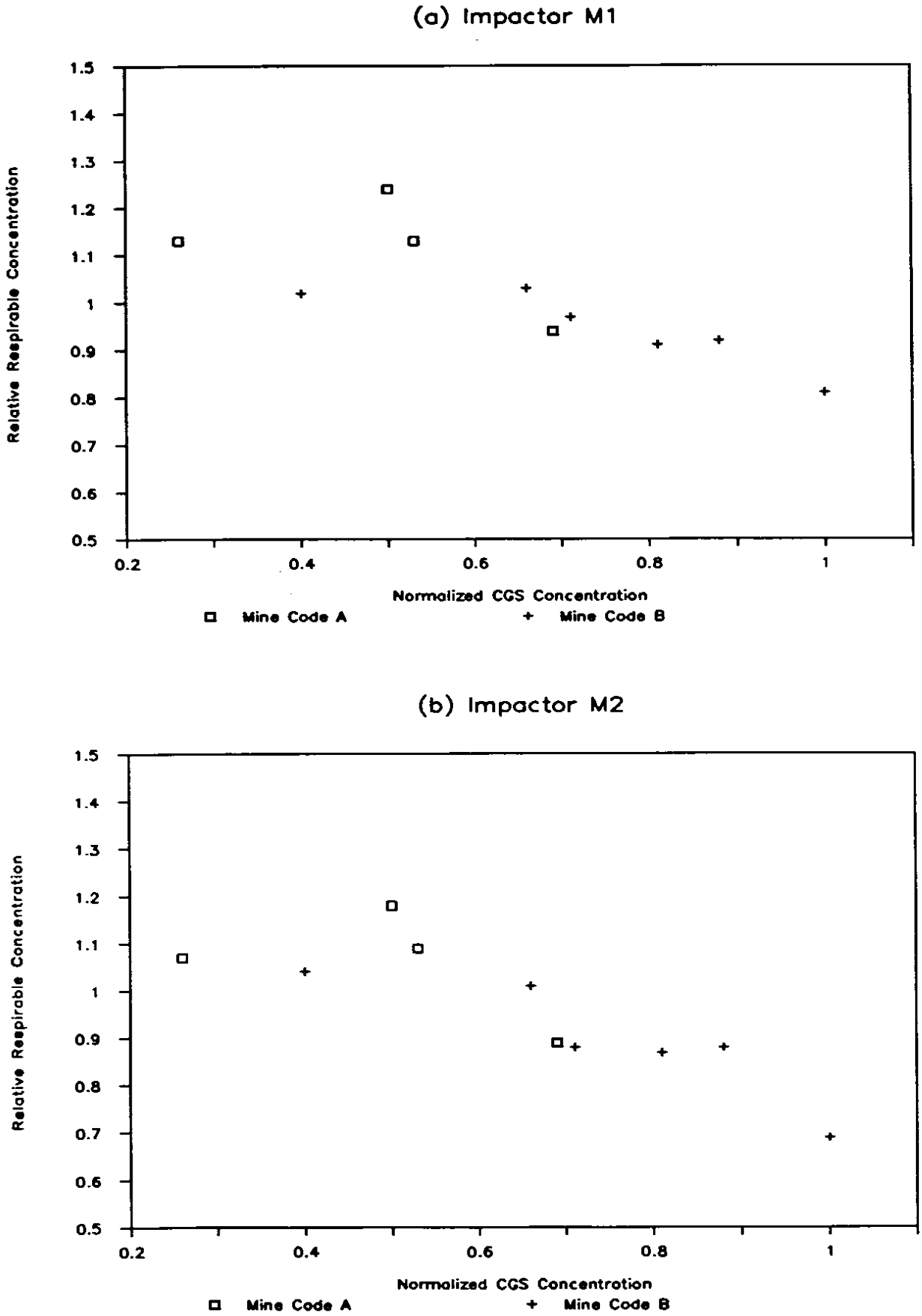
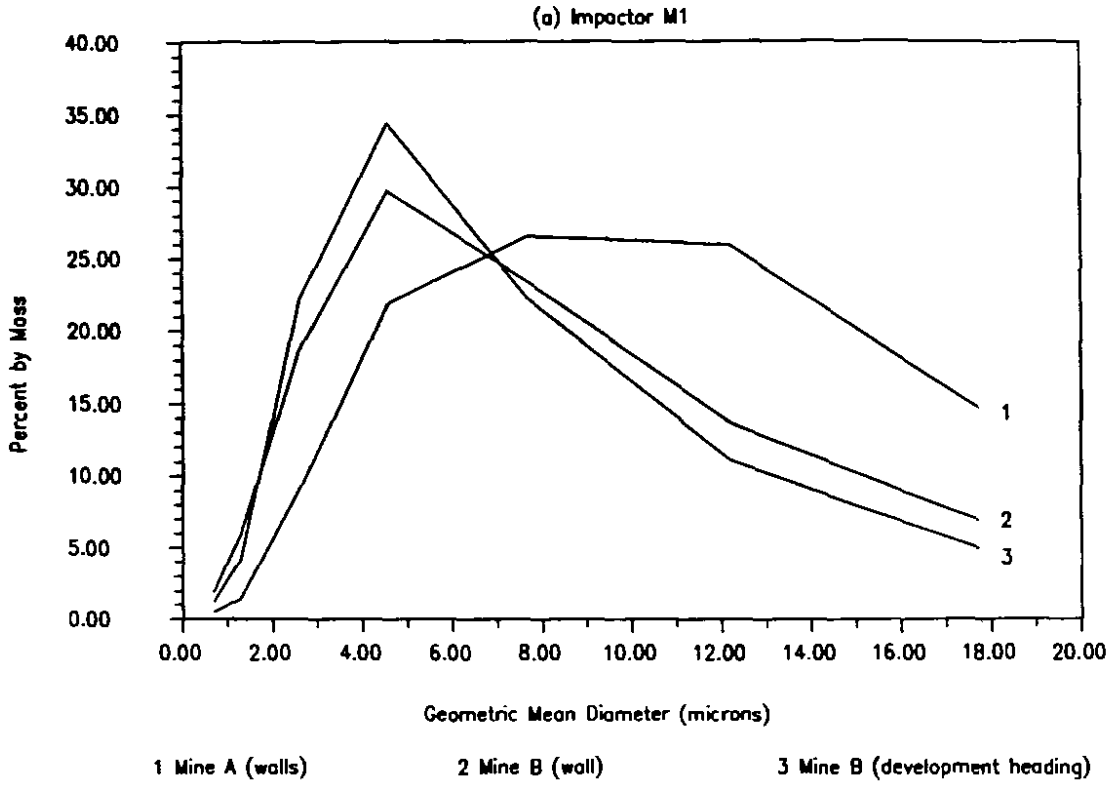


Figure 4. Relative respirable dust concentrations determined in Mine A and Mine B by the samplers (a) with the cascade impactor M1 and (b) with the cascade impactor M2.



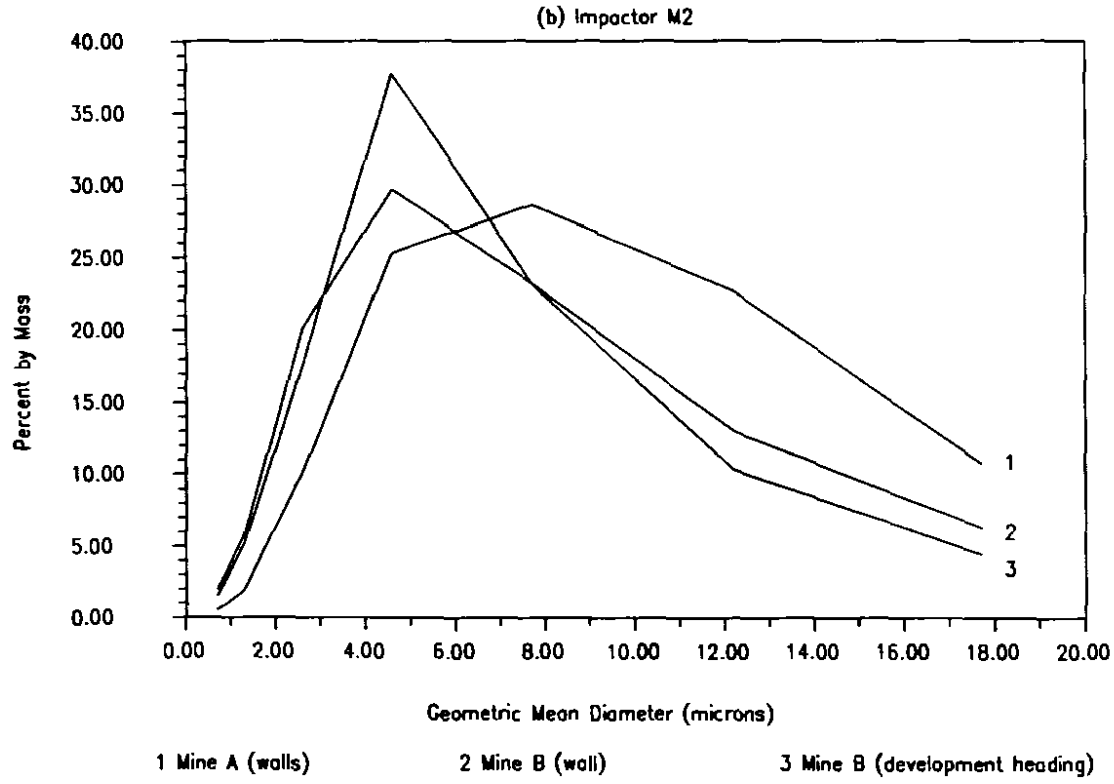


Figure 5. Average size distributions of airborne dust measured by (a) impactor M1 and (b) impactor M2 in Mine A and Mine B.

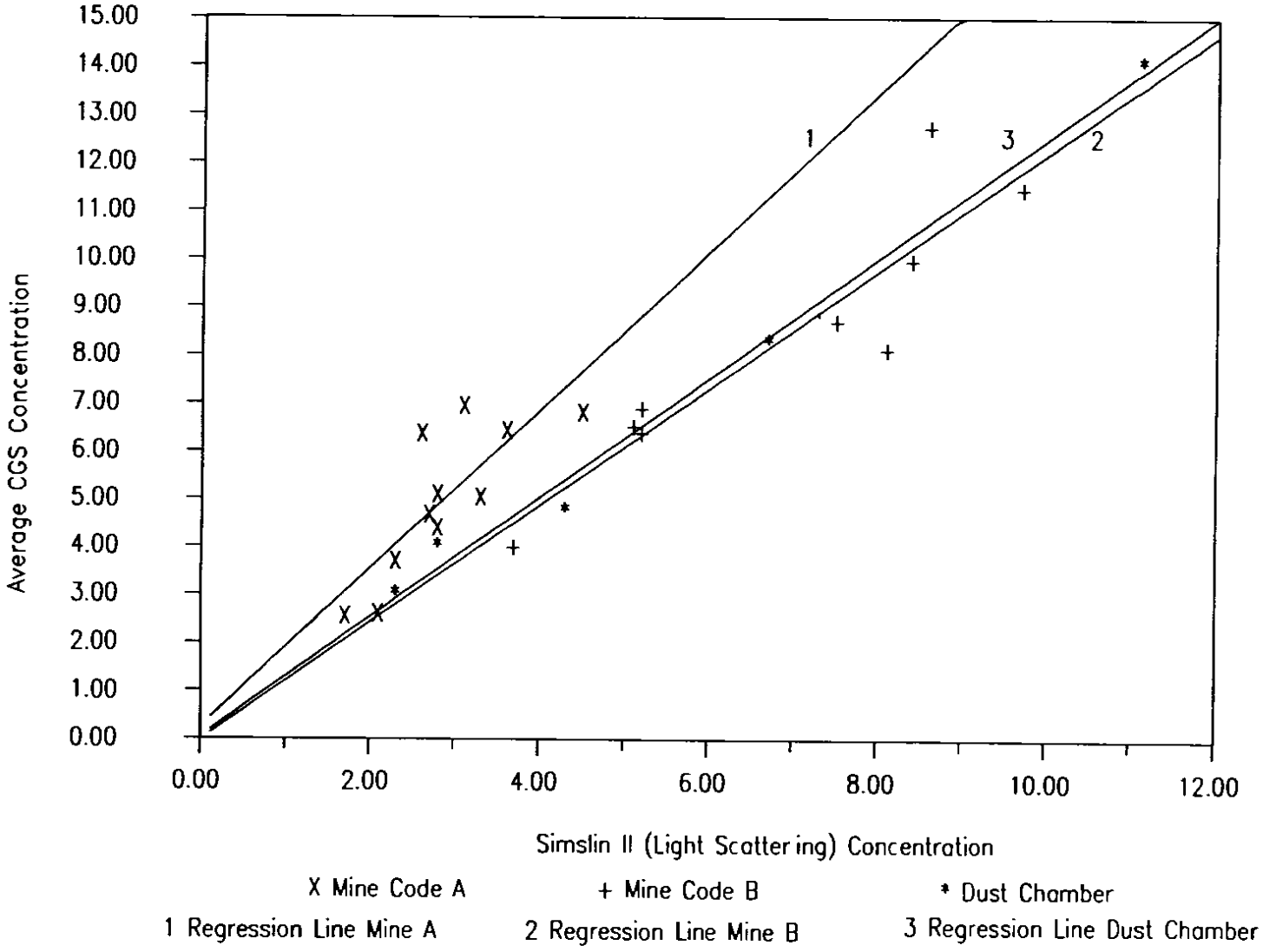


Figure 6. Linear relationships between the concentrations (in an arbitrary unit) determined by SIMSLIN II and by Casella Gravimetric Samplers (CGS) in Mine A, Mine B and in the dust chamber.

Measurements of Respirable Dust by Real-Time Dust Monitors

A factory-calibrated SIMSLIN II monitor was tested side-by-side with CGS at the control points of the longwalls of the two mines. The end of shift average concentrations determined by the SIMSLIN's light-scattering system were found to be less than the CGS concentration with an average concentration ratio 0.60 for Mine A and 0.81 for Mine B. The linear relationships between the SIMSLIN's concentration and those measured by CGS are depicted by Figure 6 for Mine A, Mine B, and the dust chamber. The regression line representing Mine A is markedly different from the line obtained in Mine B. The line derived from the tests in the dust chamber appears to be similar to the line representing Mine B.

Three shift-length tests have been carried out in Mine A in order to compare the dust concentrations determined by TM-DATA with that determined by SIMSLIN II and by CGS. Table II shows the end-of-shift average concentration relative to the CGS concentration obtained in two wall sections. The relative concentrations determined at the wall section (coded WF) by the two monitors were almost identical, but in the test at the wall WE, the relative concentration by TM-DATA was greater than that measured by SIMSLIN II. Although there are some differences at the beginning of some coal cutting periods, the concentration recordings by the two monitors appear similar (Figure 7). When a shearer started coal cutting, TM-DATA recorded a concentration peak higher than the peak registered by SIMSLIN II; such a difference may characterize TM-DATA which does not employ an elutriator as a particle size selector. TM-DATA does not have a time delay due to the fact that it has no pump and consequently no internal tubing.

DISCUSSIONS

The measurement of respirable dust concentrations by gravimetric techniques is subject to variations in the sampling flow rate of pumps, the handling of filters, and in the filter weight change caused by humidity or static electrical charges. The sampling systems, if used for personal sampling instead of fixed position sampling, are subject to more variations due to the additional movements and impacts associated with mounting the devices on mobile miners. A Casella Gravimetric Sampler's flow rate may deviate as much as 6.2%. The flow rate deviation of a personal gravimetric sampler has a maximum value of 7.1%. The overall filter weight change has been as high as 0.34 mg for a change in laboratory relative humidity of 20%.

The precision of respirable dust concentration measurements by using one type of gravimetric sampler increases with increasing mine dust levels. For the Casella Gravimetric Samplers (CGS) and the personal samplers with Casella cyclones, the percent variation may take a value as low as 1% to 3% in mine locations with a dust level above 6 mg/m^3; below 6 mg/m^3 the variation could reach a value as high as 10%. Thus, any concentration value determined by a given type of gravimetric dust sampler relative to the CGS is subject to greater percentage errors when it is employed in a lower dust level. However, the results described in this paper indicate that sucb variability also depends to some extent on the mine type. Retreat longwall mining generates airborne dust mainly by the shearer's cutting and face support movement while advance longwall mining generates the dust by the coal cutting activity as well as various activities in the headgate and the tailgate. It has been shown that dust particle size distributions are different between the two mines. Furthermore, the two mines work different coal seams and thus the nature of the airborne dust particles (e.g. mineralogical composition) may vary from one mine to the other.

When a cascade impactor is used as the size selector for the measurement of respirable dust concentration, there is evidence that the measured relative concentration varies nonlinearly with increasing mine dust level. This change in the relative respirable dust concentration has been explained elsewhere.[1] The linear relationships between the SIMSLIN's data and that obtained by the CGS in the two mines are different and thus indicate that the nature of the dust particles in addition to size distribution may also play an important role in the differences resulting from the concentration measurements made by using a light-scattering technique.[2]

Errors introduced in the measurement of respirable dust concentration imply uncertainty in assessments of the risk of pulmonary diseases in miners. This problem becomes more serious if the concentrations measured in a limited number of sampling shifts are to be used retrospectively for the evaluation of occupational dust exposure of miners. The activities of mechanized long wall mining have resulted in marked variation in shift-averaged concentration measured from time to time at the same wall section. Most of the past health studies in relation to long-term dust exposure were based on the dust levels measured by the CGS samplers, which have varying degrees of precision when used in different mine sites or in dust clouds with different dust particle size distributions. If any other type of gravimetric dust sampler were chosen to measure dust levels for the purpose of indirect risk estimation, the magnitude of errors in the estimation would be greater than that based only on the CGS measurement. Although the dust concentration measurement by a light-scattering technique provides information on instantaneous and time-averaged dust levels, the measured values may not indicate precise mass concentrations for the stated reasons. Thus those measured values are less useful for an exposure assessment. However, a real-time dust monitor is useful to evaluate relative change in dust level within a short period of time in a production shift and for determining the effectiveness of a dust suppression technique.

The following is an example to illustrate the effect of respirable dust concentration measurements on the assessment of health risk of a miner. If a mean coalface concentration is 4 mg/m^3 and if an overall error of 10% (i.e. $\pm$ 0.4 mg/m^3) were introduced by concentration measurements, the probability that a miner with no pneumoconiosis (in the International Labour Organization category 0/0) is classified into the category 2/1 or higher after 35 years of dust exposure would be overestimated by 0.0096 or be underestimated by 0.0082.[3]

With sound knowledge of the relative performance of the various samplers described, we shall routinely use for fixed position and personal sampling, the gravimetric samplers

Table II

Shift-Length Side-by-Side Tests of TM-DATA and SIMSLIN II in Two Longwalls of Mine A

Wall Code	Shift Code	Concentration Relative to the Average CGS Concentration	
		TM-DATA	SIMSLIN II
WF	#1	0.68	0.66
	#2	0.65	0.66
WE	#3	0.78	0.65

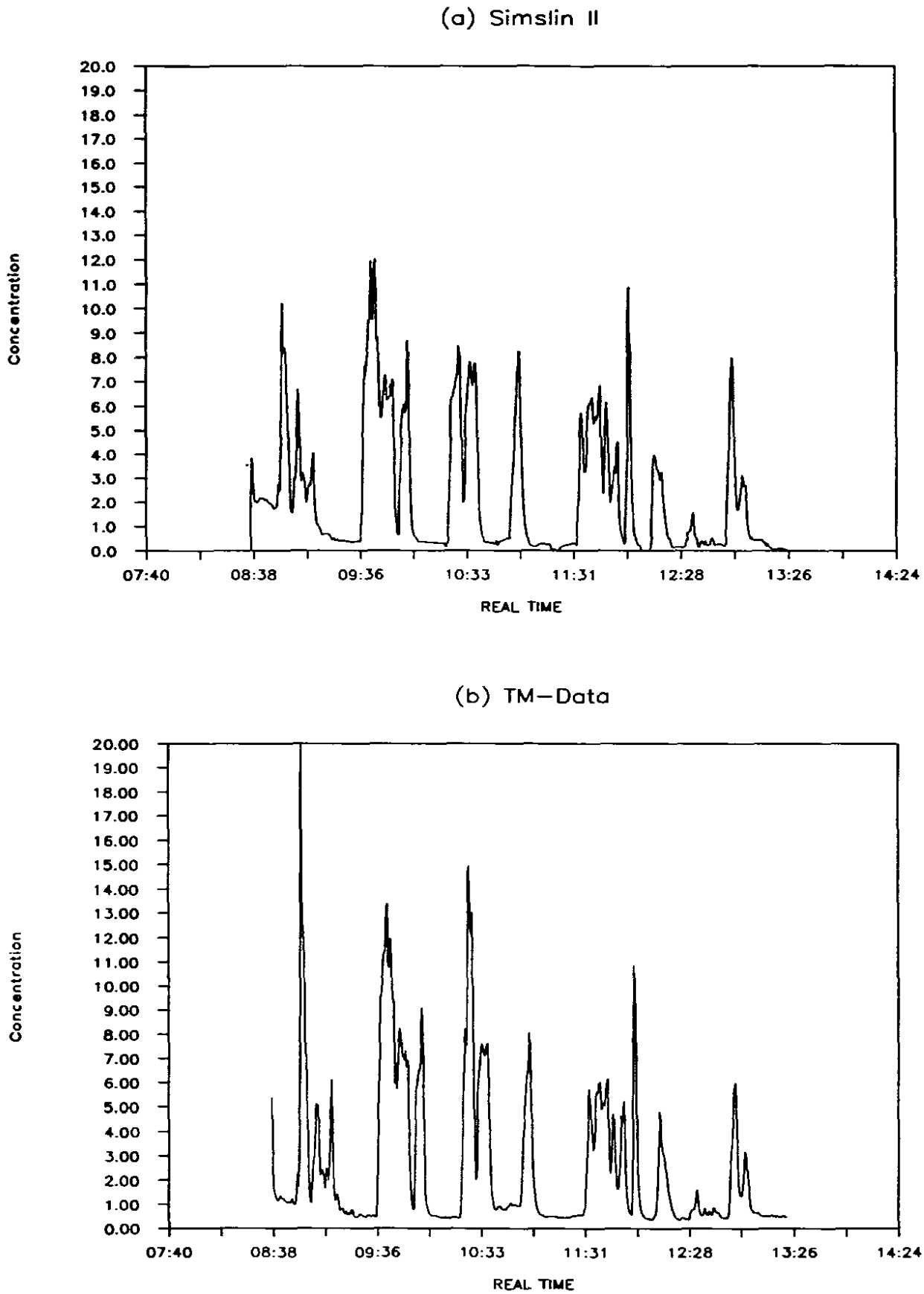


Figure 7. The shift-length concentration recordings (in an arbitrary unit) at the wall section WF of Mine A by (a) SIMSLIN II and by (b) TM-DATA. The time scales of (a) and (b) are in hours and minutes.

consisting of electronically controlled constant-flow pumps, Casella cyclones and glass fibre or the Millipore filters for respirable mass concentration measurement. Silver membrane filters have also been used for airborne dust collection for mineralogical analysis. Our dust research work will be directed more toward the assessment and promotion of dust source control technologies. For assessing the effectiveness of a dust suppression technique, a real-time dust monitor (SIMSLIN II or TM-DATA) supplemented by the gravimetric samplers chosen for our routine dust sampling work will be used.

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II

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