Chapter 33

CHARACTERIZATION OF FRESHLY GENERATED AIRBORNE QUARTZ DUST

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Abstract. A fresh dust generator was designed and built in order to study the agglomeration behavior and other characteristics of freshly generated airborne dust. The size distribution of the freshly generated quartz airborne dust produced by the generator was measured both directly in air and after dispersion in water. It was observed that same dust particles had an apparently coarser size distribution in air than in water, suggesting possible agglomeration of the dust particles. It was also observed that the size distribution obtained by a cascade impactor was very similar to the liquid dispersed size distribution, implying deagglomeration by the impactor. The agglomeration was confirmed by microscopic observations of particles in air and those collected on a microscope slide. The extent of agglomeration played a decisive role on the fraction of the dust actually becoming airborne.

It was also found that contamination of the airborne dust by the rolls of the crusher was almost twice as much as that of the product.

INTRODUCTION

For many years the problem of dust inhalation in underground mines has been of major concern in the mineral industries. During long exposure to high concentrations of dust, the workers inhale dust particles which may reach the lung tissue and cause irreversible scarring. Particles which are larger than 10 μm will usually settle in the air before inhalation. Even if they are inhaled, these particles will fall out of the air in the upper respiratory system before reaching the alveoli and can later be removed by mucous ejection. However, the particles which are less than 10 μm , referred to as respirable dust, do not settle in air even after very long times and are eventually inhaled by workers and might be harmful.

There are numerous data on the size distribution of the airborne dust in coal mines. However, almost all the data are based on the size distribution of the dust obtained either from the lungs of the deceased workers [Cartwright, 1965; Leiteritz et. al., 1965] or from the mines by depositing the dust on substrates [Corn et. al., 1972; Thakur, 1974; Brever, 1965; White, 1972; Kotrappa, 1972]. Even though this type of data provides information on the size distribution and shape of the primary particles, it does not shed light upon the actual state of agglomeration of these particles when they are actually in air. Therefore, it was necessary to study freshly generated dust in order to simulate fresh dust in mine air.

FRESH DUST GENERATOR

One objective of this investigation was to study the agglomeration and adhesion behavior of freshly generated dust. Since the surface properties of dust particles are known to change with age, it was necessary to produce dust from freshly broken particles. For this purpose a fresh dust generator was designed and fabricated. The device was a small roll crusher equipped with a feeding system for introducing material to be crushed. The airborne particles produced on fracture of the feed material were directed to flow into an observation chamber at the top of the rolls. An overall schematic diagram and some photographs of the generator are given in Figures 1 and 2. A roll crusher type device was chosen because the crushing occurs almost instantaneously and each particle undergoes crushing only once. Thus, the age of a dust particle is accurately defined. For the device shown in Figure 2, one roll was fixed in position and driven by an electric motor while the other was spring loaded and could be moved to adjust the gap between the rolls. To obtain fine particles in sufficient quantity, a gap opening of 0.1 mm was chosen. A size fraction of 10x16 Mesh was used as the feed material.

The feeding system consisted of a small vibratory feeder, a rheostat for changing the feed rate, a container for holding the material, and a feed pipe to carry the particles into the gap between the rolls. The rolls were enclosed in a plexiglass box in order to contain the large particles which might escape during the crushing process and to confine the dust in a small volume. During the operation, the rotation of the rolls

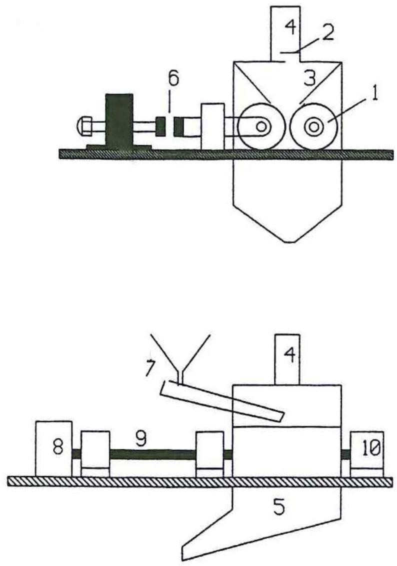

Figure 1. A schematic view of the fresh dust generator.

1-Rolls, 2-baffles to prevent unbroken particles from escaping, 3-partitions to direct the dust flow, 4-dust outlet, 5-chamber to collect crushed product, 6-spring mechanism, 7-feeding assembly, 8-motor, 9-shaft, 10-bearings.

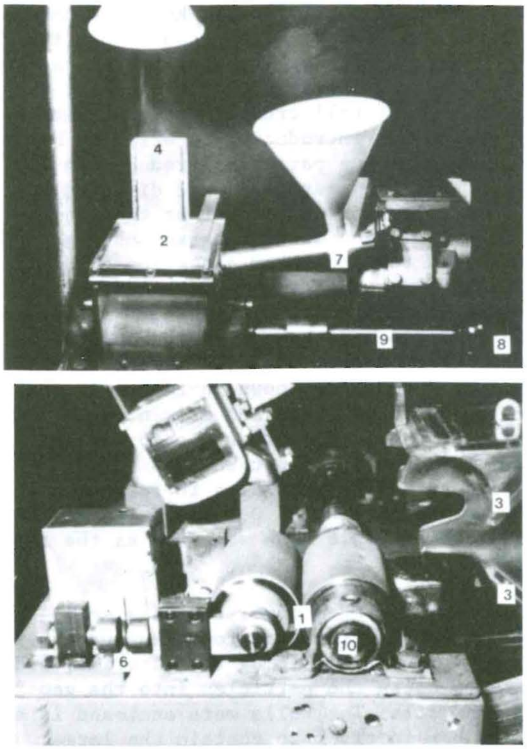

Figure 2. The fresh dust generator.

created an air flow which forced the dust to move upwards into the observation chamber (Figure 1). The observation chamber was equipped with two flat baffles located just above the rolls to prevent the coarser particles from entering the dust stream.

CHARACTERIZATION OF FRESHLY GENERATED DUST

Size distribution measurements were performed on the dust produced by the generator to characterize the airborne dust. Quartz was used for these preliminary experiments because of its homogeneity. The airborne quartz dust was characterized for:

1. the size distribution in air by:
   a) a light scattering device and
   b) a cascade impactor

2. the size distribution by light scattering after the dust was collected and re-dispersed in water.

The light scattering device was a Malvern Particle Size Analyzer (MPSA) Model 2600c. The cascade impactor used in the experiments was an Anderson Model 2000 which had 8 stages providing a size distribution range between 0 and 11.0 μm.

Size Distribution Measurements by the Malvern Particle Analyzer

Calibration of the Device. Calibration experiments were performed with narrowly sized fractions of copper beads and crushed quartz. The size range was 150 x 212 μm for the copper beads and 37 x 53 μm for the quartz particles.

For the measurements in air, the copper beads or the quartz particles were dropped into the optical path of the device whereas for the determination of size in liquid, the same particles were placed in a glass cell containing water and the size distribution was determined using the Malvern Size Analyzer in the liquid mode.

The results of these experiments are given in Figure 3 for the copper beads and quartz. As can be seen from the figure, almost identical size distribution curves were obtained for copper beads both in air and water. The d50 value for the measurement in air was 183.1 μm whereas it was 180.3 μm for the measurement in water. The difference was very small compared to the size of the particles and should be considered normal for these kinds of measurements. For the quartz particles, however, there was a slight difference between the two size distributions. The d50 values are 58.9 μm for water and 66.5 μm for air. This difference may be due to agglomeration between the quartz particles in air or due to the shape effect which is manifested differently in different media such as water and air. In any case the difference between the two size distributions was relatively small, and therefore, it was concluded that the

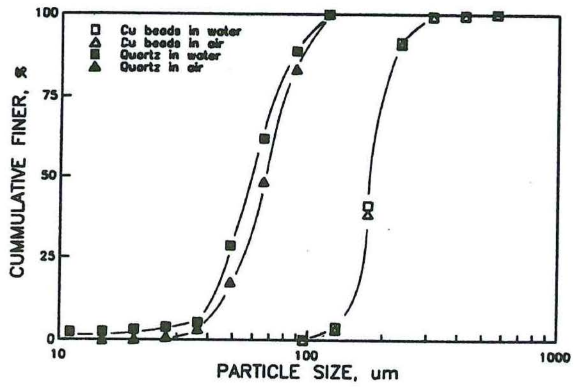

Figure 3. Calibration curves of the MPSA with Cu beads and quartz.

Malvern Particle Size Analyzer gave reasonably similar results for the same sample in different media.

Airborne and Liquid-Dispersed Size Distributions. To determine the size distribution of the airborne dust, the generator was placed such that the observation chamber was between the detector lens and the laser source of the Malvern Particle Size Analyzer. With this arrangement the dust leaving the outlet would pass through the laser beam when the crusher was turned on and the particle size distribution could be determined in-situ (Figure 4).

A filter assembly was mounted above the laser beam for collecting the particles for further analysis. The filter used was a Nuclepore Membrane Filter with an effective pore size of 0.2 μm and was held in place by an aluminum filter holder. The outlet of the filter holder was connected to a vacuum pump. A flowmeter was added to the system to control the amount of the air flow through the filter.

After the airborne size distribution measurements were completed, the generator was turned off and the sample collected on the filter was dispersed in water for the size distribution measurements. At this stage, dispersing the filter load properly was important to obtain information about the size distribution of the primary particles. A 0.1 % solution of Sodium-hexametaphosphate (Calgon) was used as the dispersant and the solution containing the particles was placed in an ultrasonic bath in order to enhance the dispersion of the particles. Following the ultrasonic treatment, a drop of the solution was placed on a microscope slide and observed under a microscope to determine if the dispersion procedure had to be continued. If the dispersion was completed, a sample of this solution was placed in a glass cell containing water for the size distribution measurements in liquid.

The in-situ and liquid-dispersed size distributions of the quartz dust obtained as explained above are given in Figure 5. It can be

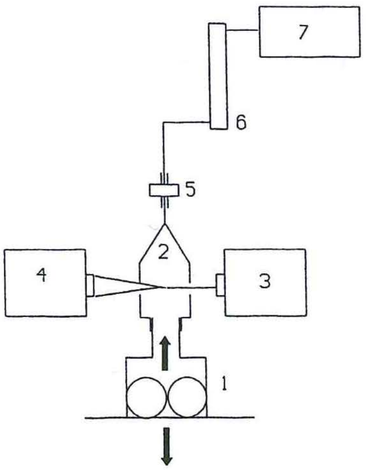

Figure 4. A schematic view of the set-up to determine size distribution of airborne dust by MPSA.

1-The dust generator, 2-observation chamber, 3-laser source, 4-detector lense, 5-filter assembly, 6-flowmeter, 7-vacuum pump.

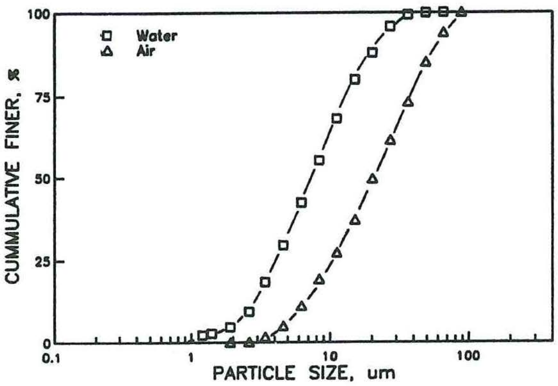

Figure 5. Airborne and liquid dispersed size distribution of quartz dust by MPSA.

seen that there is a large difference between the two size distributions. The d50 value for the dust particles collected on the filter and re-dispersed in water is 7.3 μm whereas it is 20.3 μm for the airborne particles measured in-situ. This result was rather surprising since both of the size distribution measurements were made essentially on the same sample of particles. The difference raises the possibility that the particles were agglomerated when they were airborne. If this was true, the size distribution of the airborne quartz particles would be shifted to larger sizes as was observed. However, when the particles were dispersed in water, the agglomerates would break and the size distribution would be a characteristic of the primary particles that constitute the agglomerates. Even though this hypothesis gave a plausible explanation for the observations, more experiments were deemed necessary in order to confirm that the particles were agglomerated while they were airborne.

Size Distributions with Cascade Impactor

To determine the size distribution of airborne quartz dust by cascade impactor a similar experiment was conducted with the same material. In this case, the dust leaving the generator was directly sent into a cascade impactor instead of the filter assembly.

The results of the experiment are given in Figure 6. For comparison, the size distribution data obtained by the MPSA for the same airborne quartz dust is also included. As can be seen, the d50 value of the airborne quartz particles was approximately 7.0 µm for the cascade impactor which is very close to the d50 value of 7.3 µm obtained for the dust in water. These data support the previous work done by other researchers. Dumm (1983) showed that airborne coal dust gives similar size distributions with a light scattering device using a sample dispersed in water and with a cascade impactor using an actual airborne sample.

If the hypothesis of particle agglomeration is valid, a probable explanation is that the agglomerates are fluffy and break readily due to the very high shear occurring in the impactor. Further studies were needed to confirm the extent of agglomeration, if any, in airborne dust.

Chemical Composition of the Airborne Dust

A semi-quantitative analysis of the feed material, airborne quartz dust, and crusher product was obtained using a spectrophotometric method. The results are given in Table 1. The table suggests that the composition of the rolls may affect the composition of the crushed product and the airborne dust. As one can easily see the major contaminants are Fe, Cr, Ni, Mo, Cu, and Mn which are also the main elements of the rod material out of which the rolls are made. The presence of these elements in the feed in small amounts is probably due to previous treatments of the material. The contamination is more significant for the airborne dust compared to the crusher product. This is most probably due to the fact that the airborne dust particles are very fine and have very large specific surface area, causing greater exposure between the dust particles and the crusher rolls or they are mostly produced at the region of contact between a particle and the roll surface.

AGGLOMERATION OF AIRBORNE DUST PARTICLES

A series of tests was conducted in order to obtain direct evidence for the presence of agglomerates in the airborne dust. One set of experiments involved optical and scanning electron microscopy on particles deposited on glass substrates placed in the dust cloud emerging from the crusher. In addition, the dust particles were observed directly while they were airborne using a high speed video recorder-optical microscope system (Spin Physics Model SP 2000 High Speed Motion Analyzer).

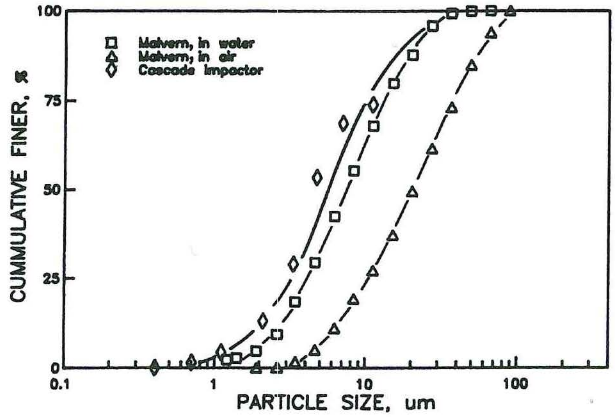

Figure 6. Size distribution of quartz dust by the MPSA and Cascade impactor.

Table 1. Analysis of the quartz material before and after crushing

Element	Feed (ppm)	Dust (ppm)	Product (ppm)	Rolls (%)
Si	Major	Major	Major	0.36
Fe	30	2000	1000	Major
Cr	<10	600	400	18.23
Ni	<20	600	300	8.63
Cu	< 5	100	100	0.31
Mo	<20	200	100	0.26
Mn	< 5	200	80	1.36
Mg	<50	<50	<50	NA*
Al	20	100	100	NA
Ca	<50	<50	<50	NA

*NA:Not available

Optical Microscopy Studies

In order to prepare a suitable sample for the optical microscopy study, a microscope slide was passed over the dust outlet of the generator very rapidly so as to have one side of the slide face the upcoming dust flow. The exposure time was kept very short in order to prevent secondary deposition on the slide which could create some agglomeration. The slide containing the dust particles was examined under a microscope and some photographs are shown in Figure 7 a and b. Even though there were some indications of agglomerated particles in these photographs, the size of the agglomerates seemed to be smaller than those in the experiments using the Malvern Particle Analyzer. This difference could be due to the fact that the agglomerates were fluffy and shattered when they impacted on the surface of the slide. To confirm this hypothesis, the above experiments were repeated using a slide coated with a high-vacuum grease. The coating was obtained by spraying the grease over the slide and then wiping it off with a lens tissue so as to leave a very thin and uniform film on the surface. It was expected that the grease film would prevent

Figure 7. Airborne quartz dust particles or an ungreased microscope slide.

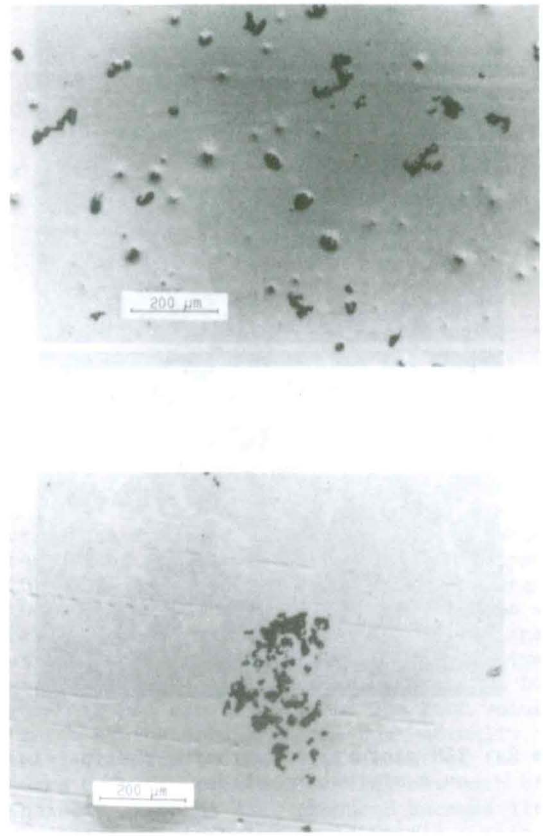

Figure 8. Airborne quartz dust particles on a greased microscope slide.

the large agglomerates from breaking apart during impaction.

The slide was exposed to the dust flow as in the previous experiment and more pictures were taken. The photographs show that the agglomerates are larger than those on the ungreased glass surface (Figure 8 a). In some cases the isolated wreckage of a broken agglomerate could be distinguished easily as shown in Figure 8 b.

To achieve better resolution with a greater depth of focus, the agglomerates were also examined with a scanning electron microscope.

Scanning Electron Microscopy Studies

The sample preparation procedure was similar to that used in the optical microscopy except that the grease film coating had to be eliminated since it would evaporate in the high-vacuum environment of the instrument. Also, the substrate had to be gold coated in order to provide conductivity for the electron beam to pass through the sample. An examination of the sample with a scanning electron microscope clearly showed that particles of different size and shape came together to form agglomerates. Some illustrative pictures are given in Figure 9. Surprisingly, there were almost no free particles on the substrate even though they had greater chances to adhere to the surface due to their very small sizes. These studies showed that all the particles were in fact agglomerates of very fine and coarser particles. These observations were in agreement with the results of the characterization experiments where the size distribution of the airborne quartz dust was much coarser than that obtained following dispersion in water. However, both the optical microscopy and the SEM studies were conducted using static samples whereas the system being examined consisted of freely moving airborne particles. Therefore, further studies were carried out to observe the particles while they were actually airborne.

High-Speed Motion Analysis & Optical Microscopy Studies

A high-speed motion analysis system coupled with a long focal length optical microscope was used to observe the dust particles in air. It was possible to take pictures at a speed of 2000 frames/second with the system used. The drawback of the system was that no internal details of agglomerates could be observed. The reason was

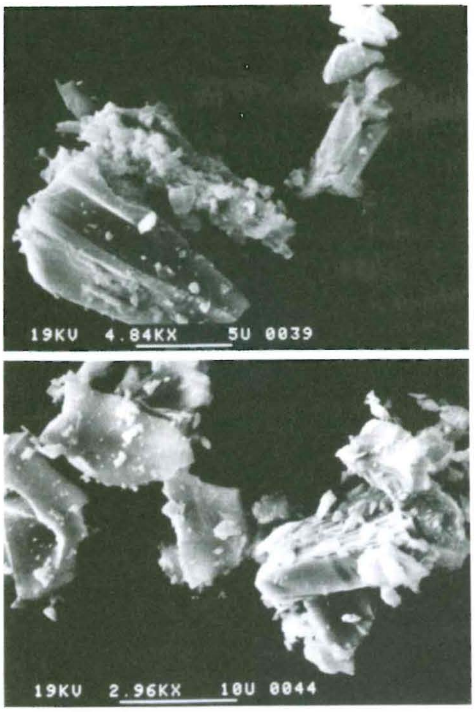

Figure 9. SEM pictures of airborne dust particles on a microscope slide.

that the dust flow was between the objective of the camera and the light source, providing only an image of the outer edges of the particles. Under these circumstances, it was relatively easy to distinguish agglomerates by their shape since the previous optical and scanning electron microscopy studies had furnished enough information on the shape of the quartz dust particles and their agglomerates. The broken quartz particles had clear angular shapes with straight edges whereas the agglomerates were irregular in shape.

More than one-hundred-thousand frames were recorded on the tapes. It was clearly seen in these recordings that the particles coming out of the dust generator were mostly agglomerates due to their distinct shapes which could only belong to an agglomerate (Figure 10).

DUST PRODUCED ON BREAKAGE OF QUARTZ

Airborne Dust

In this part of the study, the amount of airborne dust produced by the generator was measured at different feed rates. For this purpose an arrangement similar to that given in Figure 4 was utilized, except that the filter assembly was placed directly above the dust outlet, excluding the particle size analyzer, and the dust leaving the crusher was directed to the filter with a funnel. Nuclepore membrane filters of 0.2 μm effective pore diameter were used for the dust collection and an auxiliary air flow of 2 L/min was supplied by the vacuum pump.

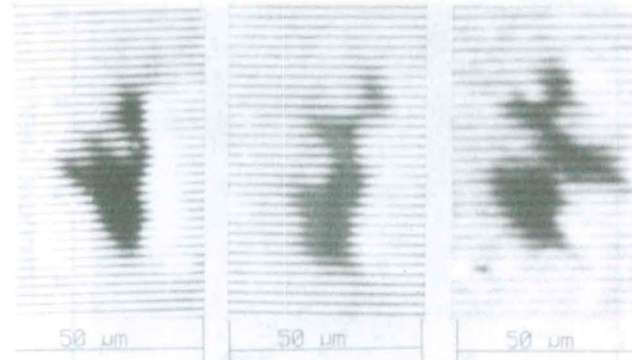

Figure 10. High Speed Motion Analyzer pictures of airborne quartz agglomerates.

For calibrating the feeder, a known amount of sample was placed in the container of the feeder and fed to the crusher at a fixed rheostat setting. The time elapsed for feeding this amount of material was measured. Dividing the amount of the material fed to the generator by the elapsed time gave the feed rate at that setting for the material used. This procedure was repeated for different settings to obtain the calibration data for quartz.

A set of experiments was carried out with quartz at the feed rates determined as explained above. During the crushing action the airborne dust produced was collected on the filter placed on top of the Fresh Dust Generator for one minute and, then, weighed. Since the sampling time was the same for each feed rate, the amount of dust collected in each case would provide information about the airborne dust produced on breakage by the material being crushed. The Airborne Dust Produced on Breakage (ADPOB) value is defined as the ratio of the airborne dust collected on the filter to the amount of feed to the crusher. The results of these experiments are given in Figure 11. It can be seen from the figure that there is an almost linear relationship between the feed rate and the amount of the airborne dust produced. The slope of the lines in Figure 11 gives the ADPOB value in units of milligrams of dust produced per gram of feed material and are given in Table 2. The table shows that quartz had an average ADPOB value of 1.4%. That is, when 100 grams of quartz material is crushed in the generator, about 1.4 grams will become airborne dust. The fact that the gentle air stream inside the box of the Fresh Dust Generator was able to carry this portion of the dust up to the filter placed on top of the crusher was the reason for this dust to be defined as airborne.

Total Dust

Some additional experiments were conducted to better understand the mechanisms which promote the production of airborne dust during the crushing action in the generator. A given amount of sample was crushed in the generator at a feed rate

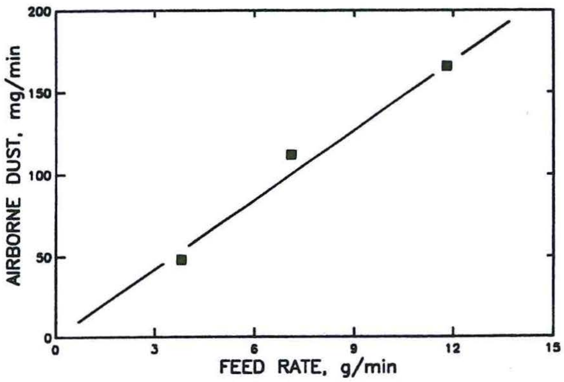

Figure 11. Amount of airborne quartz dust produced as a function of feed rate.

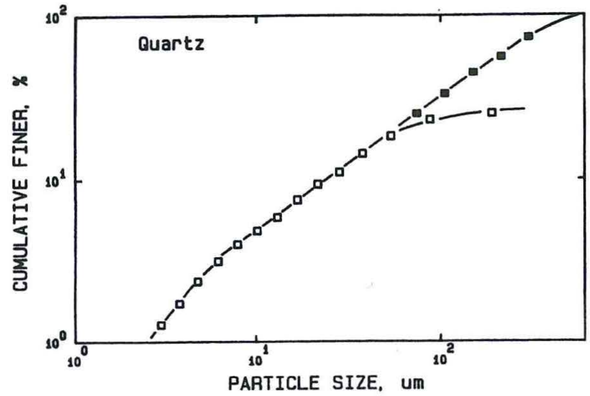

Figure 12. Size distribution of the product from the Fresh Dust Generator.

Table 2. **Airborne dust produced on breakage for quartz**

Feeder setting	Feed rate (g/min)	Average Rate (mg/min)	Dust Prod. ADPOB* (%)	ADPOB (%)
40	3.75	47.67	1.27	
60	7.14	111.50	1.56	1.41
80	11.81	165.83	1.40	

(*)ADPOB = Amnt. of airborne dust produced*100 / Amnt. of material fed to crusher

setting of 40 for each material. The size distribution of the dust produced was determined both in air and water using the procedure described previously. At this feed rate the d50 value is 7.3 μm in water and 13.1 μm in air. Similarly the d90 value is 22.0 μm in water and 35.0 μm in air.

The crusher product was also collected and subjected to size analysis by sieving down to 200 mesh (75 μm). The -200 mesh fraction was dispersed in water and analyzed using the Malvern Particle Size Analyzer. The Malvern size distribution data were normalized for combination with the sieving data. The results are presented in Figure 12.

At this point it is necessary to define the size of the particles becoming airborne for different materials. As stated above, 90% of the primary particles reaching the filter were less than 22.0 μm . Therefore, it is reasonable to define 22 μm as the limiting size for the quartz dust to become airborne. The amount in the crusher products finer than this size, on the other hand, is 9.4% This means that, when 100 grams of quartz is crushed, there will be 9.4 grams of material in the product which is less than the limiting size described above. In addition to this, there is also a certain amount of dust becoming airborne and collected by the filter. According to Table 2, this amount is 1.4%. Therefore, one can define a Total Dust Produced on Breakage (TDPOB) which is the sum of these two entities and corresponds to 10.8%. That is, the TDPOB value for a material is the ratio of the total amount of airborne size fraction produced to the amount of feed crushed. By using this information, another descriptive parameter which is the Fraction of Airborne Dust Released (FADR) can be defined. The FADR value is the ratio of the amount of the dust actually becoming airborne to the total amount of the airborne dust fraction and defines how much of the potentially airborne dust produced becomes literally airborne. This value is 13.0% for quartz and it is easy to see that it can simply be obtained by dividing the ADPOB value by the TDPOB value. Figure 13 gives the TDPOB and FADR values and the way they are calculated using the information given above. The same method can be used to calculate the dust production potentials of other materials such as coals or their mixtures. Indeed, this has been done extensively in the Masters thesis which is the basis of this paper [Polat, M.] and it was seen that the ADPOB, TDPOB, and FADR values change significantly for different materials and the FADR value is greatly affected by the extent of agglomeration among the airborne particles. This matter, however, will be discussed in detail later in another paper.

SUMMARY

Characterization experiments were conducted with quartz dust produced by a fresh dust generator of roller crusher type. The generator was designed to obtain fresh airborne dust which would resemble the dust in a mine environment. Preliminary experiments suggested that the airborne dust particles may be agglomerated since the same quartz dust had a larger size distribution in air than after redispersion in water. The presence of agglomerates was confirmed in further experiments where the agglomerated dust particles were photographed both on a microscope slide and in air.

Subsequent studies showed that a cascade impactor gave similar size distribution to the liquid-dispersed size distribution. This could

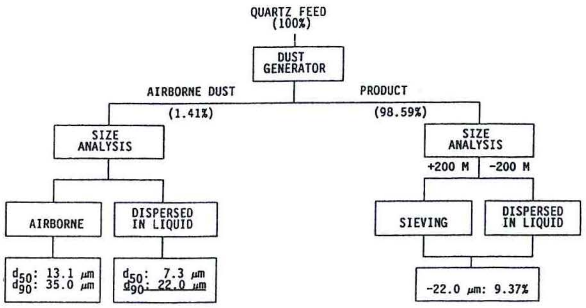

Figure 13. Airborne dust production behavior of quartz crushed in the Fresh Dust Generator.

Airborne Dust Produced on Breakage
(ADPOB): 1.41%
Total Dust PRoduced on BReakage
(TDPOB): 1.41 + 9.37 = 10.78%
Fraction of Airborne Dust Released
(FADR): 1.41*100/10.78 = 13.1%

only be explained by the breakage of the fluffy agglomerates due to high shear occurring in the impactor.

It was also observed that contamination of the airborne dust from the rolls of the crusher was more than that of the product. It was suggested that the production of the very fine dust particles occurred at the region of contact between the roll surface and a feed particle.

In another set of experiments the amount of actual airborne dust relative to the amount of feed and to the amount of the airborne size fraction in the total crushed product was studied. It was found that for quartz, about 1.4% of the total material and 13.0% of the potentially airborne dust produced actually becomes airborne.

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REFERENCES

Brever, H., "Size Distribution of Dust from Coal Mines and its Influence on the Results of Gravimetric Measuring Processes with and without Size Selection Discussion", Inhaled Particles and Vapors, Vol. II, Ed. by C. N. Davies, Proceedings of the International Symposium Organized by the British Hygiene Society, Cambridge, September, 1965, pp. 549-560.

Cartwright, J., "Airborne Dust in Coal Mines", Inhaled Particles and Vapors, Vol. II, Ed. by C. N. Davies, Proceedings of an International Symposium Organized by the British Hygiene Society, Cambridge, September, 1965, pp. 393-408.

Corn, M. and et. al., "Physical and Chemical properties of Respirable Coal Mine Dust", U.S. Bureau of Mines Open File Report 50-73, July, 1972.

Dumm, T., "An Evaluation of Techniques for Characterizing Respirable Coal Dust", M.S. Thesis, The Pennsylvania State University, 1983.

Kotrappa, P., "Shape Factors for Aerosols of Coal, UO2, and TiO2 in Respirable Size Range, Assessment of Airborne Particles", Ed. by T.T. Mercer, A Proceeding Publication of the Third Rochester International Conference on Environmental Toxicity, Rochester, New York, 1972.

Leiteritz, H., Einbrodt, H.J., and Klosterkotter, W., "Grain Size and Mineral Content of Lung Dust of Coal Mines Compared with Mine Dust", Inhaled Particles and Vapors, Vol. II, Ed. by C. N. Davies, Proceedings of an International Symposium Organized by the British Hygiene Society, Cambridge, September, 1965, pp. 381-391.

Polat M., "Characterization of Freshly Generated Airborne Dust", M.S. Thesis, The Pennsylvania State University, 1990.

Thakur, P.C., "Mass Distribution of Respirable Dust Particles from U.S. Coals", Colliery Guardian, Vol. 222, No. 7, July, 1974, pp. 236-239.

White, E.W. and De Nee, P.B., "Characterization of Coal Mine Dust by Computer Processing and Electron Microscope Information", Annals New York Academy of Science, Vol. 200, December, 1972, pp. 666-676.

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