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Formation of Airborne -Respirable Dust at Belt Conveyor Transfer Points

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A laboratory study of the formation of airborne respirable dust by the dropping of broken bituminous coal from a belt conveyor is described. It was found that about 10% of the respirable dust adhering to the broken coal becomes airborne owning to dislodgment upon impact. The specific formation of airborne dust is correlated empirically with the volume fraction of the falling coal, which is determined by the belt speed, the thickness of the coal layer on the belt surface, the material density, the bulk density, the angle of repose, the size of the broken coal, and the height of fall. Results are interpreted in terms of the shock dislodgement of dust particles adhering to the broken coal, and the dispersion of the dislodged particles by the surge of air from the space gaps in the impacting pieces.

Introduction

ALTHOUGH CUTTING AT THE FACE is probably the main source of airborne respirable dust in underground coal mining, other operations such as belt transfer and loading also contribute to the formation of the airborne dust. Techniques to control the formation of airborne dust at these secondary sources therefore must also be examined.

Over the years, various dust enclosures and collectors for transfer operations have been examined.[1,2] Major emphasis has been given to maintaining a balanced pressure inside the enclosure so that dusty air neither leaks out nor more than necessary needs to be handled by the collector. Enclosures for permanent types of locations such as at processing plants are reported to be quite successful.[3,4] Underground mining operations require a more mobile and smaller enclosure/collector ensemble; arrangements of this type are now being studied.[5]

Detailed investigations of phenomena involved in the formation of airborne dust during droping as at a transfer point are lacking. Drop tests have been used in evaluating friability,[6] breakage,[7] and dustiness[8] of coals. For example, Knight[8] found that about 10^{10} respirable particles were dispersed into the air when 1500 gm of broken coal was dropped from a triggered bucket at a height of 8 feet. No attempt, however, has been made to correlate the formation of airborne respirable dust with operation of a belt conveyor.

An earlier study[9] investigating the amount of respirable dust adhering to run-of-face broken coal indicated that an 8-foot drop of broken coal did not produce appreciable fracture and therefore did not generate an appreciable amount of new respirable dust. However, that study also indicated that about 3.7 gm of respirable dust adheres to the surface of 1 pound of the broken coal. Thus, enough respirable dust adheres to 16 pounds of broken coal to contaminate 1,000,000 cubic feet of ventilating air up to the 2-mg/m^3 level, if it were to become airborne. The potential danger of secondary handling operations as a source of airborne respirable dust is evident.

This report describes a laboratory investigation of the formation of airborne dust from ordinary broken coal during a dropping op-

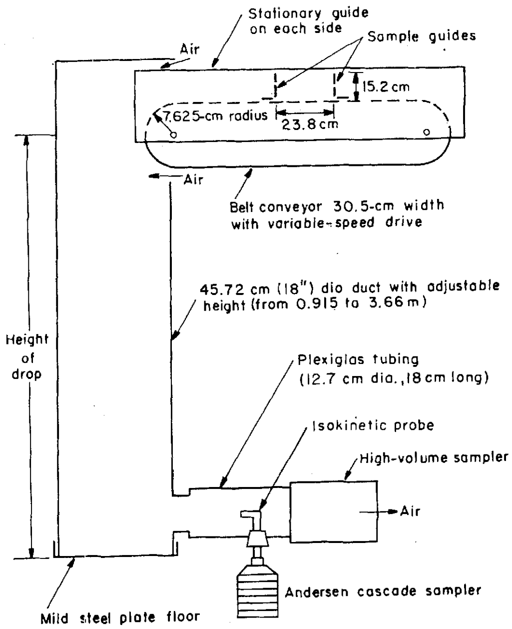

Figure 1. Drop tester.

eration such as occurs at a belt transfer point in order to determine the importance of a drop operation as a dust source. This work is a part of the research program being conducted by the Bureau of Mines to develop advance technology oriented toward the control of respirable dust in underground coal mines and thus toward the elimination of coal workers' pneumoconiosis.

Experimental Technique

Dislodgment of respirable dust adhering to the surface of broken coal was evaluated by the drop-test technique. An enclosed drop tester combined with a laboratory-size belt conveyor was used (Figure 1). The conveyor was driven by a motor through reduction gears to provide predetermined constant belt speeds. The conveyor could be set at different heights to provide falls of 30.5 cm (1 foot) to 3650 cm (12 feet). No wall impact of falling coal could occur in the drop tester.

A run-of-face sample of bituminous coal of Pittsburgh seam (coal E in reference 9) was obtained at the face. The coal was cut during a dry operation and was placed in plastic bags to maintain its natural surface

TABLE I

Size Distribution of Run-of-Face Sample

Size Ranges	Sieve Fractions (% mass)
⩾4 inches	1.145
2–4 inches	6.663
1½–2 inches	5.262
1–1½ inches	10.29
¾–1 inch	8.24
½–¾ inch	12.05
⅜–½ inch	8.24
¼–⅜ inch	10.36
2380–6350 μm	18.65
1190–2380 μm	7.97
590–1190 μm	4.48
297– 590 μm	2.81
149– 297 μm	1.61
74– 149 μm	0.96
44– 74 μm	0.44
⩽44 μm	0.83

moisture of about 0.8% as measured by a Soiltest Speedy Moisture Tester.* The size distribution was determined by sieve analysis (Table I). For a drop experiment, a coal sample was prepared by combining portions of each sieve size in the fractions given in Table I. New samples were used for each drop experiment. A coal sample had a mean lump size of 1.425 cm, a bulk density of 0.99 gm/cm^3, material density of 1.34 gm/cm^3, and an angle of repose of 40°.

Air at 1.95 m^3/min (68.7 cfm) was drawn through the drop tester by a Staplex high-volume sampler, and the airborne dust was collected by the filter in the sampler. An Andersen cascade sampler with isokinetic sampling was used to determine the size distribution of the airborne dust. The air flow of 77.6 cm/sec (153 fpm) through the vertical duct approximates the air velocity by the working face of underground coal mines.

The dust collected on the filter and at each of the six stages of the collecting plates in the Andersen sampler was weighed. The total airborne respirable dust was determined from the gross airborne dust collected by the filter

*References to specific brands in this paper are made for identification only and do not imply endorsement by the Bureau of Mines.

multiplied by the percentage of the respirable portion determined by the Andersen sampler. Sampling time was varied from 10 seconds for a 30.5-cm drop height to 2 minutes for a 366-cm height to provide about six air exchanges in the vertical duct for each test, so as to collect all airborne dust formed by dislodgment.

Wall deposition was checked for the most severe case, which involved an 8.86-gm/cm^2 conveyor loading and 366-cm drop height. Eighteen 5 × 5-cm aluminum plates were vertically attached to the inside surface of the vertical duct at six level locations, 15 cm apart from floor up. The deposited mass was weighed, and particle sizes were examined under a microscope. The total wall deposition of respirable dust was found to be less than 0.1 mg, which was insignificant with respect to the total of 1.6 gm of airborne dust collected by the Andersen cascade sampler.

Results

Three variables were investigated: drop height, belt loading, and conveyor speed. The experimental results (Table II) showed that the specific formation of airborne dust, R, increased with the increase of drop height but decreased with increase of belt loading

TABLE II
Experimental Results

1 Height of Material Fall, H (cm)	2 Belt Load, m (gm/cm^2)	3 Thickness of Coal Layer, h (cm)	4 Belt Speed, u_b (cm/sec)	5 Mean Cross-sectional Area of Discharge, A_d (Appendix 1) (cm^2)	6 Fraction Void, Φ (Appendix 2)	7 Total Respirable Dust Airborne (gm)	8 Specific Formation of Airborne Respirable Dust, R[a] (10^{-3})
30.5	3.80	3.80	11.5	43.25	0.810	1.54	0.566
	3.80	3.80	23.0	63.10	0.740	1.34	0.492
	3.80	3.80	46.0	162.5	0.740	1.33	0.490
	8.86	8.84	11.5	54.90	0.652	1.63	0.257
	8.86	8.84	23.0	109.5	0.652	1.76	0.277
	8.86	8.84	46.0	219.0	0.652	1.64	0.258
91.5	3.80	3.80	11.5	43.25	0.891	3.97	1.460
	3.80	3.80	23.0	63.10	0.850	1.93	0.710
	3.80	3.80	46.0	126.5	0.850	2.20	0.810
	6.33	6.30	23.0	89.00	0.823	3.11	0.685
	8.86	8.84	23.0	109.5	0.798	3.30	0.519
152	3.80	3.80	11.5	43.25	0.915	4.37	1.608
	3.80	3.80	23.0	63.10	0.883	3.04	1.118
	3.80	3.80	46.0	126.5	0.883	2.92	1.073
	6.33	6.30	23.0	89.00	0.862	3.82	0.844
	8.86	8.84	23.0	109.5	0.839	4.69	0.739
244	3.80	3.80	11.5	43.25	0.933	4.71	1.735
	3.80	3.80	23.0	63.10	0.909	3.98	1.480
	3.80	3.80	46.0	126.5	0.909	3.32	1.221
	6.33	6.30	23.0	89.0	0.894	5.02	1.110
	8.86	8.84	23.0	109.5	0.880	5.31	0.837
366	3.80	3.80	23.0	63.10	0.926	4.11	1.510
	6.33	6.30	23.0	89.00	0.914	5.20	1.148
	8.86	8.84	23.0	109.5	0.899	6.06	0.955

[a] R is defined as the mass of airborne dust particles less than 9.2 μm in size per unit mass of the broken coal dropped.

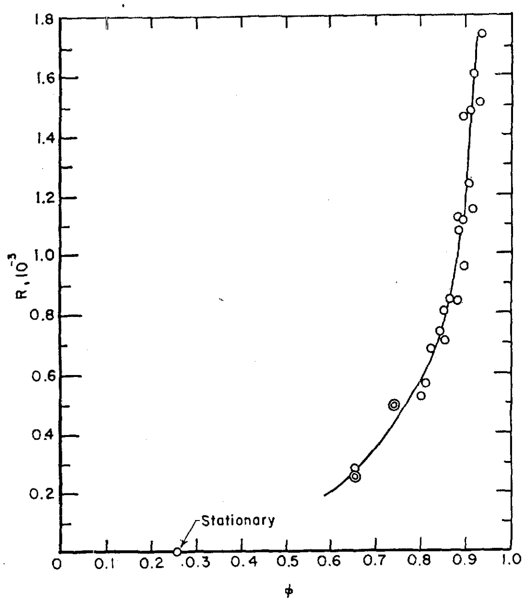

Figure 2. Relation of specific formation of airborne respirable dust with fraction voids.

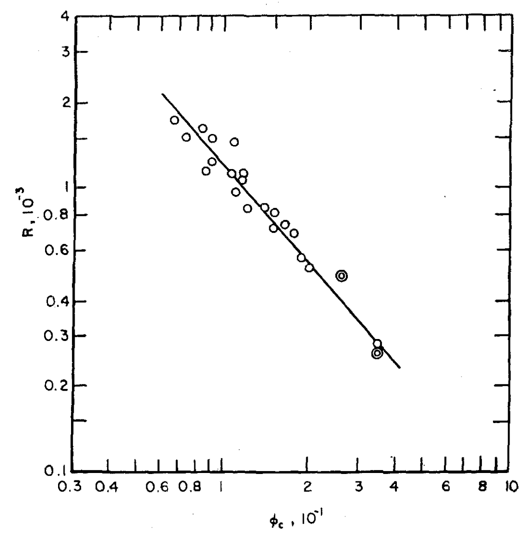

Figure 3. Relation between specific formation of airborne respirable dust and volume fractions of a dropping coal.

and conveyor speed up to a certain speed. At that speed, no further reduction in fraction void, Φ (see Appendix 2) could be obtained by increasing the conveyor speed. (For a case of $h = 3.80$ cm, we obtain $u_b = 16.4$ cm/sec, at which no further reduction in Φ occurs.)

The relation between the specific formation of airborne respirable dust and the fraction void is shown in Figure 2. When a broken coal dropped at a Φ value greater than 0.9, the value of R approached an asymptote. Tests with a stationary pile of broken coal without dropping showed no entrainment of the adhering dust. In this case, the Φ value by definition was 0.26 ($= 1 - 0.99/1.34$), which agrees with the trend of the lower range of our experimental dropping work.

The specific formation of airborne respirable dust, R, can be directly correlated to conveyor parameters through Φ_c, where Φ_c is the volume fraction of broken coal during dropping (see Appendix 2). A simple relation for the test range of Φ_c shown in Figure 3 can be obtained:

$$R = \alpha \Phi_c^{-\beta} \quad (1)$$

where α and β are the two empirical constants, equal to 8.50×10^{-5} and 1.16, respectively, for the broken coal used in this study.

According to equation 1, increasing the thickness of the coal bed on the belt surface and reducing the drop height are the main factors for reducing the formation of airborne respirable dust from untreated broken coal. Taking a typical example of a 30-inch-wide belt conveyor with a speed of 400 fpm and a drop height of 3 feet, the airborne respirable dust would be reduced only about 32% at the transfer point of reducing the transport rate from 8 to 4 tons/min, or by reducing the drop height from 3 to 1.5 feet.

It is generally accepted that the formation of airborne dust during a transfer operation is reduced by addition of water upstream of the drop point, or by the use of an inclined chute rather than a vertical drop. These aspects were briefly examined here. When broken coal with 1.5 mass % of added water was mixed briefly (4 minutes) in a cylindrical tumbler, R was reduced to 70% as compared to the unreated material. However, when the mixing time was prolonged, R increased; for example, with 20 minutes of mixing, R was about 1.5 times the value of the untreated material. Passage of untreated broken coal down a 45° inclined chute reduced R by aproximately 80% as compared to a vertical drop. However, the effects of moisture or inclination are difficult to investigate quantitatively because of problems involved in defining the degree of mixing and secondary breakage in a wet system, and the void fraction in an inclined system.

Discussion

The value of R of about 10^{-3} observed here is similar to that observed by Knight.[8] Cheng and Zukovich found that about 3.7 gm of respirable dust adheres to 1 pound of broken coal.[9] Thus, about 10% (3 to 21%) of the adhering dust is dislodged and becomes airborne during a dropping operation.

The dropping of dust-laden broken coal involves a sudden compaction of dusty mass when its fall is arrested. Airborne dust is formed as the result of the impact shock dislodging adhering dust from the massive surface. The surge of air originating from the space gaps in the impacting coal carries the freed dust away from the impacting coal. Secondary air currents will then transport the localized dusty air formed in the prior action away from the site of formation. The fraction void, Φ, which measures porosity of a falling granular mass, therefore has a direct bearing on the specific formation of airborne respirable dust.

A falling granular mass itself is a complicated system, and a complete description of its physical nature, such as shape, size, and surface properties, is very difficult. The system is, furthermore, complicated with a chaotic situation when it is subjected to impact or shock. It is extremely difficult to formulate even an approximate analysis of such a system. For example, the force of adhesion of micron-size particles is reported to be about 1 dyne by most investigators (for example, Corn[10]), in comparison with the impulsive force of about 10^6 dynes (see Appendix 3) caused by the disintegration shock in gravitational falling, and one would expect considerable more dislodgment of particles than measured here.

Therefore, while R would be expected to vary with the amount of adhering dust, moisture, and perhaps other parameters, it would seem to be very difficult to extend equation 1 to include such aspects in α and β.

The use of a steel plate floor in the drop tester (Figure 1) would give the most severe impact. However, the following two aspects minimize the importance of the impact effect: (1) An earlier study indicated that an 8-foot drop of the broken coal onto a steel floor did not produce appreciable fracture;[9] (2) in the present work a majority (92%) of the falling coal impacts onto other coal lying on the floor, and in coal mines it is estimated that more than 80% impacts onto coal in a typical case. Therefore, the floor effect may possibly occur in some belt-to-belt situations, but it does not seem to be important in ordinary cases.

Conclusions

The following conclusions can be drawn from the present exploratory study: (1) The fraction void in falling broken coal significantly affects the amount of airborne dust formed during dropping; (2) about 10% of the adhering respirable dust becomes airborne by the impact of dropping; (3) reduction of the height of material fall reduces the formation of airborne respirable dust; (4) for heavy belt loads (bed thickness $>>$ mean lump size), an increase in the thickness of the coal bed reduces the specific formation of airborne respirable dust; (5) for light belt loads (bed thickness $\sim$ mean lump size), an increase of belt speed reduces dust formation; and (6) a brief study indicated that the addition of water upstream of the drop point or the use of an inclined chute significantly reduces dust formation. A systematic study of wet or inclined systems remains to be conducted.

Appendix 1: Discharge Cross Section of a Belt Conveyor

The cross-sectional area of discharging granular material from a belt conveyor is the product of belt width and depth of discharge cross section. Letting h = thickness of coal layer on the belt and D = mean size of coal lump determined by sieve analysis, the time required for the top layer of coal to descend to the level of the belt surface during discharge is given by $\sqrt{2(h - D)/g \sin\theta}$, where g is the gravitational acceleration, and θ is the angle of repose. The time required to discharge lumps of size D from the belt conveyor is D/u_b, where u_b is the linear speed of the belt. Then the number of pieces, n, which constitute the depth of discharge cross section is given by

$$n = \frac{u_b}{D}\sqrt{\frac{2(h-D)}{g\sin\theta}} \qquad \text{(A1)}$$

Let b be the width of the belt conveyor; the mean discharge cross-sectional area A_d, then is given by

$$A_d = bu_b\sqrt{\frac{2(h-D)}{g\sin\theta}} \qquad \text{for } n > 1 \text{ (A2)}$$

$$= dD \qquad \text{for } n \lesssim 1 \text{ (A3)}$$

Appendix 2. Volume Fraction of Falling Granules

The volume fraction of broken coal is defined as the ratio of the volume of coal material to the volume of a pile. In the case of falling granules, the volume of the falling column will be used instead of the volume of a pile. Let M = total mass of broken coal dropped, $\bar{\rho}_c$ = materially density of the broken coal, A = cross-sectional area of the falling granules, H = height of fall, and M' = mass of the broken coal in the falling column of the broken coal. The volume fraction of the broken coal, Φ_c, is given as

$$\Phi_c = \frac{M/\bar{\rho}_c}{AHM/M'} = \frac{M'}{AH\bar{\rho}_c} \qquad \text{(A4)}$$

Let m be the belt loading—that is, the mass of broken coal per unit surface area of the belt conveyor—and let t be the discharge time. Then,

$$M' = \int_0^t mbu_b\,dt = mbu_b\int_0^H \frac{dH}{u} = mbu_b\sqrt{\frac{2H}{g}} \qquad \text{(A5)}$$

where u is the falling velocity of the broken coal. By substituting equation A5 in A4, we obtain the volume fraction of broken coal during falling:

$$\Phi_c = \frac{2mbu_b}{A\bar{\rho}_c\sqrt{2gH}} \qquad \text{(A6)}$$

In a column of falling solids having a rather high proportion of large pieces, such as the present case, the cross-sectional area, A, equals the discharge cross-sectional, A_d, given in Appendix 1. The fraction void is $\Phi = 1 - \Phi_c$, by definition.

Appendix 3. Impulsive Force

With a constant discharge rate, mbu_b, the mean impulsive force exerted on the fallen granular mass as its fall is arrested is $mbu_b\sqrt{2gH}$. For the discharge rates and drop heights used in this study, this force is of the order of 10^5 to 10^6 dynes.

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New General Interest Science Magazine

A new magazine describing the latest scientific and technical advances and written for laymen as well as professionals is being published by the U. S. Department of Commerce, National Bureau of Standards. This new NBS publication, *DIMENSIONS/NBS,* is directed to a "multiform" audiencee—to scientists, engineers, technologists and teachers, on one hand, and to citizens without laboratory or technical expertise, on the other hand. Among leading broad-gauge topics covered are: energy conservation, metric conversion, consumer affairs, environmental protection, health and safety, building technology, materials research, and standardization. *DIMENSIONS/NBS* was formerly the NBS Technical News Bulletin.

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Arrangements have been completed with the National Institute for Occupational Safety and Health (NIOSH) to conduct a NIOSH training course *Industrial Hygiene Measurements.* The laboratory equipment and course materials will be made available by NIOSH. Beginning in mid-1974 the course will be given in at least five different geographical locations (Boston, Philadelphia, Chicago, Houston, and San Francisco). Instructors will be selected from qualified professional industrial hygienists in the immediate area in which the course is given. Persons interested either as instructors or students should communicate with the Managing Director, AIHA, 66 South Miller Road, Akron, Ohio 44313. Announcements and details of the presentations of this course will be released at a later date.