CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

REPORT 80-27E

GENERATION AND CONTROL OF MINE AIRBORNE DUST

G. KNIGHT

MINERALS RESEARCH PROGRAM
MINING RESEARCH LABORATORIES

DECEMBER 1980

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Canada

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Ottawa, Canada K1A 0G1

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Catalogue No. M38–13/80–27E Canada: $2.10
ISBN 0-660-10958-1 Other countries: $2.50

Price subject to change without notice.

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N° de catalogue M38–13/80–27E Canada: $2.10
ISBN 0-660-10958-1 Hors Canada: $2.50

Prix sujet à changement sans avis préalable.

Errata for CANMET Report 80-27E - Generation and Control of Mine Airborne Dust by G. Knight. Corrections appear in Tables 4 (Page 8), Table 5 (Page 9), and Table 7 (Page 11).

Table 4 - Blasting

Site	Airflow (m^3/s)	Tonnes	Sampling period (min)	Number of tests	Respirable dust production (mg/t)			
					Total	Combustible	Mineral	Quartz
Total mine	450	2900	210	1	1200	540	450	300
Steep slope	2.5	180	330	1	2100	600	1400	700
Flat heading	20	270	360	1	1800	1400	300	150
Secondary	7	6	30	1	900	-	700	70
6 oversize rocks								
Mean					1500	900	750	-

Table - 7 Drilling

Site	Operation	Airflow m^3/s	Metres	Sampling period (min)	Number of tests	Respirable dust production mg/m			
						Total	Combustible	Mineral	Quartz
1	Jackleg								
	range	0.1-5	40-150	65-310	10	0-50	0-45	0-3	1.5
	mean	2	105	224		9	8	1.2	0.6
	range	4-8	60-110	145-250	5	0-12		0-3	1.5
	mean	6	85	200		2.4		.6	.3
	mean	0.6	120	200	3	4	1.2	L	L
2	Bar-arm mean	1.5	180	153	2	20	15	3	.6
3	Jumbo								
	mean	1.7	300	300	2	4.5	3	1.5	.3
	range	8-18	130-290	140-285	5	L-40	L-33	L-5	L-2.5
	mean	10	180	225		20	18	1.8	1
	mean				2	15	15	L	L
4	Mini borer				2	85	6	3.5	1
						(8)*	(0.6)*	(0.35)*	(0.1)*
5	Down the hole								
	range		46-120		4	120-1000	60-700	60-350	16-110
	mean		80			450	350	100	50
						(90)*	(70)*	(20)*	(10)*

*Values in brackets are those for equivalent length, by rock volume removed, in 50-mm diameter hole

Table 5 - Loading of rock

Site	Operation	Airflow (m^3/s)	Tonnes	Sampling period (min)	Number of tests	Respirable dust production (mg/t) Total	Combustible	Mineral	Quartz
1	Mucker in heading								
	range	1.5-3	60-90	210-330	3	40-200	12-180	14-42	7-21
	mean	2	75	260		90	80	24	11
2a	Slusher in raise								
	range		30-50	69-150	3	0-50	0-6	8-80	4-39
	mean	1.5	35	95		18	2	35	18
2b	Slusher in stopes								
	range	0.6-4	50-200	220-280	4	11-150	0-10	40-170	20-84
	mean	3	80	250		60	7	80	40
	range	.5-1.5	60-80	210-270	4	60-500	90-250	100-250	10-110
	mean		40	250	4	180	-120	90	45
2c	Slusher in stope								
	range	0.7-1.3	60-100	-	4	80-250	30-45	40-200	20-53
	mean	1	80			140	35	110	30
3a	LHD in heading								
		0.6	500	-	1	136	43	100	23
	mean				3	750	450	180	20
	range	10	200	100-180	9	225-980	240-450	100-400	29-315
	mean	10	200	140	1	600	360	240	103
3b	LHD in drawpoint								
	range	3.5-8	250-500	90-345	4	200-450	170-280	50-200	14-39
	mean	6	350	245		270	200	110	30
	range	1-17		100-350	5	260-3000	230-350	150-1300	15-130
	mean	5	160	250			270	55	55
Overall range of test means								26-540	
Overall mean								140	

GENERATION AND CONTROL OF MINE AIRBORNE DUST

by

G. Knight*

ABSTRACT

A study was undertaken to determine the sources of airborne dust in mines and to investigate control methods. Experiments have identified three airborne dust types and their sources: mineral dust from all mining processes, oil mists from lubricating oil used in compressed air-powered machines, and particulates from diesel exhaust. Rock breaking and dust dispersion were studied and results showed that the dust produced is directly dependent on the total breakage and that dispersion increases by the extent of the handling, the energy expended in creating new breakage, the kinetic energy of the rock itself, and the velocity and turbulence of the air.

Two main dust control methods are wetting and ventilation. The effectiveness of wetting depends on wetting time, rock surface properties, type of wetting agent, use of steam and on the extent of mechanical mixing; sprays are ineffective in removing fine dust that is already airborne. Controlling dust through ventilation is effected by adding air to dilute the dust concentration, exhausting or drawing dust-entrained air from the workers' zone, and by controlling airflow direction.

The CAMPEDS gravimetric dust sampling system was used for measuring the amount of dust produced and gave total respirable dust, respirable combustible dust, respirable mineral dust (ash), and respirable quartz dust. Dust measurements from six mines are given in tabular form for blasting, rock loading, transport and hauling, drilling, and ancillary operations. Results showed that blasting, crushing and vertical orepasses produced the most dust. Evacuation of personnel from the mine for a sufficient time for the dusty air to leave or settle reduces exposure to dust from blasting. Crushing and orepasses can be enclosed and human exposure avoided. In mining areas, ore handling rather than drilling as might be expected was responsible for creating most of the dust.

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*Research scientist, Elliot Lake Laboratory, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario.

Two sets of experiments were made to investigate the effect of water on dust control in LHD loading operations, locations where good wetting and ventilation are essential. It was found that wet processes in milling operations produced substantial dust and that enclosures and extraction could substantially decrease general ventilation requirements.

Recommendations are given for dust control in hard rock mines for blasting, rock handling and drilling; suggestions are made for further studies on improving loading, floor smoothing, bucket handling, wetting, use of dust filters on mobile machines and high volume exhaust systems.

FORMATION ET MAÎTRISE DE LA POUSSIÈRE DANS L'AIR DE LA MINE

par

G. Knight*

RÉSUMÉ

Une étude a été entreprise afin de déterminer les sources de poussière dans l'air de la mine et d'examiner des méthodes de maîtrise. Les essais ont permis d'identifier trois sortes de poussière et leur source: la poussière minérale provenant de l'exploitation minière, les émanations d'huile lubrifiante utilisée dans l'équipement pneumatique et les particules de gaz d'échappement diesel. L'abattage de la roche et la dispersion de la poussière ont été étudiés et les résultats ont démontré que la quantité de poussière produite est fonction directe de l'abattage total et que la dispersion augmente selon le nombre de manipulation, l'énergie requise pour effectuer l'abattage, l'énergie cinétique de la roche même et le mouvement de l'air.

Les deux principales méthodes de réduction de la poussière dans l'air sont l'humidification et l'aération. L'efficacité du procédé d'humidification dépend du temps consacré à l'humidification, les propriétés de surface de la roche, le genre d'agent d'humidification, l'utilisation de la vapeur et l'importance du mélange mécanique; les vaporisations ne sont pas efficaces contre les poussières fines déjà dans l'air. L'aération peut réduire la concentration de la poussière dans l'air soit en ajoutant de l'air dans la mine pour en diluer la concentration, en aspirant l'air poussiéreux du milieu de travail des mineurs et en contrôlant la direction des courants d'air.

Le système gravimétrique d'échantillonnage de la poussière CAMPEDS a été utilisé pour mesurer la quantité de poussière produite et a fourni les données sur la poussière respirable totale, la poussière combustible respirable, la poussière minérale respirable (cendre) et la poussière de quartz respirable. Les lectures obtenues sur la poussière provenant de six mines ont été disposées en tableaux représentant les opérations de tirage, de chargement et de transport de la roche, de forage et autres opérations auxiliaires. Les résultats indiquent que les opérations de tirage et de forage et les galeries de soutirage verticales produisent le plus de poussière.

*Chercheur scientifique, Laboratoire d'Elliot Lake, Laboratoires de recherche minière, CANMET, Energie, Mines et Ressources Canada, Elliot Lake (Ontario).

L'évacuation du personnel suffisamment longtemps pour permettre à l'air poussiéreux de s'échapper ou se déposer, réduit leur exposition à la poussière générée par le tirage. Les galeries de soutirage et les opérations de concassage peuvent être isolées ainsi évitant l'exposition des humains. Dans les zones d'exploitation minière, la manutention du minerai plutôt que le forage tel que prévu, était responsable de la génération de la majorité de la poussière.

Deux séries d'essais ont été effectuées pour étudier l'effet de l'eau sur la maîtrise de la poussière dans les opérations de chargement, endroits où il est essentiel de maintenir une bonne humidification et une bonne aération. On a découvert que les procédés humides dans les opérations de broyage génèrent une quantité importante de poussière et que des enclos et l'extraction pourraient réduire considérablement les exigences générales d'aération de la mine.

Les recommandations sont données pour maîtriser la quantité de poussière générée dans les mines de roche dure par le tirage, la manutention et le forage; on y suggère la poursuite d'études sur l'amélioration du transport, le polissage du plancher, la manipulation du godet, l'humidification, l'usage des filtres à poussière sur les appareils mobiles et des systèmes d'échappement à haut rendement.

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INTRODUCTION

Dust has long been a major health hazard in the mining industry. There has even been evidence of silicosis in Stone Age flint workers.

This report forms part of the department's program to develop technology to solve problems related to underground mine workers' exposure to airborne, and thus respirable, dust produced by various underground mining operations.

Studies were undertaken at the Mining Research Laboratories at Elliot Lake to determine the sources of fine, potentially airborne dust in mines and to develop control methods capable of reducing dust levels significantly below provincial and federal standards. Dust production measurements by the Elliot Lake Laboratory staff were taken with the CAMPEDS gravimetric sampling system to provide total respirable dust, respirable combustible dust, respirable mineral dust (ash), and respirable quartz dust.

Rock breakage, dust dispersion and rock cutting processes are described as well as control methods by wetting and ventilation. Recommendations for improving dust control in hard rock mines are given and suggestions made for further studies on improving loading, floor smoothing, bucket handling, wetting, use of dust filters on mobile machines and high volume exhaust systems.

The principles of dust generation and control are discussed in the following sections.

BREAKAGE

Dust is produced in all rock breaking processes except possibly when rock splits at a plane of weakness. In most processes examined the quantity of fine, potentially airborne dust was related to the quantity of coarser dust produced, that is, to the total amount of rock broken into finer sizes. Figure 1 shows the mean value and range of sizes of broken material from one mine for seven rock types subjected to tests in which 1-cm lumps were broken in a rotary crusher at a coarse and a medium setting. Size distribution was determined by screening and elutriation of airborne dust. The technique was intended mainly for examining the quartz content of airborne dust and will be described in a later report.

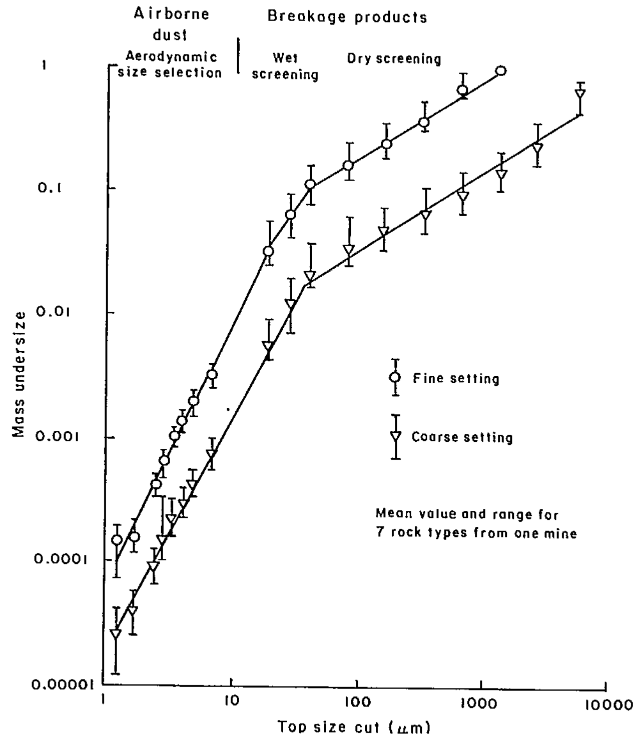

Fig. 1 - Size distribution of breakage products and airborne dust in laboratory test

Figure 2 shows the size distribution of fine dust obtained by optical microscopy transposed from number undersize to mass undersize (1). Discontinuities may occur in rocks with a marked grain size as shown in Fig. 3 (1). Such discontinuities are most often found in sedimentary rocks with strong grains in a weak matrix. However this does not alter the fact that the amount of potentially airborne dust is directly dependent on the total breakage. Generally, breakage is directly proportional to the energy input and inversely to the rock strength. Table 1 shows the estimated quantity of potentially airborne dust in the respirable size range when rock is broken to various maximum sizes for transport assuming a uniform breakage procedure. Table 1 shows that a large increase occurs when the ore is broken into finer sizes.

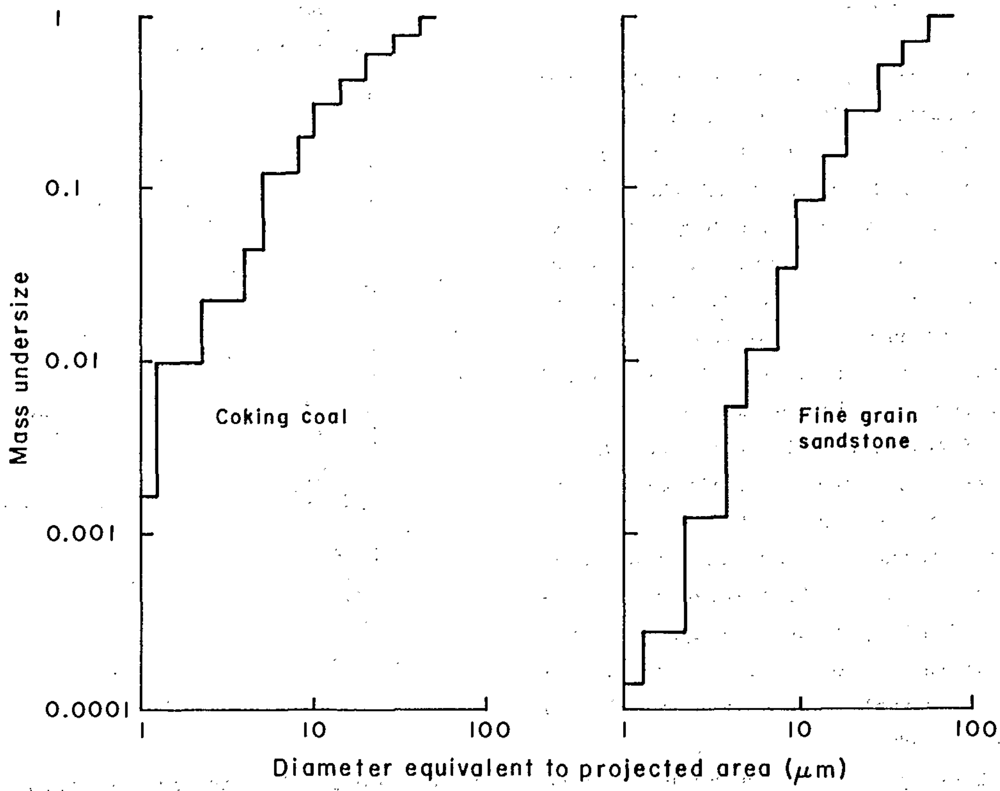

Fig. 2 - Size distribution of screened breakage products from compression test obtained using a microscope

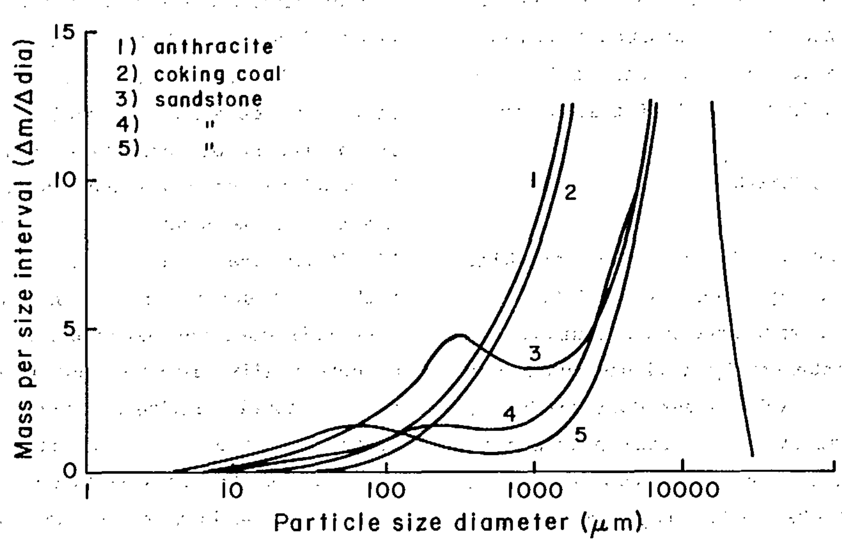

Fig. 3 - Mass distribution of debris from breakage by slow compression

DUST DISPERSION

Although all the fine potentially airborne dust could be dispersed by repeated handling in an airstream, generally, this occurs to only a proportion of it. Therefore, it is expected that in breaking dry material, the dust generation and dispersion will resemble that shown in Fig. 4. For instance, in a simple shatter test in which 50-mm lumps were dropped 2 m onto a steel plate in a gentle airstream, less than 10% of the dust from a weak coal was dispersed compared with most of the dust from a strong coal (1,2). Presumably the stress relief from the stronger coal imparted more energy or speed to the broken products and increased dust dispersion. Test results suggest that dust was directly proportional to the energy input and independent of coal strength. In contrast, potentially airborne dust increased with decreasing coal strength.

It can be surmised that dust dispersed in handling processes increases by:

1. the amount of fine dust created in the breaking process
2. the extent to which the material is stirred up during handling
3. the energy expended to create new breakage
4. the kinetic energy imparted to the freshly broken dust particles by the stress relief in the material broken
5. higher air velocities.

ROCK CUTTING PROCESSES

Rock cutting processes are used in coal mining machines, rotary drills, percussion drills, etc. The characteristic of these machines considered here is that they separate chips of rock from the main mass. Although the term cutting is used, the actual mechanics of raising a chip from the solid is complex, involving impact, fracture propagation, etc. Generally, two processes must be considered - cutting of the chip and its removal from the site.

In cutting it has been shown that the least amount of potentially airborne dust is produced when the chips are as large as possible. To

Table 1 - Estimated potential airborne dust from breaking massive rock to various sizes

Maximum size of broken rock (metres)	Potential airborne dust in respirable size range (1) (g/t)
1	19
0.75	23
0.5	31
0.25	50
0.1	105
0.05	290
0.01 (1/2 in.)	600

(1) The permissible dust concentration in air is of the order of 1 g/(m^3 x 10^3)

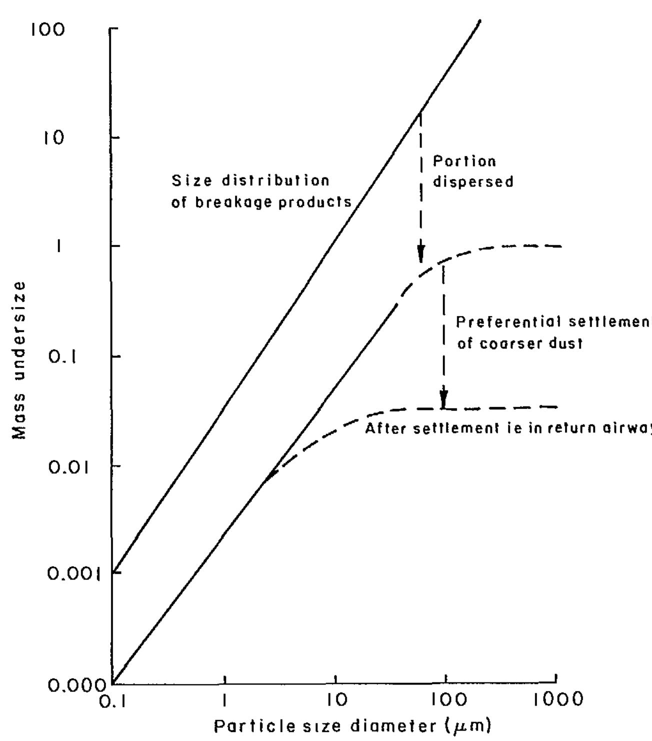

Fig. 4 - Development of the size distribution of airborne dust

achieve this, forces as high as possible must be applied to a small area and a depth of cut as large as possible made. The design of cutting tools to achieve these aims is complex, but minimum specific dust generation, i.e., dust generated per tonne, and minimum specific energy consumption are usually achieved together.

The problem of removing chips is most obvious in drilling where insufficient clearance or flushing agent may result in further breakage of the chips, in binding and resultant loss of energy from the drill rod, in decreased cutting speed, and increased specific dust generation and energy consumption.

DUST SUPPRESSION BY WETTING

Water is widely used in mines for dust control. Factors affecting dust suppression by wetting are:

1. Small potentially airborne dust particles can be attached to larger lumps and rendered non-dispersible by a thin film of liquid.
2. Water or other sprays are ineffective in removing respirable dust particles that are already airborne, unless very high accelerations are applied as in high pressure-drop wet scrubbers.
3. To be fully effective the liquid has to spread over the entire surface of the rock. The wettability of the rock depends on its surface properties and those of the liquid. Experiments have shown that most common rocks except sulphide minerals and coking coals are wettable.
4. It has been shown that it takes a long time for water to spread over the surface of a rock pile. Six samples of simulated run-of-mine material of 1 kg each and up to 4 cm in dimension were sprinkled with water and subjected to a shatter test after standing from 1 to 300 min (Table 2) (2).
5. Using wetting agents in water to improve wetting and dust suppression has been proposed. Laboratory experiments for which some results are shown in Table 3, indicate improvement, which suggest that (2):
   a. wetting agents reduce spreading time
   b. high concentration of over 1% is required
   c. the effect is most marked for difficult-to-wet rocks such as coking coals and sulphides
   d. the use of wetting agents in sprays reduces the size of droplets which can be obtained by increasing water pressure; no other measurable effect on the collection of airborne dust has been detected.

   However, mine trials have generally failed to show significant improvement in dust suppression. It is probable that this can only be obtained in certain types of operations, especially for minerals which are difficult to wet. It must be noted also that wetting agents may interfere with flotation processes used in ore preparation.
6. Obtaining a water layer by feeding steam into the rock pile is effective and decreases spreading time. Steam can be fed into moving

Table 2 - Dust raised from various materials after treatment with water

Material	Water addition level (*m* %)*	% dust dispersion time of standing (min) 1	5	30	300
Coal coking (301)	10	93	87	79	70
" bituminous (902)	10	82	61	50	35
" " (802/902)	10	-	50	32	20
Shale a	2.5	66	21	11	9
b	2.5	65	24	21	10
c	2.5	40	28	24	15

**m* = mass

Table 3 - Effect of wetting agent solution on dust dispersion

Material	Wetting agent*	Addition level	% dust dispersion			
			Concentration of commercial agent			
		(m %)*	0(water)	0.2%	0.5%	2%
Coal coking(301)	(i)(anionic)*	10	89	66	29	2.1
	(ii)(non-ionic)*	10	-	-	-	1.4
	(iii)(mixture)*	10	80	52	15	1.0
Coal bituminous(902)	(i)	10	56	50	30	10
	(ii)	10	-	-	-	10
	(iii)	10	50	38	18	6.8
Shale a	(i)	2.5	21	-	-	13.8
	(ii)	2.5	24	-	-	27.8
	(iii)	2.5	28	-	-	27.8

*The greater efficiency shown for wetting agent (iii) than for agents (i) and (ii) appears to have been solely due to the greater concentration of active material in the commercial product.

rock in an enclosure at a transfer point on a conveyor belt.

7. Gentle mechanical mixing greatly speeds up the process of spreading water over the rock surface. In laboratory tests two minutes of mixing in a low-speed tumble mill was sufficient for full control as shown in Fig. 5. Mechanical mixing may effectively improve dust suppression on conveyor belts and during drilling.
8. It has been shown in rock and coal cutting operations and drilling that water is most effective when applied as close to the cutting point as possible and that this can be achieved by feeding water through the tool bit and onto the cutting face.
9. Feeding water to machines has two major problems: (1) the human one of ensuring that the water supply is connected and turned on which can be avoided by interconnecting the water valves to the power supply and (2) clogging due to dirt and pipe scale for which it has been recommended that spray orifices have a diameter of not less than 1.5 mm and be protected by filter screens on or close to the machine.
10. Muck should be kept wet during handling and transport because of long wetting times required when dry.
11. Most liquids are effective dust suppressants. Oils and salt solutions have been used specifically to avoid drying or freezing. Drying of settled dust in underground roadways has been prevented by using hygroscopic salt as a binder. Freezing of wet ore during surface transport in winter has been reduced by oil or salt solutions.

DUST CONTROL BY VENTILATION

Ventilation can control dust by: adding air to dilute the dispersed dust; exhausting or drawing dust-entrained air away from the operation to prevent it from reaching workers, and controlling airflow direction.

It is usually assumed in dilution ventilation that an increase in airflow will lead to a corresponding reduction in dust concentration,

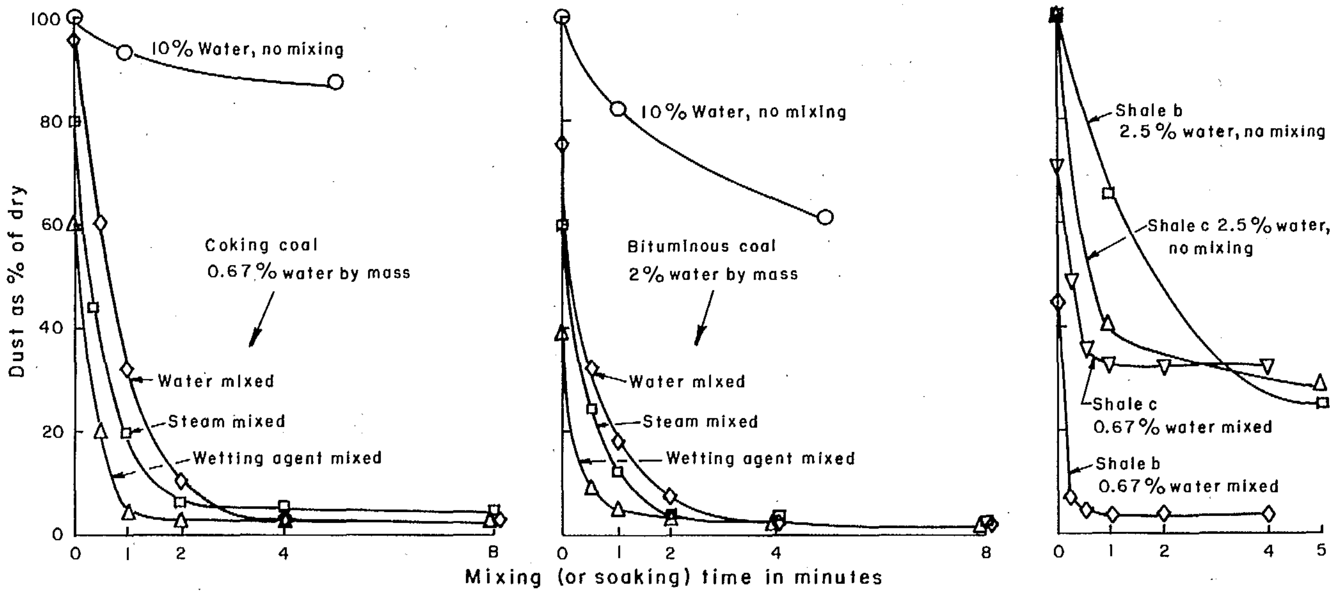

Fig. 5 - The effect of mechanical mixing or soaking after the addition of water, steam and 2% wetting agent solution

i.e., doubling airflow will halve the dust concentration. However this is not entirely true as the decrease in dust concentration is usually not as great as the increase in ventilation. It has been shown on English and German longwall coal faces that respirable dust concentration decreases with increased airflow at low velocities, reaches a minimum at 3 to 6 m/s and increases at higher velocities. Presumably increased air velocity tends to stir up the dust and disperse it, eventually off-setting the increased dilution.

Exhaust ventilation is effective when the dust source is enclosed and sufficient dust-laden air is drawn out to entrain the dust and prevent it from reaching the workers. For this, air must have sufficient velocity to pick up and retain the dust. A velocity of 1 m/s at the entrance to a hood is usually considered suitable for design purposes. However, higher values may be necessary if the ambient velocities exceed 0.5 m/s or if material moves out of the enclosure as on a conveyor belt. The exhausted air can be either passed directly to a return airway or filtered and returned to the ventilation circuit.

The quantity of air required for dust control in exhaust ventilation is decreased by:

1. reducing openings in enclosures to a minimum
2. proper maintenance of enclosures
3. lowering general air velocities
4. decreasing air turbulence from moving parts or from material within or leaving enclosure
5. avoiding pumping effects, i.e., rotating or moving components can act as fans pushing air out through holes in enclosure against pressure developed by the exhaust fan.

Exhaust ventilation generally requires much smaller volumes of air than dilution ventilation to control dust concentrations.

Airflow direction is mentioned in most manuals as a means of controlling dust but these generally do not emphasize its possibilities. Basically, it can have an intermediate effect between that of dilution and exhaust ventilation. In underground mining where airflow is necessarily controlled, dust exposure may be greatly reduced by ensuring that air from dusty operations passes directly to return airways and that most work is done on the intake side. For instance, stope drilling and mucking should be planned so that drillers are not exposed to dust from mucking and the mucking machine should be operated from the air intake side.

A two-to-one difference in the dust exposure of two men working in a development heading was found in one study over four sampling days. Presumably this was due to one man preferring to work in the stream of high velocity fresh air coming from the duct whereas the other did not.

Diffuser nozzles have been used on high speed ventilation ducts to supply a comfortable stream of clean low-velocity air to workers.

DUST MEASUREMENTS IN MINES

For discussion purposes, hard rock mining consists of:

1. separating ore from surrounding rock and breaking it into pieces small enough to transport
2. loading
3. transporting and handling
4. drilling
5. ancillary operations.

DUST MEASUREMENT TECHNIQUE

"Dust production" is the term most descriptive of dust generation and dispersion into the air at a mining operation. Dust was measured by the Elliot Lake Laboratory staff with the CAMPEDS gravimetric dust sampling system (3). The samplers operate over a full shift and have a two-stage impaction respirable dust size selection. Samples were collected on silver membranes and were weighed three times to give tare mass, gross mass and mass after ashing. They were further analyzed by X-ray diffraction for mass of quartz. These measurements gave four assessments:

1. total respirable dust
2. respirable combustible dust (defined as loss in mass on ashing at 500°C)
3. respirable mineral dust (ash)
4. respirable quartz dust.

Possible minor damage to the filter when loading and unloading the sampler can lead to large errors in estimating the mass of total respirable dust. This occurred particularly on the light samples in most of these studies and frequently caused difficulties in estimating the respirable mineral dust, which should equal total minus combustible, and the percentage of quartz in the dust. Note however, that the quartz measurement is absolute and is an order of magnitude more sensitive and accurate than weighing.

To facilitate comparison between mines, estimates of respirable mineral dust production were made from the quartz measurements and from the average value of the quartz content in heavy ashed dust samples, as well as from the measured difference between tare and ashed masses.

Sampling stations were set up in the airways both upstream and downstream from each operation. The stations were chosen to give the most uniform mixture of dust and air possible. Replicate samplers were strategically placed to obtain best readings without obstructing passage for men and vehicles. The samplers were kept running after the operations stopped to allow time for the dust to pass the return station. Airflow measurements were made at the stations and a recording anemometer was used to observe changes in airflow and to assist in estimating the total air volume passing each station.

Total dust produced at each operation was determined by multiplying the dust concentration at each station by the total corresponding airflow and subtracting the resultant figures at the intakes from those at the returns. This figure was then divided by the unit of production - tonnes of ore, length of hole drilled, or other unit as applicable - to give specific values per unit of production.

DUST PRODUCTION MEASUREMENTS

The measurements from six mines over the last five years are summarized below.

Blasting

Measurements were made on airborne dust

reaching surface after production blasting between shifts and underground after blasting in a stope and heading, and after secondary blasting in a drawpoint (Table 4).

It is difficult to measure dust produced in a blast because of disturbance to the airflow. The apparent differences between the four results in Table 4 need further study to better understand the factors involved. Future studies should determine the energy input from the explosives in at least a semiquantitative form.

Clearly, blasting in hard rock mines produces large quantities of dust, emphasizing the importance of evacuating men and allowing adequate time for ventilation to remove dust and fumes.

Loading

The following equipment was used to load broken rock for transport (Table 5):

1. rail-mounted compressed air-powered mucker emptying into a rail car in development headings
2. electric and compressed air-powered slusher operating in drifts and stopes (2a,b,c)
3. diesel-powered load-haul-dump machines (LHD) of various sizes operating in headings and drawpoints (3a,b). In some cases LHD's loaded the rock into diesel-powered trucks. A separate measurement of dust produced in this transfer was not possible because the layout of the heading and the ventilation system prevented selecting sampling stations with adequate mixing of dust with air.

It can be seen that rock loading produces substantial mineral dust. The electric-powered slushers produced negligible combustible dust. The compressed air-powered equipment produced measurable quantities, presumably of lubricating oil mist, and the diesel-powered equipment produced large quantities of combustible dust.

The quantities of mineral dust varied substantially from one site to another for which a number of factors were responsible:

1. Wetness of rock - although water was always used, apparently not all of the rock surfaces were wetted.
2. Roughness of floor - it was apparent that loading was more difficult and presumably more dust was produced on rough floors than on smooth.
3. Clean up and scaling - loading machines used for clean up at two sites produced much more dust per tonne of muck than normal loading operations.
4. Operator finesse - some drivers, especially on lower-powered machines, developed techniques for rapid loading, presumably with low energy input and low dust production.

Rock Transport and Handling

After loading, rock is transported horizontally and vertically for considerable distances to surface, usually via an underground crusher. A limited number of such operations were examined (Table 6):

Table 4 - Blasting

Site	Airflow (m^3/s)	Tonnes	Sampling period (min)	Number of tests	Respirable dust production (mg/t)			
					Total	Combustible	Mineral	Quartz
Total mine	450	2900	210	1	1200	540	450	300
Steep slope	2.5	180	330	1	2100	600	1400	700
Flat heading	20	270	360	1	1800	1400	300	150
Secondary 6 oversize rocks	7	6	30	1	9	-	700	70
Mean					1500	900	750	-

Table 5 - Loading of rock

Site	Operation	Airflow (m^3/s)	Tonnes	Sampling period (min)	Number of tests	Respirable dust production (mg/t) Total	Combustible	Mineral	Quartz
1	Mucker in heading								
	range	1.5-3	60-90	210-330	3	40-200	12-180	14-42	7-21
	mean	2	75	260		90	80	24	11
2a	Slusher in raise								
	range		30-50	69-150	3	0-50	0-6	8-80	4-39
	mean	1.5	35	95		18	2	35	18
2b	Slusher in stopes								
	range	0.6-4	50-200	220-280	4	11-150	0-10	40-170	20-84
	mean	3	80	250		60	7	80	40
	range	.5-1.5	60-80	210-270	4	60-500	90-250	100-250	10-110
	mean		40	250	4	18	-120	90	45
2c	Slusher in stope								
	range	0.7-1.3	60-100	-	4	80-250	30-45	40-200	20-53
	mean	1	80			140	35	110	30
3a	LHD in heading								
		0.6	500	-	1	136	43	100	23
	mean				3	750	450	180	20
	range	10	200	100-180	9	225-980	240-450	100-400	29-315
	mean	10	200	140	1	600	360	240	103
3b	LHD in drawpoint								
	range	3.5-8	250-500	90-345	4	200-450	170-280	50-200	14-39
	mean	6	350	245		270	200	110	30
	range	1-17		100-350	5	260-3000	230-350	150-1300	15-130
	mean	5	160	250			270	55	55
Overall range of test means								26-540	
Overall mean								140	

Table 6 - Ore handling

Site	Operation	Airflow (m^3/s)	Tonnes	Sampling period (min)	Number of tests	Fall (m)	Respirable dust production (mg/t)			
							Total	Combustible	Mineral	Quartz
1	Loading mine cars	3-73	140-420	30-114	2	3	35	15	70	8
2	Dumping on grizzly	70	800	300	1	1-3	270	-	54	27
3a	Orepasses	40	2000	320	1	300	700 (1)	low	800 (1)	400
b	Orepasses	1	200	120	1	30	105	7	70	16
c	Orepasses									
	top level, mean	40	600	200	3	300	270	90	180	18
	182 m down, mean	25	1600	140	7	300	250	80	160	16
4a	Underground crusher	3	2400	325	2	3	600	20	800	400
b		3	800	200	1		200		250	130
c		2.5	200	120	1	3	100		60	15
d		3	750	390	1	3	150		90	22
5	Big rock	3	20	390	1	3	110		35	10
6	Skip loading	5	514	210	1	6	115	15	30	16

(1) Lower total than combustible assessment is an indication of the weighing errors

1. Filling rail cars from a chute with a free fall of 1 to 2 m
2. Dumping rock onto a grizzly from diesel-powered LHD's and trucks. This operation included breaking oversize pieces with an hydraulic pick. The measured dust was not the total produced but only that part escaping the local exhaust system below the grizzly and from the filter system.
3. Nearly vertical ore and waste passes.
   a. This system had dump points every 35 m vertically with interconnections between ore and waste passes at each level; an exhaust system drew dusty air from the lowest level.
   b. The part of this system examined consisted of a 30-m section of orepass with fingers at top and bottom; the free fall of material induced airflow out through the lower finger.
   c. The system consisted of a 600-m vertical orepass with dump points at the top and at 120-m intervals; dust leakage from the top was calculated on tonnage from this level and at the second level on tonnage from both upper levels.
4. Underground crushers; although total dust was measured on systems a and b, only that leaking from the crusher and air exhaust system with filter was measured on c and d; at two other crushers, dust leakage could not be estimated because of low ventilation rates.
5. Big rock handling; rocks too large for the crusher were handled at this mine by a crane and dropped into a side heading for secondary blasting.
6. Skiploading; one skiploading facility fed from an orepass was examined.

Most ore handling operations produce large quantities of dust and many achieve partial or complete dust control through exhaust air systems.

Drilling

Drilling is a major operation in most hard rock mines and uses a substantial proportion of the total manhours. Before the advent of wet drilling it was considered the most hazardous occupation leading to silicosis.

Five drilling systems were studied as shown in Table 7. Dust production is given as mg/m of drillhole.

1. Jackleg compressed air-powered rotary percussive drills; these data could not be separated from drilling for roof bolts using a stoper; dust production is given in terms of total length of hole; bit diameter was about 40 mm.
2. Bar and arm compressed air-powered rotary percussive drills; these drilled long holes of about 50 mm in diameter.
3. Jumbo-mounted compressed air-powered rotary percussive drills; bit diameter was about 50 mm.

Table - 7 Drilling

Site	Operation	Airflow m^3/s	Metres	Sampling period (min)	Number of tests	Respirable dust production mg/m			
						Total	Combustible	Mineral	Quartz
1	Jackleg								
	range	0.1-5	40-150	65-310	10	0-50	0-45	0-3	1.5
	mean	2	105	224		9	8	1.2	0.6
	range	4-8	60-110	145-250	5	0-12		0-3	1.5
	mean	6	85	200		2.4		.6	.3
	mean	0.6	120	200	3	4	1.2	L	L
2	Bar-arm mean	1.5	180	153	2	20	15	3	.6
3	Jumbo								
	mean	1.7	300	300	2	4.5	3	1.5	.3
	range	8-18	130-290	140-285	5	L-40	L-33	L-5	L-2.5
	mean	10	180	225		20	18	1.8	1
	mean				2	15	15	L	L
4	Mini borer				2	85	6	3.5	1
					(8)*	(0.6)*	(0.35)*	(0.1)*	
5	Down the hole								
	range		46-120		4	120-1000	60-700	60-350	16-110
	mean		80			450	350	100	50
					(90)*	(70)*	(20)*	(10)*	

*Values in brackets are those for equivalent length, by rock volume removed, in 50-mm diameter hole

4. Mini borer; rotary drill, drilling down-holes of about 150 mm in diameter.
5. Down-the-hole drills; four compressed air-powered rotary percussive drills were used in the same stope for which the total production was measured on four separate shifts; bit diamter was 110 mm.

Table 7 indicates that all drills except the down-the-hole were characterized by low dust production. This made it difficult to measure the increase in dust concentration between intake and return air except at low rates of airflow.

The down-the-hole drills produced copious quantities of airborne dust because compressed air was used as the flushing agent. Although some water was used it was apparent that dust control was less effective than with any other drill even allowing for the greater quantity of rock broken per metre of hole.

Ancillary Operations

A few ancillary operations were examined for which production results are given in Table 8:

1. Drill preparation. At this particular section of the mine a 5-t capacity LHD unit was used to clean up muck left by a similar 8-t unit on production and to scrape the face ready for drilling. The dust produced per ton of muck based on the number of buckets dumped was ten times greater than in production mucking. This was partly because the muck was not properly wetted and partly because of the high energy expenditure in removing cracked rocks from the toe of the face. This half-hour operation which took place with the drill operators present produced as much dust as a 3-boom drill jumbo in two or more shifts.
2. Back filling. Back filling with fine hydraulically transported mine waste was examined on one shift. The dust was produced in the stope.
3. Conveyor belt. Two conveyor belts about 60 m long with loading chutes each carried 330 t/h. The rock was left dry to avoid freezing. Dust production was high even though the loading points were properly enclosed.

Table 8 - Ancillary mining operations

Site	Operation	Airflow (m^3/s)	Tonnes	Sampling period (min)	Number of tests	Respirable dust production (mg/t)			
						Total	Combustible	Mineral	Quartz
1	Drill preparation (ST 5)	10		30	1	1800	1000	800	400
2	Back filling	2.5	800	180	1	270	-	-	-
3	Conveyor belt	4	4000	360	12	23	1	14	5
4	Autogenous mill	2	2000	360	2	65		27	9
5	Pebble mill	2.2	500	360	2	5		11	4
6	Magnetic separator	.2	320	360	2	1		1	3
7	Flotation	.2	320	360	2	3		2	7
8	Balling drum	2.7	400	360	1	13		13	-

Operations 4 to 8 in Table 8 were in a surface mill processing iron ore. Even though all the processes were wet, substantial quantities of dust were produced. Operations 4 to 7 could be readily enclosed and dust emission controlled by a low airflow exhaust system rather than by conventional higher airflow dilution ventilation.

SUMMARY OF DUST PRODUCTION

Clearly, gravimetric assessments show that rock handling is a much greater hazard than the historically hazardous operation of drilling. Although partly due to the parameter change from number to mass for the finer dust in drilling compared with other operations, the main factor is the effective dust control achieved by feeding water to the bit. It should be noted that the down-the-hole drill used compressed air with only a little water added to flush chips from the hole and produced much larger quantities of respirable dust than any other drill, even allowing for the larger hole size.

In most of the mines examined the major mineral dust exposure was due to loading. Secondary blasting in the mining area or substantial contamination of the intake air by the ore transport system was equally important in some mines.

Mine transport systems can produce large quantities of mineral dust but effective control has been achieved by entraining dust from non-mobile operations in an airstream and filtering or directing it to a return airway.

Table 9 shows the estimated dust production for the mine where most of the experimental work was undertaken. This mine operated at depths between 240 and 600 m using horizontal track drifts and stopes on the 2- to 6-m thick ore horizon with jackleg drills and electric slushers.

Table 9 - Estimates of total dust produced for one mine shift

Operation	Tonnes	Respirable dust production g/shift				Mineral dust as % of	
		Total	Combustible	Mineral	Quartz	Entire mine	Mining area
Between shift main blast	2700	5600	2800	2600	1300	34	
Mining area							
Secondary blasting	100(1)	100	20	80	40	1	15
Slushing	2400	350	20	330	165	4	63
Mucking	400	40	30	10	5	0.1	2
Car loading	2700	115	60	56	27	0.7	10
Drilling	2700 (2200 m)	22	20	3	1.5	0.04	0.6
Scaling etc.(2) -		10	-	10	5	0.1	2
Total		637	150	487	243	5	100
Outbye							
Rail transport	2700	65	60	5	2	0.1	
Dumping into orepasses(2)	2700	60	10	50	25	7	
Orepasses	2700	2700	60	2600	1300	34	
u/g crusher	2700	1800	-	1800	900	23	
Skip loading	2700	160	40	100	50	1.3	
Total		6800	170	4600	2300	60	
Entire underground mine		11000	3100	7700	3850	100	

(1) Estimates based on a guess as to variable secondary blasting carried out.

(2) Estimate.

The ore output was 2700 t/shift and production blasting was carried out between shifts.

It can be seen that most dust was produced in the ore transport outbye of the active mining area, where in this particular mine the orepasses are near the shaft and away from the extraction area. The main dust sources were well controlled by exhaust ventilation and only a small proportion of the transport dust leaked into the working areas and travelways. The production blast was the next major source and exposure was avoided by blasting between shifts.

The mineral dust production in the active mining areas is only about 5% of the mine total. Most of this arises from handling with only little from drilling.

In a second mine where a nearly vertical orebody is worked by diesel-powered LHD's on tramming levels and the nearly vertical orepasses are placed close to the intake airway so that dust leakage can spread over most of the mining zone, an analysis was made of the sources of dust to which the LHD operator was exposed (Table 10). It can be seen that the operator's chief source of exposure occurred during the 15% of his shift when he was in the short heading to the orepass dump point*. A further 12% of his dust exposure was due to dust leaking from the orepasses into the intake air leading to the drawpoints. This leakage also forms a major part of the dust exposure of the other miners on this level. Loading was responsible for only about 10% of the operator's total dust exposure. His vehicle's diesel engine was responsible for about 30%.

DUST CONTROL EXPERIMENTS

It was shown previously that loading is one of the dustiest operations to which miners are exposed. To date two sets of experiments were made to investigate the effect of water control on dust in LHD loading operations. In the first set carried out in a drawpoint in high sulphide ore, loading was carried out dry or with 1-, 2-, or 4-bar pattern sprays arranged as shown in Fig. 6. In the second set, muck piles in headings six or more metres wide were examined using various wetting times with simple jets from hand-held or blocked-in-position hoses and nipples.

Results from the first set, based on differences between return and intake as well as between drawpoint and intake air samples, are given in Table 11. Problems occurred in assessing

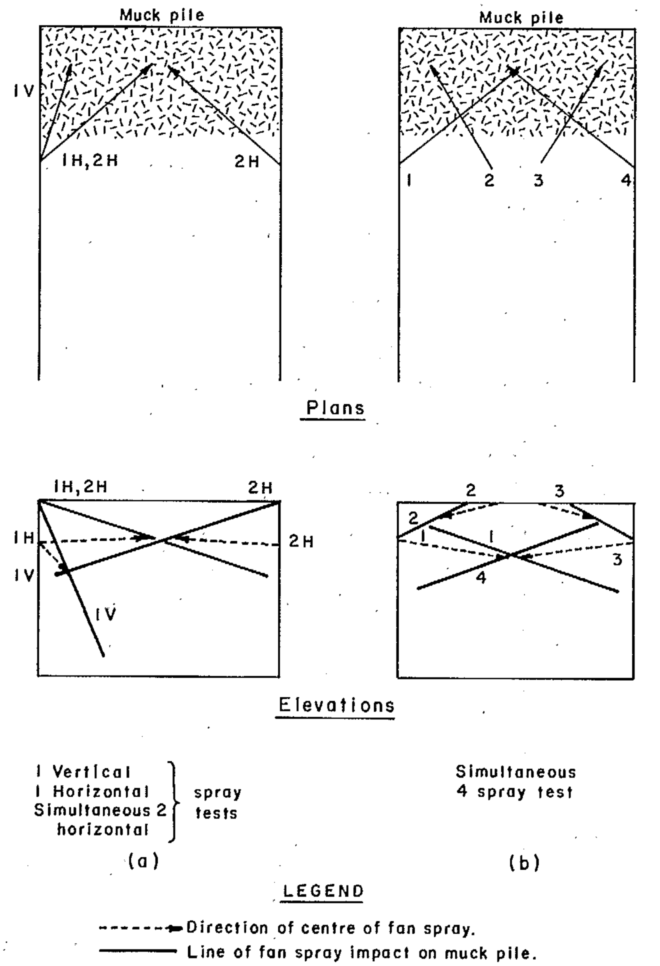

Fig. 6 - Configuration of water sprays for wetting tests in drawpoint

*The mine has since improved dust control in the orepass by installing level connectors and exhaust fans.

Table 10 - Analysis of LHD operator dust exposure

Operation	Cycle time (seconds)	Respirable dust concentration mg/m^3 Combustible	Mineral
Loading	40	2.8	4.0
Tramming	240	1.2	0.7
Dumping	60	1.2	10.0
Total	340		
Mean		1.38	2.72
Dust source		**% dust attributed to source** Combustible	Mineral
Diesel engine		30	0
Loading			10
Dumping			43
Orepass leakage			12
Other		3	2
		33	67

Table 11 - Effect of water on LHD loading high sulphide ore

Sprays No.	Sprays Dir	Respirable dust production (mg/t) Total	Combustible	Mineral	Quartz	Relative respirable dust production (ng on filter/bucket) Total	Combustible	Mineral	Quartz	Dust as % of dry Combustible	Quartz
	dry					50	19	22	6		
	dry	280	330	21	59	63	42	21	8		
1	hor	-180	-123	-5	-14	13	1	12	3		
1	vert	33	180	58	18						
1	hor	290	81	167	57	35	30	4	1		
1	hor	-20	71	-84	14	26	11	13	6		
2	hor	104	75	52	12	15	8	6	1.5		
2	hor	-114	35	-135	36	4	8	-4	1		
2	hor	29	32	-15	13		5	-	.5		
2	hor	15	3	54	4	7	-6	13	.5		
4	hor	200	130	110	13	3	-1	4	.5		
Means	dry	280	330	21	59	58	30	21	7	100	100
1	spray	18	50.15	47	20	30	20.67	8	3.5	60	42
2	spray	9	36.11	-11	16	9	4.13	5	.9	12	20
4	spray	200	130.40	110	13	3	-1.0	1.4	.5	20	15
Mean wet		61	76.23	26	21	15	8.27	6	1.6	25	30
Std dev		116	57	99	17	11	11	6	2		

Note: Negative values result when fan stabilizing airflow in tram drift also acted as dust remover and actually reduced dust concentration of return air below that of intake air. The relative respirable dust production figures were obtained by applying a correction factor assuming that the dust collector efficiency was constant.

dust production because of recirculation and dust collection by a fan introduced to stabilize the airflow, as well as by the relatively high dust concentration in the intake air.

It was clear that adding water decreased mineral dust production but not to the extent possible because dry muck was always visible immediately after loading.

Results from the second set of tests on highly siliceous rock muck piles are shown in Table 12. The first 16 tests were made on muck piles in various headings and represented normal mine operation. The last two tests were made on a similar muck pile at a site having through-ventilation. It was obvious that adding water substantially reduced dust levels to less than 20%. It was also evident in normal mine practice, especially during the first few buckets at the start of the shift in early start tests, that dry muck was frequently visible. The extra wetting tests in which loading of a muck pile was continued after the lunch break led to a further substantial reduction in mineral dust. The extra wetting consisted of the normal wetting before and during loading of the muck pile throughout the morning and afternoon as well as extra wetting by the dust survey team during the operator's lunch break.

The two tests showed somewhat erratic results on combustible dust production. Although adding water could affect ease of loading and power requirements or even modify the soot production by the engine, it is believed that the erratic results are probably due to the errors in assessing combustible dust being greater than those in assessing quartz dust, or to variation between engines.

COMPOSITION OF AIRBORNE DUST IN MINES

The experiments on dust production have identified three airborne dust types and their sources:

1. mineral dust from all mining processes
2. oil mists from lubricating oil for compressed air-powered machines
3. diesel exhaust particulates.

Mineral dusts are not all equally hazardous to health. Free silica minerals and mineral fibres (asbestos) are of an order of magnitude more hazardous than most other common minerals. Of the free silica minerals, quartz is the most common, and in this study was the only "more hazardous" mineral measured separately. In most mines tested the respirable quartz formed a constant proportion, within the limits of experimental error, of the respirable mineral dust. This proportion was always less than that in the rock mined. In one mine with a massive sulphide ore there was some evidence that the quartz content was higher in the airborne dust in the mining zone than in the crusher room. Presumably, by the time the rock reached the crusher the silicate components were well wetted and their dust was better controlled by the various water additions en route.

In jackleg drilling it was found that 90% of the dust collected on the filter was combustible. It was presumed but not proven that this was lubricating oil atomised by the high energy of the exhaust air. A simple calculation showed that the measured quantity of respirable combustible dust was about 0.33% of the amount of lubricating oil sent underground for use in drills.

The diesel exhaust particulates are a complex mixture of soot, unburnt hydrocarbons, partially oxidized hydrocarbons, and sulphuric acid. The sulphuric acid mist is produced by oxidation of some of the sulphur dioxide in the catalytic purifier, and may be absorbed onto the soot particles.

In this report only the total exhaust particulates as indicated by the respirable combustible dust, i.e., loss in mass on ashing, are considered.

Table 13 shows the composition of the dust produced at various operations and its probable source. In view of the limited number of operations examined, the extent of variation in composition is probably too low and the figures should be used only as an indication of the possible hazards.

Table 12 - Effect of water on LHD loading high silica ore

Description	Tonnes	Respirable dust production (mg/t)				Dust as % of dry	
		Total	Combustible	Mineral	Quartz	Combustible	Quartz
Normal mine practice							
	168	750	750	92	46		
	176	1300	1100	116	58		
	152	800	550	114	57		
	160	650	450	59	29		
	424	485	420	70	35		
	160	530	390	124	62		
	160	225	240	90	45		
	160	1090	470	630	315		
	216	460	380	80	40		
mean		700	525	150	75	105	25
Early start	128	900	750	200	100		
	32	750	600	170	85		
mean		825	675	185	92	135	31
Extra wetting	200	800	750	96	48		
	176	1500	1300	58	29		
	194	600	600	66	33		
	32	700		28	14		
mean		900	825	62	31	165	10
Dry test	120	900	500	600	300	100	100
Dry test after 1 1/2 hours wetting	88	800	700	110	55	140	18
Overall mean		780	625	160	80	125	27
Overall wet tests		770	630	130	65	125	22

Table 13 - Composition of airborne dust produced by various operations

	Ash	Mineral dust total	Combustible dust Total	Oil mist	Diesel exhaust
	%	%	%	%	%
Blasting	88	50-70	12		
Loading					
C.A. mucker	25	25	75	75	
C.A. scraper	70	70	30	30	
Electric slusher	95	95	5		
Diesel LHD	20-40	20-40	60-80		60-80
Drilling	10	10	90	90	
Orepasses	100	100	0		
Crushing	100	100	0		

RECOMMENDATIONS FOR DUST CONTROL IN HARD ROCK MINES

BLASTING

Because of both dust and fumes, blasting should be carried out so that men are not exposed to contaminated air either in the area itself or to the air leaving it. Blasting techniques should aim at producing a minimum of fines and oversize lumps, and producing the smoothest floor possible (4).

ROCK HANDLING

Rock breaking produces large quantities of airborne dust, and although the broken ore needs further reducing, additional breakage should be minimized at all sites where men may be exposed and confined to such areas as crushers where enclosures and filtration can capture most of the dust. In handling rock, attention should be given to:

1. Minimizing free fall as the amount of dust produced is proportional to the distance dropped.
2. Using slides as sliding a given vertical distance reduces dust production compared with falling freely.
3. Making floors as smooth as possible to minimize energy required to pick up or drag rock.
4. Locating and designing sites for secondary breakage of oversize rock such as grizzlies or dumps, so that the dust dispersion can be entrained and either directed to a return airway or collected by filtration; in particular, they should not be located in main airways where high air velocity increases dust dispersion.
5. Vertical orepasses. These are a major source of dust because of the piston effect of falling rock pumping air out of the orepass into the work place. Pressures can be developed high enough to lift 1-cm thick steel plate doors.

Although pressure can be reduced by interconnecting ore and waste passes at each level, there will still be some leakage of dusty air and elaborate precautions may be necessary to divert this from the work areas.

Siting orepasses close to the return airways may be well worthwhile.

The use of off-vertical orepasses could possibly decrease dust production by transforming free falling to a sliding motion, decreasing fresh breakage. A controlled feeder can prevent the formation of plugs and greatly decrease the pumping of dusty air.

6. Wetting broken rock. This can prevent fine dust from becoming airborne by binding it to large pieces of muck. To be effective a thin liquid layer must cover all free surfaces in the rock pile. For the liquid to spread over the rock its surface must be wettable. Silica rocks are usually readily wettable whereas some sulphide minerals are not. Even for silica rocks, wetting times of more than two hours can be required to completely wet a muck pile and minimize dust dispersion during loading. For sulphide rocks wetting times may be much longer.

   The quantity of water required however is not great - a few tens of litres per tonne and the use of mist sprays applying water at a low rate evenly over the top of the muck pile for hours is probably most effective. A hand-held hose jet is usually not satisfactory and encourages inadequate wetting.

   The mechanical mixing involved in rock movement in orepass and crusher operations spreads the water much faster and quickly traps any dust created by new breakage.

7. Some ventilation is essential to dilute the dust concentration. Whenever possible, airflow direction should be such that the air flows away from workers towards the dust source.
8. Enclosure of dust handling operations is effective in decreasing air velocity over moving rock and reduces the dispersion of dust.
9. Where breakage is unavoidable, such as in orepass and crusher operations, enclosures and air extraction are almost always required for good dust control.

DRILLING

Normal wet drilling is not a substantial source of dust as the application of water close to the cutting edge and its virtual immersion in water in the hole prevents dust escape. However, large quantities of potentially respirable dust are formed so that dust control must be considered in any change in drilling technique, such as when going to down-the-hole drilling (Table 7).

LHD's, and probably other machines, when preparing faces for drilling apply high forces and expend much energy, thereby causing fresh breakage and creating more potentially airborne dust. The LHD bucket is thus a poor tool for cleaning faces and alternatives are required.

RECOMMENDATIONS FOR FURTHER STUDIES

Further studies are required to better understand the effects of floor roughness, loading techniques, wetting times and applying filtration devices to mobile equipment.

Loading of broken rock is still a major source of dust and four main approaches are recommended for further study:

1. Improving the loading process by smoothing the floor and by better bucket handling.
2. Devising better wetting techniques - wetting is time-consuming but requires little water. Studies are required to investigate:
   a. effects of wetting agents on sulphide ores and on subsequent flotation processes;
   b. mist sprays initiated by the blast and determining minimum wetting times for various types of rock and sizes of muck pile; integrating these into the mining cycle;
   c. techniques for wetting standing ore in stopes as wetting muck only at drawpoints cannot be fully effective because of the short exposure time; mist sprays are a possibility as is also extraction ventilation from each drawpoint;
   d. use of water stemming which introduces water directly into the blasted rock pile during blasting when rapid loading is essential.
3. Using small machine-mounted filters which are now being used successfully on coal cutting

machines. It is possible that filters and air exhaust systems could be mounted directly on LHD's to decrease both mineral and diesel exhaust dust. Because equipment is subject to abuse, components would have to be built in rather than added on, necessitating machine redesign. Other possible applications of such filter units would be on rock breakers, toe cleaning machines, down-the-hole drills, etc.

4. Improving ventilation techniques - most active mining sites produce substantial quantities of dust only when rock loading or scaling are in progess. The dust sources and breathing zones may be separated by enclosures or partitions or by controlling airflow direction:
   a. as well as low volume forcing systems consideration should be given to high volume exhaust systems which are turned on only when most needed during the dustier operations. This has obvious application in multiple drawpoint operation but is harder to apply in stopes and headings;
   b. studies should be made on the design and effectiveness of airflow direction control at the outlet of fresh air ducts, such as the use of diffusers to blow relatively low velocity air towards the workers' breathing zone.

DIESEL ENGINE EXHAUST PARTICULATES

Combustion engine-powered vehicles are attractive in mines because of their mobility and low ancillary support needs. As the diesel (compression ignition) is the main type of engine used and obviously produces substantial quantities of contaminants, reduced exposure is recommended as the health hazard has not yet been completely evaluated. Active research on control of exhaust pollutants is in progress elsewhere in CANMET (5).

ACKNOWLEDGEMENTS

The author wishes to acknowledge with thanks the kind cooperation and assistance of the management and other staff members of the mines who preferred to remain anonymous, but without whom this report could not have been prepared. The author also wishes to thank other employees of CANMET for their cooperation in gathering dust data and related information. W. Stefanich, the dust laboratory technician, was of great assistance in most of the field work.

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