

# LABORATORY STUDY OF ROCK DUST INERTING REQUIREMENTS: EFFECTS OF COAL VOLATILITY, PARTICLE SIZE, AND METHANE ADDITION

**K. L. Cashdollar and M. Hertzberg**  
*Bureau of Mines, Pittsburgh Research Center, USA*

## ABSTRACT

The Bureau of Mines has conducted a systematic study of the rock dust inerting requirements for various coals, using a 20-L laboratory test chamber. Particle sizes of the coals ranged from very fine pulverized dusts to coarse (minus 20 mesh) dusts. The data show that, with respect to the rock dust inerting requirement, the particle size of the coals has as much of an effect as the standard volatility. In testing various  $\text{CaCO}_3$  rock dusts against a bituminous coal dust, the finer sized rock dusts were more effective. The laboratory rock dust inerting data also showed reasonable agreement with full-scale mine data. Laboratory data on the effect of added methane gas also showed good agreement with mine data.

## INTRODUCTION

There have been over 500 major dust and/or gas explosions in United States coal mines during the past 100 years (Nagy 1981). The frequency and magnitude of these explosion disasters have decreased as a result of regulations that require the addition of rock dust to the coal dust and that require the dilution of methane by ventilation air. However, the explosion hazard has not been completely eliminated, and major coal mine explosion disasters still occur.

The Bureau of Mines has been studying dust explosions in both laboratory and full-scale experimental mine tests since 1910. In the United States, the mining regulations have always been based on the results of the full-scale mine tests. Laboratory chambers have been used for preliminary screening tests before full-scale mine tests were conducted. Because the laboratory tests can be conducted in a much shorter time than the mine tests, a wider range of coal types and sizes can be studied in the laboratory chambers. During the past dozen years, the Bureau has designed an 8-L laboratory chamber (Hertzberg and Cashdollar 1977 and Cashdollar et al 1983) and a 20-L laboratory chamber

(Cashdollar and Hertzberg 1985); data from these chambers agreed reasonably well with those from mine tests.

The 20-L chamber has become the standard laboratory test chamber at the Bureau for testing the explosibility and inerting of fuel dusts and gases. Some data on the explosibility of coals and other carbonaceous dusts as measured in the Bureau 20-L chamber have been reported previously. Those previous papers have discussed the inerting of a high volatile bituminous coal by various inhibitors (Hertzberg et al 1985), the ignition energy requirements for accurate measurements of flammability limits of dusts (Hertzberg et al 1988a), a volatility model for coal dust flame propagation (Hertzberg et al 1988b), a comparison of laboratory and mine research on lean explosibility limits and rock dust inerting of various coals (Cashdollar et al 1987), and the effect of volatility on the explosibility limits of coals and other carbonaceous dusts (Cashdollar et al 1989).

The present paper compares 20-L data on the limestone rock dust inerting of three bituminous coals with data from full-scale mine tests. There

is also new 20-L data on the rock dust inerting of various sizes of bituminous coals. In this paper, the terms "flammability" and "explosibility" are used interchangeably to refer to the ability of an airborne dust cloud to propagate a flame after it has been initiated by a sufficiently strong ignition source. The terms refer to a rapid deflagration and not a detonation.

## EXPERIMENTAL APPARATUS AND DUST ANALYSES

The dust explosibility data in this paper were obtained in the 20-L laboratory chamber (Cashdollar and Hertzberg 1985) shown in figure 1. The near-spherical chamber is made of stainless steel and has a pressure rating of 21 bar. Optical dust probes (Cashdollar et al 1981) are used to measure the uniformity of the dust dispersion. The strain gauge pressure transducer measures the explosion pressure and a differentiator amplifier allows the direct measure of the rate of pressure rise. The dust to be tested can be placed either in the dust reservoir or on top of the dispersion nozzle at the bottom of the chamber. The standard test procedure was to partially evacuate the chamber to 0.1 bar absolute so that the blast of air (which dispersed the dust) raised the chamber pressure to about 1 bar absolute at the time of ignition. The standard ignition source used for the rock dust inerting measurements was a 5,000 J electrically activated pyrotechnic ignitor.

The proximate analyses of the four bituminous coals that were tested most extensively are listed in table 1. The coals were desiccated before testing, as shown by the low moisture contents in the table. The standard ASTM volatilities are listed for reference only. Other measurements have shown that the true volatilities are higher at the high heating rates found in dust flame fronts (Hertzberg and Ng 1987, Cashdollar et al 1989).

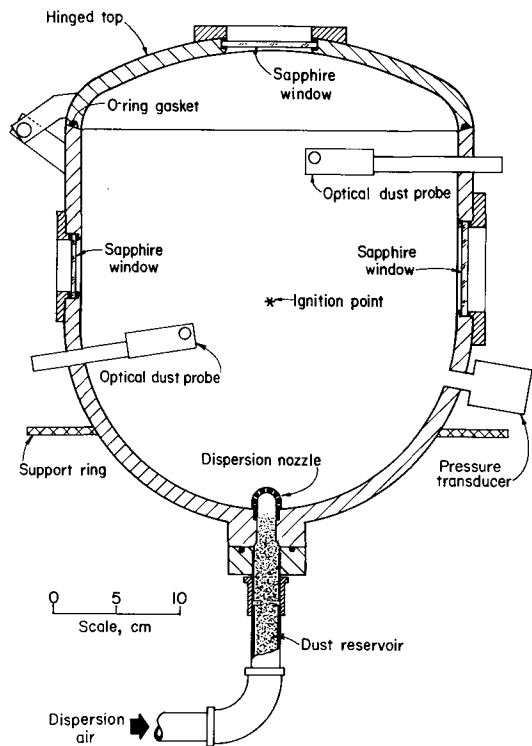


Figure 1. - Vertical cross section of the 20-L laboratory test chamber.

The particle size analyses for the various pulverized batches of these four bituminous coals are listed in table 2. The size distributions were determined from a combination of sonic sieving data and Coulter counter data. The first column lists the coal seam and identifies the various batches of each seam by number. The Pittsburgh seam is abbreviated as Pgh and the Pocahontas as Poc. The second and third columns list the weight percent of each dust that is less than 20 or 75  $\mu\text{m}$ , respectively. In the fourth and fifth columns,  $D_s$  is the arithmetic surface mean diameter and  $D_w$  is the arithmetic volume or mass mean diameter. Since particle size distributions generally approximate a log-normal distribution, the geometric size parameters are also listed in the table in the sixth and seventh columns. In the sixth column,  $D_g$  is the geometric mass mean diameter. If the size distribution were exactly log-normal,  $D_g$  would also be

Table 1: Proximate analyses of selected coals

Coal dust, seam and state	Moisture, %	Ash, %	Volatility, %	Fixed carbon, %
Sunnyside, UT	0.8	6.6	38.5	54.1
Pittsburgh, PA	0.9	6.0	36.5	56.6
Freeport, PA	0.9	7.6	22.5	69.0
Pocahontas, VA	0.6	6.0	17.1	76.3

Table 2: Size analyses of the pulverized coals

Coal dust	<20 $\mu\text{m}$ , %	<75 $\mu\text{m}$ , %	$D_s$ , $\mu\text{m}$	$D_w$ , $\mu\text{m}$	$D_g$ , $\mu\text{m}$	$\sigma_g$
Sunnyside-1	12	83	36	52	44	1.8
-2	25	73	24	62	40	2.7
-3	41	86	17	40	26	2.6
-4	18	100	28	38	33	1.7
Pgh-1	16	81	31	51	40	2.0
-2	24	100	25	35	30	1.8
-3	47	97	18	28	23	1.9
-4	100	100	8	9	8	1.5
-5	100	100	5	6	6	1.5
Freeport-1	27	73	23	55	37	2.6
-2	47	97	16	29	22	2.2
Poc-1	10	78	38	55	46	1.8
-2	27	65	19	63	39	3.0
-3	38	75	18	60	32	3.2
-4	43	86	16	40	25	2.7
-5	67	94	11	23	15	2.4
-6	67	100	13	17	16	1.6
-7	100	100	5	6	5	1.5

identical to the mass median particle diameter. For these pulverized coals, the size distributions are close enough to a log-normal distribution so that  $D_g$  usually differs by only a few percent from the mass median diameter. In the seventh column,  $\sigma_g$  is the geometric standard deviation based on the volume or mass distribution. For a log-normal curve, the characteristic width of the distribution is from  $D_g/\sigma_g$  to  $D_g\sigma_g$ . For example, the Pgh-1 coal has  $D_g = 40 \mu\text{m}$  and  $\sigma_g = 2.0$ . Therefore, one sigma smaller than the mean would be  $D_g/\sigma_g = 20 \mu\text{m}$  and one sigma larger than the mean would be  $D_g\sigma_g = 80 \mu\text{m}$ . The larger  $\sigma_g$  is, the broader is the size distribution. For a perfectly monodisperse size distribution,  $\sigma_g$  would be 1.0. Most

of the particle size distributions shown in table 2 are for pulverized coals from various pulverizers. The smallest sizes of the Pittsburgh (Pgh 3,4, and 5) and Pocahontas (Poc 6,7) seam coals were centrifugally classified.

Table 3 lists similar size data for the three coarse bituminous coals that were studied. The second through fifth columns list the percent passing through various sieves or, equivalently, the percent less than a certain particle size. For the coarse coals, the size distributions are skewed and therefore the mass median diameters are about 35 to 40% larger than the listed geometric mean diameters.

Table 3: Size analyses of the coarse coals

Coal dust	-200 mesh, <75 $\mu\text{m}$ , %	-100 mesh, <150 $\mu\text{m}$ , %	-40 mesh, <425 $\mu\text{m}$ , %	-20 mesh, <850 $\mu\text{m}$ , %	$D_s$ , $\mu\text{m}$	$D_w$ , $\mu\text{m}$	$D_g$ , $\mu\text{m}$	$\sigma_g$
Sunnyside	20	35	69	100	92	311	199	3.0
Pittsburgh	21	35	67	99	89	325	202	3.2
Pocahontas	20	34	67	99	77	323	199	3.3

Table 4 lists particle size data for the rock dusts used in this study. The first is the standard limestone rock dust used at the Bureau for mine explosion tests. The second is this same limestone rock dust with 0.5% magnesium stearate added as a fluidizing agent to make the dust disperse more easily. The third is a sample of the stone dust used in tests at the Experimental Mine Tremonia in Dortmund, Germany. The fourth is a rock dust made from pulverized marble; this rock dust is used in some coal mines in the southern United States. The first three rock dusts have very similar size distributions. The marble rock dust has a higher percentage minus 200 mesh (less than 75  $\mu\text{m}$ ), but it also has less fines below 20  $\mu\text{m}$  than the other rock dusts. The fifth rock dust in table 4 is the minus 325 mesh size fraction sieved from the regular limestone rock dust. The sixth is a very fine, centrifugally classified limestone dust.

#### ROCK DUST INERTING DATA

Figures 2, 3, and 4 are examples of the rock dust inerting data for Pgh-1 coal in the 20-L chamber. To test whether a particular percentage of rock dust will inert a coal, tests are conducted over a wide range of coal dust concentrations. Figure 2 shows the explosibility data for mixtures of 40% fluidized limestone rock dust and 60% coal dust. In the top part of the figure, the maximum rate of pressure rise for each test is plotted versus the coal dust concentration. For the 20-L data, the rate of pressure rise data are size normalized by multiplying by the cube root of the chamber volume. In the bottom part of figure 2, the

pressure ratio is the maximum explosion pressure (corrected for the pressure rise due to the ignitor by itself) divided by the pressure at ignition (about 1 bar). Therefore, the pressure ratio (PR) is approximately the maximum absolute explosion pressure in bar or atm. For comparison, the dashed lines in figure 2 show the data for the coal dust without any added rock dust. Based on previous data (Hertzberg et al 1988a), the criteria for significant flame propagation are  $PR > 2$  and  $(dP/dt)V^{1/3} > 1.5$ . Using these criteria the 40% rock dust tests produced explosions at all coal concentrations above  $\sim 80 \text{ g/m}^3$ . At higher concentrations, the explosion pressures for the coal-rock mixtures were slightly lower than those for the coal by itself. However, the rates of pressure rise were only about half of those for the coal alone.

Figure 3 shows the data for mixtures of 70% rock dust and 30% coal dust. For these mixtures, both the maximum explosion pressures and rates of pressure rise are significantly lower than those for the coal alone or for the 40% rock dust mixture. However, almost all of the tests at high concentrations produced explosions, and therefore 70% rock dust is still insufficient to inert the mixture. In figure 4, the data show that only a few tests at 75% rock dust produced explosions. However, more than half of the tests at coal concentrations of 200 and  $700 \text{ g/m}^3$  did produce explosions.

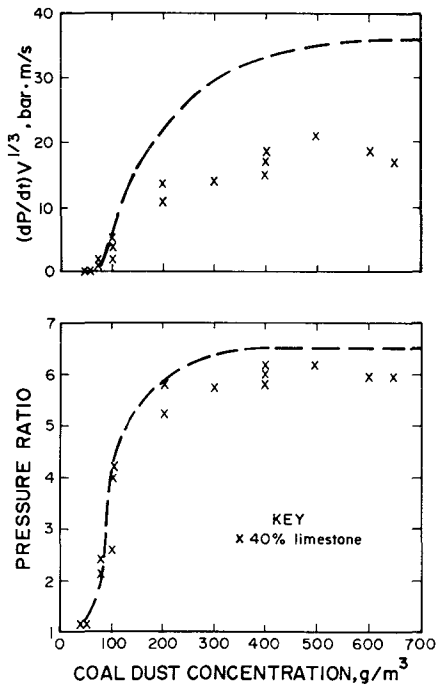


Figure 2. - Explosibility data for mixtures of 60% coal and 40% limestone compared to the dashed line data for coal alone.

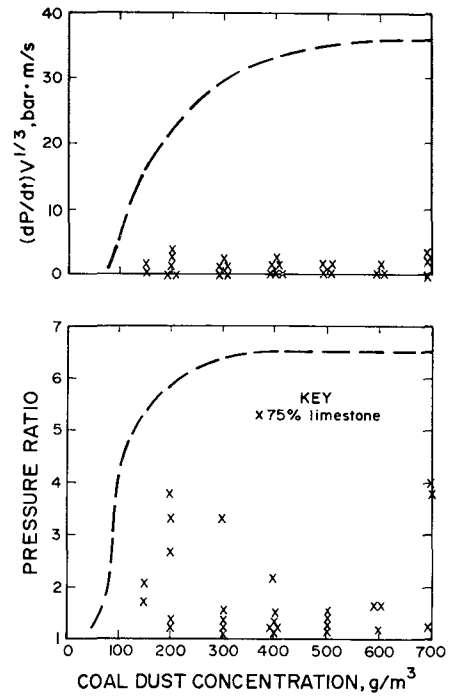


Figure 4. - Explosibility data for mixtures of 25% coal and 75% limestone compared to the dashed lines for coal alone.

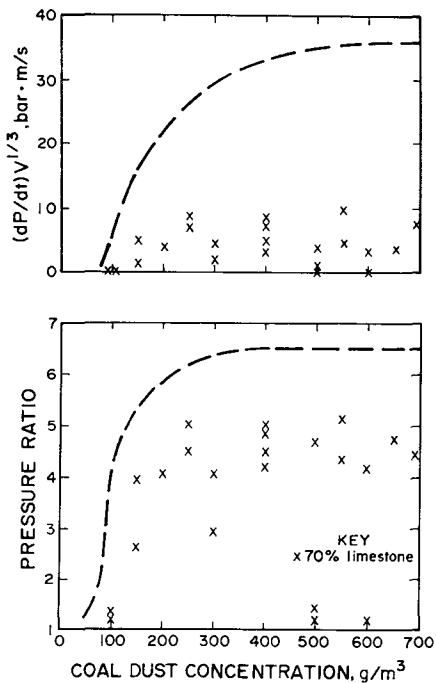


Figure 3. - Explosibility data for mixtures of 30% coal and 70% limestone compared to the dashed lines for coal alone.

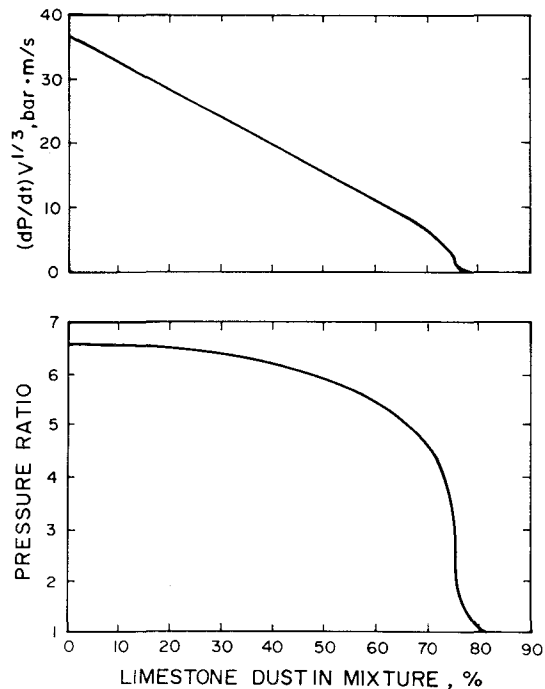


Figure 5. - Maximum explosion pressure and rate of pressure rise data for coal-rock dust mixtures.

Table 4: Size analyses of the CaCO<sub>3</sub> rock dusts

Rock dust	<20 $\mu\text{m}$ , %	<75 $\mu\text{m}$ , %	D <sub>s</sub> , $\mu\text{m}$	D <sub>w</sub> , $\mu\text{m}$	D <sub>g</sub> , $\mu\text{m}$	$\sigma_g$
Limestone, regular	53	77	12	42	22	3.2
Limestone, fluidized	46	73	14	49	26	3.2
Limestone, German	51	79	15	41	24	2.9
Marble	34	94	18	35	26	2.2
Limestone, -325 mesh	75	100	8	14	11	2.1
Limestone, very fine	100	100	3	4	4	1.4

Therefore, the amount of fluidized limestone rock dust necessary to completely inert the Pgh-1 coal dust would be slightly more than 75%. That conclusion was confirmed by the fact that tests of an 80% rock dust mixture produced no explosions at any concentration.

A summary of all such 20-L data for mixtures of Pgh-1 coal dust and fluidized limestone rock dust is shown in figure 5. For each mixture tested, the average maximum pressure and rate of pressure rise values (measured at high coal dust concentrations) are plotted versus the amount of rock dust in the mixture. The pressure ratio declines only slightly with increased inhibitor content until a high percent of rock dust is reached. Near the inerting level, the pressure ratio decreases rapidly from a value of 4 at 73% rock dust to a value of about 1.1 at 80% rock dust. Based on the flammability criteria and the data in figure 5, the amount of fluidized limestone rock dust necessary to inert this Pittsburgh seam coal is about 76%. This is the inerting level as measured in the 20-L chamber using 5000 J ignitors. Because of the possible dependence on apparatus and the known variation with ignition energy, this inerting level should be considered not as an absolute value, but rather as a relative one. This will be discussed in more detail later in the paper when the data are compared to mine test data.

Data similar to those in figures 2 through 5 were obtained for all the coals listed in tables 2 and 3.

Table 5 lists the fluidized limestone rock dust inerting data obtained in the 20-L chamber for all the pulverized coals from table 2. The repeatability of these data is about  $\pm 2\%$ . The amount of rock dust necessary to inert the Sunnyside, Utah coal ranged from 76 to 83% depending on the coal particle size distribution. In general, the finer pulverized coals required more rock dust to inert them. However, the inerting data do not correlate precisely with any one measure of the coal particle size in table 2 because the exact size distribution cannot be described by only one parameter. For these relatively broad size distributions, either an increase in finer particles (<20  $\mu\text{m}$ ) or a decrease in the larger particles (>75  $\mu\text{m}$ ) results in an increase in the amount of rock dust required to inert the coal-rock mixture. The same general observations can be made for the various sizes of Pittsburgh seam coal. The two finest sizes (Pgh-4 and Pgh-5) were centrifugally classified to remove all the large particles, and these two sizes required the greatest amount of rock dust to inert the coal-rock mixtures.

The two Freeport coals show the same size effects, with the finer size requiring more rock dust. The Pocahontas seam coal data in table 5 show the same correlation with particle size as the other coals. However, this lower volatility coal requires a somewhat lower amount of rock dust to inert, if similar sizes of the coals are compared. For example, Pgh-1 and Sunnyside-1 are

Table 5: Amount of fluidized limestone rock dust necessary to inert various fine size, pulverized coals.

Coal dust	Amount to inert, %
Sunnyside-1	76
-2	78
-3	83
-4	79
Pgh-1	76
-2	79
-3	79
-4	87
-5	89
Freeport-1	73
-2	79
Poc-1	63
-2	67
-3	74
-4	78
-5	83
-6	78
-7	84

similar in size to Poc-1, but they require 76% rock dust to inert compared to 63% for the Pocahontas. Also, Pgh-5 is comparable in size to Poc-7 but requires 89% to inert compared to 84% for the Pocahontas coal. Note that the difference in inerting amount required for the Pittsburgh versus Pocahontas coals is smaller for the finer sizes of the coal dusts. This may be due to increased amount and rate of volatiles generation from the finer dusts (Hertzberg and Ng 1987), especially for the lower volatility coal.

A comparison of the inerting effectiveness of the regular and fluidized limestone rock dusts in the 20-L laboratory chamber is listed in tables 6 and 7. The dashes in the tables indicate that no tests were made. For both the Pittsburgh and Pocahontas seam pulverized coals, somewhat more of the fluidized rock dust was required to inert the mixture. The reason for this may be that although the fluidized rock dust

disperses better (which should make it more effective), it may also allow the coal dust to disperse better. Also listed in tables 6 and 7 are the Bureau data from the Bruceston Experimental Mine (BEM) and Lake Lynn Experimental Mine (LLEM). The BEM data are based on previous tests with a wide range of coals (Rice and Greenwald 1929 and Richmond et al 1975). Those early data have also been presented in more recent papers (Nagy 1981, Cashdollar et al 1987, and Weiss et al 1989). The coarse Pocahontas coal was not actually tested in the BEM, and the data listed in table 7 are for a coarse bituminous coal of similar volatility. The LLEM data are from the paper at this conference by Weiss et al (1989). In those other papers describing the mine results, the amount to inert was usually presented as the total incombustible content rather than just the limestone content as listed in tables 6 and 7. (The total incombustible includes the moisture and ash in the coal in addition to the limestone.) The data listed in tables 6 and 7 show that larger amounts of rock dust are required in the larger cross section entry of the LLEM compared to those required at the BEM, particularly for the lower volatility Pocahontas and for the coarse size coals. The 20-L laboratory data show reasonably good agreement with the mine data, especially for the pulverized coals. It is unrealistic to expect that a laboratory chamber would always give exact agreement with large-scale mine data over a wide range of coal volatility and particle size. However, the relative data from the 20-L chamber can be used for preliminary screening tests before full-scale mine tests. This provides a cost effective method of reducing the number of mine tests needed to document the inerting requirements for coals.

Table 8 lists inerting data for the various CaCO<sub>3</sub> rock dusts listed in table 4. All were tested against the Pgh-1 pulverized coal dust in

Table 6: Amount of limestone rock dust (%) necessary to inert pulverized bituminous coals

	20-L chamber		BEM	LLEM
	fluidized	regular	regular	regular
Sunnyside-1	76	-	77	75-79
Pgh-1	76	72	76	78-80
Poc-1	63	58	50-55	>68

Table 7: Amount of limestone rock dust (%) necessary to inert coarse bituminous coals

	20-L chamber		BEM	LLEM
	fluidized	regular	regular	regular
Sunnyside	51	-	59	68-72
Pittsburgh	50	47	58	>65
Pocahontas	42	37	30-35	52-56

Table 8: Amount of various rock dusts (%) necessary to inert Pittsburgh pulverized coal dust.

Rock dust	Amount to inert, %
Limestone, regular	72
Limestone, fluidized	76
Limestone, German	76
Marble	76
Limestone, -325 mesh	68
Limestone, very fine	63

the 20-L chamber. The German stone or rock dust has a size distribution similar to those of regular and fluidized limestone rock dusts from the United States. Its effectiveness is comparable to that of the fluidized rather than regular rock dust even though the optical dust probes show that its dispersion characteristics are comparable to those of the regular rather than fluidized limestone. The marble rock dust is also less effective than the regular limestone and comparable to the fluidized limestone rock dust. In this case also, the optical dust probes show that the dispersion characteristics of the marble are comparable to those of the regular limestone. From table 4, the marble dust has a higher percentage of mass below 75  $\mu\text{m}$  but less below 20  $\mu\text{m}$  than the other rock dusts. The smaller amount of very fine particles may

reduce its effectiveness as a heat sink. The minus 325 mesh limestone was finer in size than the other rock dusts and required less to inert the coal. The very fine sized limestone was the most effective of these rock dusts. The explanation is that the finer dusts are probably more effective heat sinks.

The effect of small amounts of added methane gas on the inerting effectiveness of rock dust is shown in table 9. More rock dust is required to inert the mixture when the atmosphere contains added methane. Based on previous tests in the Bruceton Experimental Mine (Rice and Greenwald 1929), a formula was developed for the additional amount of rock dust, A, necessary for each percent of methane present. The formula is  $A = (100 - I)/5$ , where A is in percent and I is the total incombustible percent required in the absence of methane. The data in table 9 from the 20-L laboratory

Table 9: Amount of fluidized limestone rock dust (%) necessary to inert pulverized coal with added methane gas.

Coal dust	0% CH <sub>4</sub>	1% CH <sub>4</sub>	2.5% CH <sub>4</sub>
Pgh-1	76	80	87
Poc-1	63	71	-

chamber also follow this empirical formula. Thus there is good agreement between the data from the 20-L laboratory tests and those from full-scale mine tests for the inerting requirements of mixtures of coal dust and methane.

A summary of rock dust inerting requirements measured in the 20-L chamber for a very wide range of carbonaceous dusts is shown in figure 6. Some of these data were presented previously (Cashdollar et al 1989), but the figure now contains new data for the pulverized coals in table 2. Data for the very fine, centrifugally classified coal dusts were not included. The graph shows the amount of fluidized limestone rock dust necessary to inert the various fuel dusts as tested in the 20-L chamber using 5000 J ignitors. The amount to inert is shown in two ways as a function of the standard ASTM volatility (on an "as received" basis). The first (open circles) is the total incombustible, which includes both the limestone and the ash and moisture in the coal. The coals tested include low volatile anthracites and various bituminous coals. The data have been extended to higher volatility by also testing a polyethylene-graphite mixture (50% volatility), gilsonite (a mined, asphaltic material with 85% volatility), and polyethylene (100% volatility). Proximate analyses of these dusts are listed either in table 1 or in the previous paper (Cashdollar et al 1989). The data curve for total incombustible required versus volatility agrees rather well with previous data for pulverized coals tested in the Bruceton experimental mine (Rice and Greenwald 1929 and Richmond et al 1975).

In the second way of presenting the data in figure 6, the triangles are the inerting data points for which the fixed carbon char is also considered to be part of the inert material. These data show that all of the fuel dusts are inerted at a

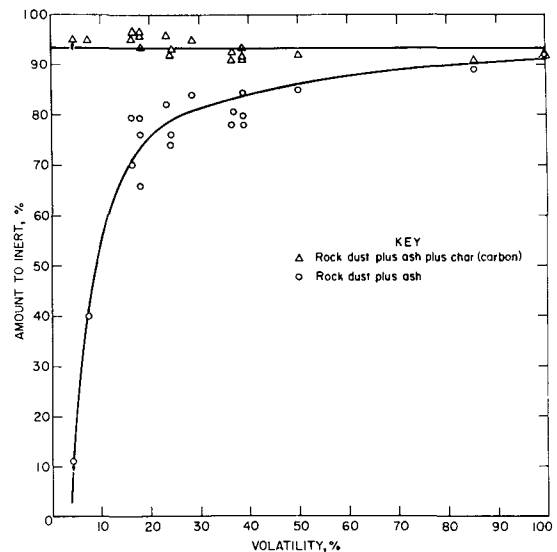


Figure 6. - Rock dust inerting requirements for carbonaceous dusts over a wide range of volatility.

volatility, when the fixed carbon is considered part of the inert. This shows that the added limestone rock dust, the ash and moisture in the coals, and the fixed carbon are all of similar effectiveness in inerting the dusts during the short time scale of flame propagation. As another test, graphite powder was used to inert the polyethylene dust, and 94% graphite was sufficient to inert the polyethylene-graphite mixture. This was only slightly more than the 92% limestone required to inert the polyethylene-limestone mixture.

#### DISCUSSION AND CONCLUSION

The data show that the particle size distribution of coals can have as much of an effect on the rock dust inerting requirements as the volatility of the coals. In general, the finer the size of the coal, the more rock dust is required to inert. However, any single measure of particle size (such as the percent minus 200 mesh) is insufficient to characterize the particle size distribution and rock dust inerting requirement. The data also show that finer sized rock dust

is more effective in inerting coal dust.

The 20-L laboratory data presented here are consistent with laboratory rock dust inerting data of other researchers (Banhegyi and Egyedi 1983, Vukanic and Vukanic 1983, Foniok 1985, and Krzystolik 1987). However, an exact comparison is difficult because of insufficient details of the experimental apparatus, test procedures, and propagation criteria used by the other researchers.

There is sufficiently good agreement between the 20-L laboratory chamber data and the experimental mine data to justify the use of the laboratory chamber for preliminary screening tests, thus improving the cost effectiveness of the full-scale mine testing program.

#### REFERENCES

Banhegyi, M. and Egyedi, J., Method for Determining the Explosive Limits of a Mixture of Coal Dust, Methane and Inert Matter, paper E5 in proceedings of the 20th International Conference of Safety in Mines Research Institutes, Sheffield, England, October 3-7, 1983.

Cashdollar, K. L., and Hertzberg, M., 20-L Explosibility Test Chamber for Dusts and Gases, Rev. Sci. Instrum., v. 56, 1985, pp. 596-602.

Cashdollar, K. L., Hertzberg, M., and Richmond, J. K., Inhibition of Coal Dust Explosions: Comparison of the 8-Liter Laboratory Chamber and Experimental Mine, paper F-4 in proceedings of the 20th International Conference of Safety in Mines Research Institutes, Sheffield, England, October 3-7, 1983.

Cashdollar, K. L., Hertzberg, M., and Zlochower, I. A., Effect of Volatility on Dust Flammability Limits for Coals, Gilsonite, and Polyethylene, in Twenty-Second Symposium (International) on Combustion, The Combustion Institute, 1989.

Cashdollar, K. L., Liebman, I., and Conti, R. S., Three Bureau of Mines Optical Dust Probes, Bureau of Mines RI 8542, 1981, 26 pp.

Cashdollar, K. L., Sapko, M. J., Weiss, E. S., and Hertzberg, M., Laboratory and Mine Dust Explosion Research at the Bureau of Mines, in Industrial Dust Explosions, STP 958, ASTM, 1987, pp. 107-123.

Foniok, R. Hybrid Dispersive Mixtures and Inertized Mixtures of Coal Dust: Explosiveness and Ignitability, Staub Reinhalt. Luft, v. 45, 1985, pp. 151-154.

Hertzberg, M. and Cashdollar, K. L., Lower Flammability Limits, Ignition Energies, and Flame Temperatures of Coal Dust/Air Mixtures, in proceedings of the 17th International Conference of Scientific Research on Safety of Mining Works, Varna, Bulgaria, October 3-7, 1977, pp. 298-309.

Hertzberg, M., Cashdollar, K. L., and Zlochower, I. A., Flammability Limit Measurements for Dusts and Gases, in Twenty-first Symposium (International) on Combustion, The Combustion Institute, 1988a, pp. 303-313.

Hertzberg, M., Cashdollar, K. L., Zlochower, I., and Ng, D. L., Inhibition and Extinction of Explosions in Heterogeneous Mixtures, in Twentieth Symposium (International) on Combustion, The Combustion Institute, 1985, pp. 1691-1700.

- Hertzberg, M. and Ng, D. L., A Microscopic and Kinetic Study of Coal Particle Devolatilization in a Laser Beam, in Fundamentals of the Physical-Chemistry of Pulverized Coal Combustion, NATO ASI Series E, 1987, pp. 104-124.
- Hertzberg, M., Zlochower, I. A., and Cashdollar, K. L., Volatility Model for Coal Dust Flame Propagation and Extinguishment, in Twenty-first Symposium (International) on Combustion, The Combustion Institute, 1988b, pp. 325-333.
- Krzystolik, P. A. and Sliz, J., Effectiveness of Ignition Sources of Dust-Air Mixtures, in Proceedings of the 22nd International Conference of Safety in Mines Research Institutes, Beijing, China, November 2-6, 1987, pp. 501-509.
- Nagy, J., The Explosion Hazard in Mining, Mine Safety and Health Administration IR 1119, 1981, 69 pp.
- Rice, G. S. and Greenwald, H. P., Coal-Dust Explosibility Factors Indicated by Experimental Mine Investigations, 1911 to 1929, Bureau of Mines TP 464, 1929, 45 pp.
- Richmond, J. K., Liebman, I., and Miller, L. F., Effect of Rock Dust on the Explosibility of Coal Dust, Bureau of Mines RI 8077, 1975, 34 pp.
- Vukanic, B. and Vukanic, R., Contribution to the Investigation and Modelling of Grain-Size Distribution and Inert Material Influence on Oligo-Miocene Coal Explosiveness, paper F5 in proceedings of the 20th International Conference of Safety in Mines Research Institutes, Sheffield, England, October 3-7, 1983.
- Weiss, E. S., Greninger, N. B., and Sapko, M. J., Recent Results of Dust Explosion Studies at the Lake Lynn Experimental Mine, in 23rd International Conference of Safety in Mines Research Institutes, Washington, DC, September 11-15, 1989.

ETUDE APPROFONDIE EN LABORATOIRE DES CONDITIONS D'INERTIE DES  
POUSSIERES DE ROCHES : EFFETS DE LA VOLATILITE DU CHARBON, DE LA  
TAILLE DES PARTICULES ET DE L'APPORT DE METHANE

Kenneth L. Cashdollar, Martin Hertzberg

Une étude systématique des conditions d'inertie des poussières de calcaire a été effectuée dans une chambre de laboratoire de 20-L. Les données d'inertie ont été comparées aux données des limites maigres d'explosibilité pour les mêmes charbons. La taille des particules de charbon s'échelonnait des poussières pulvérisées de 100 pct passant à la maille de moins de 200 aux poussières épaisses de 20 pct passant à la maille de moins de 200. Les poussières examinées comprenaient des poussières d'antracites et de charbons bitumineux dont la volatilité allait de faible à élevée.

En ce qui concerne les conditions d'inertie des poussières de roches, les données révèlent que la taille des particules de charbon a autant d'influence que leur volatilité. Elles révèlent également que le composant fixe de carbone ou de charbon animal des charbons est essentiellement inerte au cours d'explosions de courte durée.

Les données d'inertie des poussières de roches obtenues en laboratoire rejoignent celles obtenues par des essais miniers à grande échelle.

UMFASSENDE LABORSTUDIE DER ANFORDERUNGEN AN DAS EINSTAUBEN MIT STEINSTAUB:  
EFFEKTE DER FLÜCHTIGEN BESTANDTEILE DER KOHLE, KORNGRÖÖE UND METHANGASZUSATZ.

Kenneth L. Cashdollar, Martin Hertzberg

Eine systematische Studie über die Anforderungen an das Einstauben mit Kalksteinstaub wurden in einer 20 l fassenden Laborkammer durchgeführt. Die Daten wurden mit den Daten, die sich aus den Experimenten mit den Explosivitätsgrenzen für dieselben Kohlen ergaben, verglichen. Die Korngröße der Kohlen reichte von 100% minus 200 Maschenweite bis zu groben Stäuben mit 20% minus 200 Maschenweite. Die Studie umfaßte Anthrazitkohle, sowie niedrig und hoch flüchtige Steinkohle.

In Bezug auf die Wirksamkeit des Einstaubens mit Steinstaub zeigen die Daten, daß die Korngröße des Staubes einen ebenso großen Einfluß hat wie die Flüchtigkeit. Außerdem zeigt sich, daß feste Kohlenstoffanteile oder Schwelkohleanteile in der Kohle während der kurzen Zeit der Explosion inert bleiben.

Die Ergebnisse dieser Studie werden mit denen aus Großversuchen in Gruben verglichen, und ihre Übereinstimmung wird aufgezeigt.

ВСЕСТОРОННЕЕ ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ УСЛОВИЙ  
ИНЕРТНОСТИ ПОРОДНОЙ ПЫЛИ: ВОЗДЕЙСТВИЕ ЛЕТУЧЕСТИ УГЛЯ,  
РАЗМЕРА ПЫЛЕВЫХ ЧАСТИЦ И ДОБАВЛЕНИЯ МЕТАНА.

Кеннеф Л. Кашдоллар и Мартин Херцберг

Систематическое изучение условий, необходимых для увеличения инертности известняковой пыли для различных видов угля, было проведено в лабораторной камере #20-Л. Инерционные данные сравнивались с данными по пределам отощенной взрывоспособности для тех же видов угля. Размер угольных частиц варьировал от пульверизованной пыли, состоящей на 100% из фракции минус 200 меш до крупной пыли состоящей на 20% из фракции минус 200 меш.

Результаты показывают, что в рассмотрении условий, необходимых для увеличения инертности породной пыли, размер угольных частиц имеет столь же большое значение, как и летучесть. Результаты также подтверждают, что связанный углерод или древесная составляющая угля, в основном, инертны в течение того короткого промежутка времени, когда происходит взрыв. Лабораторные данные были сопоставлены с результатами полномасштабных полевых испытаний в шахте: было показано хорошее совпадение результатов.

岩粉惰性化要求的综合实验室研究：  
煤的挥发性，颗粒大小，及甲烷掺合的影响

肯尼斯 L. 凯希达勒 及 马丁 赫兹伯格

我们在 20 升实验室容器里用各种煤炭作了石灰岩粉惰性化要求的有系统的研究。这惰性化的数据结果用来与同样煤炭的爆炸性下限值作了比较。煤粒的大小从细粉百分之百下筛 200 孔，到粗粉百分之 20 下筛 200 孔。研究的粉末包括无烟煤和低挥发至高挥发的烟煤。

就岩粉惰性化要求而论，数据指出煤的颗粒大小与挥发性有相等的影响。数据并指出煤里的固定炭和灰成份在短促的爆炸过程里并不起任何作用。

实验室岩粉惰性化数据与实尺度矿里试验结果相比，十分接近。



U.S. BUREAU OF MINES  
OPEN FILE REPORT

**OFR 27-89**

# **PROCEEDINGS OF THE**

**23RD INTERNATIONAL CONFERENCE OF SAFETY IN MINES  
RESEARCH INSTITUTES**

**23 МЕЖДУНАРОДНАЯ КОНФЕРЕНЦИЯ  
НАУЧНО-ИССЛЕДОВАТЕЛЬСКИХ ИНСТИТУТОВ  
ПО ГОРНОЙ БЕЗОПАСНОСТИ**

**23. INTERNATIONALE KONFERENZ GRUBENSICHERHEITLICHER  
VERSUCHSANSTALTEN**

**23<sup>ème</sup> CONFERENCE INTERNATIONALE DES INSTITUTS DE  
RECHERCHES SUR LA SECURITE DANS LES MINES**

**第23届采矿安全研究学院国际会议**

**Washington, DC  
September 11-15, 1989**

**Organized by the U.S. Department of the Interior, Bureau of Mines**