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# Influence of specific surface area on coal dust explosibility using the 20-L chamber

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ABSTRACT

The relationship between the explosion inerting effectiveness of rock dusts on coal dusts, as a function of the specific surface area ($cm^2/g$) of each component is examined through the use of 20-L explosion chamber testing. More specifically, a linear relationship is demonstrated for the rock dust to coal dust (or incombustible to combustible) content of such inerted mixtures with the specific surface area of the coal and the inverse of that area of the rock dust. Hence, the inerting effectiveness, defined as above, is more generally linearly dependent on the ratio of the two surface areas. The focus on specific surface areas, particularly of the rock dust, provide supporting data for minimum surface area requirements in addition to the 70% less than 200 mesh requirement specified in 30 CFR 75.2.

## 1. Introduction

Past studies (Amyotte et al., 1995; Amyotte, 1996; Dastidar et al., 2001; Cashdollar and Hertzberg, 1985; Cashdollar et al., 1987, 1989; Cashdollar, 1996, 2000; Harris et al., 2015; Cybulski, 1975; Man and Harris, 2014; Rice, 1911; Rice et al., 1927a, 1927b; Richmond et al., 1975; Sapko et al., 2000) have shown the influence of coal's volatility and particle size on its explosibility and rock dust inerting requirements. Such studies led to the formulation of the initial legal requirement that mine dust in bituminous coal mines (anthracite mines are exempted due to their much lower volatility) must have an inert content of at least 65% in entries and 80% in air return passageways (CFR, 2010). This distinction was due to two reasons: (1) the fineness of the coal dust that is carried by the ventilation currents into the returns, and (2) the finding from experimental mine studies, conducted in both the Bruceton Experimental Mine (BEM) and the larger entries at the Lake Lynn Experimental Mine (LLEM), that coal dust with 80% passing through a 200-mesh screen ($< 75\,\mu m$) required an 80% total incombustible content to be non-explosible (Cashdollar et al., 2010). The total incombustible content was defined as including the ash component of the coal and any moisture in the inspector-collected mine sample.

The advent of newer mining machinery with higher shearing power produced finer coal particle sizes. Therefore, the original 65% requirement pertinent to coal sizes with 20% passing through 200-mesh sieves was no longer adequate or realistic. Using data from an extensive survey of coal mines throughout the U.S. by the Mine Safety and Health Administration (MSHA), the National Institute for Occupational Safety and Health (NIOSH) found that the average of the mines sampled had coal dust containing about 40% passing through a 200-mesh screen, and many mines produced even finer coal dust (Cashdollar et al., 2010). The difference between the coal dust in mining entries and returns is thereby diminished. NIOSH therefore recommended that the minimum total incombustible content of mine dusts in both entries and returns be set at 80%. This was later codified into law in title 30 CFR 75.2 (CFR, 2011).

Recent studies have shown that the specific surface areas (SSAs) of both coal dusts and rock dusts are relevant to issues of the explosibility of their mixtures (Man and Harris, 2014; Harris et al., 2015). It is desirable, however, to have a more quantitative relationship at hand. This study is focused primarily on the coal dust surface area. Those surface areas were determined primarily for fractions of the pulverized Pittsburgh coal (PPC) that has been used over many years in studies reported by U. S. Bureau of Mines (USBM) and NIOSH researchers. The surface areas of fractions of a particular reference limestone rock dust are also at issue and will be quantitatively related to inerting efficiency. That reference rock dust, which meets the 30 CFR 75.2 size standard (70% through 200-mesh), is the one used to inert the fractions of the two types of coal dusts reported here, and is the one that has been used predominantly in the USBM and NIOSH 20-L chamber studies and at

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the NIOSH LLEM.

This study is based primarily on explosion tests of mixtures of the reference rock dust with high-volatility bituminous coal (37% volatiles, Pittsburgh Seam) and low-volatility bituminous coal (17% volatiles, Pocahontas (Poc) Seam No. 3) in the Pittsburgh Mining Research Division (PMRD) 20-L explosibility chamber. Both coals have a 6% ash content. Reference is also made to the seminal work in Poland by Cybulski (1975) on inerting Polish coal (the Wujek mine coal having 36% volatiles and 14% ash) by clay-slate rock dust in the Barbara mine gallery. The inerting concentration of rock dust (RD) in a rock dust – coal dust mixture in the 20-L chamber is the minimum RD content (mass %) that will provide a non-explosible mixture.

## 2. Experimental

### 2.1. Particle size/area measurement

The particle size distribution of the coals, limestone rock dust, and their size fractions that were tested was determined using a Beckman-Coulter LS 13 320 laser scattering instrument in its air entrainment mode of operation. The operating procedures recommended by the manufacturer were followed. This instrument measures the scattering of a 780-nm laser beam by the air-dispersed dust at various angles to the beam direction, and uses the Mie scattering theory to analyze the particles in terms of equivalent spherical particle scatterers. The complex index of refraction ($n + ik$) of both the particle and medium must be specified. For air, this is simply 1.00 without an imaginary ($i$) component ($k = 0$). For limestone rock dust, this is taken as 1.68 without an imaginary component ($k = 0$). This value, taken from handbooks for dolomite ($CaMgCO_3$) and aragonite ($CaCO_3$), is more appropriate for white (non-absorbing) dusts (CRC, 1984). Colored limestone will, however, have an imaginary component, $i \geq 0.1$. Inclusion of such an imaginary component could change the calculated specific surface area by 1–2% for $k = 0.1$ and 40% for $k = 0.5$. For coal, the complex refractive index has both a very significant imaginary component (it is strongly absorbing) and is not well characterized. It was taken as $1.80 + 0.3i$ as previously reported (Harris et al., 2015). This complex refractive index for bituminous coal is also cited by Menguc et al. (1994). The above values for limestone and coal are those listed by the instrument maker for $CaCO_3$ and carbon. The introduction of a degree of arbitrariness in the scattering parameters requires that analyses be based on consistency in these parameters. The significant differences observed when using different light-scattering instruments and using other SSA methods also mitigates against combining such data. The size distribution given by the laser scattering instrument is based on equivalent spherical scatterers, and the calculated specific surface area is based on the $D_{32}$ surface averaged diameter

$$\boldsymbol{D}_{32} = \frac{[\sum \boldsymbol{N}_i \boldsymbol{d}_i^3 \boldsymbol{\delta d}]}{[\sum \boldsymbol{N}_i \boldsymbol{d}_i^2 \boldsymbol{\delta d}]} \tag{1}$$

with $N_i$ as the number of particles in that size range with a constant width, $\delta d$. The numerator is seen to be proportional to the total volume of the particles treated as spheres, while the denominator is seen to be proportional to the total surface area of the particles treated as smooth spheres.

This average diameter of an equivalent spherical particle and its density are then related to the SSA of such a collection of smooth spherical particles by

$$\boldsymbol{A} = \frac{6}{\boldsymbol{\rho D}_{32}(\boldsymbol{cm})} = \frac{60{,}000}{\boldsymbol{\rho D}_{32}(\boldsymbol{\mu m})} \tag{2}$$

where A is the area in $cm^2/g$, $\rho$ is the density in $g/cm^3$, and $D_{32}$ is the mean diameter in cm or μm. A ($cm^2/g$) is calculated from the area to volume ratio of spheres of $6\pi D^2/\pi D^3$, or $6/D$. This gives $6/\rho D_{32}$ as the surface area per gram of the particles. For the coals in question, the density is taken as $1.3\ g/cm^3$, while it is $2.7\ g/cm^3$ for the limestone rock dust.

**Table 1**
The inerting concentrations of the reference limestone rock dust (RD) with Pittsburgh Seam coal dusts (CD) expressed as the ratio %RD/%CD (Z) and %Incombustible/%Combustible (Z′) n the rock dust-coal dust mixtures. The surface weighted average dust diameter ($D_{32}$) and specific surface areas, SSA ($cm^2/g$), of the dusts are given, as well as the ratio of the SSA of the coal to rock dusts ($A_{cd}/A_{rd}$). The numbers in parentheses alongside the coal and rock dust designations are the references to the data sources: (1) refers to recent data.

| | %RD to Inert | % Incomb. | Z | Z′ | $D_{32}$ (μm) | $SSA_{(calc)}$ ($cm^2/g$) | $A_{cd}$ $A_{rd}$ |
|---|---|---|---|---|---|---|---|
| Reference RD (1) | NA | 100 | NA | NA | 7.4 | 3000 | NA |
| PPC (1) | 76 | 77.4 | 3.17 | 3.44 | 17 | 2700 | 0.90 |
| Pgh coarse −60 m (1) | 66 | 68.0 | 1.94 | 2.13 | 23 | 2000 | 0.67 |
| Pgh coarse (1) | 44 | 47.4 | 0.79 | 0.90 | 71 | 650 | 0.22 |

Coal Density $\rho = 1.3\ g/cm^3$; Limestone Density $\rho = 2.7\ g/cm^3$; $SSA = 60{,}000/\rho D_{32}$.

It must be emphasized that this area is not equivalent to the area given by a BET measurement (multi-layer gas adsorption) which takes into account the surface roughness and crevices. The BET areas are consistently greater due to the fact that the particles in question are neither spherical nor smooth. However, the laser scattering instruments are in wider use and may be used for relative area measurements. Nor is it clear that the actual surface areas are as important as their geometric areas ($\pi d^2$ for a spherical surface and $\pi d^2/4$ for its scattering cross section). That is certainly the case for the radiation shielding effect of inert particles mixed with coal dust. Even the coal particle temperature rise and consequent liberation of fuel vapors by the advancing flame front is more a matter of particle size than actual surface area. While the surface reaction rate with air oxygen is a function of accessible surface area, that may be of less importance than the release of flammable volatiles from the particle interior i.e., collisions and consequent reaction between oxygen and fuel molecules in the gas phase are far more frequent than the collisions of oxygen molecules with coal particle surfaces.

The data on coal particle size relative to explosibility reported by Cashdollar (1996) and which is presented here is based on a combination of sieve analysis and Coulter counter measurements. The latter instrument featured the passage of individual particles in a stirred liquid through a small orifice into a counting cell. The counts were based on the effective volume and capacitance change in the cell due to the moving particle. The results can, therefore, not be directly compared to the laser scattering results, but can serve to relate the average particle size and surface area of both the coal and rock dusts with the inerting requirements for those sets of measurements. The 20-L chamber described in Cashdollar (1996) is the same as that used by NIOSH researchers in subsequent years, as is the criterion for explosibility.

The Blaine apparatus for surface area measurement, which involves air permeation through a packed bed of particles, was used by the Polish researchers (Cybulski, 1975) and is referenced here. The Blaine apparatus has the advantage of simplicity and low cost. It also appears to correlate with the more direct specific surface area measurement techniques, but can be more operator dependent.

### 2.2. Explosion chamber

The 20-L explosion chamber is a near-spherical steel chamber designed by the late Kenneth L. Cashdollar (Cashdollar and Hertzberg, 1985) and has been in use since 1982 by the USBM and NIOSH. It is also the default explosion chamber illustrated in the ASTM standard for measuring the minimum explosibility concentration of flammable