

Explosibility hazard of iron sulphide dusts as a function of particle size

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Abstract

The explosion characteristics of pyrite and pyrrhotite have been determined as a function of particle size. Explosion tests were conducted in a 20 l Siwek chamber using various size fractions of mine samples. It was determined that the critical mass mean diameter for explosibility (i.e. maximum explosible diameter) lies in the range 49–63 μm for the pyrrhotite sample and 85–145 μm for pyrite. A decrease in particle size for each material was found to cause an increase in explosion pressure and rate of pressure rise, and a decrease in the minimum explosible concentration. That pyrite is more of an explosion hazard than pyrrhotite was confirmed and quantified. Testing with FeS and FeS₂ chemicals demonstrated the limited applicability of commercial samples to prediction of explosibility behaviour of mine samples. Previous work on coal and metal dusts was analysed to suggest the importance of both homogeneous and heterogeneous reactions in explosion propagation for sulphide dusts.

Keywords: Dust explosions; Iron sulphide dust

1. Introduction

Sulphides of various types are encountered in underground metal mines. These materials, in particular the iron sulphides, have a tendency to undergo spontaneous combustion leading to mine fires. Such exothermic reactions generate considerable amounts of heat and, in the case of the sulphides, highly toxic and corrosive sulphur dioxide gas. Under certain conditions these minerals can also cause explosions. There have been several incidents of sulphide dust explosions in underground mines, most

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Table 1
Reported cases of sulphide dust explosions [1]

Date	Country	Fatalities	Injuries
1924	U.S.A.	1 (SO ₂)	6 (SO ₂)
1924	U.S.A.	1 (SO ₂)	1 (SO ₂)
1924	U.S.A.	2 (SO ₂)	1 (SO ₂)
1926	U.S.A.	3 (burns)	1 (burns)
1960s	Canada	2 (SO ₂)	None
1969	Sweden	2 (SO ₂)	2 (SO ₂)
1985	Canada	1 (SO ₂)	2 (SO ₂)

Note: SO₂ fatalities or injuries were due to toxic gas generated by explosion; burn fatalities or injuries were due to heat generated by explosion.

occurring during blasting operations. Details are given in Table 1 [1]. Other incidents that have resulted in economic losses to the hard-rock mining industry (without fatalities) are listed in Table 2 [1].

Five major parameters comprise the *dust explosion pentagon*: presence of combustible dust in a finely divided form, availability of oxidant, presence of an ignition source, some degree of confinement, and a state of mixed reactants. When all five parameters are satisfied and a dust explosion occurs, there is a rapid increase in pressure accompanied by a flame front. Although the pressure rise typically associated with sulphide dust explosions is low compared to that experienced in, for example, a coal dust explosion, the explosion pressure can still cause extensive damage. The presence of SO₂ also constitutes a serious hazard. As previously mentioned, this gas is toxic and corrosive; furthermore, SO₂ requires a long time to be exhausted from the mine ventilation system.

In comparison to coal dust, relatively little work has been done on the explosibility of the sulphides. Gardner and Stein [2], as early as 1928, concluded that sulphide dusts are explosible and thus pose a hazard in underground mines. However, since then few research projects have been undertaken in this area. A review of the literature showed that of these projects, most have been conducted at the laboratory scale; for example, Enright [1], Mintz and Dainty [3], Liu and Katsabanis [4], and Weiss et al. [5]. Work has

Table 2
Other reported incidents of sulphide dust explosions [1]

Year	Mines
1974	Fox mines, Canada; Preska, South Africa
1979	Ruttan Operations, Canada
1981	Mattabi mines, Canada
1985	Elura mines, Australia; Lynn Lake, Canada
1986	Brunswick Mining and Smelting, Canada
1986	Langsele mines, Sweden; Dumagami, Canada; Woodlawn, Australia
1987	Elura mines, Hellyer mines, Australia; Trout Lake, Westmin Resources, GECO Mines, Canada

also been done at the laboratory scale on metal dusts by Hertzberg et al. [6,7]. Other than the early work described by Gardner and Stein [2], the only mine-scale work on sulphide dust explosions identified in the literature review was conducted by Weiss et al. [5] at the Bruceston Experimental Mine, US Bureau of Mines.

Most of these previous studies, with the exception of Liu and Katsabanis [4], have involved sulphide ores which have several components (e.g. Fe, Cu, Zn, Pb, Si); information obtained for the individual minerals has therefore been mostly qualitative. Other than the work of Liu [8], a detailed study of the effects of particle size, size distribution and sulphur content has not been done for a single-sulphide dust, such as the iron sulphides. Because FeS and FeS₂ are the most reactive among the sulphide minerals [8], they are expected to contribute the most to pressure rise in a sulphide dust explosion. Additionally, these are the most commonly occurring forms of the iron sulphides in a sulphide ore body [8]. It was therefore the objective of this study to characterize these two sulphides in terms of their explosibility.

2. Experimental

2.1. Sulphide dusts

Mine samples of pyrite (FeS₂) and pyrrhotite (Fe_{1-x}S) were used. These samples were obtained from the massive ore deposits at Kidd Creek Mines, Falconbridge Operations in Timmins, Ontario. In addition to the mine ores, tests were also done with FeS and FeS₂ which approximate pure forms of pyrrhotite and pyrite, respectively. The sample of FeS was purchased from BDH Chemicals; the FeS₂ was obtained from EM Scientific.

The chemicals were tested as received. The mine samples were prepared by first crushing the ore; subsequent size reduction was performed by pulverizing in a shatter box. The samples were then sieved into various size fractions.

All dusts were analysed for composition and particle size at the Minerals Engineering Center, TUNS. Sulphur and iron contents were determined to be those shown in Table 3. For the mine samples, the remaining components most probably include silicon, copper, zinc and other trace elements. Particle size measurements were made using a Malvern Instruments (2600 Series) analyser based on the principle of light scattering. The results of these measurements are given in Tables 4 and 5.

Table 3
Iron and sulphur contents of FeS, FeS₂, pyrrhotite and pyrite samples

Material	Weight% Fe	Weight% S
FeS	64.6	28.5
FeS ₂	42.4	46.2
Pyrrhotite	38.6	32.7
Pyrite	34.2	46.4

Table 4
Particle size distributions of sulphide dusts

Material	< 200 μm (wt.%)	< 125 μm (wt.%)	< 75 μm (wt.%)	< 45 μm (wt.%)	< 20 μm (wt.%)	D_w^a (μm)
FeS	100	100	100	99	86	11
FeS ₂	100	100	87	60	31	40
Pyrrhotite (PO-90)	100	87	33	3	1	90
Pyrrhotite (PO-64)	100	100	68	3	2	64
Pyrrhotite (PO-49)	100	100	90	39	14	49
Pyrrhotite (PO-16)	100	100	100	100	66	16
Pyrite (PY-146)	85	29	4	1	1	146
Pyrite (PY-85)	99	92	29	3	2	85
Pyrite (PY-50)	100	100	85	27	6	50

^a D_w = volume or mass mean diameter.

Table 4 gives the actual size distribution at selected intervals, along with the mass mean diameter, D_w . For ease of reference the samples have been coded with the letters PO for pyrrhotite and PY for pyrite, along with the mass mean diameter in μm . Table 5 shows the size distributions in a different manner by giving the particle diameters greater than those of both 10 and 90 wt.% of the particles. The mass mean diameter is repeated in Table 5 for convenience. Tables 4 and 5 show that in most cases the size distributions of the samples are fairly narrow.

2.2. Explosion tests

The explosion tests were conducted using a stainless steel, spherical vessel (Siwek apparatus [9]) having a volume of 20 l (Fig. 1). The explosion sphere is enclosed by a water jacket that removes the heat generated by an explosion so as to maintain uniform test temperatures. Prior to each run, the required mass of dust was placed in a 0.6 l dispersion reservoir that was subsequently pressurized to 20 bar (g), where “ g ” denotes

Table 5
Ten and ninety percent boundaries of particle size distributions of sulphide dusts

Material	D_{10}^a (μm)	D_{90}^b (μm)	D_w (μm)
FeS	3	24	11
FeS ₂	6	79	40
Pyrrhotite (PO-90)	62	130	90
Pyrrhotite (PO-64)	54	84	64
Pyrrhotite (PO-49)	13	75	49
Pyrrhotite (PO-16)	4	30	16
Pyrite (PY-146)	103	218	146
Pyrite (PY-85)	65	119	85
Pyrite (PY-50)	38	80	50

^a D_{10} = particle diameter greater than those of 10 wt.% of particles.

^b D_{90} = particle diameter greater than those of 90 wt.% of particles.

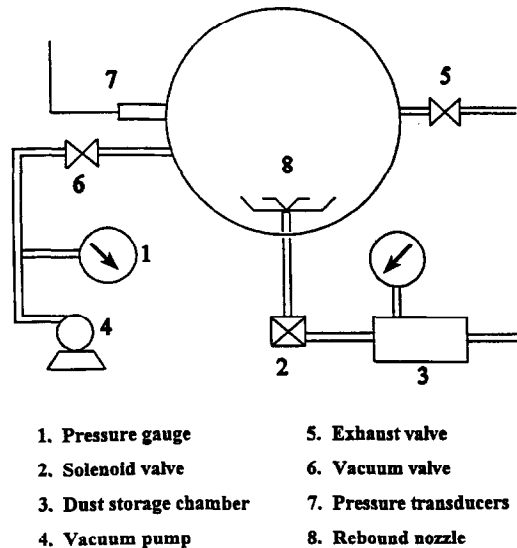


Fig. 1. Schematic diagram of 201 Siwek chamber and auxiliary equipment.

gauge pressure. Dust dispersion through a rebound-type nozzle was achieved by opening the solenoid valve and thus permitting the stored dust/air mixture to enter the explosion chamber. Also before each run, the chamber was evacuated to 0.4 bar(*a*), where “*a*” denotes absolute pressure, so that the dispersion pulse raised the vessel pressure to 1 bar(*a*) at the time of ignition.

Each sample was tested over a range of dust concentrations starting from below the minimum explosible concentration. The highest dust concentration tested for any of the samples was 2500 g m^{-3} .

Ignition was by a chemical ignitor having a stored energy of 5 kJ, centrally mounted in the explosion chamber. A fixed time delay of 60 ms between commencement of dust dispersion and ignition was used in all tests.

Pressure development during an explosion was measured by two piezoelectric transducers mounted in the chamber wall. A personal computer was used to record the pressure–time data. The computer was also used to control the dust dispersion and ignition sequence by opening the solenoid valve and firing the chemical ignitors at the appropriate times.

Parameters extracted from each pressure–time trace were the explosion pressure, P_{ex} , and the rate of pressure rise, $(dP/dt)_m$. (The latter of these two parameters is actually the maximum value of rate of pressure rise at a given dust concentration.) The explosion pressure, P_{ex} , is subsequently corrected by software to correspond to values measured in ISO (International Standardization Organization) 1 m^3 vessel tests. Corrections are required due to vessel cooling and chemical ignitor pressure effects; the result is the corrected explosion pressure, P_m . All values of explosion pressure reported in this paper are P_m values; they are, therefore, overpressures or gauge pressures.

3. Results and discussion

3.1. Effect of particle size

Of the four size fractions of pyrrhotite tested, the two largest (i.e. PO-90 and PO-64) did not explode at dust concentrations up to 2500 g m^{-3} (where an explosion is defined by a P_m value of $1 \text{ bar}(g)$, as described later in this section for the minimum explosible concentration). The smaller samples, PO-49 and PO-16, did produce explosions, as shown by Figs. 2 and 3 where P_m and $(dP/dt)_m$ are plotted as functions of dust concentration. At all dust concentrations in Figs. 2 and 3, both P_m and $(dP/dt)_m$ are increased as the mass mean diameter is decreased from 49 to $16 \mu\text{m}$. Although the influence of particle size on P_m becomes less significant at higher dust concentrations, $(dP/dt)_m$ continues to show a marked increase at the highest concentration tested as particle size is decreased. The increase in $(dP/dt)_m$ with decreasing particle size is a consequence of the well-established inverse relationship between particle size and particle surface area.

Other features of the particle size effect are evident in Figs. 2 and 3. First, the peak value of P_m is shifted to a leaner dust concentration as particle size is decreased. This peak value and the concentration at which it occurs (called the optimum concentration) are $2.7 \text{ bar}(g)$ at 1500 g m^{-3} for PO-49 and $3.2 \text{ bar}(g)$ at 1250 g m^{-3} for PO-16.

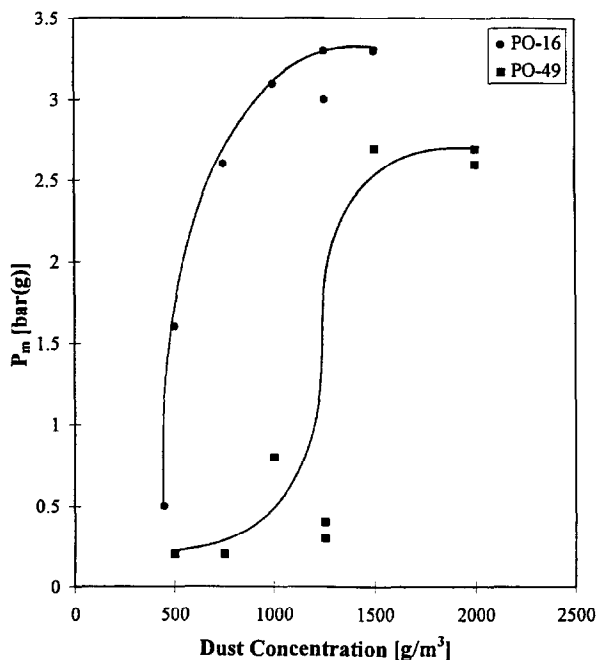


Fig. 2. Effect of particle size on corrected explosion pressure for pyrrhotite.

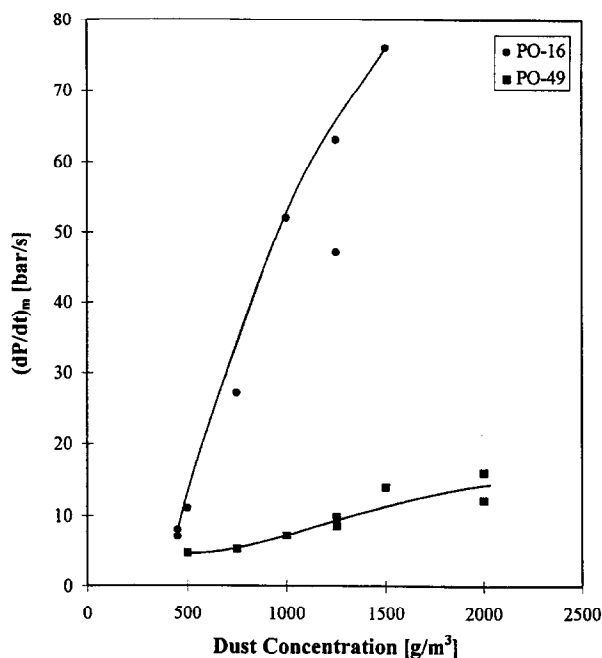


Fig. 3. Effect of particle size on rate of pressure rise for pyrrhotite.

Second, the minimum explosible concentration (MEC) also decreases as particle size decreases.

Here we have used the ASTM [10] criterion for the MEC: an overpressure of 1 bar(g) excluding ignitor effects (i.e. $P_m = 1 \text{ bar}(g)$). With this criterion, the MEC values are approximately $1375 \text{ g m}^{-3} \pm 10\%$ for PO-49 and $475 \text{ g m}^{-3} \pm 5\%$ for PO-16. These results clearly show that a reduction in pyrrhotite particle size can lead to a substantial reduction in the minimum explosible concentration. The different data trends for P_m shown in Fig. 2 are discussed in the last section of the paper on reaction mechanisms.

Returning to the non-explosibility of the PO-90 and PO-64 samples, it is possible to identify a critical value of mass mean diameter, $D_{w,\text{critical}}$, above which the pyrrhotite is non-explosible. From the size fractions tests, the critical diameter for explosibility lies in the range 49–63 μm . It should be noted that this is not a range of individual particle diameters but rather a range of mass mean diameters for the size distributions given in Tables 4 and 5. Nevertheless, specifying a range for $D_{w,\text{critical}}$ is helpful in better understanding the contributions of various particle sizes in a broad size distribution to explosibility.

Several authors (e.g. Liu and Katsabanis [4], Hertzberg et al. [7] and Cashdollar [11]) have emphasized that it is the fines that most significantly contribute to the explosion hazard in sulphides and metals. Further, Amyotte et al. [12] have explained that broad particle size distributions can be thought of as a series of narrow size distributions, each of which makes a contribution to the explosibility of the sample. Characterizing a dust in

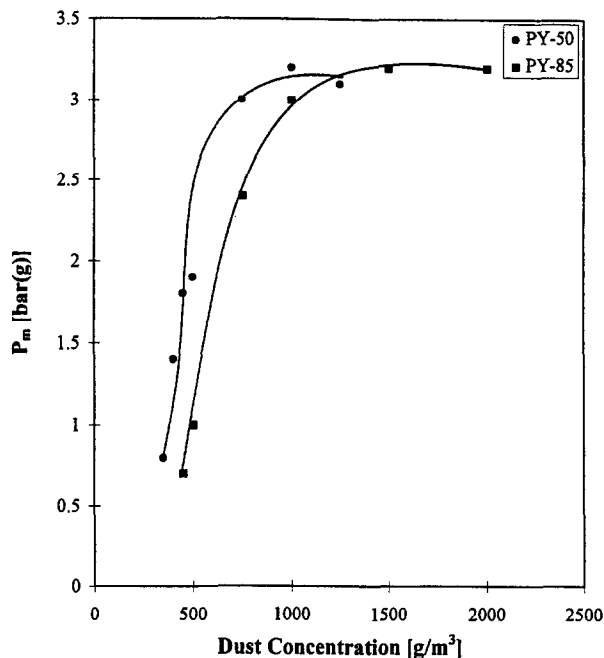


Fig. 4. Effect of particle size on corrected explosion pressure for pyrite.

terms of $D_{w,critical}$ is, therefore, not only of fundamental value, but also of practical significance.

In the case of the pyrite samples, PY-146 (the largest size) did not explode at dust concentrations up to 2500 g m^{-3} . The smaller samples, PY-85 and PY-50, did, however, produce explosions. This means that the $D_{w,critical}$ value for pyrite lies in the range $85\text{--}145 \mu\text{m}$.

Figs. 4 and 5 show the explosion behaviour of the PY-85 and PY-50 samples. The same comments as made for pyrrhotite with respect to Figs. 2 and 3 can be made here. At all dust concentrations in Figs. 4 and 5, both P_m and $(dP/dt)_m$ are increased as the mass mean diameter is decreased from 85 to $50 \mu\text{m}$. Also, the influence of particle size on P_m becomes less pronounced at high dust concentrations, possibly due to excessive dust loading.

The shift in optimum dust concentration to a leaner value can also be seen in Fig. 4. The peak value of P_m and the optimum concentration are $3.2 \text{ bar}(g)$ at 1500 g m^{-3} for PY-85 and $3.2 \text{ bar}(g)$ at 1000 g m^{-3} for PY-50. The shift in MEC to a leaner value is also apparent. Using the ASTM criterion of $P_m = 1 \text{ bar}(g)$, the MEC values are approximately 500 g m^{-3} for PY-85 and $375 \text{ g m}^{-3} \pm 7\%$ for PY-50.

3.2. Comparison between pyrite and pyrrhotite

Figs. 6 and 7 compare pyrite (PY-50) and pyrrhotite (PO-49) samples with nearly the same mass mean diameter. These figures indicate that pyrite is more explosible than

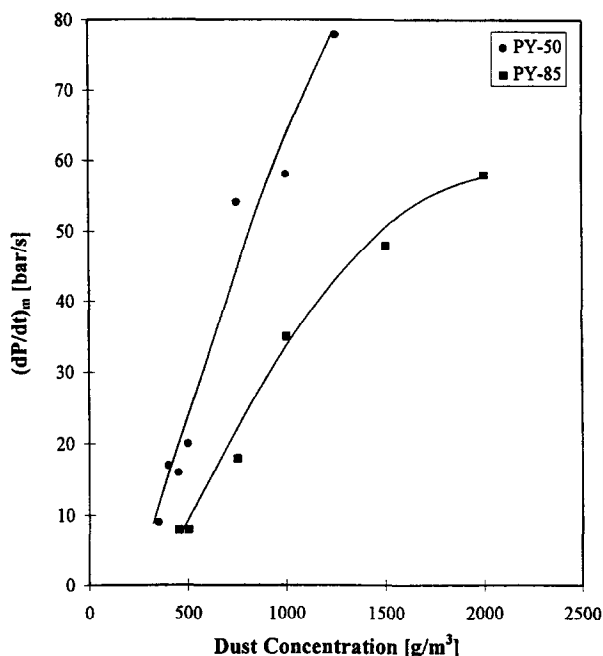


Fig. 5. Effect of particle size on rate of pressure rise for pyrite.

pyrrhotite, since the pyrite sample shows a much lower MEC and higher P_m and $(dP/dt)_m$ values occurring at leaner dust concentrations. This is consistent with finding a larger critical mass mean diameter for pyrite.

Comparing Figs. 2 and 3, Figs. 4 and 5, and Figs. 6 and 7 further suggests that somewhat similar effects are brought about by an increase in particle size and an increase in sulphur content (from 32.7% for pyrrhotite to 46.4% for pyrite).

Although it has been stated that pyrite is more explosible than pyrrhotite, this in no way implies that pyrrhotite is not an explosion hazard. As with pyrite, pyrrhotite has a tendency to undergo spontaneous combustion thereby causing mine fires; all necessary precautions must therefore be taken when pyrrhotite is present. Also, it was observed during sample crushing in the present work that the pyrrhotite generated considerably more fines than the pyrite. This is due to the more friable nature of pyrrhotite.

3.3. Comparison with other workers

Previous observations on the effect of particle size for pyrrhotite and the greater explosibility of pyrite are in agreement with Mintz and Dainty [3]. They also did laboratory-scale work on pyrite and pyrrhotite, using a 201 explosion chamber of the US Bureau of Mines design.

Other workers have tested sulphide ore samples consisting of 100% pyrite and 45% pyrite (with the remainder sphalerite, galena, chalcopyrite and gangue) in vessels ranging in size from 81 [1], to 201 [3,5], to 1 m³ [4]. Despite differences in sample

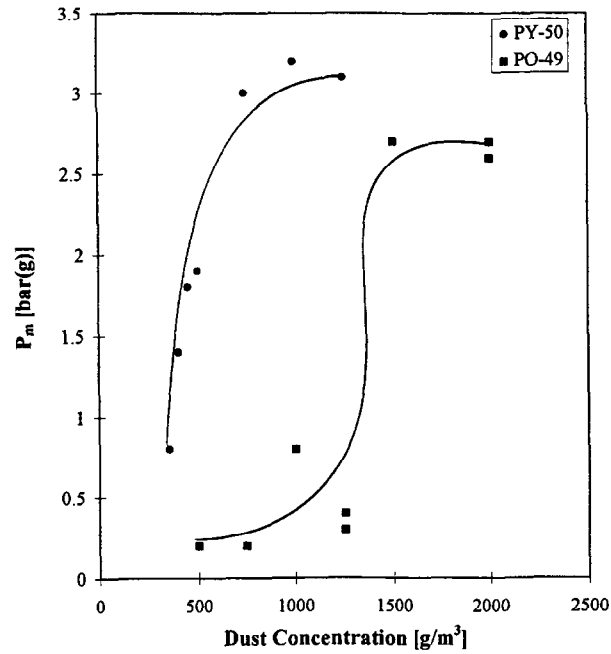


Fig. 6. Comparison of corrected explosion pressures for pyrrhotite and pyrite.

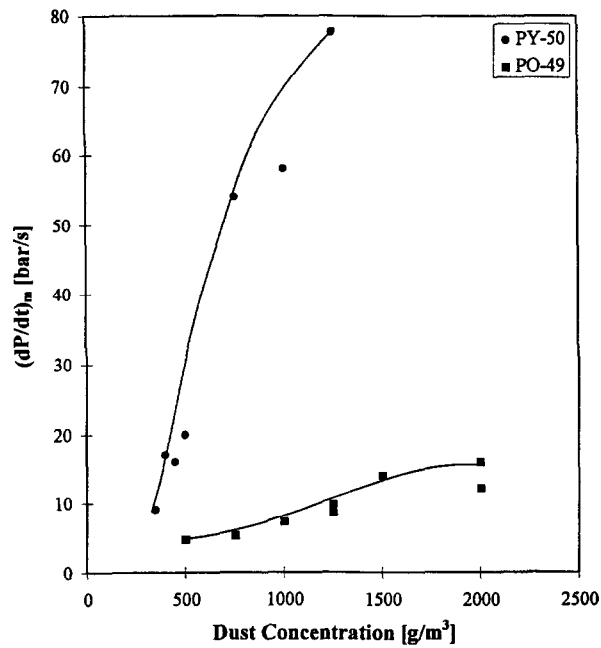


Fig. 7. Comparison of rates of pressure rise for pyrrhotite and pyrite.

sulphur content, particle size and experimental procedure (such as ignition source strength), the comparison is favourable, with the range of 3–4 bar (g) for the peak value of P_m reported by other workers [1,3–5] corresponding to the maximum P_m of 3.3 bar (g) for pyrrhotite (PO-16) and 3.2 bar (g) for pyrite (PY-50 and PY-85) obtained in the present work.

In comparing peak values of $(dP/dt)_m$ it is convenient to employ the concept of the size-normalized maximum rate of pressure rise, K_{St} :

$$K_{St} = (dP/dt)_{\max} \cdot V^{1/3}$$

where $(dP/dt)_{\max}$ = maximum value of $(dP/dt)_m$ for a given sample; V = vessel volume.

K_{St} is a parameter whose primary use lies in the design of explosion relief vents. Determination of K_{St} values is done by following the test procedure outlined in ASTM [13]. Although this procedure was not followed exactly in the present work, nor by others [1,3–5], the term K_{St} is being used here simply for convenience to compare $(dP/dt)_{\max}$ values from different size vessels (i.e. these K_{St} values are not appropriate for any purpose other than making a relative comparison). It should also be noted that although K_{St} may provide a degree of size normalization, experimental data on rates of pressure rise from different vessels may still differ greatly due to differences in turbulence level.

The highest value of K_{St} found here is approximately 20 bar m s^{-1} . Comparison with previous work is again favourable, as this value is at the upper boundary of the range of K_{St} values determined by other researchers [1,3–5], with the exception of Liu and Katsabanis [4] who determined K_{St} s of almost 50 bar m s^{-1} for sulphide dusts ignited by high-energy content Detasheet. As previously mentioned, Liu and Katsabanis [4] carried out their work using a 1 m^3 explosion chamber (which may be contrasted with the 201 chamber used in the present work). Scaling of sulphide dust explosions (i.e. the effect of vessel size) has been addressed by these authors.

3.4. FeS and FeS₂

To determine how closely commercial samples behave in terms of explosibility to mine samples of pyrrhotite and pyrite, tests were done with the FeS and FeS₂ dusts previously shown in Tables 3–5. FeS₂ and pyrite have the same sulphur content while the FeS and pyrrhotite sulphur contents are closely matched, although not identical. The FeS sample is much finer than the FeS₂; the FeS is comparable to PO-16, while the FeS₂ is closest to PY-50 (although it has more fines than PY-50).

The results of the explosion tests for FeS and FeS₂ are given in Figs. 8 and 9. These data show that the higher sulphur content of the FeS₂ is offset by the finer particle size distribution of the FeS. The general shape of the curves and trend in the data are consistent with the previously reported results for pyrrhotite and pyrite. There are, however, some significant differences.

Comparing first the FeS and PO-16 samples, the peak values of P_m are nearly the same, with FeS peaking at 1500 g m^{-3} and PO-16 at 1250 g m^{-3} . The rates of pressure rise, however, are greatly different; the maximum value of $(dP/dt)_m$ for FeS is

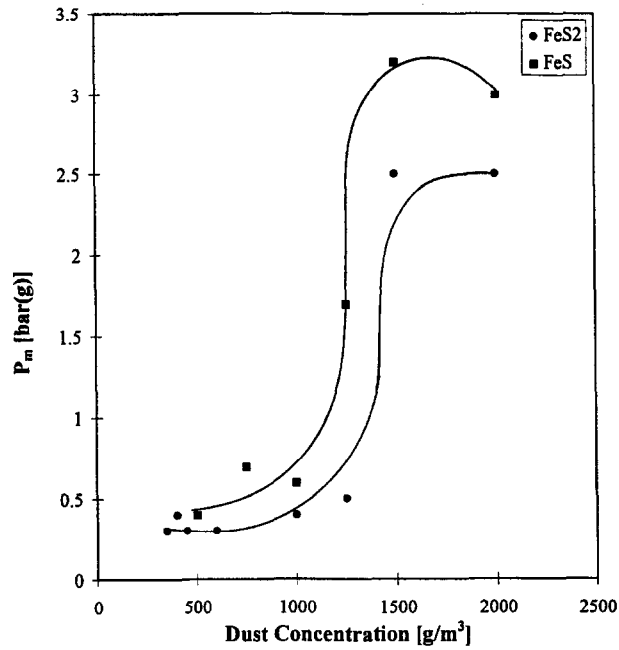


Fig. 8. Comparison of corrected explosion pressures for FeS and FeS₂.

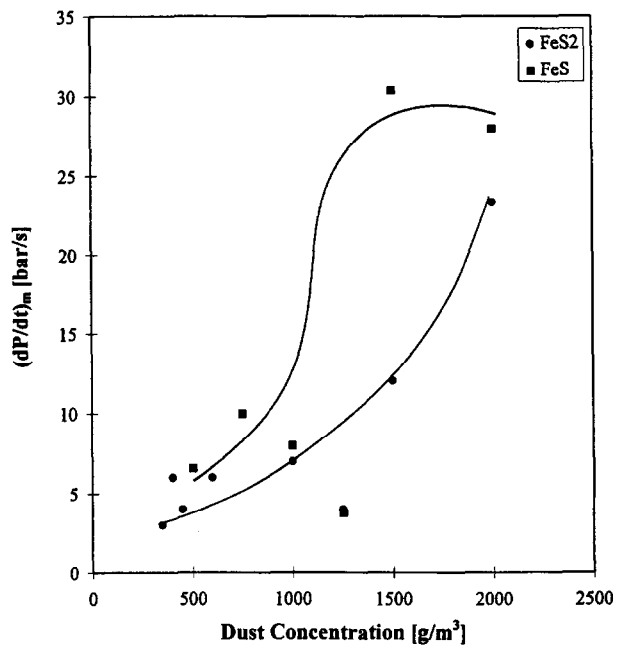


Fig. 9. Comparison of rates of pressure rise for FeS and FeS₂.

30 bar s⁻¹ at 1500 g m⁻³, whereas the highest value of $(dP/dt)_m$ for PO-16 is 78 bar s⁻¹ at the same concentration. (This value of 78 bar s⁻¹ is not a maximum value for PO-16 as $(dP/dt)_m$ is still increasing at 1500 g m⁻³.) A similarly large difference is noted for the MECs: 1125 g m⁻³ ± 10% for FeS and 475 g m⁻³ ± 5% for PO-16.

In addition, for FeS₂ and PY-50:

- The peak value of P_m for FeS₂ is 2.5 bar (g) at 1500 g m⁻³, whereas the corresponding value for PY-50 is 3.2 bar (g) at 1000 g m⁻³.
- The highest value of $(dP/dt)_m$ for FeS₂ is 23 bar s⁻¹ at 2000 g m⁻³, whereas the corresponding value for PY-50 is 78 bar s⁻¹ at 1250 g m⁻³. (Note that neither of these $(dP/dt)_m$ values are maxima.)
- The MEC for FeS₂ is 1375 g m⁻³ ± 10%, whereas the corresponding value for PY-50 is 375 g m⁻³ ± 7%.

Although the overall reaction yield (as reflected by P_m) is the same or nearly the same for the chemical samples and the ore samples, the rate of reaction (as reflected by $(dP/dt)_m$) for the ore samples is two to three times that for the chemical samples. As a consequence, the MEC of the ore samples is two to three times lower than the chemical samples. This clearly demonstrates the limited usefulness of commercially prepared chemicals in predicting the explosion behaviour of mine samples of sulphide dusts. It is essential to know the mineralogy of the ore being investigated. Except where the mineralogy of different samples is similar, sulphur content alone cannot be used as a predictive tool for explosion risk [3].

3.5. Reaction mechanisms

Two alternative mechanisms have been proposed for dust explosions: a homogeneous (gas-phase) mechanism and a heterogeneous mechanism. The present work lends support for both mechanisms.

It is well-established that explosions of carbonaceous dusts such as coal proceed by devolatilization of the coal particles and subsequent burning of the volatiles (i.e. homogeneous, gas-phase combustion). A comparable model for a sulphide dust such as pyrite is the decomposition of pyrite to pyrrhotite, with sulphur vapour release followed by oxidation of the sulphur vapour to sulphur dioxide at the particle surface. This has been shown in the TGA work of Dunn et al. [14], and the importance of the percent sulphur in the original sample has been stressed by Mintz and Dainty [3].

The data and observations made here for sulphide dusts are similar in several ways to those for coal dust. For example, the particle size effects described here are identical to those observed by Amyotte et al. [12] for various coal dusts. Also, in the present work, peak values of P_m were generally found in the range of 1000–1500 g m⁻³. This range is 2.5–4 times the stoichiometric values of dust concentration for the sulphides (430 g m⁻³ for FeS and 370 g m⁻³ for FeS₂). Again, the appearance of an optimum concentration at several times the stoichiometric concentration is also typical of coal dust.

There are other examples of similarity between sulphide dust and coal dust. It was determined in this work that the less reactive pyrrhotite has a lower $D_{w,critical}$ (i.e. upper particle size boundary for explosibility) than the more reactive pyrite. This is similar to coal dust in terms of the characteristic coal particle diameter for independence of the

MEC (Hertzberg et al. [15]), and in terms of the characteristic rock dust particle diameter for independence of the inerting level (Amyotte et al. [16]).

All these points suggest at least partial similarity between the reaction mechanism for coal dust and sulphide dust explosions. They cannot, of course, be taken as conclusive evidence; rather the observed particle size effects permit the possibility of homogeneous combustion playing a role in propagation of sulphide dust explosions.

A heterogeneous reaction mechanism is also likely to be important in sulphide dust explosions. Dunn et al. [14] also showed through TGA that following pyrite decomposition and sulphur evolution, rapid diffusion of oxygen through the pyrrhotite pores resulted in the formation of hematite. (They also suggested that pyrolytic decomposition of pyrite may be preferred at higher heating rates due to the reduced time available for oxygen diffusion.) Further, hematite was determined to be a combustion product in the explosion tests conducted by Mintz and Dainty [3] for pyrite and pyrrhotite.

Further support for the importance of a heterogeneous mechanism can be found in work conducted at the US Bureau of Mines for metal dusts [6,7,11]. Explosion testing carried out by these authors for iron dust yielded values of P_m and (dP/dt) comparable to those obtained in the present work for pyrite and pyrrhotite. As noted by Hertzberg et al. [6], their results appear to imply a heterogeneous, surface combustion mechanism because of the very low vapour pressure of iron at the adiabatic limit flame temperature.

In the case of pyrrhotite, a heterogeneous mechanism may help to explain the results shown in Fig. 2 for the corrected explosion pressures of the two size fractions. The larger fraction, PO-49, shows a more distinct break in explosibility than the smaller size, PO-16. The PO-16 sample, consisting mainly of fines, will experience a high heating rate with rapid diffusion of oxygen through the particle pores and subsequent reaction. This type of heterogeneous reaction has been described by Essenghigh et al. [17] as a direct attack of the reactant gas (i.e. oxygen) on the solid (i.e. pyrrhotite). Although evidence of gaseous sulphur evolution was observed in the TGA work of Dunn and Chamberlain [18] for synthetic pyrrhotite, it is likely that the heating rates involved in their study were significantly less than those encountered in explosion testing. For the PO-49 sample, the larger particles present here will undergo less rapid heating to the extent that the sample does not explode until a high enough dust concentration is reached ($1250\text{--}1500\text{ g m}^{-3}$). At these concentrations, sufficient fines exist to counter the influence of the larger particles, some of which are non-explosible.

4. Conclusion

One of the most important conclusions from this work is the clear distinction in explosibility obtained by studying different size fractions. The critical mass mean diameter for explosibility (i.e. maximum explosible diameter) was determined to be in the range $49\text{--}63\ \mu\text{m}$ for pyrrhotite and $85\text{--}145\ \mu\text{m}$ for pyrite. Because both dusts were mine samples, these results are directly applicable to the practice of explosion prevention and protection. Effects of a decrease in particle size that were identified for sulphide dusts are increases in P_m and $(dP/dt)_m$ and a decrease in MEC. The fines in a broad particle size make a significant contribution to explosibility.

Pyrite is clearly more explosible than pyrrhotite; this has been established by other workers and quantified further in the present work (e.g. by means of the $D_{w,critical}$ values). Testing with commercial samples of FeS and FeS₂ has demonstrated the limited applicability of such tests to actual mine sample explosibility, and has emphasized the need for a knowledge of ore mineralogy. Finally, there is evidence to support the importance of both homogeneous and heterogeneous reactions in the propagation of iron sulphide dust explosions.

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