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The “PYRITE METHOD” as a new approach to determining SULPHIDE ore DUST EXPLOSIon propensity

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ABSTRACT

As a new approach, a system of calculation formulae, named the “Pyrite Method”, has been developed to predict the relative explosibility of sulphide ore dusts. The significant advantage of this method is that dust explosion propensity can be calculated from the sulphide ore mineralogical composition without the undertaking of costly and time consuming explosion tests. This method is derived from standard explosion test results on pure or near pure sulphide minerals. Comparative studies on the explosibility of five mine sulphide dust samples confirmed that the predicted results from the “Pyrite Method” were highly compatible with the values from full explosion tests. The analysis of the calculation accuracy also demonstrated that the “Pyrite Method” gives acceptable levels of confidence for a practical mine environment.

In developing the approach, five concentrate samples of sulphide minerals and five samples of ore dusts sampled from sulphide orebodies were investigated through experimental study. The mineralogical and chemical composition of the dust samples were analysed by X-ray powder diffraction and atomic absorption techniques. The explosion tests were conducted in a 20 litre Siwek explosion chamber that, due to the number of units in use around the world, many regard as a standard international testing system for conducting dust explosion studies.

Derivation of the calculation approaches which form the basis of the method are detailed. Results from actual explosion tests are given and compared with predicted values.

INTRODUCTION

The aim of the study was to develop a system of calculation formulae, named the “Pyrite Method”, to predict the relative explosibility of sulphide ore dusts. The significant advantage of this method is that dust explosion propensity can be calculated from the sulphide ore mineralogical composition without the undertaking of costly and time consuming explosion tests. This method is derived from the results of standard explosion tests on pure or near pure sulphide minerals. Comparative studies on the explosibility of five mine sulphide dust samples are described which confirm that the predicted results from the “Pyrite Method” are highly compatible with the values from full explosion tests.

Utilisation of dust explosion testing systems that meet international standards for testing and evaluating the dust behaviour is expensive and time consuming. To provide a simple calculation method for mining engineers and mine safety officers to predict and evaluate the explosibility of sulphide dust, a series of standard tests evaluating explosion indices of five major explosive sulphide minerals were carried out. From these results the relationship between the explosibility and mineralogical composition of the sulphide dust was derived. Comparative study on the explosibility of five sulphide dust samples demonstrated that the “Pyrite Method” is a practical method to predict the relative explosibility of the sulphide dust.

ANALYSIS OF MINERALOGICAL COMPOSITION OF SULPHIDE ORE DUST SAMPLES

Preparation of Sulphide Dust Samples

Five sulphide ores from Australian metalliferous mines designated as mines A, B, C, D and E were collected to allow investigation of sulphide dust explosibility across a range of samples. These mines have all reported significant sulphide dust explosions. In order to investigate the key mineral that controls the explosibility of the sulphide dust, analyses of the explosion characteristic of pure or near pure samples of major explosive sulphides were considered critical. Therefore highly concentrated sulphide minerals of the five major explosive sulphide minerals, namely, pyrite (FeS_2), pyrrhotite ($Fe_{1-n}S$, n = 0 ~ 0.2), sphalerite (ZnS), galena (PbS), and chalcopyrite ($CuFeS_2$) were concentrated in mineral processing laboratories.

The dust explosion testing system requires a dust sample with a mean particle size of 63 μm and with 90 per cent passing 400 μm. This is a critical requirement in preparing dust samples, as with this mean size, the dust explosibility is considered to be particle size independent (Cesana and Siwek, 1991). To obtain the required dust sample size distribution samples were processed by crushing in three stages. Pulverising then followed in two stages. Laser sizing using a Malvern instrument was undertaken and particle size analyses conducted after each stage of pulverising of the dust sample until the sample reached the required size distribution. The size distribution analysis results for the 10 sulphide samples are listed in Tables 1.

TABLE 1
Particle Size Analysis Results for Sulphide Dust Samples

Sample Type	Sample Symbol	50% Pass Size (μm)	90% Pass Size (μm)
Concentrated sulphide minerals	ZnS	9.40	46.71
	PbS	13.20	45.12
	$CuFeS_2$	28.75	82.14
	$Fe_{1-n}S$	37.43	115.62
	FeS_2	8.38	58.16
Sulphide ore dust samples	A	13.24	255.22
	B	37.49	126.99
	C	19.47	163.67
	D	29.64	117.15
	E	31.92	108.32

Analysis of Chemical Composition

The percentage sulphur content in the sulphide dust was used as a major diagnostic parameter in evaluating the relative propensities of the sulphide dusts to explode. It is generally accepted that the maximum explosion pressure and maximum rate of pressure rise of a sulphide dust explosion are associated with the sulphur content of the sulphide dust. The higher the sulphur concentration, the higher the probability of a sulphide dust explosion (Wheeland and McKinnon, 1986). Atomic absorption examination results of sulphur content in the samples of sulphide ore and concentrated sulphide minerals are listed in Tables 2.

TABLE 2
Sulphur Contents in Sulphide Samples

Sulphide concentrate	FeS_2	$Fe_{1-n}S$	$CuFeS_2$	ZnS	PbS
Sulphur Content (%)	42	38	34	32	18
Sulphide ore	**A**	**B**	**C**	**D**	**E**
Sulphur Content (%)	32.7	31.6	29.6	36.3	36.7

Examination of Mineralogical Composition
A sulphide ore deposit usually made up of several types of minerals, unlike coal which is mainly carbon,. The friability and reactivity of seemingly similar sulphide ores can vary significantly. The same blasting practice can cause a dust explosion in one mine, but not necessarily in others. For this reason, it is worthwhile to investigate the mineralogy of the major sulphide minerals and, thus, to determine the type of sulphide mineral that most influences the dust explosions.

Although the sulphur content has been taken as a parameter to predict the explosibility of sulphide dusts, the varying mineral assemblage in different sulphides can have different influences on the explosibility of sulphide dusts. This assumption also leads to the need for analysis and identification of the mineralogical composition. This has been achieved for the samples under study by applying X-ray powder diffraction analysis. The major quantitative analysis results for the sulphide samples are shown in Tables 3.

TABLE 3
Mineralogical Composition Contents of Sulphide Samples

Sulphide	Mineralogical Composition (%,w/w)					
Sample	FeS_2	$Fe_{1-n}S$	$CuFeS_2$	ZnS	PbS	Others
ZnS	11.1			79.2	8.5	1.2
PbS	6.4		13.3		73.3	7.0
$CuFeS_2$	4.3		87.2			8.5
$Fe_{1-n}S$	16.8	55.0			13.2	15
FeS_2	64.0	11.3	2.9		6.9	14.9
A	53.2	24.3			2.9	19.6
B	44.0	28.5	0.3		8.4	18.8
C	41.3	14.9	29.5		0.2	14.1
D	54.1	23.8			12.4	9.7
E	57.4	31.1			4.4	7.1

EXPLOSIBILITY STUDY ON THE SULPHIDE MINERAL CONCENTRATES

Dust Explosion Testing System
The Siwek system used for dust explosion testing is made up of a 20 litre explosion chamber, gas control unit, measurement and control system, dispersion chamber, ignition system, water chiller and vacuum pump system. The explosion chamber was designed by Siwek and Kuhner in 1988 primarily with an aim of obtaining maximum explosion pressure and pressure rise rates in agreement with data from the 1 m^3 International Standards Organisation (ISO) vessel. As the 20 litre Siwek explosion sphere provides an acceptable correlation of explosion parameters to the 1 m^3 standard ISO vessel, it has been adopted by a number of laboratories internationally for dust explosion testing. The chamber is essentially a scaled version of the 1 m^3 ISO vessel. It consists of a stainless steel sphere with a volume of 20 litre and is surrounded by a water jacket that permits a thermostatically controlled temperature. The dust is held in a storage chamber under an air pressure of 2.0 MPa and is dispersed into the partially evacuated sphere through a nozzle. The explosion is initiated by two 5 kJ ignition energy chemical igniters. Undertaking three identical tests at each concentration and five tests at each limit concentration tests repeatability of results. Siwek (1982) describes the design and standard method of operation of the chamber for the laboratory determination of dust and gas explosibility.

The explosion pressure (P_m) and the rate of pressure rise ($(dP/dt)_m$) are two major indices used to describe the violence of reaction of dust and air mixtures after ignition in the explosion chamber. The maximum explosion pressure (P_{max}) and the maximum rate of pressure rise ($(dP/dt)_{max}$) of the dust are determined by means of tests over a wide range of concentrations. The lower explosive limit (LEL), P_{max} and $(dP/dt)_{max}$ are most important indices for risk evaluation of sulphide dust explosions in underground mining.

Siwek (1980) describes the research that validated the reliability of the recommended measurement procedure. Within the explosion testing system, the stated measured error or, more correctly, the uncertainty of measurement of the explosion pressure is less than ±10 per cent and that of the rate of pressure rise is less than ±30 per cent. The values of P_m and $(dP/dt)_m$ presented in this chapter are averaged values of the testing results at a particular measured dust concentration. Theoretically, the "true value" of P_m lies anywhere between 1.1 and 0.9 times the tested mean value. Similarly, for $(dP/dt)_m$, the "true value" lies anywhere between 1.3 and 0.7 times of the tested value. In addition, as the lower explosive limit (LEL) is determined as the concentration that after three tests repeatedly exhibits a defined change in explosion pressure, its uncertainty of measurement is the same as that of explosion pressure, that is ±10 per cent. As there is no practical method to determine the "true values" of LEL, P_m, P_{max}, $(dP/dt)_m$ and $(dP/dt)_{max}$, the averaged testing results, or the tested mean values, were taken to represent the values of LEL, P_m, P_{max}, $(dP/dt)_m$ and $(dP/dt)_{max}$.

New guidelines accepted by the ISO standards (Sewik,1994) state that the parameters pertaining to a dust or gas explosion can be accurately measured with three tests. The expl;osion pressure and rate of pressure rise parameters will be measured with error of 10 and 30 per cent respectively as described above. However, averaging final results from three tests will minimise the resulting error to less than 2 per cent overall (Siwek and Cesana, 1992). Such standardised results have been shown to accurately reflect explosions within a real mining environment (Siwek and Cesana, 1992; Torrent and Arevalo, 1993)

Explosibility Analysis of the Sulphide Mineral Concentrates

Dust Explosion Tendency
The test results of the LEL of the concentrated sulphide minerals (Figure 1 demonstrate that the explosibilities of different sulphide minerals vary significantly. The pyrite has the highest explosion tendency with the lowest LEL of 140 g/m^3, while the LEL of the sphalerite, the least active one among the tested sulphide minerals, is as high as 390 g/m^3. The LEL values for pyrrhotite and chalcopyrite are the same. The overall explosion tendency among the five major sulphide minerals is from high to low: pyrite, pyrrhotite and chalcopyrite, galena and sphalerite.

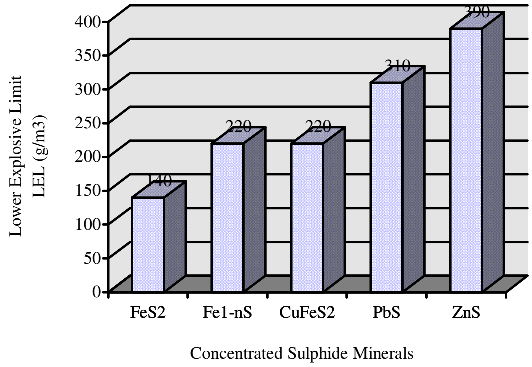

Figure 1 Lower Explosive limit of Concentrated Sulphide Minerals

Dust Explosion Strength

The relationships between the explosion pressure and rate of the pressure rise against dust concentrations are plotted in Figures 2 and 3 respectively. All tested five sulphide minerals except pyrite display similar explosion pressure profiles especially when the dust concentrations are higher than 1000 g/m^3. Similarly, when taking the high uncertainty of measurement of the rate of pressure rise into account, there are not significant differences among these four sulphide minerals for the rates of pressures rise indices.

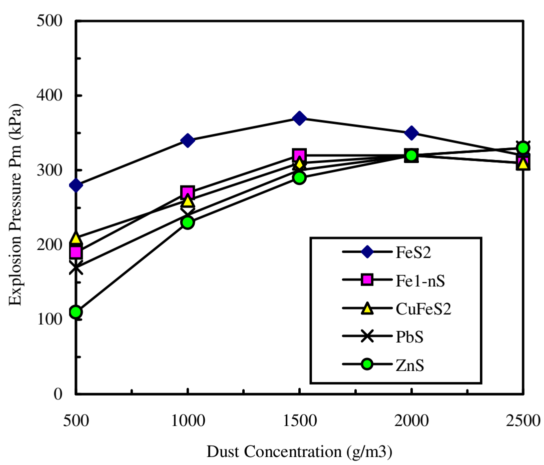

Figure 2 Explosion Pressure P_m of the Concentrated Sulphide Minerals

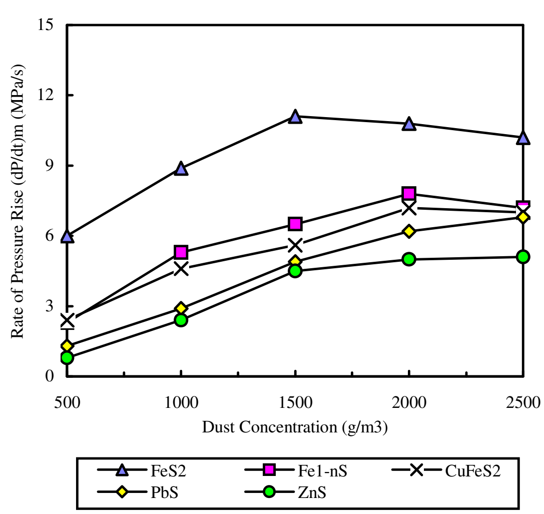

Figure 3 Rate of Pressure Rise $(dP/dt)_m$ of the Concentrated Sulphide Minerals

From Figures 2 and 3, even taking the uncertainty of the measurement into account, pyrite demonstrated its higher explosion parameters than the other four sulphide minerals. The explosion pressure curves revealed that the explosive characteristics of the pyrite were much stronger than those of other sulphide samples. The explosion pressure developed by pyrite was at least 16 per cent higher than those of other sulphide minerals at dust concentrations lower than 1500 g/m^3. The general trend is that the explosion pressure increases as the dust concentration increases to a maximum value or turning point and then slowly decreases.

The maximum explosion pressure was mostly obtained with dust concentrations between 1500 and 2500 g/m^3. There is a trend that the sulphide minerals with higher explosibility tend to reach their P_{max} at a lower dust concentrations. Taking the uncertainty of the measurement into account as shown in Figure 4 with accuracy bars (these bars should in no way be compared with statistical confidence signs used to illustrate standard deviation about a mean), only pyrite demonstrated a significantly higher P_{max} than any other of the four sulphide minerals. In practical terms, damage to equipment from a dust explosions could be equally severe from any of the four sulphide minerals.

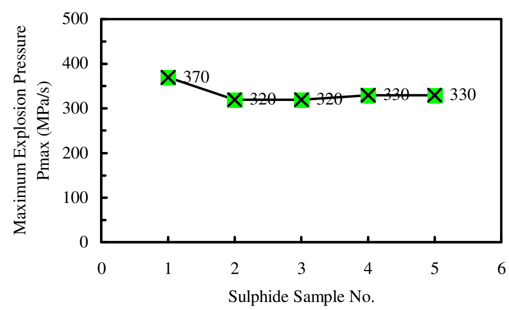

Figure 4 Maximum Explosion Pressure of Concentrated Sulphide Minerals (Sample No.: 1 - FeS_2 concentrate, 2 - $Fe_{1-n}S$ concentrate, 3 - $CuFeS_2$ concentrate, 4 - PbS concentrate, 5 - ZnS concentrate)

Analysis of the rate of the pressure rise shows that the $(dP/dt)_m$ has a similar trend of change to the P_m curve. The lower the LEL of a sulphide sample, the higher the $(dP/dt)_m$ of the sample. The higher the $(dP/dt)_{max}$ of a sulphide sample, the lower the optimum dust concentration (or concentration at which maximum rate change is seen) at which the $(dP/dt)_{max}$ is reached. The optimum dust concentration is found to be between 1500 and 2500 g/m^3 (Figure 5). By comparing the rate of pressure rise and the LEL, it is found that the explosive sequence indicated by the maximum rate of pressure rise of the sulphide minerals is the same as that for LEL.

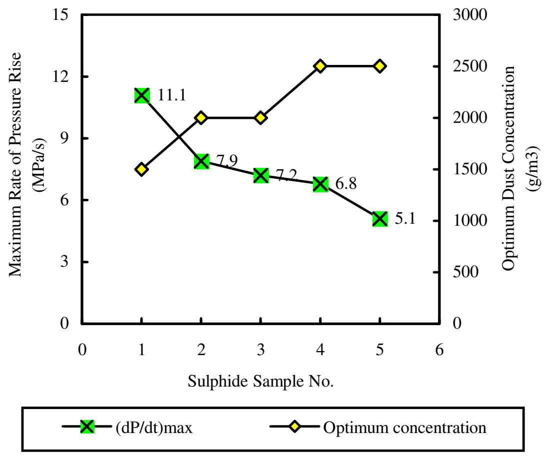

Figure 5 Maximum Rate of Pressure Rise of Concentrated Sulphide Minerals (Sample No.: 1 - FeS_2 concentrate, 2 - $Fe_{1-n}S$ concentrate, 3 - $CuFeS_2$ concentrate, 4 - PbS concentrate, 5 - ZnS concentrate)

Among the five major sulphide minerals, pyrite demonstrates not only the highest tendency to ignite, as indicated by its LEL, but the strongest explosion as indicated by its $(dP/dt)_{max}$ and P_{max}. Therefore, pyrite is the most explosive component among the major explosive sulphide minerals.

DEVELOPMENT OF THE PYRITE METHOD

To assist in prediction of sulphide ore dust explosion propensity, a set of calculation formulae, named the "Pyrite Method", have been developed. To allow quantitative comparison and analyse of the explosibility of different sulphide dusts, parameters to evaluate the explosion tendency and the explosion strength were examined. As the LEL, P_{max} and $(dP/dt)_{max}$ are the three most commonly available and standard experimental parameters or explosibility indices, three factors derived from them were developed by the authors. The derivation uses pyrite as a base as it has been found to be the most explosive sulphide mineral of those examined. The factors are defined as follows to evaluate the relative explosibility of a given pure or near pure sulphide mineral in comparison with the explosibility of pyrite.

Explosion Tendency Factor (K_t):

$$K_t = (\text{LEL of pyrite})/(\text{LEL of the sulphide sample}) \quad (1)$$

Explosion Strength Factor (K_s):

$$K_s = (P_{max}\text{ of the sulphide sample})/(P_{max}\text{ of pyrite}) \quad (2)$$

Explosion Rate Factor (K_r):

$$K_r = ((dP/dt)_{max}\text{ of the sample})/((dP/dt)_{max}\text{ of pyrite}) \quad (3)$$

The K_t factor represents the tendency for dust ignition. The K_s factor demonstrates the explosion severity of the dust explosion. The K_r factor indicates the relative rate of the explosion pressure rise.

Taking the uncertainty of measurement of P_{max} and $(dP/dt)_{max}$ into account, there are no unique values for K_t, K_s and K_r but a range for each of them. To simplify the calculation process, the tested mean values of the P_{max} and $(dP/dt)_{max}$ were taken to represent their "true values". In this way, the calculations of explosibility factors has been made workable.

The Pyrite Method works from setting the K_t, K_s, and K_r values of the pure pyrite mineral (which is the most explosive dust among the five major sulphide minerals) all equal to 1.0. The explosibility factors K_t, K_s, and K_r for the other major sulphide minerals are consequently set at a definite value between 0 to 1.0. As the values of LEL, P_{max}, and $(dP/dt)_{max}$ (mean value) of the major sulphide minerals have been determined, their explosibility factors can be calculated by applying the above calculation formulae. The calculated results for K_t, K_s, and K_r factors of the major sulphide minerals are listed in Table 4.

To evaluate explosibility of the actual sulphide ore dust, the contribution to the dust ignition of each sulphide mineral is weighed by accounting for percentage content and respective explosibility factors. The calculated explosibility factors of a particular sulphide dust can be determined by the following formulae once the mineralogical composition of a given sulphide dust sample is analysed:

Explosion Tendency Factor (K_t):

$$K_t = 1.00\times\%FeS_2 + 0.64\times(\%Fe_{1-n}S + \%CuFeS_2) + 0.45\times\%PbS + 0.37\times\%ZnS \quad (4)$$

Explosion Strength Factor (K_s):

$$K_s = 1.00\times\%FeS_2 + 0.86\times(\%Fe_{1-n}S + \%CuFeS_2) + 0.89\times(\%PbS + \%ZnS) \quad (5)$$

Explosion Rate Factor (K_r):

$$K_r = 1.00\times\%FeS_2 + 0.71\times\%Fe_{1-n}S + 0.65\times\%CuFeS_2 + 0.61\times\%PbS + 0.46\times\%ZnS \quad (6)$$

The relative explosibility of a sulphide dust sample can be evaluated by comparing its explosibility factors with those of other explosive sulphide dusts. The higher the K_t factor value, the higher the possibility of the sulphide dust being ignited. The higher the K_s and K_r value, the severer the dust explosions will be.

For any given sulphide ore dust with known mineralogical composition, explosibility factors can be calculated by applying formulae 4 to 6. The values of LEL, P_{max}, and $(dP/dt)_{max}$ of the given sulphide ore sample can be factored from the values for pyrite of LEL, P_{max}, and $(dP/dt)_{max}$ determined through standard experimental tests. The relevant calculation formulae are as follows.

Lower Explosive limit (LEL):

$$LEL = 140 \text{ x } 1/K_t \quad (g/m^3) \quad (7)$$

Maximum Explosion Pressure (P_{max}):

$$P_{max} = 370K_s \quad (kPa) \quad (8)$$

Maximum Rate of Pressure Rise [$(dP/dt)_{max}$]:

$$(dP/dt)_{max} = 11.1K_r \quad (MPa/s) \quad (9)$$

where, 140, 370 and 11.1 are the mean values of LEL (g/m^3), P_{max} (kPa), and $(dP/dt)_{max}$ (MPa/s) respectively of the pyrite mineral. By applying the tested mean values of LEL, P_{max} and $(dP/dt)_{max}$ of pyrite to represent its true values, the same order of error or uncertainty of measurement is introduced. Therefore, the calculation errors of LEL, P_{max} and $(dP/dt)_{max}$ are within ±10, ±10 and ±30 per cent respectively.

Since these K_t, K_s, and K_r factors have been defined and calculated in relation to the explosibility of the pyrite, the approach has been named the "Pyrite Method".

EXPLOSIBILITY STUDY OF FIVE MINE SULPHIDE ORE SAMPLES

Estimation of Explosibility by use of the "Pyrite Method"

To establish validity of the method, the explosibility of the five sulphide ore dusts sampled from underground mines were estimated by applying the calculation formulae of the "Pyrite Method". The calculations cover determination of the explosibility factors (K_t, K_s, and K_r) by applying formulae 4 to 6 and prediction of the explosibility parameters (LEL, P_{max}, and $(dP/dt)_{max}$) by applying formulae 7 to 9 appropriately for each of the five sulphide samples.

The initial data needed for the explosibility calculation are the percentage contents of each of the major explosive components, of pyrite, pyrrhotite, chalcopyrite, galena, and sphalerite. By applying the mineralogical compositions of the sulphide dust samples listed in Table 3, the explosibility factors and the explosibility parameters of the sulphide dust samples can be directly calculated. The major calculated results are all presented in Table 4. As an example, the calculation processes for dust sample A are presented:

TABLE 4
Calculation Results of the Explosibility Parameters on Five Sulphide Dust Samples

Sulphide Sample	LEL (g/m^3)	P_{max} (kPa)	$(dP/dt)_{max}$ (MPa/s)	Explosibility Factor K_t	K_s	K_r
A	191	296	8.4	0.73	0.80	0.76
B	212	281	7.7	0.66	0.76	0.70
C	215	270	7.2	0.65	0.73	0.65
D	186	318	8.8	0.75	0.86	0.79
E	177	326	9.1	0.79	0.88	0.82

Explosion Tendency Factor (K_t):

$$K_t = 1.00\times\%FeS_2 + 0.64\times(\%Fe_{1-n}S + \%CuFeS_2) + 0.45\times\%PbS + 0.37\times\%ZnS$$
$$= 1.00 \times 53.2\% + 0.64 \times (29.3\% + 0) + 0.45 \times 2.9\% + 0.37\times 0$$
$$= 0.73$$

Explosion Strength Factor (K_s):

$$K_s = 1.00\times\%FeS_2 + 0.86\times(\%Fe_{1-n}S + \%CuFeS_2) + 0.89\times(\%PbS + \%ZnS)$$
$$= 1.00 \times 53.2\% + 0.86 \times (29.3\% + 0) + 0.89 \times (2.9\% + 0)$$
$$= 0.81$$

Explosion Rate Factor (K_r):

$$K_r = 1.00\times\%FeS_2 + 0.71\times\%Fe_{1-n}S + 0.65\times\%CuFeS_2 + 0.61\times\%PbS + 0.46\times\%ZnS$$
$$= 1.00 \times 53.2\% + 0.71 \times 29.3\% + 0.65 \times 0 + 0.61 \times 2.9\% + 0.46 \times 0$$
$$= 0.76$$

Lower Explosive limit (LEL):

$$LEL = 140K_t = 140 \times 0.73 = 191 (g/m^3)$$

Maximum Explosion Pressure (P_{max}):

$$P_{max} = 370K_s = 370 \times 0.80 = 296\ (kPa)$$

Maximum Rate of Pressure Rise [$(dP/dt)_{max}$]:

$$(dP/dt)_{max} = 11.1K_r = 11.1 \times 0.76 = 8.4\ (MPa/s)$$

Actual Explosibility Tests on the Five Mine Ore Samples

The second stage of the validation process was to physically undertake explosibility tests on all five mine ore samples and compare results with those obtained from the calculation method.

LEL test results for the five ore dust samples are listed in Table 5. To minimise number of tests required to determine LEL the following procedure was adopted. Establishing LEL is an iterative process undertaken most efficiently if an approximation to the value is initially known. As the LEL of every dust sample had been estimated with the "Pyrite Method", the LEL test started directly from a concentration that was about 20 g/m^3 lower than the calculated LEL value. For example, as the calculated LEL of sample A was 191 g/m^3, its LEL explosion test started from 170 g/m^3 rather than 100 g/m^3, the normally accepted starting point in LEL testing practice. In this way, at least five tests became unnecessary in each sample's LEL testing and the testing cost was consequently reduced.

The indices of maximum explosion pressure (P_{max}) and maximum rate of pressure rise [$(dP/dt)_{max}$] are determined through the P_m and $(dP/dt)_m$ tests. The dust concentrations tested ranged from 500 to 2000 g/m^3 in increments of 250 g/m^3. The major P_m and $(dP/dt)_m$ testing results are shown in Figures 6 and 7 and the P_{max} and $(dP/dt)_{max}$ are listed in Table 5.

TABLE 5
Explosibility Test Results for Five Mine Sulphide Samples

Dust sample	LEL (g/m^3)	P_{max} (kPa)	$(dP/dt)_{max}$ (MPa/s)
E	170	370	10.2
D	180	360	8.9
A	180	330	8.7
B	230	290	5.9
C	230	260	5.5

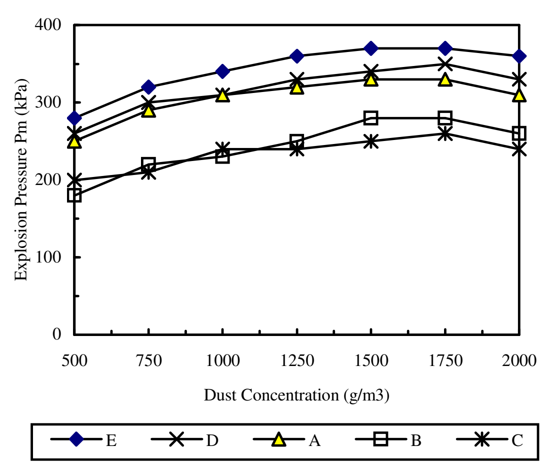

Figure 6 Explosion Pressure P_m of Sulphide Dust Samples

Accepted explosion testing practice requires that at least two series of tests are carried out in order to ensure that reliable LEL, P_{max} and $(dP/dt)_{max}$ values are obtained (Cesana and Siwek, 1991; 1994). As the LEL, P_{max} and

$(dP/dt)_{max}$ for all the dust samples had been predicted by calculation as shown in Table 5, special attention was given when the explosion tests showed that either test values were close to its calculated values. With the early indication of the correct LEL, P_{max} and $(dP/dt)_{max}$, only the dust concentrations close to the predicted P_{max} and $(dP/dt)_{max}$ required double checking. Compared with normal practice, this approach saved about 30 per cent of the total testing time and cost without sacrifice in the accuracy of test results.

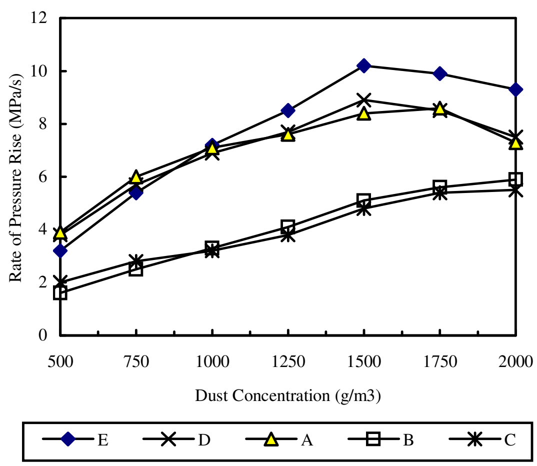

Figure 7 Rate of Pressure Rise $(dP/dt)_m$ of Sulphide Dust Samples

Both the explosion pressure and the rate of pressure data demonstrate that the ore dust samples from mines A, D and E are more explosive than B and C mine samples. The E mine sample shows the highest explosibility in terms of the LEL, P_{max} and $(dP/dt)_{max}$. A and D samples exhibit the same explosibility while B and C samples together are at similar level, especially when dust concentrations are lower than 1250 g/m^3.

The E mine sample with a LEL of 170 g/m^3 was found to be the most explosive sample. The LEL of both D and A samples is 180 g/m^3, while that of both B and C sample is 230g/m^3. The P_{max} and $(dP/dt)_{max}$ of the five samples also show similar relationships to those of LELs. The explosion strength, indicated by P_{max} and $(dP/dt)_{max}$ and the explosion tendency indicated by the LEL are all in the following sequence (from high to low): E, D, A, B and C mine samples.

The sulphur contents of E, D, A, B and C mine ore samples are 36.7, 36.3, 32.7, 31.6, and 29.6 per cent respectively. The sulphur content of D sample is about the same as that of E sample and much higher than that of the A sample. From the explosibility test results it is noted that the explosibility of the D sample is much lower than that of the E sample, but almost the same as that of the A sample. Comparing the sulphur contents of the five dust samples with their explosibility parameters, there is no clear correlation between the sulphur content and the P_{max} or $(dP/dt)_{max}$ of the sulphide dust samples.

Comparison of Explosibility Test Results with Predictions from the "Pyrite Method"

Explosibility tests on different sulphide minerals in this study demonstrated that pyrite has a higher explosion tendency and explosion strength than other sulphide minerals. The explosion characteristic of a particular sulphide dust sample is a combination of all the major explosive sulphide minerals contained within it. To evaluate the explosibility of a sulphide dust, all the major explosive sulphide components should therefore be taken into account. This is the basic principle of the "Pyrite Method".

In order to validate the reliability of the calculated results from the Pyrite Method, the calculated explosibility parameters of the five sulphide dust samples are compared with explosion testing results (mean values). The relationships between the calculated and tested results for LEL, P_{max} and $(dP/dt)_{max}$, are plotted in Figures 8 to 10.

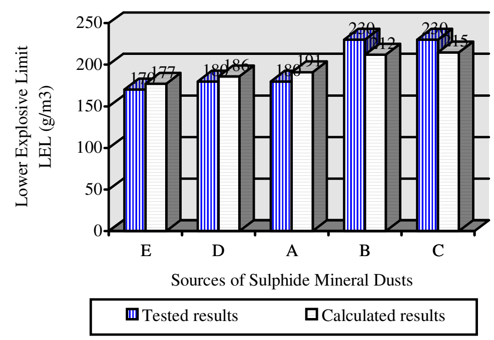

Figure 8 Comparison of Tested and Calculated LELs for the Sulphide Dusts

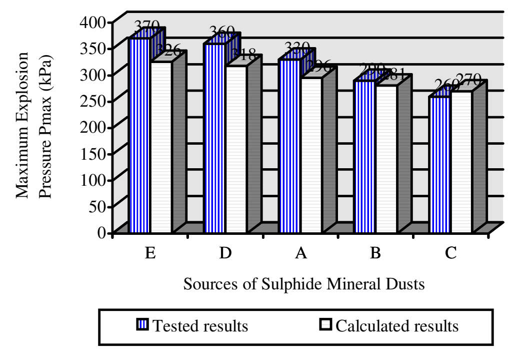

Figure 9 Comparison of Tested and Calculated P_{max} for the Sulphide Dust Samples

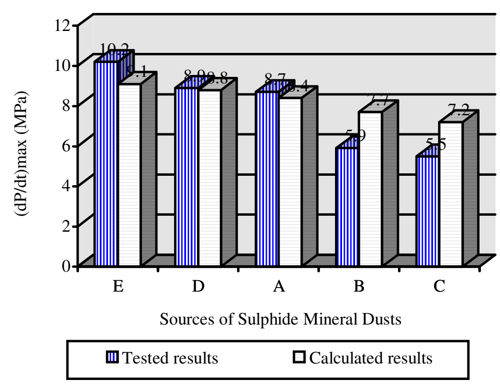

Figure 10 Comparison of Tested and Calculated $(dP/dt)_{max}$ for the Sulphide Dusts

It is evident that the calculated results demonstrate, in general, a high agreement with explosion test data. Across the explosibility indices the calculated LELs of the dust samples show the best agreement with the tested LELs with a difference of less than 10 per cent (Table 6).

The calculated P_{max} also demonstrates good agreement with the test results with differences for the five ores between 3 and 12 per cent. This variation range is quite acceptable for a general examination of sulphide dust explosibility.

TABLE 6
Explosibility Calculation Error Compared to the Test Results on Five Sulphide Ore Dust Samples

Sulphide sample	LEL Error (%)	P_{max} Error (%)	$(dP/dt)_{max}$ Error (%)
E	4.1	11.9	10.8
D	3.3	11.7	1.1
A	9.4	10.3	3.4
B	7.8	3.1	30.5
C	6.5	3.8	30.9

The calculated $(dP/dt)_{max}$ values present the highest discrepancy with the test results. The variations in the calculated $(dP/dt)_{max}$ in the case of E, D and A samples are from 1 to 12 per cent. However, the errors in the case of B and C samples are at almost 31 per cent. This may reflect the considerable error (as high as 30 per cent) in repeatibility of measurement of $(dP/dt)_{max}$ in the Siwek dust explosion chamber.

Analysis of variations confirms that the calculated explosibility results are generally compatible with the test results. The differences between the calculated and tested results are generally within 12 per cent, although 2 of the 15 key values show errors as high as 31 per cent. The differences can be attributed to both explosion testing system error and error from the mineralogical analyses. Considering the uncertainty of the measurement within this testing system is ±10 per cent for LEL and P_{max} and ±30 for $(dP/dt)_{max}$, the accuracy of the calculation results are satisfactory.

The explosion testing results demonstrate that the calculation of the “Pyrite Method” is a competent method to approximately predict sulphide dust explosibility. As the mineralogical composition data of the ore bodies in most underground metalliferous mines are available, the relative explosibility of the sulphide dust in the mine can be conveniently predicted with the “Pyrite Method”. The predicted explosibility data can provide immediate information about the dust explosion potential for mine operators concerned about safety precautions.

CONCLUSION

A new approach based on a system of calculation formulae, named the “Pyrite Method”, has been developed to predict the relative explosibilities of sulphide ore dusts. The significant advantage of this method is that dust explosion propensity can be calculated from the sulphide ore mineralogical composition without the undertaking of costly and time consuming explosion tests. The explosibility of five concentrated samples of major explosive sulphide minerals and five samples of ore dusts sampled from sulphide orebodies were investigated through experimental study. Based on the analyses of the relationship between the explosibility and the mineralogical contents of the sulphide mineral samples, the “Pyrite Method” was developed and calculation formulae were derived to predict the explosibility of any given sulphide dust.

Comparative study of the explosibility of five sulphide dust samples confirmed that the predicted results from the “Pyrite Method” were highly compatible with the values from explosion tests. The analysis of the calculation accuracy also demonstrated that the approach is a practical method to predict the relative explosibility of a sulphide dust.
Testing and evaluating the dust explosibility is expensive and time consuming. The “Pyrite Method” provides a simple calculation method for mining engineers and mine safety officers to approximately predict and evaluate the explosibility of sulphide ore dust. This approach also enables dust explosion researchers to gain an initial indication of explosibility indices and so reduce the testing range and number of tests necessary for a full evaluation.

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