

ASSESSMENT OF DUST EXPLOSION HAZARDS:
EFFECT OF CHANGES IN TEST METHODS AND CRITERIA

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The effect on risk assessment of changes in the test methods and criteria used to characterise the flammability of dust clouds and their potential explosive violence is considered.

It is shown that, although certain Group B dusts can be ignited they are unlikely to cause significant explosion damage.

A comparison is made of the Hartmann and 20 Litre Sphere tests for pressure-time data and guidelines provided on the use of the data to specify explosion vents.

KEYWORDS: Flammability, Dusts, Explosion, Hartmann, Venting, Pressure

INTRODUCTION

The key questions in the assessment of dust explosion risk are (a) Is the dust cloud flammable or non-flammable? and (b) what will be the potential violence of any dust explosion?.

In the U.K. flammability is assessed by forming a dust cloud in the presence of ignition sources and noting whether flame propagates away from the ignition source. Prior to 1970 the tests involved the use of both localised and extended ignition sources. The more recent Group A/Group B classification is based solely on localised ignition sources with the dust cloud dispersed at or near ambient temperature. Industrial ignition sources can have energies greater than those used in the tests and consideration has to be given to the possibility of Group B dust clouds being ignited in industrial procedures.

The violence of an explosion is determined from pressure-time data. The traditional Hartmann Bomb (volume 1.3 litres; ignition source: localised electric spark) is being replaced by the Sphere Test (volume: 20 litres; ignition source: 10,000J chemical ignitor). This change not only increases the volume of the test cell but introduces an ignition source of a type rarely, if ever, present in powder manufacturing plants.

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These changes in flammability and pressure-time tests require that consideration be given to the following:

- (1) The possibility of Group B dusts presenting an ignition risk in industrial situations.
- (2) The possibility of an anomaly arising with a dust classified as Group B by reason of it not igniting in the localised source tests but igniting in the Sphere Test using the 10,000J source.
- (3) The relevance to industrial situations of pressure-time data obtained with a 10,000J ignition source.
- (4) The validity of existing pressure-time data obtained with the Hartmann Bomb and its relationship to data obtained in the Sphere Test.

Data for 900 powders has been surveyed and a detailed study made on selected materials to assess the effect of changes in test methods and criteria on dust explosion hazard assessments. Sufficient data are now available to provide guidelines that can be of practical value to industry.

FLAMMABILITY OF DUST CLOUD

A flammability classification is required, not only to assess dust explosion risk, but also to define statutory requirements. In the U.K. Section 31 of the Factories Act (1961) requires that all practical steps be taken to restrict the spread and effects of a dust explosion in plants handling dusts that are liable to explode on ignition.

Tests and Criteria for Flammability Characterisation

Historically the Horizontal Tube and Godbert-Greenwald Furnace tests have been used to assess flammability (1). The former uses a localised hot coil ignition source with the dust dispersed at or near ambient temperature. In the latter the dust is dispersed into a heated enclosure with wall temperatures upto 1000°C.

Powder characterisation was based on a visual observation of flame propagation and use of the following criteria.

- CLASS I - ignition and flame propagation in the Horizontal Tube test <1300°C
- CLASS II- ignition and appearance of flame at the bottom of the Goldbert-Greenwald Furnace test < 1000°C.
- CLASS III- no appearance of flame at 1000°C in the Godbert Greenwald Furnace test.

Both Class I and II were considered flammable. Class I indicated the possibility of ignition from localised heat sources, Class II indicated that extended sources and possibly heated environments were required for ignition. It can be argued that the Godbert-Greenwald Furnace at 1000°C is an unrealistically severe test in that powders could be decomposed prior to ignition and visible flame could be due to ignition of decomposition products rather than the powder per se. On the other hand it provided a clear definition of non-flammability. Class III dusts would not ignite in any powder manufacturing situation.

The distribution of powders handled in the organic chemical industry (eg. dyes, pigments, pharmaceuticals, pesticides) was Class I 43%, Class II 50% and Class III 7%. The procedure may therefore have over-emphasised the potential hazard of 50% of powders. Detailed analysis of the data suggests that, in multi product plants the uncertainty was restricted to 10-15%.

In the more recent Group A/Group B procedure (2) characterisation is based on the degree of flame propagation away from hot coil and continuous spark ignition sources when the dust cloud is formed at or near ambient temperature.

GROUP A - dusts which ignite and propagate flame away from the ignition source.

GROUP B - dusts which do not propagate flame away from the ignition source.

Early Work at the Fire Research Station (3) suggested that the possibility of Group B powders causing a dust explosion was extremely small. More recently, it has been suggested that the Group B classification may not be valid in all industrial situations. It is considered that the classification afforded by the Group A/B standard tests is strictly only valid in air at ambient temperatures. If the dust is to be handled (eg dried) a higher temperature the classification may not be valid. Some Group B dusts are known to present a fire hazard and may be explosible at higher temperatures. (2)

A review of existing data (900 samples) showed that about 25% of Group B dusts ignited in the Godbert Greenwald Furnace. They could represent an industrial hazard provided that the Furnace test is not unrealistic in terms of industrial ignition sources.

Initiation of combustion in dust clouds is a complex phenomenon. The ignition capability of a source depends not only on its total energy but on the distribution of this energy with respect to space and time. The ranking of powders in terms of ignition sensitivity depends upon the nature of the ignition source.

Comparison of data obtained with hot coil, Godbert-Greenwald Furnace and spark ignition sources indicate poor correlation in the ranking of materials (Figures 1,2).

No one test can simulate the ignition characteristics of all industrial sources. However it is necessary to consider how Group B dusts could react to the more common industrial ignition sources namely electric sparks, pyrophoric material and flames whose energies exceed those used in the standard tests.

Explosion Risk with Group B Dusts

The flammability of 9 dusts has been examined with 5 ignition sources in the vertical tube apparatus. Seven of the dusts were classified as Group B in the standard tests and two were on the borderline of Group A/Group B in that a small flame was produced around the test ignition source but this did not propagate through the dust cloud.

The ignition sources used to simulate the industrial situation were a capacitative spark discharge (10J), two chemical pyrophoric ignitors (84J and 250J), a small cool flame and a large hot flame.

The results are shown in Table.1.

The two samples (PVC-Low Mol.Wt and Intermediate B) that were on the Group A/Group B interface were not ignited by the spark ignition source but exhibited full or partial flame propagation with all the other sources.

As the energy of the ignition sources increased only one Group B dust (Urea) continued to give no indication of ignition. This material had a high Furnace Ignition Temperature (950-1000°C). The other seven Group B dusts ignited with one or more of the ignition sources and in two cases (PVC-High.Mol.Wt, Sodium dihydroxy naphthalene disulphonic acid) the flame propagated through the dust cloud with the higher energy sources.

There is some indication in the results that ignition/propagation is more likely to occur for Group B dusts having Furnace Temperatures less than 700-800°C.

The data indicate that the possibility of Group B dusts igniting in industrial situations cannot be definitely excluded.

Pressure Development in Explosions involving Group B Dusts

Ignition and flame propagation in the above tests does not, per-se, necessarily indicate a significant dust explosion risk, account has also to be taken of the associated pressure development.

The rate of pressure rise associated with seven of the powders was measured in the Sphere Test using the standard source (10,000J chemical ignitor), a pyrophoric chemical ignitor (250J) and a Fusehead/Guncotton source (650J).

The results are shown in Table 2.

With the two ignition sources that have similar energies to industrial sources the rates of pressure rise for the Group B dusts are negligible. The 10,000J source produced significant maximum pressures (5-6 bar) and significant, albeit low, rates of pressure rise \bar{m}_1 the maximum value of 255 bars \bar{m}_1 corresponds to a Kst value of 69 bar m.s. \bar{m}_1 ie a weak St.1. classification.

Intermediate B categorised as Ap produced low but significant pressure effects with all ignition sources.

Discussion

For a powder that is classified as Group B in the standard procedure, the possibility of ignition and flame propagation with greater but realistic ignition source energies cannot be definitely excluded. This uncertainty can be reduced, by accepting partial propagation in the standard procedure as a Group A classification.

Although Group B dusts may ignite, the data in Table 2 indicate that industrial sources, should not induce pressure rises in Group B dust clouds capable of extensive explosion damage except in sealed vessels. Adventitious gaps, will normally prevent dangerous pressure development.

The significant pressure rises produced in the Sphere Test using the 10,000J source indicate that the parallel use of the Group A/Group B system to define flammability and the Sphere Test to measure pressure-time data could lead to inconsistent characterisation of materials. This however will produce problems of interpreting statutory requirements rather than uncertainty in identifying hazards and the need to provide safety measures.

PRESSURE DEVELOPMENT CHARACTERISATION

Historically pressure-time data has been obtained using the Hartmann Bomb. Dust, in the base of the test cylinder (length 31cm, diameter 6.8cm volume 1.3 litres), is dispersed by an blast of air. The ignition source in most common use is a continuous electrical discharge.

Defects of the Hartmann systems are (1) poor dust dispersion (2) ignition can occur before a dust cloud is fully established throughout the test volume (3) when the flame reaches the cell walls, cooling occurs before combustion in the vertical direction is complete. An example of the effect of cooling on a pressure-time trace is shown in Figure 3.

Some users have adopted a discrete spark as the ignition source to provide more control of the dispersion - ignition sequence. In the ICI test (4) the ignition source is a cerium magnesium fuse head (84 J energy). This allows control of the ignition sequence and provides a multipoint ignition source which reduces the effect of poor dust dispersion and wall cooling. Maximum values are obtained for P_{max} and dP/dt from tests with varying dispersion-ignition intervals and with different dust concentrations. This procedure has proved successful in providing data from which explosion vents can be designed.

Bartknecht (5) has introduced the Sphere Test. This consists of a 20 litre spherical test volume into which dust is dispersed via a ring, nozzle. The ignition source is a 10,000J chemical ignitor initiated 60ms after dust dispersion. The prescribed test procedure provides data that can be mathematically converted to be applicable to larger volumes by use of the Cube Root Law.

For the Sphere test to be acceptable as a "standard", data obtained from it must be reproducible.

The manufactures provide two reference powders - Irganox 1010 and Tinuvin 320 - that can be used to compare the performance of purchased equipment with the manufacturer's "standard". The results for the "I.C.I. sphere" are summarised below.

Material	Maximum Explosion Pressure (bar)		Kst. Value (bar.m.s ⁻¹)	
	Kuhner	I.C.I.	Kuhner	I.C.I.
Irganox 1010	7.3 ± 0.3	6.9 ± 0.7	145 ± 10	160 ± 10
Tinuvin 320	8.1 ± 0.7	7.7 ± 0.3	254 ± 22	274 ± 29

This indicates good agreement between the two systems.

Six powders have also been tested in the I.C.I. sphere and the results compared with those published by the Fire Research Station (6). Comparison of $\frac{dp}{dt}$ data is shown in Figure 4. The difference between the two sets of data is less than 10%.

It has been concluded that the Sphere Test offers advantages over the Hartmann Bomb in terms of reproducibility of data obtained with different test vessels.

A 10,000J chemical ignitor is used in the Sphere Test to ensure that, for a specified dust concentration and degree of turbulence, the maximum values of P_{max} and $\frac{dp}{dt}$ are measured. The energy of this source however exceeds that found in powder handling plants and the validity of the data obtained with this high energy source to industrial situations has to be considered.

For example, the U.K. classification of P.V.C. is Group A but the pressure rise is reported as zero (2). Continental data based on the Sphere Test characterise PVC as an St.1. dust. Thus there is confusion as to whether or not P.V.C. powder handling plants require protection against dust explosions.

Effect of Ignition Source on Pressure-Time Data

The effect of ignition source energy on pressure-time data has been investigated using the standard Sphere Test source (10,000J) and a 500J chemical ignitor. The latter energy level is near the maximum found in industrial powder handling plant.

Ten powders have been tested. Six were Group A and had Kst values covering the range 110-333 bar.m.s⁻¹. The other four had been found to be difficult to ignite in the earlier work.

The results are summarised in Table 3 and Figure 5.

These data show that the larger source does not enhance the rate of pressure rise except at low values of Kst (< 100 bar m.s⁻¹).

The latter effect confirms the earlier data on Group B dusts. The key question for these powders is not the validity of the Sphere Test data as such but whether or not a 10,000J source can be present in industrial plants.

A possible explanation of the anomalous PVC data is that the high energy 10,000J source decomposes the P.V.C. prior to ignition and the evolved gases contribute to the explosion. Some support for this has been obtained from experiments in which P.V.C. dispersed in an inert nitrogen atmosphere and was subjected to 10,000J and 500J chemical ignition sources. Spectrophotometric analysis of the atmosphere in the sphere after the test showed that ethene, ethylene, hydrogen chloride and but-1,3-diene were present after the 10,000J source but were not detected after use of the 500J source. The presence of flammable gases before combustion was complete could enhance pressure effects as in hybrid mixtures (5).

This work is being extended to cover ignition sources other than chemical ignitors but the evidence to date indicates that 10,000J source does not produce an unrealistic measure of the violence of an explosion except in border line cases where the primary uncertainty is whether or not industrial sources could cause ignition.

Relationship between Hartmann Bomb and Sphere Test Data

Although in future definitive pressure-time data will be obtained from the Sphere Test, there is value in the continued use of the large amount of existing Hartmann Bomb data. Furthermore 500g of material is required for the Sphere Test whereas Hartmann Bomb data can be obtained from 50g. The provision of the larger sample is not always possible eg pure drugs in pharmaceutical industry. Certain powders have a physical form that inhibits dispersion through the Sphere Test nozzle. Hartmann Bomb tests will continue to have value in these situations.

The primary use of pressure-time data is in the specification of explosion vents.

The following empirical correlation described by Palmer (7) and Schofield (8) has been widely used.

Maximum Rate of Pressure Rise (bar.s ⁻¹)	Vent Ratio (m ⁻¹)
<345	1/6.1
>345 <690	1/4.6
>690	1/3.1

In the chemical industry a vent based on K Factor (Cross-Sectional Area of Plant/Area of Vent) of 3 has been used to protect plant handling powders with $\frac{dp}{dt}$ values upto 700-800 bar s⁻¹ measured in the Hartmann Bomb (9).

Sphere Test data are directly linked to the vent nomographs developed by Bartknecht (5) and recommended in recent guides on explosion venting (10).

Although the vent areas calculated from these methods differ in detail, in equivalent situations, the differences are not significant in terms of the effectiveness of the protection afforded by the vent (9). The Sphere Test data is however becoming an internationally accepted specification for powders and the nomograph method provides a vent specification that covers a wider range of vessel volumes, strength and vent designs.

The use of the nomograph with the existing Hartmann Bomb would be of practical value. Rates of Pressure Rise data from the Hartmann Bomb and Sphere Test are compared in Figure 6. Although there is a trend indicating that Sphere Test values increase as the Hartmann Bomb Values increase, there is no precise relationship between the two sets of data. However powders with values of $\frac{dp}{dt} < 450 \text{ bar s}^{-1}$ in the Hartmann Bomb are all classified as St.1. This correlation is of practical value because about 90% of powders measured in the Hartmann Bomb have $\frac{dp}{dt} < 450 \text{ bar s}^{-1}$ - see Figure 7. This link has now been confirmed independently by the Fire Research Station (6).

In the recent "Guide to Dust Explosion Prevention and Protection: Part 1 - Venting" (8) it is accepted that, if the rate of pressure rise is less than about 500 bars^{-1} , in the Hartmann Bomb, it can be considered to be an St.1. dust.

Although vent specifications will in future be based on Sphere Test data, if existing Hartmann Bomb $\frac{dp}{dt}$ values are less than 500 bars^{-1} then the St.1 nomograph can be used to size the explosion vent.

PRACTICAL GUIDANCE AND CONCLUSIONS

Although the study is still in progress, the data to date provide the following guidelines of practical value to industry.

1. In the standard tests a powder should be classified as Group A if it ignites and any flame propagates fully or partially away from the ignition source. This is now accepted by I.C.I. and by Fire Research Station (2).
2. Although a Group B dust may be ignited by industrial ignition sources, the rate of pressure development will be low and unless the vessel is sealed adventitious venting will protect against extensive explosion damage. In addition to this the guidance provided by I.Chem.E (11) should be followed if the dust cloud temperature exceeds 110°C .
3. In the Sphere Test, Group B dusts can develop significant pressure effects. The significance of this in interpreting the statutory requirements of Section 31 Factories Act needs clarification.
4. The Sphere Test provides a means of obtaining, reproducible pressure-time data and can form the basis of an internationally recognised standard.
5. Although the energy of the $10,000\text{J}$ ignition source exceeds that of industrial sources, the pressure-time data obtained from the test provides a realistic measure of the potential violence of an explosion provided $K_{st} > 100 \text{ bar.m.s.}^{-1}$. and for Group B dusts the test may indicate pressure effects that cannot be obtained with industrial sources. In particular situations this problem may be resolved by considering the possibility of the plant sources igniting a dust cloud of the material.
6. Although there is no precise correlation between Hartmann Bomb and Sphere Test data, rates of pressure rise of less than $450\text{-}500 \text{ bar s}^{-1}$

in the Hartmann indicate an St.1 dust and the appropriate nomograph can be used to calculate vent areas. However, the more specific K_{ST} nomographs should not be used.

Table 1. Effect of Ignition Source on Flammability

Sample	A/B	Ignition Source					G.G.
		Class	Spark (10J)	Fuse- Head (84J)	Cool Flame Ignitor (250J)	Hot Flame	
1 Calcium Citrate	B	b	ap	b	ap	ap	500-550
2 Sodium Dihydroxy Naphthalene Disulphonic Acid	B	b	ap	ap	a	a	500-550
3 Calcium Gluconate	B	b	b	ap	ap	b	600-650
4 PVC - low Mol.Wt.	Ap	b	ap	a	ap	a	600-650
5 PVC - High Mol Wt	B	b	b	ap	ap	a	650-700
6 44'Diamino Stilbene Disulphonic Acid	B	b	ap	ap	ap	ap	650-700
7 Intermediate B	Ap	b	a	ap	ap	ap	800-850
8 Intermediate A	B	b	b	b	b	ap	950-1000
9 Urea	B	b	b	b	b	b	950-1000

Symbols.

- A - Group A - flame propagation in standard test
- B - Group B - no ignition/propagation in standard test
- Ap - partial propagation in standard test.
- a - propagating flame.
- ap - partial propagation in non-standard test.
- b - no ignition.

Table 2 Pressure-Time Data-Group B Dusts

SAMPLE	Group		PRESSURE-TIME DATA				
	A/B	Standard Source (10,000J)	Chemical Ignitor (250J)	Fusehead/Gun cotton (650J)			
	P max (barg)	d_P/dt_{-1} (bars ⁻¹)	Pmax (barg)	d_P/dt_{-1} (bars ⁻¹)	Pmax (barg)	d_P/dt_{-1} (bars ⁻¹)	
Calcium Citrate	B	5.1	149	0.5	<1	0.2	5
Sodium dihydroxy Naphthalene Disulphonic Acid	B	5.9	255	0.5	<1	-	-
Calcium Gluconate	B	6.6	251	0.5	<1	0.5	5
PVC-Low Mol.Wt	Ap	6.1	246	0.5	<1	-	-
PVC-High Mol.Wt.	B	5.8	126	0.5	<1	0.3	3
44'Diamino Stilbene Disulphonic Acid	B	6.6	218	0.5	<1	5.0	39
Intermediate	B Ap	6.5	363	4.0	35	6.2	145

TABLE 3 COMPARISON OF K_{st} VALUES FROM 20 LITRE SPHERE TESTS
WITH 2x5000J AND 2x250J CHEMICAL IGNITERS

DUST	2x5000J K _{st} /(bar m/s)	2x250J K _{st} /(bar m/s)
ALUMINIUM	333	356
TINUVIN	279	302
IMPREZ	227	217
IRGANOX	161	158
ACRYLIC	129	113
DEXTRINE	111	73
SODIUM DIHYDROXY NAPHTHALENE DISULPHONIC ACID	69	<1
CALCIUM GLUCONATE	68	<1
PVC LOW MOLECULAR WT.	67	<1
PVC HIGH MOLECULAR WT.	34	<1

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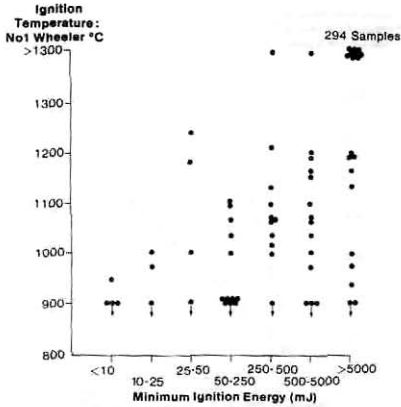


Fig 1 Classification of Products : Dust Cloud Not Wheeler Ignition Temperature against Minimum Ignition Energy

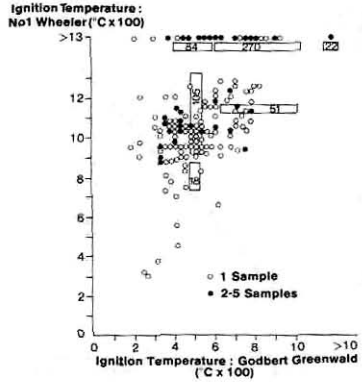


Fig 2 Comparison of Ignition Temperature of Dust Clouds

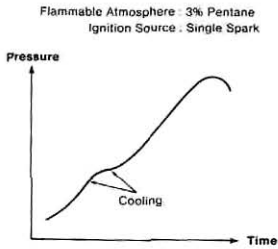


Fig 3 Pressure-Time Trace Indicating Wall Cooling in the Hartmann Bomb

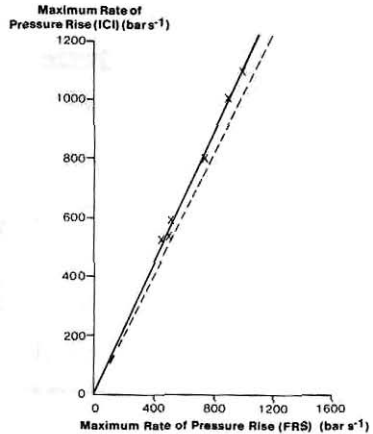


Fig 4 Comparison of 20 litre Spheres

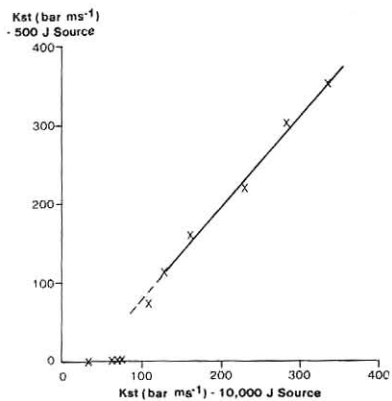


Fig 5 Kst Values - 20 litre Sphere 10000J v 500J Sources

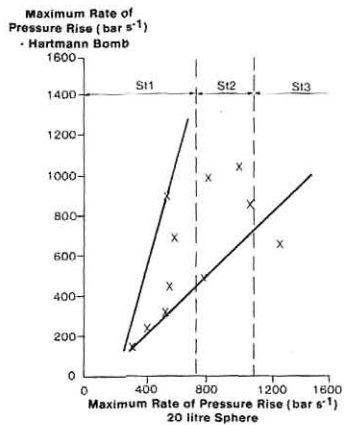


Fig 6 Maximum Rates of Pressure Rise - Comparison of Hartmann and 20 litre Data

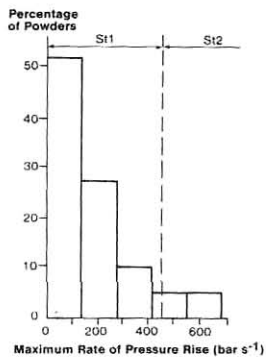


Fig 7 Survey of Hartmann Bomb Data