DUST EXPLOSION HAZARD ASSESSMENT

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Measurement of dust explosibility in the Hartmann apparatus is known to be unreliable. It is shown that this arises because the Hartmann test method uses a continuous, rather than a discrete ignition procedure.

The problem of turbulence, within the context of hazard assessment, is discussed and the inclusion of a turbulence factor within the cube law proposed.

INTRODUCTION

It is well known that dusts, wh®n dispersed as a cloud, can explode. The quantification of the severity of explosion that is likely with a particular dust is of vital importance to the constructed of industrial plant, the designers of explosion protection measures, and to the user industries. In the United Kingdom the Hartmann vertical tube apparatus is used extensively for this purpose. However, it has been shown experimentally (1, 2) that this test procedure can severely underestimate explosibility parameters, and that there is no simple correlation between results obtained in this, and large volume (~&- Tm3) test apparatus.

Active explosion protection measures, such as venting and explosion suppression, must be designed such that their operational effectiveness can be assured. The work described below arose out of the necessity to make explosion protection measures more cost effective than those based on an unquestioned dependence on a Hartmann apparatus assessment of the hazard. This article investigates the limitations of the Hartmann apparatus test procedure, discusses alternative test methods and the applicability of such test results to the industrial environment. In particular, the importance of turbulence on the growth of an explosion is discussed.

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EXPLOSION PARAMETERS

Measurements of the maximum explosion pressure, P_{max}, and the maximum rate of pressure rise, $(dP/dt)_{max}$, at the most explosible fuel concentration are used to quantify the potential explosion hazard of a combustible gas or dust. Maximum pressure is essentially vessel volume independent. Maisey (3) identified a cube law relation between $(dP/dt)_{max}$ and volume V for quiescent gas explosions in near spherical test vessels:-

$$(dP/dt)_{max} \cdot V^{1/3} = K_r \text{ (explosion rate constant)}$$

Vessel geometry, initial pressure and temperature, the nature of the ignition source, mixture homogeneity and the turbulence level prevailing at ignition all influence the rate of explosion propagation. Turbulence, in particular, has a major influence on the resultant explosion severity. Since it is not possible to realise a quiescent dust explosion, inevitably dust turbulence levels differ according to the chosen dust dispersion methodology and departures from the cube law occur. Bartknecht (4) has shown that the cube law relation remains valid for dust explosions in large (1-60 ITP) volumes using a particular dust dispersion procedure. In practice, hazard assessment requires an assessment of turbulence level, inasmuch as it influences explosion severity in the industrial environment.

EXPLOSIBILITY MEASUREMENT

The explosibility of an industrial dust is usually measured in the Hartmann vertical tube apparatus (5) - see Figure 1. A weighed sample of the dust is dispersed upwards into the 1.23 dm^3 explosion tube, and onto a continuous ignition source which is either a hot coil or a train of induction coil sparks. The pressure/time history of the resultant explosion is recorded and P_{max} and $(dP/dt)_{max}$ ascertained.

Bartknecht (1) has shown that the explosion rate constant, K, determined from a Hartmann measurement is generally 2-3 times lower than a corresponding measurement in a larger (^ Tm3) test apparatus. Furthermore, certain dusts, which are seemingly only mildly explosible when assessed using the Hartmann apparatus, may explode violently in a larger test apparatus. These results are summarised in Figure 2. This observation suggests that dust hazard assessment can only be meaningfully undertaken in large scale tests. A IITP test apparatus was proposed (6) for this purpose. Recently, it has been demonstrated that results, comparable with those obtained in large volumes, can be achieved in 20 dm3 (7) and 43 dm^3 (8) spherical explosion test apparatus.

The various alternatives to the standard Hartmann apparatus use a discrete pyrotechnic, or high energy spark ignition source, which is activated at a predetermined time interval after the activation of the dust dispersion system. In general, this ignition delay (t.) is chosen such that the explosion is ignited when the complete dust sample is effectively dispersed into the test vessel in the most turbulent condition for the particular dispersion methodology.

THE INFLUENCE OF IGNITION PROCEDURE

_:: THS HART:-IA?;>: TEST APPARATUS

The standard Hartmann test procedure uses a continuous rather than a discrete ignition source. Dust dispersion into the Hartmann explosion tube was filmed with a high speed cine camera. It was determined that the dust cloud reaches the ignition source some 60ms after activation of the solenoid valve, and that the dust is completely dispersed after 100ms. Cellulose dust explosion tests, which were undertaken with preset ignition delays and induction coil spark ignition (8), have demonstrated that this particular dust cannot be ignited with an induction coil spark, when ignition delays are less than 100ms. Furthermore, the measured explosion severity decreases with increasing ignition delay. It is interesting to note that an explosible concentration of cellulose dust is in the vicinity of the ignition source for some 40ms before effective ignition is achieved. The observed decrease in dust explosibility with increasing ignition delay is probably directly attributable to the corresponding decrease in turbulence at ignition.

The results of hot coil ignition standard Hartmann dust explosibility tests, which had been undertaken for industry over several years, were re-examined. The effective ignition delay for the most explosible concentration of each dust sample was estimated from the pressure/time records of the appropriate tests. Figure 3 shows a scatter diagram of the measured (dP/dt)   values of various dusts in relation to the estimated ignition delay. Extended ignition delays are in evidence for a significant percentage of the dusts tested, and it is probable that the reported Hartmann results for at least some of these dusts represent an underestimate of the potential explosibility of the material. The correspondence between Figure 3 and Bartknecht's results in Figure 2 is evident.

Further evidence of the influence of test procedure on the measured explosion severity of dust in the Hartmann tube was established in a series of experiments which compared measured explosibilities of a range of industrial dusts using two alternative ignition procedures:-

i) the standard continuous hot coil

ii) a discrete 100J* capacitive spark ignition source which was activated after a predetermined ignition delay (t) of 80ms.

* An induction coil spark from an auxiliary electrode located between the main spark gap was used to trigger the discharge of a 40uF capacitor across the 4mm gap.

The results of these tests are presented in Table 1. The ratio of the measured $(dP/dt)_{max}$ values:-

/-_ (dP/dt) max - spark ignition at t = 80ms
max - hot coil ignition

and the measured actual ignition delay of tests with hot coil ignition, are also tabulated.

Note that most dusts which have a measured ignition delay greater than the value of 80ms, which was arbitarily chosen for the discrete ignition source tests, have 6 values greater than unity. The interelation between the measured explosibility,& , and t (hot coil ignition) is shown in Figure 4. It is apparent that there is general correspondence between £ and t , and that the less explosible dusts are more likely to have longer ignition delays, and hence to be ignited in lower turbulence conditions. During these experiments it was established that certain granular dusts could not be effectively ignited with a 100J spark, even at long ignition delays, whereas they would explode with the hot coil ignition procedure.

THE INFLUENCE OF TURBULENCE

A 43 dm spherical explosion test apparatus is shown in Figure 5. A series of quiescent and turbulent gas explosion tests were carried out to evaluate the influence of turbulence on an explosibility measurement. To produce turbulent gas explosions the 43 dm3 sphere was,filled with an explosible gas concentration at NTP, and the 0.9 dm dispersion canister was charged with the same explosible mixture to a pressure of 1.64 MPa. The injection of the compressed explosible gas/air mixture, via the spray ring, into the 43 dm3 vessel produced a turbulent explosible mixture which was ignited centrally after a preset ignition delay, t . The shorter this ignition delay, the more severe was the explosion at ignition.

Comparable dust explosion tests were undertaken. A weighed dust sample was loaded into the 0.9 drrP dispersion canister. The canister was pressurised to 1.64 MPa with compressed air. Activation of the solenoid valve dispersed the dust into the explosion chamber and the explosion was ignited centrally after a predetermined ignition delay, t . The influence of ignition delay on the measured explosion severity of the most explosible concentration of fuel gases and of cellulose dust is shown in Figure 6. The measured explosion severity decreased with increasing ignition delay, which corresponds with the reduction in turbulence at ignition. Since effective dispersion of a dust sample in the 43 dm3 apparatus takes 2r 200ms the most explosible dust concentration is not attained at ignition for experiments in which an ignition delay of less than 200ms is used. For this reason, lower $(dP/dt)_{max}$ values are observed at t_v « 200ms with dusts,

Since a quiescent dust explosion is impractical the influence of turbulence can only be inferred by considering the ratio of test results at specific ignition delays. The results of tests on a range of dusts, and comparable data on turbulent flammable gases,

TABLE 1 - Comparison of Dust Explosibility Results in the Hartmann Apparatus Using Hot Coil and 100J Spark Ignition,

DUST SAMPLE	t_v (ms) Hot Coil ign.	$(dP/dt)_{max}$ (MPa s^{-1}) Hot Coil ign.	100J Spark ign. *	S
Sodium Stearate	163	11.5	20.4	1.77
Industrial Dust A	155	1.5	4.9	3.27
Industrial Dust B	132	4.0	6.7	1.68
Soya Flour	110	2.8	4.2	1.50
Cornflour	85	22.7	18.9	0.83
Benzene Sulphonamide	83	7.9	8.5	1.07
Maize Starch	81	30.8	28.5	0.92
Cellulose	78	33.6	36.6	1.09
Saccharin	69	19.2	13.6	0.71
Pharmaceutical Dust A	68	19.7	12.1	0.61
Pharmaceutical Dust B	63	13.8	8.2	0.59
Stearic Acid	58	32.2	18.2	0.56
Industrial Dust C	50	31.6	24.2	0.77
Sulphur	45	21.2	11.5	0.54

Ignition delay for 100J Spark Ign. = 80ms.

TABLE 2 - Turbulent Dust and Gas Explosibjlity Measurements in "43 dm^ Spherical Apparatus at Defined Ignition Delays.

EXPLOSIBLE FUEL	$(t_v = 265)$ max (MPa -1	$(t = 210)$ max / $(t = 265)$ max	$(t_v = 320)$ max /dP\ dt /max / $(t_v = 265)$
DUST			
Cellulose	35	1.18	0.77
Magnesium Stearate	67	1.16	0.69
Pharmaceutical Product	30.2	1.14	0.79
Phenolic Resin	56.4	1.06	0.55
Gum Arabic	25.7	1.31	0.62
GAS			
9 Vol % CH_4	123	1.17	0.77
14 Vol % 70/30 CH_4/H_2	143	1.18	0.76

are summarised in Table 2. It is evident that the resultant explosibility ratios are fairly similar, although the range of (dP/dt) values varies from 27 to 143 MPa s-1. Furthermore, a reasonable correspondence between gas and dust explosibility test results is evident. These results suggest that:-

i) the influence of turbulence on dust explosibility is, to a first approximation, independent of the absolute explosibility of the material.

ii) absolute turbulence of a particular dust dispersion procedure may be estimated by comparable explosion **tests** **with** quiescent and turbulent gas, where the turbulence level is defined as the ratio:

$$\frac{(dP/dt)_{max} \text{ - turbulent}}{(dP/dt)_{max} \text{ - quiescent}}$$

Nagy (9) has shown experimentally and theoretically that both P and (dP/dt) measurements are proportional to the initial presl-ure, P . To quantify the influence of turbulence using comparable gas explosion test procedures, a turbulence factor,«C, must be defined:~

$$\alpha = \frac{(dP/dt)_{max} \times 1/P_o \text{ - Turbulent conditions}}{(dP/dt)_{max} \ 1/P_o \text{ - Quiescent conditions}}$$

Limited data for the Tm and 43 dm test procedures are summarised in Figure 7. It is apparent that at the standard ignition delay-times of 265 and 600ms for the test procedures used in **the** 43 dm and lm3 vessels respectively, similar levels of turbulence prevail.

To account for turbulence differences which occur, the cube law should be restated as:-

$$(dP/dt)_{max} \,.\, V^{*} = U \,.\, Kq$$

where Kq is the explosion rate constant specific to the fuel in a quiescent state (a theoretical parameter) and od is the turbulence level corresponding to the test condition or the industrial environment.

HAZARD ASSESSMENT

Explosion hazard quantification of combustible dusts, and of flammable gases, in industrial applications is a pre-requisite to the design of suitable explosion countermeasures. The severity of the hazard is dependent on the conditions prevailing in normal and abnormal working within the industrial plant. In particular turbulence and air flow levels within a plant processing segment can have a major influence on the resultant explosion-severity. In standard test equipment, such as the Bartknecht lm apparatus, a specific turbulence level for dust explosibility measurement is employed. Such an explosibility determination may represent an underestimate, or an overestimate, of the explosion severity likely in an industrial application. Hence an explosibility determination gives a measure of the relative explosiveness of the combustible material dispersed as a cloud in air, but does not quantify the actual hazard per se.

One philosophy of safety is to seek to determine the severest explosion experimentally possible with a particular material under the harshest experimental conditions, and to accept this determination as an estimate.of the actual risk. In practice, this would preclude the application of conventional explosion protection measures for many of the commonly encountered explosible materials, because the risk would be assessed as 'too severe'. Plant designers would be required to seek alternative safety measures, for example, rigid plant construction such that the plant can withstand the maximum explosion pressure. This philosophy, therefore, imposes a severe economic burden on the plant operator.

An alternative philosophy is to quantify the severest explosion possible under both normal and abnormal plant operating conditions, and to estimate the severity of the hazard based on an experimental determination which represents the worst case limit for the particular application. For example a dust dispersion methodology which rapidly injects dust into an explosion chamber through multiple small nozzels or through spray rings is considered to represent the severest level of turbulence generally encountered (turbulence factor as 4.5). This procedure is representative of the explosion hazard associated with micronizers and grinders. The severest explosion risk associated with most silos, however, is more meaningfully represented by a dust dispersion methodology which thrusts dust into the explosion chamber through large diameter spray nozzels using a pressure differential in excess of 1 MPa (turbulence factor & 3.0). Explosion protection measures would be designed for each application, based on such a meaningful estimate of the risk. The designed explosion protection system, itself, would be based on experimental tests, and.include safety factors. The effectiveness of explosion protection by both venting and suppression applied in accordance with this philosophy has been proven over 2 5 years of operational history.

CONCLUSIONS

The accepted experimental procedure using the Hartmann test apparatus to determine dust explosibility data is a major cause of the-disparity between Hartmann and large volume test apparatus results. The Hartmann procedure uses continuous, rather than discrete ignition sources, and hence the dispersed dust cloud homogeneity and turbulence at ignition are not constant for each experiment. The longer the delay between dust dispersion and ignition, the lower will be the dust cloud turbulence at ignition. Dusts which are insensitive to ignition tend to exhibit long ignition delays in the Hartmann test, and therefore explode when the dust cloud turbulence is lower. In consequence, the measured $(dP/dt)_m$ values represent an underestimate of the explosibility of such Susts, when compared to explosibility results of dusts which are sensitive to ignition. In conclusion, the measured explosibility of a dust in the Hartmann apparatus using the standard test methodology is dependent on the ignition sensitivity of the dust sample. The use of an alternative test methodology which is based on a 100J capacitive spark discrete ignition procedure has been shown to resolve this problem.

The problem of turbulence within the context of hazard assessment has been discussed. Limited experimental evidence suggests that the influence of turbulence on dust explosibility can be inferred by referring to comparable turbulent gas explosibility data. The inclusion of a turbulence factor c£ in the cube law relationship is suggested:-

(dP/dt)max • ^ = o^.Kq

The recognition of the difficulties of explosion hazard assessment enables explosion protection measures to be more accurately tailored to the requirement of each specific application. It is now the practice (10) to design explosion suppression systems which cater for a more meaningful estimate of the hazard, than that afforded by the use of unreliable explosibility data, and to take account of the different turbulence levels that prevail in industrial processing.

ACKNOWLEDGEMENT

The author is indebted to Graviner Ltd for their support of this experimental work, and for their kind permission to publish the results.

SYMBOLS USED

initial pressure (MPa)

maximum explosion pressure (MPa)

dP/dt maximum rate of pressure rise (MPa s)

container volume (m)

explosion rate constant (MPa m s)

explosion rate constant for quiescent explosible mixture (MPa m s^{-1})

ignition delay time (ms)

explosibility ratio; spark ignition : hot coil ignition

oi turbulence factor

REFERENCES

1. Bartknecht, W. , 1971, Staub-Reinhalt Luft,., 31, (3), 28.

2. Bartknecht, W., 1978, Explosionen Ablauf und Schutzmassnahmen, Springer Verlag, Berlin.

3. Maisey, H.R., 1965, Chem. Process Engn., October, 527.

4. Bartknecht, W., 1971, Forshunqsbericht F45, Bundesinstitut fur Arbeitsschutz.

5. Raftery, M.M., (Revised by P. Field, 1974), Fire Research Station Technical Paper No. 21.

6. Beck, H.A.J., 1976, Staub-Reinhalt Luft, 36, (1), 49.

7. Bartknecht, W., 1978, VDI-Berichte,; 34, 47.

8. Moore, P.E., 19 79, Chem. Ind. (London), 430.

9. Nagy, J.,, 1971, US Bur. Mines RI 7507.

10. Moore, .P.E., 1979, Phys. Technol., 10, 202.

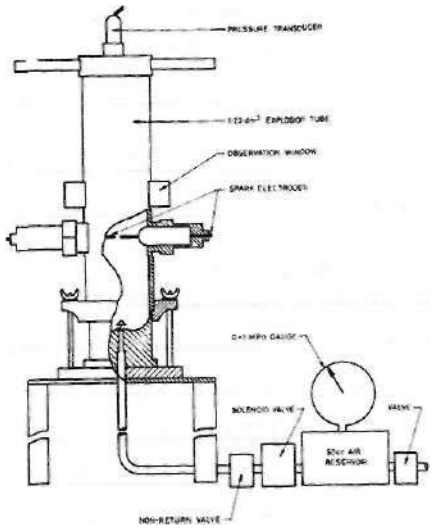

Figure 1 Hartmann vertical tube apparatus.

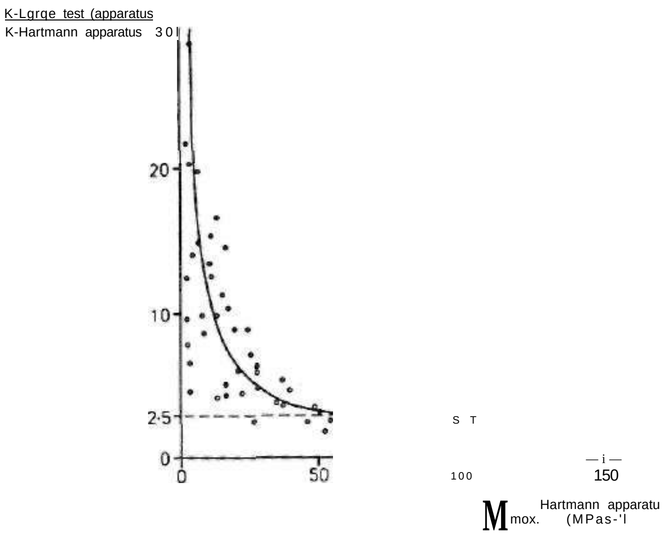

Figure 2 Comparison of Hartmann and large volume dust explosibility data - reference 1.

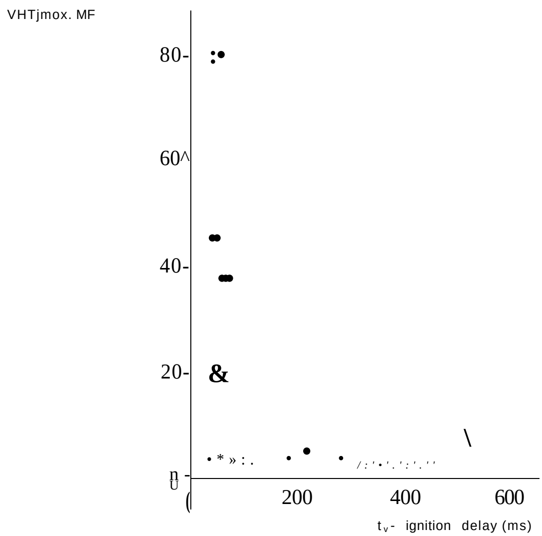

Figure 3 Relation between (dP/dt) and measured ignition delay in Hartmann tube using hot coil ignition.

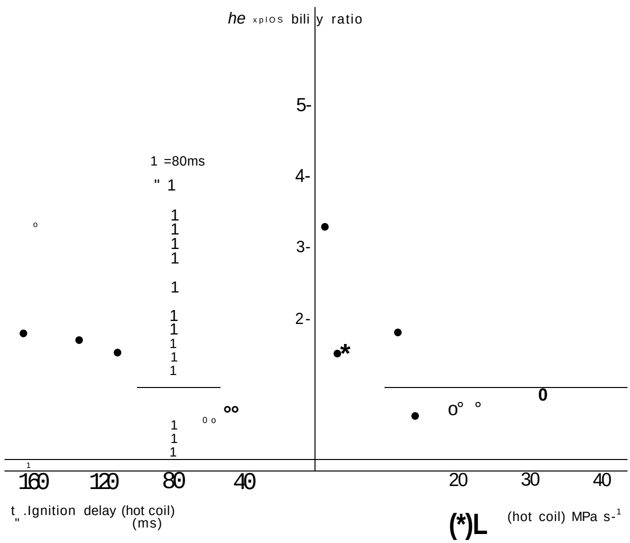

Figure 4 Comparison of dust explosibility results measured in Hartmann tube using discrete and continuous ignition sources.

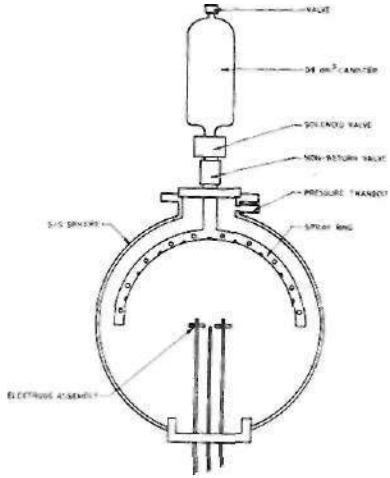

Figure 5 43 dm spherical apparatus.

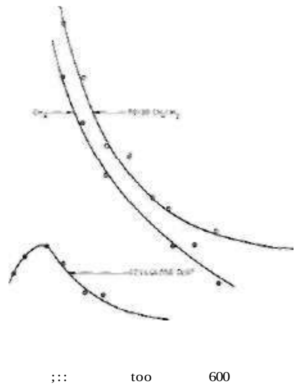

Figure 6 Influence of ignition delay in 43 dm3 apparatus.

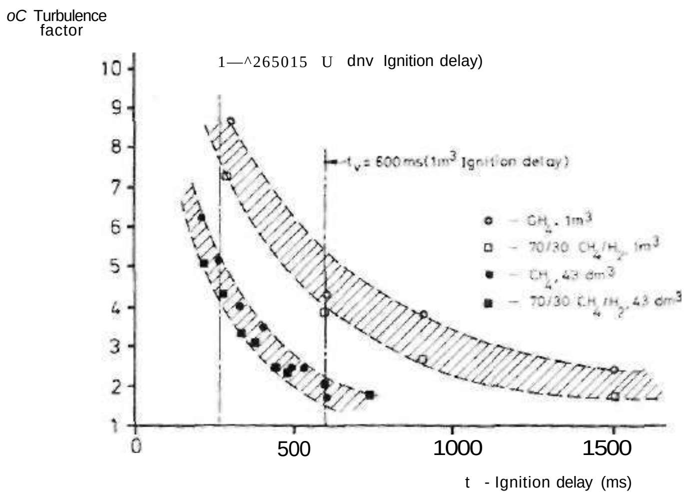

Figure 7 Relation between ignition delay and turbulence in lmf and 43 dm3 vessels.