USE OF INTRINSICALLY SAFE CIRCUITS AND ENCLOSURES TO CONTROL IGNITION RISK FROM EQUIPMENT IN POWDER HANDLING PLANT

D.J. Harper, K.E. Plain, J.S. Wilton,
Zeneca Ltd., Blackley, Manchester, U.K.
N. Gibson,
Burgoyne Consultants Ltd., Ilkley, LS29 9HU, West Yorkshire, U.K.

Electrical and mechanical equipment can present an ignition risk in the presence of flammable atmospheres. The control of the ignition risk in powder handling plants by the use of intrinsically safe circuits for electrical equipment and the use of enclosures for electrical and mechanical equipment is discussed. Guidance is given on the design and validation of equipment for it to be safe to use in the presence of powders.

INTRODUCTION

Equipment can present a potential ignition risk in the presence of flammable atmospheres. Explosion protection is achieved by preventing the occurrence of explosions or by ensuring that any internal explosion is not transmitted to a surrounding explosive atmosphere.

In the case of electrical equipment and installations, specifications exist that ensure safety for gases and vapours (1, 2, 3) and for dusts (4) when these are present alone in manufacturing plant. Problems arise however when gases / vapours and dust are present simultaneously.

Two methods in common use with gases and vapours to ensure safety are (1) intrinsically safe circuits and (2) flameproof enclosures. In the case of dusts, enclosures are used that are specified as dust tight (IP6X) or dust protected (IP5X). The use of apparatus complying with gas / vapour requirements (1, 2) in the presence of combustible powders is considered in B.S. 7535 (5). It is stated that intrinsically safe apparatus should have enclosures providing a degree of protection of at least IP5X in Zone Y (Zone 22) and at least IP6X in Zone Z (Zones 20, 21). In circumstances where the BS-EN50020 (intrinsically safe apparatus) does not have an IP5X or an IP6X enclosure it is recommended that an assessment of suitability should be carried out by examination and, where necessary, testing, to show that the required integrity of the intrinsically safe circuit is maintained in the presence of dust.

When gas / vapour safety is based on flameproof enclosures, B.S. 7535 requires that, in the presence of combustible dusts, the enclosure should also satisfies the requirement of IP6X in Zone Z and IP5X in Zone Y. This approach can present difficulties, e.g. on the introduction of dusts into existing plant where equipment suitable for vapours alone is already installed. In addition commercially available equipment that meets the combined requirements is limited.

No corresponding standards exist for mechanical equipment. The European Directive No.

94/9EC (The ATEX Directive) is a "New Approach" Article 100A Directive dealing with the design and construction of equipment and protective systems intended for use in potentially explosive atmospheres. It encompasses electrical and non-electrical equipment. CENELEC committee CENTC/305 has been mandated to write standards to implement the new directive for non-electrical equipment. An important part of this work is the consideration of the enclosure design appropriate to mechanical equipment.

The purpose of this investigation was two fold.

(A) to assess the possibility of applying to powders the intrinsically safe circuit concepts and tests developed for gases / vapours.

(B) to assess the ability of flameproof equipment to prevent powder combustion propagating through gaps in the enclosure and to obtain data to provide guidance on safe enclosure gaps required for mechanical equipment.

(A) USE OF INTRINSICALLY SAFE CIRCUITS TO CONTROL IGNITION OF POWDERS

For a circuit to be regarded as intrinsically safe it should satisfy the following conditions:-

(1) discrete discharges ("sparks") must not be produced in normal or maloperation (e.g. by component or connection failure) that can ignite the flammable dust.

(2) continuous or quasi continuous discharges ("currents") must not be produced in normal or maloperation that can ignite the flammable dust.

Assessment of Risk from Discrete Discharges (Sparks)

The incendivity of a spark discharge in dust clouds is traditionally assessed by comparing the total energy in the spark with the minimum spark energy required to ignite the flammable dust. The latter is determined by passing sparks of different energy from a capacitative circuit through the dust and noting the minimum energy required for ignition (6). Typical data are shown in Figure 1. These indicate that 10-15% of organic dusts can be as sensitive to ignition by sparks as are flammable solvent vapours.

These data may not, however, represent the sensitivity of the material to ignition by discharges from electrical equipment. The total energy in a discharge is not uniquely related to its igniting power. The igniting power of a discharge not only depends on its total energy but also upon the distribution of this energy with respect to space and time. Discharges in electrical equipment may originate from components with significant inductance and resistance in addition to capacitance. In general the discharges from such components have a longer duration than those from predominantly capacitative sources and less total energy may be required to ignite the dust. Results reported by Eckoff (7) indicate that energies of one tenth of the capacitative minimum ignition energy may be sufficient to cause ignition if the optimum combination of capacitance, inductance resistance is used in the discharge circuit.

The incendivity of sparks and the safety of electrical equipment in which they may be produced can be assessed using the concept of minimum ignition energy, but the traditional capacitative test circuit needs to be modified to incorporate the capacitance, inductance and resistance values that are present in the equipment under consideration.

Assessment of Risk from Discharge Currents

Flammable dusts can be ignited by the interuption or the starting of current flow ("Make and break sparking"). Little information for dust clouds is available on the incendivity of these discharge "currents" or arcs. The minimum igniting currents of dust clouds have, therefore, been determined using the equipment specified in BS-EN50020(1) for gases and vapours modified to produce discharges in a dust cloud.

Equipment and experimental procedure

The equipment is shown schematically in Fig. 2. The standard sparking disc and wires are in a glass tube and approximately 5 cm above the cup of a Hartmann dispersion system (6). Powder, placed in the cup, is dispersed by a blast of air to form a dust cloud in the glass tube.

Prior to dust testing the equipment was checked with methane-air flammable atmospheres using the resistive and inductive circuits prescribed in the procedure for gases and vapour. The results shown in Figures 3 and 4 confirm that the equipment gave data in agreement with the B.S. calibration curves for methane.

Approximately 5g of the dust under test was placed in the dispersion cup and the air reservoir pressurised to 8 bar.g. The break flash apparatus was placed over the cup, the drive motor started to check the spark production and a cloud was then formed in the tube. The concentration of this cloud increased to a maximum and then decreased as the dust was blown up the tube and then fell back into the dispersion cup. As the dust cloud died away the solenoid valve was opened again to produce a new cloud. Thus, an almost continuous cloud was formed in the tube with concentrations that passed through the flammable range. The dust cloud is not of constant, uniform concentration throughout the dispersion cycle but this technique is that recommended for the determination of spark ignition energies of dust clouds (6). After about 20 revolutions (80 sparks) of the break flash equipment most of the dust had coated the tube walls, the break spark wires and rotor. At this stage, or when an ignition had occurred, the current and rotor were switched off and the apparatus cleaned, replenished with dust and the test restarted. The number of revolutions of the rotor, the number of dust dispersions, the circuit current and the number of ignitions were noted.

Test samples and experimental results

Ten dusts were examined in this study. They were chosen because of their low minimum spark ignition energies when measured with the conventional capacitative spark and/or their low dust cloud ignition temperatures - see Table 1. Before testing the dusts were dried to constant weight and passed through a 75 micron sieve. They are representative of the more sensitive powders used generally in the chemical industry.

The ignition data are shown in Tables 2 and 3. Sulphur was studied in more detail because it had a minimum igniting current less than that of methane. Data for a resistive circuit at 24V are given in Table 3. Results for different voltages and for the inductive circuit at shown in Figures 5 and 6.

Discussion

The minimum igniting currents for all the dusts tested, except sulphur, were greater than the corresponding values for methane. The minimum igniting current - circuit voltage relationship for sulphur (Fig. 5) follows the data for Group IIB Gas (7.8% Ethylene) over the voltage range 24-50V and then moves to cross the Group IIA (5.25% Propane) and Group I (8.3% Methane) data at higher voltages. With an inductive circuit (1.3mH) at 24V the minimum igniting current is between the Group IIA and Group IIB data.

It should be noted that the data referring to one ignition per 400 revolutions are not directly comparable with those obtained for gas atmospheres. In the latter case the gas concentration remains constant whereas the dust concentration was continuously varying during the 400 revolutions and discharges did not always occur in the most sensitive dust air mixture. The production of a uniform dust cloud of known concentration throughout the test sequence is not possible because of dust settling. Consequently values in the ideal situation may be less than those quoted in Tables 2 and 3.

The data indicate that intrinsically safe electrical equipment certified as safe for use for a flammable Group I gas may present an ignition risk in the presence of dust clouds with ignition sensitivities akin to that of sulphur. However sulphur is atypical of the majority of dusts processed in the fine chemical industry in that its Godbert Greenwald Furnace Ignition Temperature of 220-240°C is significantly less than that of the majority of powders (Figure 7). The other test samples have Furnace Ignition Temperatures more typical of chemical industry powders. Their minimum igniting currents were 1.5A or above for the capacitative circuit and greater than 1.0A for the inductive circuit. This indicates that circuits certified as intrinsically safe for gas / vapour should not present an ignition risk for all but the most ignition sensitive dust clouds provided the current does not cause ohmic heating of layers that produces burning material.

(B) USE OF ENCLOSURES TO CONTROL IGNITION OF POWDERS

In powder handling plants, enclosures for electrical equipment are required to prevent the entry of amounts of dust that:

(a) could interfere with the satisfactory operation of the enclosed apparatus.

(b) could, in weak plant, produce an internal dust cloud which, if ignited by arcs or sparks, could cause an internal explosion.

(c) could produce localised dust deposits which, if ignited by arcs or sparks, or hot surfaces could propagate combustion externally via dust deposits on flanges, etc., and be a potential source of ignition of external flammable materials.

These requirements are met by the use of IP6X (dust tight) or IP5X (dust protected) enclosures (4). To satisfy the requirements of the IP6X specification stringent control of flange gaps and of the sealing at spindles, shafts, etc. is required. The specification for IP5X enclosures is less exacting. They are intended to protect against harmful internal deposits of dust but some ingress of dust can occur. Flameproof enclosures for use in gas / vapour situations do not prevent the entry of the flammable atmosphere but the flanges and gaps are designed to quench any flame originating from an ignition inside the enclosure and prevent it from igniting an external flammable atmosphere. In B.S. 7535(5) it is considered that flameproof equipment may be used in mixed vapour / gas / powder environments provided the degree of protection by the enclosure is also IP6X (Zone Z) or IP5X (Zone Y). All flameproof equipment does not meet the IP6X or IP5X requirements. A problem can arise in existing plants when powders are introduced into the plant that has hitherto been processing only gas / vapours and the electrical safety is based on use of flameproof equipment.

In the case of mechanical equipment the likelihood of powder ingress interfering with the operation of the equipment is less than in the case of electrical equipment. For most equipment the dominant factor influencing the enclosure design is the need to prevent combustion propagating through the enclosure gaps.

To ensure safety the enclosure gap must (a) prevent the transmission of a dust explosion through it and (b) prevent the propagation of combustion (smouldering or flame) of powder through it. The risk of explosion transmission can be assessed by determination of the Maximum Experimental Safe Gap (MESG). This is defined as the largest width of a slot that will just prevent transmission of flame in a dust cloud inside an enclosure to a dust cloud outside it. Jarosinski et al (10) obtained an MESG of 1.5 - 2.2mm for maize starch. Schuber (10,11) has investigated the influence of various parameters on MESG and obtained a linear relationship between MESG and the group (M.I.E. X (Ign. Temp + 273))/273. For gaps of length 15mm and 50mm the MESG for organic dusts and coals ranged from 1mm to 6mm.

Work published to date has not considered combustion via powder in or around the gap. This is the subject of this study. The data will assist in the development of gap specifications for electrical and mechanical equipment and prevent too stringent requirements being placed on them.

A study of the propagation of combustion through gaps requires consideration of (1) the burning properties of powders, (2) the geometry of the gap, (3) the temperature of the gap surfaces, (4) the distribution of dust within the gap and (5) air flow in the gap.

Burning Properties of Powders / Details of Test Samples

The combustion mechanisms involved in the burning of dusts are complex, vary from dust to dust and are not yet fully understood.

Factors important to propagation through gaps are:-

(1) the stages of ignition - for many dusts the ignition sequence would appear to contain three stages namely : increase in temperature of the solid, evolution of flammable gases and ignition of the gases.

(2) the form of the combustion zone - materials can be realistically be divided into two types - a combustion zone that remains in the solid phase or a situation in which the material melts ahead of the combustion zone to form a burning pool of liquid.

In the assessment of general fire risks dusts are characterised in the Train Firing or Flammable Solids Tests (8,9). Essentially a layer or train of dust (10cm long, 2cm wide, 2cm deep) is placed on a thermal insulating base and ignited at one end with a flame. The nature of the combustion (smouldering or flame) and the rate of combustion propagation is used to characterise the fire properties of the material. The Train Firing Properties of the seven powders selected to cover the range of combustion types are summarised in Table 4. Samples 1, 2 and 3 typify materials that appear to burn directly from the solid phase. Material 3 burns with flame whilst the other two propagate by smouldering. In the case of samples 4, 5 and 6 the dust layer melts when exposed to the flame ignition source and subsequently has the appearance of a burning liquid. Sulphur is to some extent an atypical material in that it tends to form globules of liquid rather than a liquid layer when exposed to the flame. Sample 7 is representative of a small number of dusts that burn with large amounts of flame. On application of the ignition source the material melts but the subsequent combustion and flame tends to obscure the combustion front once it has become established. An important feature of the combustion is the evolution of large amounts of flammable gas when the material is subjected to heat.

Experimental Procedure

The test equipment used is shown schematically in Figure 8. It consisted of a 130mm diameter metal hot plate above which could be placed a metal bar of rectangular cross-section 20mm x 3.2mm, the latter being the distance the combustion had to propagate to pass through the gap. The minimum gap width in electrical equipment depends on the type of equipment but it was considered that the distance 3.2mm though quite small was not too unrepresentative of the width of a narrow flange joint of the distance between the inside and outside of an enclosure where such components as rotating spindles and shafts pass through the enclosure. This probably represents a minimum distance, it was used because with distances greater than this propagation is less likely to occur. Initial trials showed that dust did not readily propagate combustion through 1mm high gaps. A plate separation of 2.5mm was therefore also used. Such gaps would probably not be permitted in electrical enclosures because the amount of dust ingress could interfere with the normal operation of the equipment. They could be present however in mechanical equipment. The length of the gap was 100mm; this value was chosen to avoid "end effects" from the bar supports and permit a number of different powder patterns to be used. This choice is arbitrary but not an unreasonable one.

It is known that heat losses to the surrounding metal influence the propagation of flame from burning gases and vapours through gaps in electrical equipment. Therefore tests have been carried out at elevated temperatures. Exposure to high temperatures can have a more complex effect on dusts than is the case with gases and vapours. A significant number of dusts decompose when exposed to temperatures in the range 100 - 200°C. To prevent the test temperature inducing decomposition the maximum temperatures were limited to 90 - 140°C.

The amount and distribution of powder within the gap determines not only the amount of fuel but also the amount of oxygen available to support combustion. The five powder patterns, shown schematically in Figure 9, were used to simulate a range of possible plant conditions. In patterns A and B the dust completely filled the gap. A layer of dust was placed on the base plate and then the bar place in position. This produced a certain amount of compression of the dust but no other attempt was made to positively compact the dust. Patterns C and E simulate dust contamination in which air is present in the gap; in the former the air layer was above the powder and in the latter it was between ridges of powder. In form D no powder was present in the gap and this simulates the condition where, for propagation, the combustion must bridge a distance where no dust fuel is present.

Results and Discussion

The results are shown in Table 5. In all tests no propagation occurred with a 1mm wide gap at either 25°C or 140°C. Two of the materials, sulphur and an inorganic pigment propagated combustion at 25°C with a 2.5mm gap and the pharmaceutical powder could propagate through the 2.5mm gap if the temperature was raised to 140°C and the gap was clear of powder. The last result was due to the powder evolving flammable gases which filled the gap and permitted the passage of a flame which ignited the powder on the other side. In this situation a flameproof enclosure would be required to stop propagation.

The results tend to show that propagation required air in the gap. Blockage of the gap ahead of the combustion front may well be responsible for the non-propagation of combustion in many of the tests. The propagation of burning will, as in the case of gases and vapours, tend to be inhibited or prevented by heat losses to the surrounding metal that reduce the temperature of the material to below that at which it will continue to support combustion. However, in the case of dusts a second factor, not present in the combustion of gases or vapours, is the change in physical form that can occur when the material decomposes. This change can be divided into two general classes; (a) a change from the solid to the liquid state as the material melts, or (b) a change in the solid form in which the individual particles tend to agglomerate and/or expand to produce a more extended mass of solid material. In both cases, the change tends to block the gap. If it occurs at temperatures below that in the combustion region then such a change and blockage could be produced ahead of the combustion front and this would tend to inhibit or prevent propagation.

In all situations examined, combustion did not propagate through the 1mm gap but propagation through the 2.5mm gap occurred with a number of powder types. This indicates that flameproof equipment should prevent combustion of powder from inside to outside the enclosure and vice-versa.

However, one other situation needs consideration. It is just conceivable that powder present in the gap has already started to burn when an explosion occurs inside the equipment. The force of the explosion could push the powder through the gap and give an ignition risk outside. The work of Silver (13) can be used to assess this ignition risk. It gives the relationship between the particle diameter and the temperature needed to produce the ignition of flammable atmosphere (methane is used which, for hot particle ignition, can be considered as more sensitive than dust clouds). An example of the results is that a 2mm diameter particle needs to be at 1150°C. The maximum size of the particles blown through the gap will be the height of the gap, e.g. 2mm. Therefore, the minimum temperature required for ignition is 1150°C. This is above the burning temperature of particles of almost all organic dusts, though not of reactive metals. Consequently where the gap is small enough to prevent the direct propagation of an explosion (e.g. 1.5-2mm for maize starch) and will stop the direct propagation of burning (<2mm for the powders examined here) then it will also be small enough to prevent the transfer of combustion by forced propagation.

In the development of enclosure specifications for non-electrical equipment, the specification of maximum permitted enclosure gap depth are likely to be in the region 1-2mm provided the gap width exceeds 3mm.

Conclusions

(A) Intrinsically Safe Circuits

A.1 Intrinsically safe circuits can, in principle, be used as a basis for the design of electrical equipment that will not present an ignition risk in the presence of flammable dust.

A.2 Certain dusts (e.g. sulphur) with low Dust Cloud Ignition Temperatures could have minimum igniting currents less than methane and equipment for Group I and Group IIA gases/vapours may not be inherently safe.

A.3 Provided ohmic heating is not present the design of intrinsically safe circuits for a dust will require a knowledge of:

(a) the minimum igniting current of the dust - the necessary data can be obtained using the established gas / vapour test modified to permit the use of a dust cloud.

(b) the minimum spark ignition energy - the necessary data can be obtained using a test circuit that includes the capacitance, inductance and resistance of the equipment under evaluation. Data from the traditional capacitative circuit is not applicable to discharges from many types of electrical equipment because they contain inductive and resistive elements.

(B) Enclosure Design

B.1 It is unlikely that combustion of powder will propagate through gaps of 1mm or less in depth and greater than 3mm wide but depending on the combustion characteristics of the dust, it may propagate through gaps of 2.5mm in depth.

B.2 Gaps designed to flameproof standards are unlikely to permit combustion to propagate from inside to outside an enclosure and vice-versa.

B.3 In the design of enclosures etc. for non-electrical equipment to be used with organic powders it is probably that control of combustion propagation will require gaps not to exceed 1-2mm in depth with a gap width greater than 3mm. Special consideration may be needed for metal powders.

References

(1) BS-550020 Electrical Apparatus for Potentially Explosive Atmospheres Parts 1-9.

(2) B.S. 6941 Specification for Electrical Apparatus for Explosive Atmospheres with Type of Protection N.

(3) B.S. 5345 Selection, Installation and Maintenance of Electrical Apparatus for Use in Potentially Explosive Atmospheres.

(4) B.S. 6467 Electrical Apparatus with Protection by Enclosure for Use in the

Presence of Combustible Dusts.

(5) B.S. 7535 Electrical Apparatus Complying with B.S. 5501 or B.S. 6941 in the *Presence of Combustible Dusts.*

(6) B.S. 5958 Control of Undesirable Static Electricity Part 1.

(7) R. Eckoff "Dust Explosions in the Process Industries" Butterworth - Heinemann U.K.(1991).

(8) J. Abbott "Prevention of Fires and Explosions in Dryers". 2nd Edition The Institute of Chemical Engineers (1990).

(9) Manual of Tests and Criteria: Recommendations on the Transport of Dangerous Goods. ST/SG/AC. 10/11 Rev. 2. United Nations (1995). ISBN 92-1-139049-4.

(10) J. Jarosinski, J.H.S. Lee, R. Kuystautus Archivum Combustions Vol. 7 p.267 (1987).

(11) G. Schuber Humanisierung des Arbeitslebens Vol. 72 VDI-Verlag Dusseldorf (1988).

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(13) R.S. Silver. Philos Mag. Ser. 7p.633 (1937).

TABLE 1: Dust Flammability Characteristics - Spark Ignition Tests

Powder	Dust Cloud Minimum Ignition Temperature (°C)	Dust Cloud Minimum Ignition Energy (mJ)
Sulphur	220 - 240	< 2.5
Methylol Stearimide	375 - 400	3 - 5
Anthraquinone	550 - 600	2.5 - 4
4 Hydroxy Benzaldehyde	550 - 600	< 2.5
Octyl Phenolic Resin	400 - 450	2.5 -4
Benzoic Acid	600 - 675	2.5 - 4
Irganox 1010	500 - 550	4 - 14
Propathene	450 - 500	2.5 - 4
p-Nitrophenol	500 - 550	2.0 - 2.5

TABLE 2: Minimum Igniting Currents for Flammable Dust Clouds and Methane

Sample	Minimum Igniting Current (A)	
	Resistive Circuit	Inductive Circuit
Methane	1.35	0.91
Sulphur	0.6 - 0.7	0.6 - 0.7
Methylol Stearimide	2.5 - 3.0	1.4 - 1.5
Anthraquinone	2.5 - 3.0	1.5 - 2.0
4 Hydroxy Benzaldehyde	1.5 - 2.0	1.0 - 1.5
Octyl Phenolic Resin	No ignition at 3.0A	1.5 - 2.0 after 118 revs at 1.5A
Benzoic Acid	1.5 - 2.0	1.0 - 1.25
p-Nitrobenzoic Acid	2.0 - 2.5	1.5 - 2.0
Irganox 1010	No ignition at 3.0A	1.5 - 2.0 after 116 revs
Propathene	No ignition at 3.0A	No ignition at 2.0A
p-Nitrophenol	2.0 - 2.5	1.0 - 1.5

TABLE 3: Example of Resistive Circuit Results for Sulphur

Current (A)	Resistance (ohms)	Inductance (μH)	Number of Revolutions	Number of Dispersions	Ignition
0.96	25.2	9.9	3	2	Yes
0.60	39.8	9.0	29	20	No
0.60	39.8	9.0	31	25	No
0.60	39.8	9.0	29	20	No
0.60	39.8	9.0	27	20	No
0.7	34.3	9.0	3	1	Yes
0.6	41.0	9.0	27	20	No
0.6	41.0	9.0	28	20	No
0.6	41.0	9.0	29	20	No
0.6	41.0	9.0	30	20	No
0.6	41.0	9.0	29	20	No
0.6	41.0	9.0	27	20	No
0.6	41.0	9.0	34	25	No
0.6	41.0	9.0	32	25	No
0.6	41.0	9.0	28	20	No
0.6	41.0	9.0	28	20	No
Self Capacitance 6.6pF Device Resistance 3.5			Self Inductance 2.8 μH Circuit Voltage 24V		

TABLE 4: Train Firing Properties of Test Samples

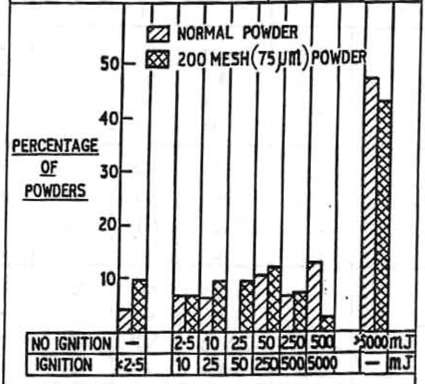
Sample	Material	Train Firing Properties
1	Silicon/ Lead Dioxide Mixture (2:1 w/w)	The application of a flame induces a vigorous exothermic reaction. The temperature reaches red to white heat but melting does not occur. The smouldering moves rapidly along the train of powder.
2	Pigment	A flame induces smouldering of the material. The smouldering moves moderately quickly along the train and is accompanied by small flashes or sparks from the combustion front.
3	Nitrobenzene Sulphonic Acid Sodium Salt	A flame induces smouldering of the material. The smouldering propagates quickly along the train and is accompanied by the occasional emission of small burning particles from the combustion front.
4	Rubber Additive A	A flame induces immediate rapid burning of the material with flame. The burning propagates quickly. No melting is visible.
5	Sulphur	A flame melts the powder into a viscous liquid, which ignites and burns with a very weak flame approximately 1cm high. The flames propagate slowly the train of powder.
6	Intermediate A	A flame melts the powder and ignites the liquid produced. This burns with a vigorous flame 4-8cm high. The burning propagates quickly down the train.
7	Rubber Additive B	A flame melts the powder, boils the liquid and causes ignition. The liquid burns quickly with a flame approximately 10cm high.
8	Intermediate B	A flame melts the powder and ignites the liquid which burns with intense flames propagates very quickly and vigorously along the train in sudden surges.

TABLE 5: Combustion Propagation Data

Material	*Gap* (mm)	*Temp.* (°C)	**Results**				
			Powder Pattern Type				
			A	**B**	**C**	**D**	**E**
1. Silicon/Lead Dioxide Mixture	1.0	20-25	P	P	NP	NP	P
	1.0	100	NT	NT	NP	NP	NT
	2.5	20-25	P	P	P	NP	P
	2.5	> 25	NT	NT	NT	NT	NT
2. Pigment	1.0	20-25	NP	NP	NP	NP	NP
	1.0	100	NP	NP	NP	NP	NP
	2.5	20-25	NP	NP	NP	NP	P
	2.5	> 25	NT	NT	NT	NT	NT
3. Nitrobenzene Sulphonic Acid Sodium Salt	1.0	20-25	NP	NP	NP	NP	NP
	1.0	100	NP	NP	NP	NP	NP
	2.5	20-25	NP	NP	NP	NP	NP
	2.5	100	NP	NP	NP	NP	NP
4. Rubber Additive A	1.0	20-25	NP	NP	NP	NP	NP
	1.0	140	NP	NP	NP	NP	NP
	2.5	20-25	NP	NP	NP	NP	NP
	2.5	140	P	P	P	P	P
5. Sulphur	1.0	20-25	NP	NP	NP	NP	NP
	1.0	100	NP	NP	NP	NP	NP
	2.5	20-25	NP	NP	P	NP	NP
		> 25	NT	NT	NT	NT	NT
6. Intermediate A	1.0	20-25	NP	NP	NP	NP	NP
	1.0	90	NP	NP	NP	NP	NP
	2.5	20-25	NP	NP	NP	NP	NP
	2.5	90	NP	NP	NP	NP	NP
7. Rubber Additive B	1.0	20-25	NP	NP	NP	NP	NP
	1.0	90	NP	NP	NP	NP	NP
	2.5	20-25	NP	NP	NP	NP	NP
	2.5	90	NP	NP	NP	NP	NP
8. Intermediate B	1.0	20-25	NP	NP	NP	NP	NP
	1.0	140	NP	NP	NP	NP	NP
	2.5	20-25	NP	NP	NP	NP	NP
	2.5	140	NP	NP	NP	P	NP

Symbols:
P combustion propagated through gap
NP no propagation of combustion through gap
NT no test carried out

FLAMMABLE MATERIAL	TYPICAL M.I.E. VALUES(MILLIJOULES)
SENSITIVE DETONATOR EXPLOSIVES	0·001 —0·1
VAPOUR OXYGEN MIXTURES	0·002 —0·1
VAPOUR AIR MIXTURES	0·1 —1·0
CHEMICAL DUST CLOUDS	1 —5000



MINIMUM SPARK IGNITION ENERGY DATA

Figure 1

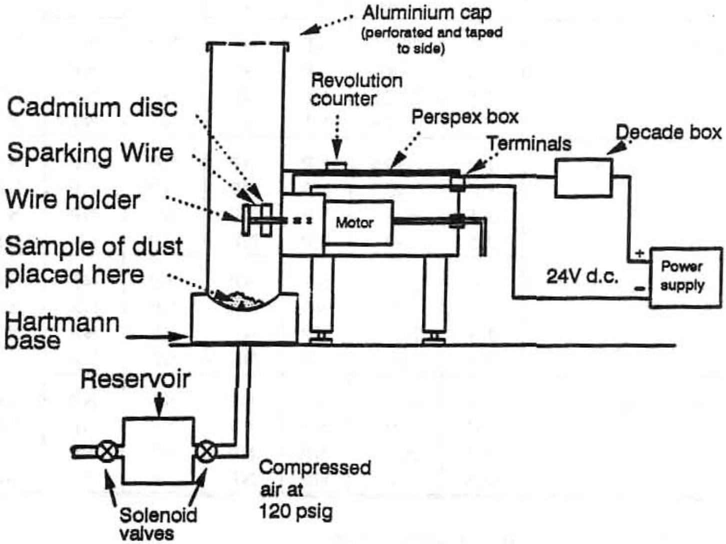


Figure 2 Diagram of the apparatus used for dust cloud ignitions by "make & break" sparking

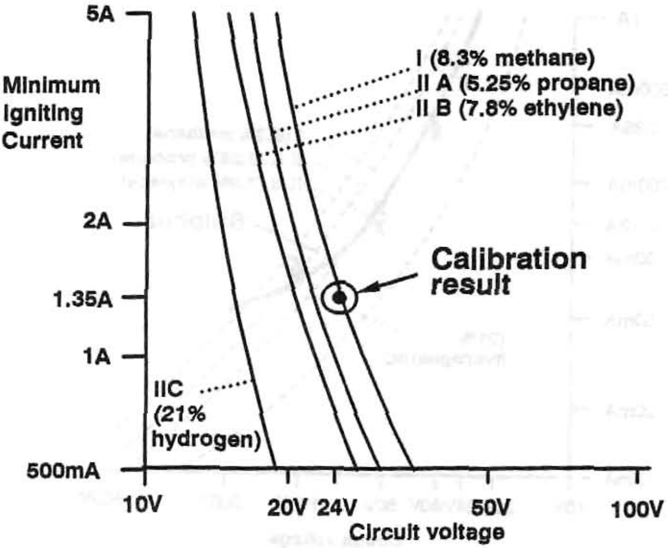


Fig 3 Methane Calibration - Resistive Circuit

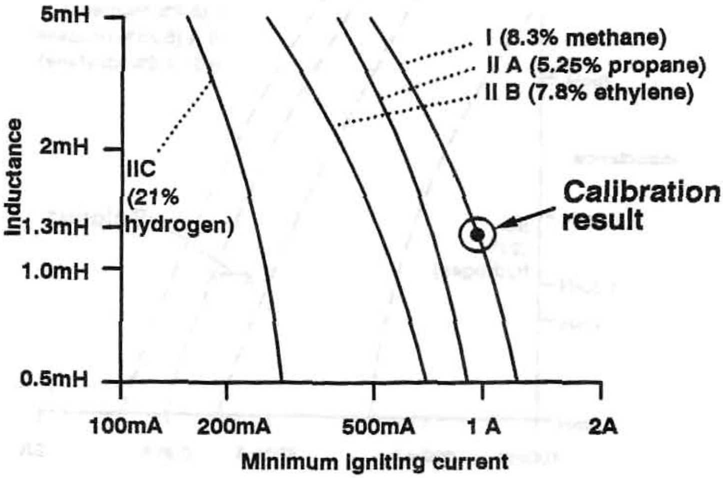


Fig 4 Methane Calibration - Inductive Circuit

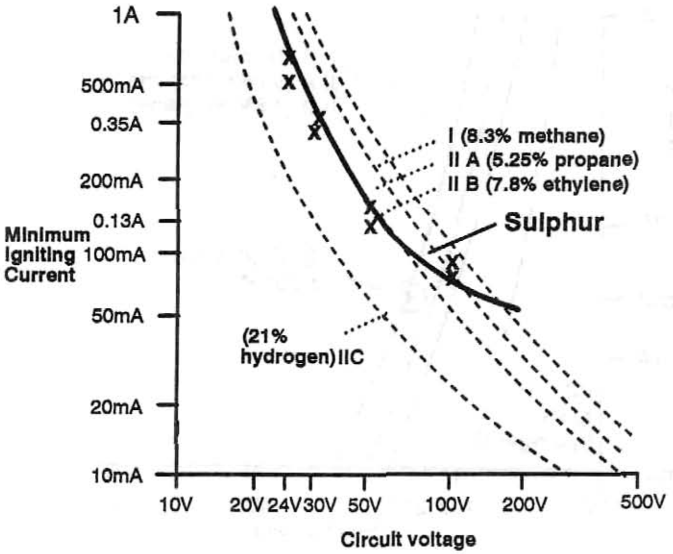


Fig 5 Comparison of sulphur clouds with gases - resistive circuit

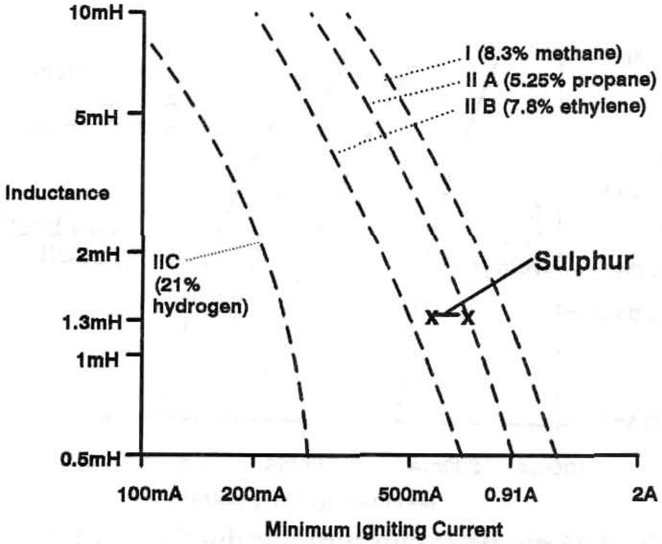


Fig 6 Sulphur - Inductive circuit (24 volts)

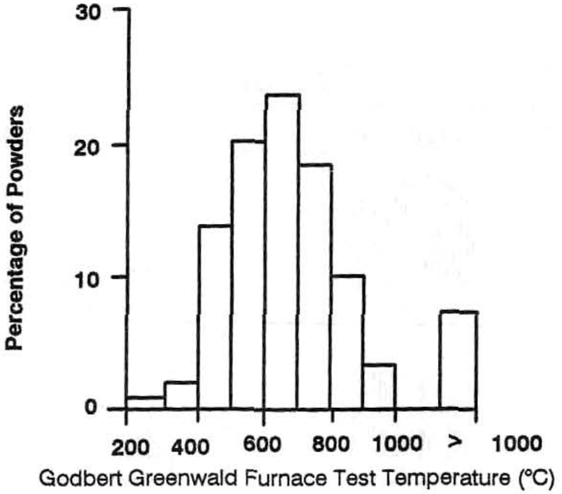


Fig. 7 Ignition Temperatures of Dust Clouds

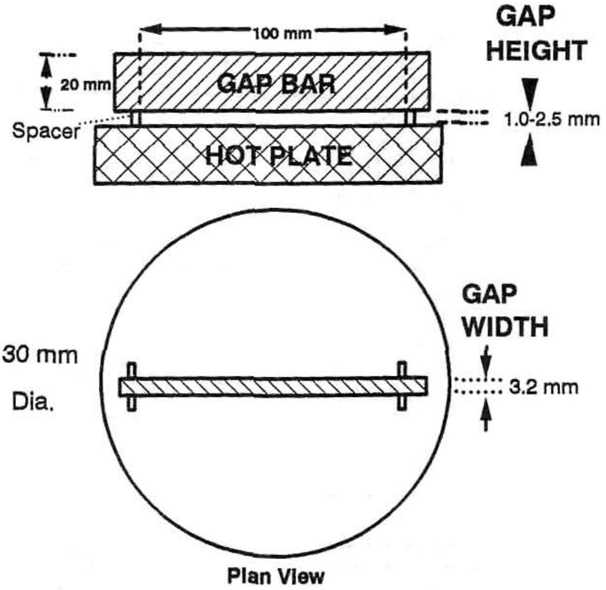


Fig. 8 Propagation of burning through gaps - schematic diagram of the test equipment

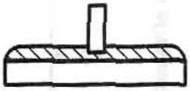
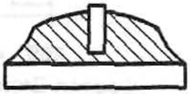
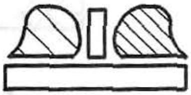
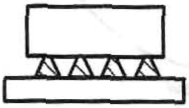
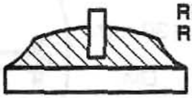
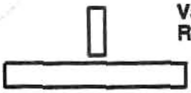
Pattern Reference	Powder Pattern	
	Plan View	Side View
A		
B		
C		
D		
E	 Front View 	 Ridge Region  Valley Region

Fig 9 Schematic diagrams of powder distributions