(Paper presented at the seminar "ATEX: Explained and Applied", organised by the Institution of Mechanical Engineers in London on 10 October 2002)

FLAMMABILITY CHARACTERISTICS OF POWDERS

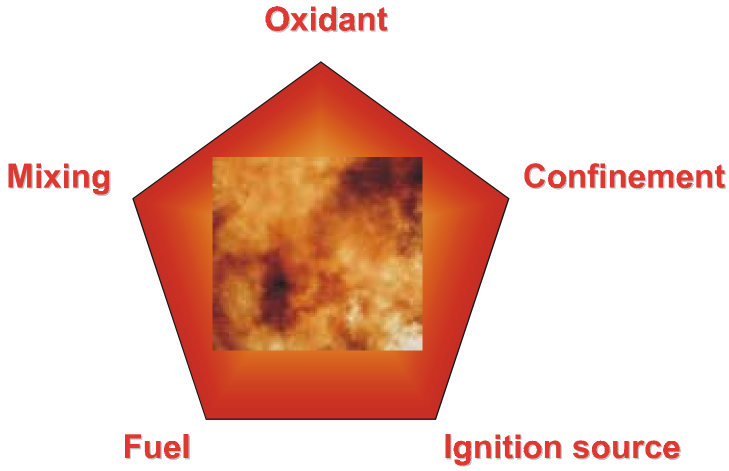
By Pieter Zeeuwen
Chilworth Technology Ltd, Beta House, Chilworth Science Park, Southampton, SO16 7NS, UK

1 INTRODUCTION

This paper presents a brief review of the flammability characteristics of powders and dusts and addresses some fundamentals of uncontrolled combustion phenomena.

For an explosion to occur within an enclosure, it is necessary for a minimum quantity of gas, vapour or finely divided powder to be dispersed into the atmosphere in the presence of a sufficiently powerful ignition source.

When ignition occurs, flame propagates through the gas, vapour or dust cloud, releasing energy into the gaseous products of combustion as heat. The heat generated by the passage of the flame front causes the products of combustion to expand or, if the expansion is constrained by an enclosure, pressure to be generated.



The Explosion Pentagon Showing the Factors Required for an Explosion

It is the release to atmosphere of the pressure generated during the combustion process that produces the phenomenon termed an explosion, that is, a sudden release of stored energy capable of producing pressure effects, blast waves or missiles. If the combustion process is not constrained, then it will simply result in a flash fire which, nevertheless, can cause severe burns to any personnel caught in its path.

The fire and explosion hazards associated with powders are generally less well understood than those associated with liquids and gases.

It will be clear from the above description that dust explosions are comparable in many respects to gas and vapour explosions. However, the fact that dust particles are much larger than gas and vapour molecules has implications for the course of an explosion and the flammability characteristics.

One important effect of the particulate nature of powders is that the surface area and surface structure (and often the moisture content) can vary widely from sample to sample, depending on how the powder was manufactured and handled. This means that it is virtually impossible to use flammability data published in literature for dusts, while that is quite acceptable for gases and vapours.

It has been estimated that most organic powders (circa 70%) are combustible. According to the circumstances under which the combustion process occurs, such powders may cause fires or dust explosions. Certain substances will also decompose rapidly on heating to produce large volumes of gas, even without an oxidising medium present.

2 PROPERTIES OF FLAMMABLE POWDERS

2.1 Flammability

The concept of flash point that is used to indicate flammability in vapours is not appropriate to dusts.

The flammability of dusts is defined on the basis of two tests:

- the vertical tube, and
- the Godbert - Greenwald (GG) furnace.

In the Vertical Tube test a dust cloud is formed at ambient temperature in the presence of a standard source of ignition by dispersing material by an air jet.

If ignition occurs, and the flame moves away from the source, the material is classified as Group A (flammable). If ignition does not occur the material is classified as Group B and is not considered flammable at ambient temperatures (i.e. up to 110 °C), although some can be ignited by very powerful ignition sources.

If a dust is handled at elevated temperatures it may be flammable, even if it was classified as Group B in the vertical tube test.

Dusts that are handled at elevated temperatures are tested in the GG Furnace. If spontaneous ignition occurs at furnace temperatures in excess of 800 °C the material is regarded as flammable. If ignition does not occur the material is considered not to be capable of forming flammable dust clouds under general plant conditions.

Group A/B Test

The ignitability of dust clouds is affected by the particle size of the dust. Where the particles exceed diameters of about 500 μm, flammable dust clouds will not be formed in general. Flammable gases/vapours will increase the flammability of a dust cloud, even at concentrations below the LEL.

Maximum ignitability occurs with particle sizes of 75 μm and smaller, and material of this fineness should always be used for tests.

2.2 Limits of Flammability

In the same way as gases and vapours, dusts in the form of a cloud are only ignitable over a range of concentrations.

In principle, the concepts of LEL and UEL are applicable to dust clouds, but only the LEL is of practical use. This is because of the inherent difficulties in achieving homogeneous dust clouds at high concentrations. For dusts the LEL is often called Minimum Explosible Concentration (MEC).

The MEC for most dusts is in the range 20 - 60 g/m^3; although some materials have values much higher than this, reaching 250 - 300 g/m^3. The presence of flammable gas/vapour in the dust air mixture (a "hybrid" mixture) will reduce the value of the MEC.

Temperature and pressure will influence the limits of flammability for dusts in a similar way to those for gases and vapours. However, it is of little practical significance as the UEL is not used, and the change in the small concentrations at the MEC usually will have little effect on the hazards.

2.3 "Auto-Ignition Temperature"

In dust flammability, two "auto-ignition temperatures" are recognised; for dust clouds and dust layers.

The minimum ignition temperature (MIT) or dust cloud ignition temperature is measured using the GG furnace mentioned above.

MIT Test

The layer ignition temperature (LIT) is measured by exposing a layer of material on hot plate, and noting the temperature at which smouldering or combustion occurs.

LIT Test

The LIT varies with the material being tested, and generally falls as the thickness of the layer increases. In Europe tests are usually carried out on 5 mm thick layers. The LIT should not be confused with the onset temperature for thermal decomposition that would apply for dust deposits in warm surroundings.

The ignition temperatures obtained from the tests can be influenced by the thermal prehistory of the material, so that it is important to ensure that the sample submitted for testing is representative.

2.4 Minimum Ignition Energy (MIE)

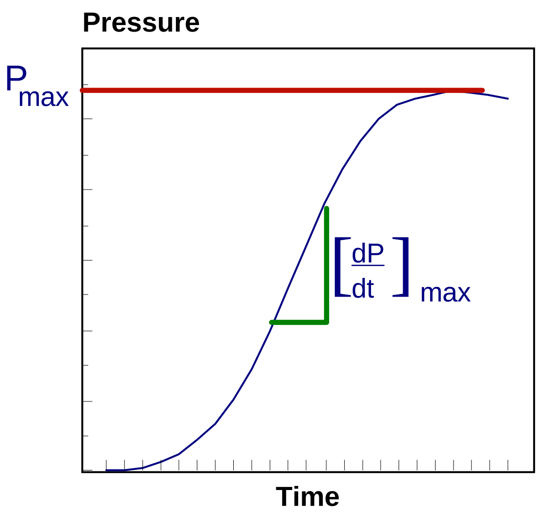
The minimum ignition energy is determined by passing sparks of known energy into dust clouds in an apparatus similar to the vertical tube. The smallest energy of spark that will ignite the most sensitive dust cloud is the minimum ignition energy for that material.

The MIE is reduced significantly at elevated temperatures and by the presence of flammable gas/vapour, even below the LEL.

Minimum ignition energies for dusts are not used in area classification, nor in the specification of apparatus. Their primary use is in the control of electrostatic hazards.

2.5 Explosion Severity

When a dust air mixture is exploded in a closed vessel, the pressure increases with time up to a maximum value, following a typical "S-curve", after which the pressure decreases due to cooling of the combustion gases.



Idealised Pressure – Time History of an Explosion in a Closed Vessel

The maximum pressure rise and rate of pressure rise for a given material are determined in a 1-m^3 vessel or, more commonly, a 20-litre sphere. The maximum explosion pressure, found for the optimum mixture composition, is independent of the vessel volume, although it depends on the initial temperature and is proportional to the (absolute) initial pressure. The maximum rate of pressure rise (dp/dt)max, however, depends on the volume and for convenience it is converted into an "explosion constant" using the so-called cubic law:

$$K_{st} = ((dp/dt)_{max}) \times V^{1/3}$$

The speed of the explosion, or K_{st} value, depends on the degree turbulence in the mixture. The standard test conditions are representative of industrial conditions, but do not represent an absolute worst case. Increased levels of turbulence increase the speed of the explosion dramatically.

20 Ltr Sphere

For convenience, dusts are often divided in dust explosion classes or St-classes.

2.6 Limiting Oxygen Concentration

When the oxygen concentration in the air is reduced, the reaction becomes slower, until at a limiting value, the Limiting Oxygen Concentration (LOC) no more self-sustained propagation of the flame occurs. The LOC is important when inerting is used as preventive measure. LOCs are usually measured in the same equipment and with similar procedures as used to determine the explosion severity.

The value of the LOC depends on the dust, but also on the initial pressure and temperature and on the inert gas used.

2.7 Powder Volume Resistivity and Charge Relaxation Time

The powder volume resistivity is a measure of the resistivity through the bulk of the powder and indicates the ability of the powder to retain charge. It is used to assess the likelihood of accumulating electrostatic charge on the bulk powder, especially when the MIE is low, say below 25 mJ.

For liquids, the charge relaxation time, i.e. the time for the charge level to decay to 1/e of the initial value, can be calculated when the liquid conductivity is known. For powders the calculation does not always give reliable answers, and the charge relaxation time is usually measured directly.

2.8 Burning Behaviour of Deposits

Dust layers and deposits can be ignited by a variety of ignition sources such as sparks, incandescent particles, hot surfaces etc. The burning behaviour in practice depends on many details such as the geometry of the deposit and the temperature, but it is useful to have an indication of the burning behaviour for the hazard assessment.

In the *Train Firing* test powder is placed in strip and ignited at one end. Depending on the result, a powder is classified as Highly Flammable Solid for transport classification (UN Class 4.1). The detailed results of the test can, however, also be used to assess whether the deposit did not ignite at all, smouldered only locally, or propagated the flame. A variation of this test (using shorter strips of powder) is used in Europe; the "burning number" or "combustibility class" is a number describing whether the reaction propagated and in what manner (smouldering, open flame, rapid flash).

2.9 Thermal Instability of Powders

A large number of organic and some inorganic powders decompose exothermically on heating, leading to product degradation and spontaneous combustion.

The critical temperature for handling and storage of such powders is not a fundamental property of the material and depends on the conditions.

For chemically unstable substances it is common to assess the thermal stability in small-scale tests such as Differential Scanning Calorimeters (DSC). For powders that react with the oxygen in the ambient air, such measurements can be very misleading, because the small sample in the closed test cell will rapidly use all available oxygen and the heat is lost to the environment.

More suitable test methods do adequately mimic the availability of oxygen in the plant, and the relevant test must be selected based on the plant or storage conditions:

- Where air is available around the powder and must diffuse into the bulk of the powder, the *Diffusion Cell Test* would be appropriate.
- Where air is blown through the powder, such as in fluid beds, the *Aerated Cell Test* is more suitable.
- Where air is blown over the powder, but not through it, the *Air Over Layer Test* is relevant.

For storage or handling or large scale, *Basket Tests* can be performed to enable extrapolation to the relevant scale (mass and surface area).

3 PROPERTIES OF HYBRID MIXTURES

Atmospheres containing both flammable gas or vapour and dust are called hybrid mixtures. Their flammability parameters are difficult to define; generally falling somewhere between those for the gas or vapour, and those for the dust. Because dust can only remain suspended if the atmosphere is turbulent, the gas explosion properties are those of the turbulent mixture.

An important feature of hybrid mixtures is that they can be flammable even when both components are below their respective LELs.

In cases where the gas or vapour content exceeds, say, 25 % of its LEL, the mixture should be assumed to have the characteristics of the gas or vapour.

4 CONCLUSION

The flammability characteristics described above are used in the assessment of dust explosion hazards in plant and for the specification of preventive and protective measures. It is important that the data used for those purposes have been determined using the correct methods and on a representative sample.

As the test data depend on the details of the test method, following the correct test standard is imperative. European Standards are becoming more and more available as a result of standardisation work to support the ATEX Directives.

Using representative samples often causes more problems and there is always pressure to test fewer samples and perform fewer tests, preferably relying on some published data. However, the law requires industry to work safely, and that requires a suitable "Basis of Safety" for all plant and processes. Under the Machinery Directive and the ATEX "equipment" Directive the manufacturers of equipment have to ensure that the equipment is safe to use. This equally requires a Basis of Safety, which again requires adequate flammability data.

For further information on products and services available from Chilworth Technology please telephone or write to the Marketing Department:-

Chilworth Technology Ltd

Beta House, Chilworth Science Park, Southampton, SO16 7NS, UK

Tel: +44 (0)23 8076 0722 Fax: +44 (0)23 8076 7866

Web: www.chilworth.co.uk Email: info@chilworth.co.uk

AR20203 Flamm Characteristics of Powders.doc