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## **EXPLOSIONS PART 1 OF 3: HOW LABORATORY TESTS CAN BE USED TO IDENTIFY THE HAZARDS AND CONTROL THE RISKS OF EXPLOSION ON PLANTS**

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### **Introduction**

In this article we look at explosion of gases, aerosols and dust clouds and specifically at how laboratory tests can be used to identify the hazard and assess and control the risk of explosion on chemical plant. In a subsequent article we will address the area of hazardous powder decompositions.

There is a wide range of physico-chemical hazards associated with the processing and handling of chemicals:

- Many vapours, dispersed dusts, dispersed liquids (aerosols) and gases will, of course, explode under certain fuel-oxidant-ignition source conditions.
- Powders in bulk can self-heat leading to spontaneous combustion. They may also decompose to liberate gas which itself may be flammable, and in extreme cases powders may decompose with sufficient speed to be classified as explosive.
- With multi-component reacting systems, heat release and gas evolution rates can be so high as to again lead to over-pressurisation and explosion.

*So how do we deal with this array of potential hazards waiting to catch us out?*

*How do we know if the chemicals or reaction we are running could be liable to explode, run away or self-ignite?*

*What precautions do we need to take to guard against this?*

The answer lies in formalised hazard assessment, but clearly this requires input from the laboratory.

### **Hazard assessment**

Any powder or liquid handling or processing operation should be the subject of a hazard assessment that includes study of the risk of explosion. Such an assessment must begin with the collection of flammability data on the materials being handled. The assessment will begin with the identification of the hazards in the operation. This will then allow risk assessment to be performed on those identified hazards that takes into account both the likelihood of explosion and also the consequence of such an event to people and the environment. Risk assessment can be followed by risk control study to decide the basis on which the operation may be considered safe. This could, for example, be because a

flammable atmosphere will be avoided, ignition sources will be excluded, or because some explosion protection devices are installed.

The flammability properties determined in the laboratory will have a major influence on the outcome of the hazard assessment, giving valuable information on how likely an explosion is to occur, how severe the consequences can be and how explosion protection measures should be designed to protect people and plant. Yet for many the interpretation of this data is one of the most difficult tasks of the hazard assessment. We therefore turn to dust explosion data and gas/vapour/aerosol explosion data that comes from the laboratory and indicate its use in the assessment of hazard.

### The dust explosion

While most finely divided powders will ignite and explode if dispersed in sufficient concentration in air, there are some which will not. A group A/B flammability classification test in a one-litre combustion cylinder is therefore often performed at the hazard identification stage to establish if dust explosion is possible.

If an explosible dust is identified, then important information about the likelihood of dust explosions is given by tests for minimum ignition energy (MIE) and minimum ignition temperature (MIT) of the dust cloud.

MIE data will tell us if electrostatic sparks can ignite the powder and also help us decide the precautions we take. Some powders are so sensitive to static spark ignition, for example, that the use of standard polypropylene "big bags", or even the use of polythene liners would not be recommended.

MIT data for a powder tells us the surface temperature above which a dust cloud may self-ignite. Apart from the more obvious use of ensuring drying temperatures (for example spray drying) are sufficiently low to prevent ignition, MIT is also used as one of the parameters to specify the temperature "T" rating for electrical equipment in dusty atmospheres. It can also be used (in conjunction with MIE) to assess the risk of ignition by impact spark in power handling operations such as conveying and milling.

The consequence of a dust explosion will of course depend on the strength of dust explosion as well as the details of the design of plant. Explosion severity can vary from weak to very strong and, indeed, many powders explode with a violence (rate of pressure rise) which exceeds that of common solvents. The 20 l sphere test is designed to measure explosion strength by virtue of the  $K_{st}$  parameter, which is a normalised rate of pressure rise with values ranging from 0 to over 600 bar  $ms^{-1}$ . Foodstuffs fall into the lower part of this range, typically up to 200 bar  $ms^{-1}$ . Many fine chemicals and pharmaceutical stretch the range up to 300 bar  $ms^{-1}$  or above, whereas finely divided aluminium flake could



Figure 1 Measurement of minimum ignition temperature.

reach  $K_{st}$  values of  $600 \text{ bar ms}^{-1}$  or more. For comparison purposes, a quiescent hydrogen air explosion has a  $K_G$  value of  $550 \text{ bar ms}^{-1}$ .

### **Operating safely**

Establishing a suitable basis of safety for an operation will require the use of the above test data and others besides. For example, if it is decided to protect plant by the installation of explosion relief vents, then 20 l sphere  $K_{st}$  information will be needed to design plant in accordance with IChemE (Institution of Chemical Engineers) guidelines. Similarly, explosion suppression equipment design requires  $K_{st}$  data to decide how many and what size of suppressor are needed; and 20 l sphere data is also used if plant is to be designed to be strong enough to contain the full overpressure of an explosion

If a safety case based on avoidance of ignition sources is to be made, then much of the above mentioned test data is needed to verify this. For example, a drying process may need MIT, MIE and thermal stability data to ensure electrostatic, auto-ignition and self-heating could not cause explosion. Other test data may also be needed since all normal and abnormal operating conditions should be considered and provision for ignition source avoidance in all of these must be made if this basis of safety is chosen.

Gas evolution from powders, though not an explosion, can occur quickly giving rapid pressure rises in closed plant equipment. Decomposition can occur under vacuum and in a nitrogen atmosphere. Higher pressures can be generated than in an explosion as the oxygen present limits the minimum oxygen concentration (MOC) pressure in an explosion, but in decomposition there is no limit.

### **Vapour, Gas and Aerosol Explosions**

Hazard identification in any assessment that considers gas or vapour explosion risk will begin with flash point data. The flash point is, of course, the minimum temperature at which a liquid gives off enough vapour to form an ignitable mixture in air. In general, a liquid with a high flash point relative to its local temperature in the process will not present an explosion risk, although there are situations where this does not apply, of which the hazard assessor should be aware. When a mist or aerosol of a high flash point liquid is formed, more fuel can be present in the oxidant than would occur with a vapour in equilibrium with its liquid. Consequently aerosols can be readily ignited below the flashpoint. Tests are available to study aerosol flammability.

As with powders, important information on likelihood of ignition can be obtained with MIE and auto-ignition temperature (AIT) data. This information can also be used on plant to help eliminate sources of ignition. Unlike powder, though, the MIE data of many common solvents is in a narrow range (typically 0.1 to 1 mJ) but there are notable exceptions such as hydrogen and carbon disulphide mixtures with air. The exceptionally low MIW of these vapours demands special handling precaution are taken.

**Table 1: Gas and vapour flammability tests and their uses**

Test parameter	Risk assessment	Hazard identification and risk control
Flash point		Screening for flammability
MIE (minimum ignition energy) AIT (auto ignition temperature)	Likelihood	Identification and control of electrostatic and hot surface ignition risk
K <sub>st</sub> index	Consequence	Design of explosion protection
Maximum explosion pressure UEL and LEL (upper and lower limits) Maximum oxygen concentration	Risk reduction	Design of explosion prevention systems

**Table 2: Dust explosion flammability tests and their uses**

Test parameter	Risk assessment	Hazard identification and risk control
Group A/B explosibility test		Screening for flammability
MIE (minimum ignition temperature) MIT (minimum ignition temperature cloud)	Likelihood	Identification and control of electrostatic hazards, powder hot surface temperatures and impact spark ignition. Also use in specifying electrical equipment
K <sub>st</sub> index Maximum explosion pressure Gas evolution	Consequence	Design of explosion relief vents, suspension systems and vessels for explosion containment
MEC (minimum explosible concentration) MOC (maximum oxygen concentration, to prevent explosion)	Risk reduction	Explosion prevention by avoidance of flammable atmospheres

AIT data is also important since, once again, this can be compared with process temperatures to ensure appropriate ignition prevention precautions are taken. And AIT data is also needed in the specification of electrical equipment in hazardous areas.

Explosion consequence can again be examined by using a measure of explosive violence, K<sub>G</sub>, together with plant design data. It is fortunate that many common solvents have K<sub>G</sub> values in the region of 40 to 80 bar ms<sup>-1</sup> but again there are exceptions, such as acetylene and hydrogen in mixtures with air.

Gases and vapours are in many ways more predictable than dust clouds. It is, for example, more straightforward to design ventilation for flammable gases to ensure flammable concentrations are never reached. Both flammable limits data and minimum oxygen concentration data find application here.

A lot of data exists in the literature on gas and vapour flammability, but there are occasions where tests or careful judgement are required. For example, with mixtures of solvents, parameters such as flashpoint, AIT and lower flammable limit can often not be found, and estimation may not be sufficient. Measurement is then required. Testing is particularly useful when the unusual oxidants are involved since data is unlikely to be in the literature. These oxidants include chlorine and oxides of nitrogen such as nitrous oxide, nitric oxide

and nitrogen tetroxide. And unusual environmental conditions such as higher temperature or pressure, or if oxygen levels deviate from atmospheric, may also require testing. Most parameters change in non-standard oxidants and modified environmental conditions, and often in unpredictable ways.

Finally, flammability testing may be required where a third component, such as nitrogen, is added to a fuel and oxidant necessitating the generation of so-called triangular diagrams.

### **Hybrid mixtures**

Any hazard assessment requires particular care where mixtures of powder and solvent vapours may occur, and material testing may again be required. It is known that the sensitivity to ignition of a dust cloud as measured by its minimum ignition energy will be increased by the addition of small quantities (below the lower explosible limit) of a solvent vapour. The lower explosible limit will also be reduced and furthermore, explosion violence of a dust cloud as measured by the  $k_{st}$  value can greatly increase when a flammable vapour is present with the dispersed dust.

In summary, laboratory test data is seen as playing an essential part in any assessment of explosion hazard on chemical plant. With care, explosion indices such as flash point, MIE, MIT,  $K_{st}$  and so on can be used to identify hazards, and to anticipate the likelihood and consequence of an explosion. They then act as essential input in selecting a basis of safety for a process and are used in ensuring that explosion likelihood is minimised and that adequate protection measures are installed.

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