EXPLOSION RISK IN AGRICULTURAL INDUSTRY

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INTRODUCTION

In 1979 a major dust explosion took place in a feedstuff manufacturing installation located in Lérida, Spain. Ten people were killed and the plant was severely affected, with the elevator building nearly destroyed. This was not an isolated accident in the agricultural industry: deaths and devastation were again produced in Pozoblanco (Córdoba) 1984, Nogales (Palencia) 1993 and Fuentepeleyo (Segovia) 1993.

The occurrence of explosions is not a new event, but an old problem associated with the handling of solids that produce dust. In 1785 the first documented dust explosion happened in a flour warehouse in Turin. Numerous devastating grain dust explosions (see figures 1 and 2) have occurred in different countries, as it is the case of the well known explosions in Norway (Port silo in Stavanger), Germany (Flour mill in Bremen), Argentina (Terminal de Grano in Bahía Blanca), France (Malt silo in Metz), USA (Grain silo plant at Corpus Christi, Texas), etc. [1][2].

All this catastrophic explosions led to intense research with the aim not only to look after the cause of the explosion, but also to find solutions to impede future accidents in similar plants.
We have gained a lot of experience in the last 200 years. However still severe accidents occur, as it is the case of the very recent explosion in a grain silo at Blaye, (France) in August 1997 (see figure 3) producing 11 fatal victims [3] and the grain dust explosion at a terminal elevator in Haysville, Kansas (USA) last June 8th, 1998, causing 7 men killed, 10 injured, very extensive property damage and a very intense week-long rescue effort estimated itself in $850,000. [4]

Agricultural industry has a long history of accidents. Dust explosions have and can occur in grain elevators, feed mills, flour mills, cereal and food plants, etc. Professor Schoeff (Dept. of Grain Science and Industry, KSU) in cooperation with Ralph Regan (Safety Director, US Department of Agriculture) has compiled statistics on grain dust explosions in USA during the last years. During the 1980s the number of reported incidents averaged 17. In the period 1988-1997 they averaged 13 (more than one per month) and ranged from 6 to 16. Property damage estimates averaged $7.7 million.

EXPLOSION RISK

Most oxidable solid materials are susceptible of developing a rapid combustion process when the particle size is small enough. Under confinement, that combustion will acquire conditions for giving rise to an explosion, producing hot expanding gases which generate a pressure pulse. As in the case of gas explosions, for a dust explosion an ignition source and a explosive atmosphere are required at the same time. However, the behaviour of combustible dust is quite different from that of gases. While flammable gases easily diffuse in the air reaching an homogeneous concentration, dust particles trend to settle down, producing accumulations in the form of heaps and layers. Particles can remain in suspension for a time, depending on their density and the particle diameter, and can travel from the point they are released to other locations in a plant. They can leak from equipment and also can get into other pieces of
equipment (for instance, from a hopper to an electrical terminal box). They accumulate on the floor, pipes, equipment surfaces, wire trays, radiation surface of electrical engines, etc.

Particles can be in contact with ignition sources when accumulated in layers and also forming a dust cloud when they are put in suspension accidentally or by a “normal” operation (cleaning operations by sweeping).

If a potentially explosive dust cloud gets in contact with a source of ignition sufficiently powerful (some milijoules can be sometimes enough) an initial ignition will be produced. This is the primary explosion.

This initial flame will produce hot expanding gases, which develop a pressure wave. Deposited nearby dust will easily put into suspension, forming a fresh unburnt dust cloud just in front of the flame: again we have an ignition source together with a flammable mixture and this will lead to the propagation of the explosion towards new dust deposits which will be entrained producing the secondary explosion which can have devastating consequences in the whole plant.

**DUST FLAMMABILITY AND EXPLOSIBILITY**

Flammability and explosibility of different dusts can be measured by means of standardized laboratory methods which provide very useful information for a subsequent risk analysis.

The most frequently parameters used for characterising the sensitivity to ignition are the following:

- **Minimum Ignition Temperature.** It is the lowest temperature at which the dust ignition process starts. It determines whether a present heat source is able of initiating the process or not. The corresponding test can be done either with the dust forming a cloud (MIT-c) or deposited in a layer (MIT-l). The test device used for MIT-c consists of a vertical cylinder, the inside of which is electrically heated at a certain temperature, where the dispersion is produced. The appearance of flames makes ignition evident at the fixed temperature.

  The test apparatus used for MIT-l is a metallic plate whose temperature can be varied, upon which the dust is deposited forming a 5 mm thick layer. If the temperature within the layer exceeds over the plate temperature, it is understood that ignition has been produced, even if no flame is seen.
- **Minimum Explosible Concentration.** There is a range of dust cloud concentrations within which the dust-air mixture results potentially explosive. The lower limit is the MEC. The traditional test procedure is based on the so-called Hartmann Tube, which consists of a dispersion plate where the dust sample previously weighed is deposited, and a vertical tube where the dust dispersion is produced, passing through an ignition source. When an open flame is observed, ignition is assumed for the concentration obtained in the known tube volume. Also, a 20 litre spherical vessel can be used for this test.

- **Minimum Ignition Energy.** It is the lower electrical energy obtained by means of a capacitive discharge which is able to produce the ignition of a dust cloud. The test device is a Hartmann Tube or a 20-litre spherical vessel. Energy is calculated from the equation \( E = \frac{1}{2} C V^2 \), where \( C \) is the capacity of the capacitors connected to the discharge circuit and \( V \) is the voltage applied.

During an explosion in a closed vessel, pressure changes determine a curve in which the following parameters can be defined:

- **Maximum Explosion Pressure.** It is the difference between the pressure at ignition time (normal pressure) and the pressure at the culmination point. It is measured in the 20-litre apparatus or in a 1 \( \text{m}^3 \) vessel at different fuel concentration. The test is done over a wide range of fuel concentrations, obtaining in each case a maximum value. MEP is defined as the highest of those maximum values.

The 20-litre spherical explosion chamber is a hollow sphere made of stainless steel. A water jacket serves to dissipate the heat of explosions or to maintain thermostatically controlled test temperatures. For testing, the dust is dispersed into the sphere from a pressurised storage chamber via the outlet valve and a nozzle (known as the rebound nozzle). The outlet valve is pneumatically opened and closed by means of an auxiliary piston. The valves for the compressed air are activated electrically.

A control unit provides all the timing and control signals to drive the tests. Compressed air is used to power the outlet valve and is also connected to the inlet valve of the storage chamber. The pressure in the storage chamber corresponds directly to that of the external compressed air system (20 bar g).

Prior to dispersing the dust, the sphere is evacuated to such a degree, that the remaining pressure, together with the air contained in the storage chamber, results in the desired starting pressure for the explosion test (normally 1 bar abs). Two piezoelectric pressure sensors provide independent measuring channels giving good security against erroneous measurements and allow self checking.
- **Maximum rate of pressure rise.** It is the maximum slope of the tangent to the pressure vs. time curve at nominal fuel concentration. The test is done over a wide range of fuel concentrations, obtaining in each case a maximum value. MRPR is defined as the highest of those maximum values.

When these parameters are obtained it is then possible to know about the sensitivity of the product to ignition and also its severity of explosion. As an example, table I [5] gives the explosibility parameters of some agricultural samples. It must be noted that these data are just orientative and very important variations can be found from different information sources. This is due to the strong dependence of the explosibility parameters with the physical and chemical properties of the product. Particularly, moisture content and particle size have a critical influence on those values.

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>MIT (ºC)</th>
<th>MEC (g/m³)</th>
<th>MIE (mJ)</th>
<th>MEP (bar)</th>
<th>MRPR (bar/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>460</td>
<td>100</td>
<td>320</td>
<td>6.1</td>
<td>76</td>
</tr>
<tr>
<td>Almond shell</td>
<td>440</td>
<td>65</td>
<td>80</td>
<td>7.0</td>
<td>97</td>
</tr>
<tr>
<td>Barley, milled</td>
<td>370</td>
<td>50</td>
<td>15</td>
<td>9.6</td>
<td>732</td>
</tr>
<tr>
<td>Cocoa powder</td>
<td>500</td>
<td>65</td>
<td>120</td>
<td>5.0</td>
<td>93</td>
</tr>
<tr>
<td>Corn starch</td>
<td>390</td>
<td>40</td>
<td>30</td>
<td>10.0</td>
<td>656</td>
</tr>
<tr>
<td>Grain, distillers dried solubles</td>
<td>420</td>
<td>60</td>
<td>128</td>
<td>5.5</td>
<td>48</td>
</tr>
<tr>
<td>Malt</td>
<td>400</td>
<td>50</td>
<td>35</td>
<td>6.6</td>
<td>304</td>
</tr>
<tr>
<td>Rice</td>
<td>440</td>
<td>50</td>
<td>50</td>
<td>7.3</td>
<td>187</td>
</tr>
<tr>
<td>Soya flour</td>
<td>550</td>
<td>60</td>
<td>100</td>
<td>6.5</td>
<td>56</td>
</tr>
<tr>
<td>Sugar</td>
<td>330</td>
<td>15</td>
<td>30</td>
<td>7.6</td>
<td>345</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>380</td>
<td>50</td>
<td>50</td>
<td>7.6</td>
<td>256</td>
</tr>
</tbody>
</table>

*Table I.* **Explosibility parameters of agricultural products**
IGNITION SOURCES

A dust explosion can occur when an explosible dust concentration is brought together with an ignition source of sufficient energy to initiate flame propagation. Among the main ignition sources the following can be included [6]:

- Flames
- Hot surfaces
- Burning material
- Spontaneous combustion
- Welding or cutting operations
- Friction heating or sparks
- Impact sparks
- Electric sparks
- Electrostatic discharge sparks

Some of these ignition sources may be present during process operations in agricultural plants. The first safety task should be the identification of them and their control, removing them wherever possible.

Recent statistics [4] show that in 129 agricultural dust explosions occurred in the USA between 1988 and 1997, the probable cause of ignition was identified in 70% of the cases, following the distribution shown in table II. Table III presents the location of primary accident, identified in 91% of the 129 cases studied.

<table>
<thead>
<tr>
<th>CAUSE OF IGNITION</th>
<th>% OF THOSE IDENTIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fires</td>
<td>16</td>
</tr>
<tr>
<td>Bearing Failure</td>
<td>15</td>
</tr>
<tr>
<td>Sparks</td>
<td>10</td>
</tr>
<tr>
<td>Welding/Cutting</td>
<td>9</td>
</tr>
<tr>
<td>Hot metal Surface</td>
<td>8</td>
</tr>
<tr>
<td>Electrical failure</td>
<td>3</td>
</tr>
<tr>
<td>Foreign Material</td>
<td>3</td>
</tr>
</tbody>
</table>

Table II. Probable cause of ignition. Agricultural dust explosions (USA, 1988-1997)
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>% OF ACCIDENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bucket Elevator</td>
<td>43</td>
</tr>
<tr>
<td>Bin</td>
<td>16</td>
</tr>
<tr>
<td>Dust Filter</td>
<td>8</td>
</tr>
<tr>
<td>Dust System</td>
<td>6</td>
</tr>
<tr>
<td>Grinder / Hammermill</td>
<td>4</td>
</tr>
<tr>
<td>Drag Conveyor</td>
<td>2</td>
</tr>
<tr>
<td>Unidentified</td>
<td>9</td>
</tr>
</tbody>
</table>

Table III. Location of primary accident. Agricultural dust explosions (USA, 1988-97)

PREVENTION OF EXPLOSION: BASIC RECOMMENDATIONS

Prevention of explosions is the basic tool for a safe design of operations. Under the concept of prevention many different actions can be included, some of them being easily implemented and at a low cost and some others with more requirements from the point of view of productivity and economic weight.

It is important to graduate the possible preventive measures so as to establish a systematic plan in order to gradually introduce more elaborated actions. For example, before installing a very sophisticated explosion suppression system in the plant, it would be wise to assure that smoking is definitely forbidden in any dangerous area, and the purchase and installation of some warning wall signals represents a real low cost and can be very useful in avoiding potential ignition sources which can be brought by workers from a subcontracted company.

In order to prevent an explosion, one must fight in two fields: both the flammable atmosphere and the ignition source should be avoided. Then, two groups of actions can be taken:
a) Avoiding flammable atmosphere  
- Redesign any operation which produces dust clouds.  
- Equipment must be tight to impede dust coming out.  
- Any source of dust must be closed, covered or removed.  
- Dust collection is advisable, installing filters and cyclons preferably outside the buildings. Localized aspirations are recommended in any loading, unloading and transfer point.  
- Dust accumulations must be cleaned up: a detailed cleaning program must be implemented. It must be periodically revised and cleaning should be inspected. Aspiration is advised.

b) Avoiding ignition sources  
- Electrical equipment must be certified to be used in dusty environments.  
- Metals and foreign materials must be removed before entering the process.  
- All parts of equipment must be grounded.  
- Moving parts must be carefully maintained to avoid friction. Maintenance programs must be exhaustive under a safety point of view.  
- Establish and inspect hot permits system.  
- Survey, watch and inspect very frequently the installation to avoid appearance of ignition sources.

Figure 6. All potential ignition sources must be controlled
A fundamental point is the formation of personnel, giving all kind of information about the risks and dangerous operations. Once the staff is aware of the risks, their attitude will change, being more sensible to detect and notify dangerous situations and more conscious for not generating themselves potentially risky situations.

Here it is important to emphasize the role of Health and Safety Centres particularly implicated in the agricultural industry. In Spain, the Centro de Seguridad y Condiciones de Salud en el Trabajo [7], in Lérida, the province with the highest production and the largest number of agricultural companies in the country, has been developing extensive safety campaigns, gathering manufacturers, enterprises, administration representatives, mutual societies and this testing station to promote and spread basic information to workers, managers and owners. We have learnt that Safety is not a question of just attending a seminar, but an everyday attitude to face any imaginable potential risk.

REFERENCES

[2]. EXPLOSION GROUP TU DELFT. http://dutges01.geo.tudelft.nl/explosion
[7]. CENTRO DE SEGURIDAD Y CONDICIONES DE SALUD EN EL TRABAJO- LÉRIDA. Fax: 00 34 973 21 06 83.