Criteria for fire and explosion prevention and protection on industrial sites

SAFETY

Real Decreto 681/2003 of 12 June for improving the safety and health protection of workers potentially at risk from explosive atmospheres in the workplace has now come into force. This royal decree lays down the bases for explosion risk assessment on those sites that are prone to generate explosive atmospheres of this type. Nonetheless, many doubts have been thrown up when it comes to implementing this royal decree and applying the assessment criteria. This article puts forward a series of guidelines that help to establish a particular modus operandi to suit the industry or site in question. An in-depth knowledge of the process involved is a sine qua non of effective protection against ATEX risks.

By XAVIER DE GEA. Director LPG Prevención y Protección de explosiones.

On 1 July 2003 Real Decreto 681 / 2003 became enforceable and binding on all new industrial establishments with a risk of explosive atmospheres. As from 30 June 2006 it also became enforceable for all industrial establishments with a risk of explosive atmospheres. As a result of this new legislation all these establishments are now bound to draw up an explosion protection document.

Without getting too bogged down in legal niceties, which have been dealt with in many articles elsewhere, we do need first and foremost to understand the phenomenon of “combustion”.

Once we understand the general principle of fire, combustion, conflagration, explosion, etc... we then have to see whether and how far this might affect our activity; it is well worthwhile here to pause a moment and put on our safety glasses (by which we mean not donning safety goggles but seeing things from the safety viewpoint) and check whether we are actually in a risk situation.

Despite not having had any accident for years, the ingredients might still be there, biding their time. We can look for guidelines in the accidents that have occurred in our sector, as telltale signs of whether or not we are handling “hazardous” substances.

For example, an analysis of the dust explosion figures in the American grain sector over the last four decades of the twentieth century shows that this risk is not negligible: (15 explosions per year, 6 deaths per year and 25 injuries per year, plus the economic losses, which are not mentioned in this report).

Total 1958 to 1998
After several accidents the American authorities decided to regulate the sector. The OSHA Grain Handling Facilities Final Rule was duly published on December 31, 1987 with an effective date of March 30, 1988, greatly helping thereafter to cut down the accident rate.

**Annual means.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of explosions</th>
<th>Number of deaths</th>
<th>Number of injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1958 to 1987</td>
<td>15.7</td>
<td>7.3</td>
<td>29.1</td>
</tr>
<tr>
<td>1988 to 1998</td>
<td>13.2</td>
<td>2.3</td>
<td>13.2</td>
</tr>
</tbody>
</table>

This same effect is expected from the European ATEX Directive 92/99, which has been implemented into Spanish law as Real Decreto 681/2003.

This successful example will doubtless be convincing proof that regulation works and is necessary. On this assumption we will now analyse the phenomenon of fire, since any improvement depends on a proper understanding of the risk involved.

**What exactly is fire?**

Fire is an oxidation reaction in which a combustible product, the fuel, is oxidised by another product called the oxidant or combustion agent. This reaction is started with the input of activation energy and the effects of this exothermic reaction are heat, radiation or flames and the emission of subproducts in the form of gasses and solid particles or smoke.

Combustion is therefore the reaction in which the fuel and combustion agent are not mixed, so the continued feeding of oxidant into the fuel will make it burn more or less constantly. This will allow constant oxidation that will last for as long as the fuel exists or until there is no more oxidant input.

For example, a burner of a stove or a household:

A fire is an uncontrolled combustion and an explosion is a very rapid fire, therefore a very quickly spreading uncontrolled combustion.

We are now going to look at the various types of explosions:

- **Deflagrations**, subsonic combustion, i.e. one in which the pressure front generated by the oxidation travels at less than the speed of sound (340 m/s). Such an explosion is characterised by the fact that "the pressure front goes ahead of the flame front”.

- **Detonation** is a supersonic explosion with devastating consequences due to the sheer speed and pressure built up. This type of explosion is habitual in explosives and in conducted deflagrations accelerated to detonation, as in piped gasses. Here “the pressure and flame front travel together”.

After analysing what an explosion is, our next concern is to
establish the borderline between a combustion and a deflagration. To do so we first need to be clear about what a combustion consists of and the difference between this and a deflagration.

For a deflagration to take place the fuel and combustion agent must be mixed and there must be a necessary activation input to kick off the oxidation reaction. After the flash point the reaction spreads quickly to the rest of the “explosive mixture”; the immediate consequence of this propagation is the release of energy in heat form; this in turn increases the volume of heat-receiving gasses, which are then responsible for the expansion wave or blast. The first consequence of this is that the traditional extinguishing systems do not have enough time to check this rapid advance and are hence useless: so quickly does the reaction spread to neighbouring zones that there is no time for extinguishing it.

If a deflagration occurs inside a container of any sort there is then a danger of an explosion due to the increase of internal pressure. The hazardousness will depend on the volume of the container and the pressure it can withstand.

In sum, therefore, a deflagration releases heat and builds up pressure inside a container, causing irreversible damage.

A sine qua non of a deflagration, therefore, is an explosive atmosphere or ATEX.

**Where is there an ATEX?**

The first thing we need to establish is whether the substances involved are flammable and, if so, where their sensitivity limits lie and how severe the explosion would be. It is essential to find out the risk involved:

In the case of a solid fuel we have to find out the following parameters:

<table>
<thead>
<tr>
<th>IGNITION SENSITIVITY</th>
<th>EXPLOSION SEVERITY</th>
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<tbody>
<tr>
<td>MIT-Layer</td>
<td>Pmax</td>
</tr>
<tr>
<td>MIT-Cloud</td>
<td>Kmax</td>
</tr>
<tr>
<td>MEC</td>
<td>LOC</td>
</tr>
<tr>
<td>MIE</td>
<td></td>
</tr>
</tbody>
</table>

If these substances are flammable, therefore, the next step we need to take in an industrial site is to localise the explosive atmospheres (colloquially shortened to ATEX) and prevent them from igniting or, if the ignition does in fact occur, control the generation of released energy.

An ATEX is a mixture of fuel and oxidant. The fuel may be in the form of gas, vapour, dust or fibres and the oxidant is usually the oxygen in the air.

Neither should we forget that the ATEX generation may be **temporary or accidental**; here is where the ATEX zoning classification comes in; this classification needs to be thorough but without overdoing it. For example, an industrial building ten metres high should not be classified as ATEX zone 22 on the grounds that there is or might be flammable dust on the floor, for the direct consequence of this is that its lighting and electricity system would have to be category 3D, meaning that it could be repaired in the future only by an authorised installer. Such overzealous zoning would hence lead to an unnecessary and
available surcharge for the user concerned.

After identifying the ATEX risk we need to take the ignition prevention measures to suit this explosive atmosphere. The typical measure is to remove the ignition sources by bringing the site’s equipment into line with the identified ATEX zone and establishing safe working methods.

The first measure to be taken by the entrepreneur is the training and awareness raising of his/her workers, since this single measure will slash the hazardousness drastically.

If not already in place, a work permit system should be set up, with special stress on heat work (cutting and welding).

No one allows fireworks to be set off on his/her site but they do allow a blowpipe or abrasive-disc sander to be used:

The next step is to find out all the ignition source prevention techniques and ascertain which are applicable to our particular process. For example, if we wish to prevent sparks of a mechanical origin, a very efficient measure might be a turning-speed limit, or a magnet in a mill inlet might prevent the entrance of nails, etc.

Thus, to control the ignition sources we need to see where we have permanent explosive atmospheres and establish whether they are a hazard to people if the explosion actually occurs.

To control the damaging aftermath of an explosion there are two types of techniques: passive and active.

**Passive techniques** consist of the control of pressure build-up by fitting relieving devices such as explosion venting panels and explosion doors. We also need to lead the flames towards a safe area; if the equipment is indoors we also need to lead them outside or set up gas venting with flame arrestor.

Explosion venting calls for a given surface area. For calculation purposes there is the standard UNE EN 14491 for dust and UNE EN 14994 for gasses. These standards allow us to size and determine the safety gap. The area depends on the substance in question (its explosiveness), on the container resistance, its geometry and volume, on whether or not the venting is ducted and the length and shape of this duct. There is software for rapid and trustworthy calculation of these variables (such as LPGVENT).

The explosion venting techniques have to take into account the flame and pressure safety gaps, which depend on the volume and pressure of the container.

**Active techniques** involve controlling the emission of energy, i.e., halting the deflagration process. This is achieved by means of explosion suppression systems, calling for an optical or pressure detection system and suppression containers, which very quickly release an extinguishing agent in the environment, checking the advance of the explosion.

In industrial processes it is very important to isolate the explosion to head off the dreaded secondary explosions, which could cause more site damage. This isolation could be chemical or mechanical, one or the other being used to suit the characteristics of each site.

It is hence very important to prevent explosions and protect people and plant from their effects. Nonetheless, no protection system is complete unless we bear in mind the fact that an explosion might spark off a fire in a given area or, conversely,
that a fire in an ATEX zone might produce an explosion.

After we have established the presence of an ATEX, ascertained the likelihood of its formation and found out the existing prevention and protection techniques, the main question begged is then the following.

**When should I protect myself and when not?**

The answer is "it depends". But on what? On the likelihood of the coexistence of effective ignition sources and an ATEX.

There are two concepts here:

- **COEXISTENCE**: For example, if we have to weld a petrol tank the first thing we have to do is remove the ATEX from the tank, so that, after being cleaned and inerted, it can be safely welded. There will then be no coexistence of ignition source and ATEX.

- **EFFECTIVE Ignition Source**: If a solid has a very high minimum ignition energy (MIE) of over 1 Joule, we can rule out the possibility of ignition by an electrostatic discharge. Conversely, the vapours of a flammable liquid have an ignition energy of less than one milijoule and static electricity therefore becomes an effective ignition source.

The great doubt is whether we can be sure about the coexistence of an ignition source and an ATEX:

Here is where we have to take a decision. In some cases it is crystal clear and in other cases fuzzier. Here is where the company's experience comes into its own, i.e., the incidents suffered in the plant and/or in the sector.

For example, returning to the study of dust explosions in the US grain industry we find two critical points: the mills and the bucket elevators. The elevators have been analysed because of the very serious consequences of any explosion, since any explosion in an elevator would probably spread to a silo and then to the whole factory.

**Of the total of explosions produced**

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Explosions</td>
<td>25</td>
<td>18</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Injuries</td>
<td>50</td>
<td>19</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Deaths</td>
<td>20</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

**The cause is the bucket elevator**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosions</td>
<td>21</td>
<td>12</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Injuries</td>
<td>47</td>
<td>10</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Deaths</td>
<td>19</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

An analysis of the above figures shows that there has been a reduction of cases since US legislation on the matter came into force. A comparison of the periods 1978-1982 and 1993-1997 shows that explosions fell by 71%, injuries by 91% and deaths by 95%, the bucket elevator being by far the biggest explosion
cause. In the first period, bucket elevators accounted for 84% of accidents, this figure than falling to 43% in the latter period.

Here it is very clear that preventive action on the most accident-prone piece of equipment (the bucket elevator) has borne fruit. We do need to scratch the surface of these figures, however, as a single plant may have one hundred elevators of different types and different risks in terms of ignition and aftermath. We need to determine which elevators are the main cause of the accidents: the elevators involved in the receipt, handling or storage of the grain, the silo-filling elevators, the production feeding elevators, the high or low elevators, wide-leg-casing or narrow-leg-casing elevators, those that are permanently operating or occasionally, single- or double-leg-casing elevators, etc... If we take the different types of elevators into account, we find that some are more accident prone than others. But we will be able to come up with the best reply only if we understand the phenomenon of combustion and apply it to our plant and equipment.

Unfortunately there are no studies of this level in other sectors and it is even difficult to glean general statistics in Europe. Not so in the United States, where the U.S Safety Chemical Board identified about 281 dust explosions in the 1980 to 2005 period, which killed 119 workers and injured another 718.

We are now going to lay down the guidelines to follow:

The first question we need to answer is:

**How might the substance deflagrate?**

To deflagrate, dust needs to reach ignition point in cloud form, i.e., in suspension. Deflagrations are therefore very dangerous in sites with dust deposits, since the pressure front raises the layers into suspension and then this dust is ignited by the flame front running behind the pressure front.

To know the hazardousness of the substance we need to find out its characteristics, i.e., its ignition sensitivity and deflagration severity.

**If an explosion should occur, where will it start and where are the consequences catastrophic?**

It is crucial for equipment with potential ignition sources and/or ATEX to be identified and for the explosion aftermath to be analysed, bearing in mind that this may vary from sector to sector.

Ignition sources may be various, their predominance varying from sector to sector:

<table>
<thead>
<tr>
<th>Ignition source</th>
<th>% in general industry</th>
<th>% in plastics industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical sparks</td>
<td>26,1</td>
<td>21,2</td>
</tr>
<tr>
<td>Embers or sparks</td>
<td>11,3</td>
<td>9,6</td>
</tr>
<tr>
<td>Mechanical heating</td>
<td>8,9</td>
<td>9,6</td>
</tr>
<tr>
<td>Electrostatic discharge</td>
<td>8,7</td>
<td>34,6</td>
</tr>
<tr>
<td>Fire</td>
<td>7,8</td>
<td>'--'</td>
</tr>
<tr>
<td>Self-combustion</td>
<td>4,9</td>
<td>'--'</td>
</tr>
<tr>
<td>Hot surface</td>
<td>4,9</td>
<td>3,9</td>
</tr>
</tbody>
</table>
Welding and heat work  4,9  '--
Electrical equipment  2,8  '--
Unknown  16,0  11,5
Others  3,5  9,6

Source (4), The equipment to be protected would vary from sector to sector

If we know the typical equipment where dust explosions occur:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>% incidents for industry in general</th>
<th>% incidents in the wood industry</th>
<th>% incidents in the metal industry</th>
<th>% incidents in the food industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silos</td>
<td>20,2</td>
<td>35,9</td>
<td>'--</td>
<td>22,9</td>
</tr>
<tr>
<td>Bag filters</td>
<td>17,2</td>
<td>18,0</td>
<td>45,6</td>
<td>9,5</td>
</tr>
<tr>
<td>Mills</td>
<td>13,0</td>
<td>7,0</td>
<td>5,3</td>
<td>18,1</td>
</tr>
<tr>
<td>Conveyors</td>
<td>10,1</td>
<td>4,7</td>
<td>'--</td>
<td>26,7</td>
</tr>
<tr>
<td>Driers</td>
<td>8,0</td>
<td>'--</td>
<td>'--</td>
<td>7,6</td>
</tr>
<tr>
<td>Mixers</td>
<td>5,4</td>
<td>'--</td>
<td>3,5</td>
<td>'--</td>
</tr>
<tr>
<td>Shotblasters</td>
<td>4,5</td>
<td>3,9</td>
<td>22,8</td>
<td>'--</td>
</tr>
<tr>
<td>Sieves</td>
<td>2,8</td>
<td>4,7</td>
<td>3,5</td>
<td>2,8</td>
</tr>
<tr>
<td>Others</td>
<td>14,1</td>
<td>25,80</td>
<td>19,30</td>
<td>12,40</td>
</tr>
</tbody>
</table>

Source (4), The equipment to be protected would vary from sector to sector

These are bag filters, the abovementioned bucket elevators, mills, silos, sprayers, fluidised beds, conveyors, worms, mixers, etc... In sum, all equipment that might produce mechanical or electrical sparks and in presence of an ATEX.

The first point is therefore to identify the permanent ATEX zones, i.e., zones 20 for dust or 0 for gas, since the appearance of an ignition source would produce a deflagration. These zones 20 or 0 will build up only inside the equipment.

We then need to pinpoint occasional ATEX zones 21 or 1, and then the rare ATEX zones, 22 or 2.

The criterion is to invest in ignition source prevention measures in ATEX zones 20 and 21.

I wish to stress here that the foremost preventive measure should be worker training and awareness-raising in ATEX risks, since this measure has proven to be highly effective.

When the preventive measures do not sufficiently cut down the risk of the appearance of effective ignition sources, then we have to move on to protection measures.

Thus we have to protect ATEX zones 20 and 0 or reduce them to 21 or 1 by means of inerting.
In a nutshell:

The following examples will help to illustrate all the above:

1. Let us take the example of a grain processing plant (for example a flour mill): this will have several elevators, many mills, several sieves, many silos, several filters. Where do we start? At the very beginning, with the wheat:

   - Where does it come from? Do I have it under control? If it comes directly from the wheatfield with iron grit and foreign bodies, then the wheat-reception hopper elevator will have to be isolated against explosions, since we can never be sure that the wheat might not one day come intermingled with “something else”.
   - Does the wheat come after a cleaning and dust removal process? In this case there is unlikely to be any dust in the elevator; its interior is therefore zone 21, so preventive measures should provide sufficient safety levels.

We now move onto the mills. These mill the clean wheat but, even so, there is still a separation of metal objects and foreign bodies. This should be sufficient, providing that these preventive measures are properly maintained, since the inside of a mill is usually ATEX zone 21 because it is “very full” and there is not enough room for the dust to be placed in suspension.

As for filters, the wheat-reception hopper filler might capture an ember, for example a cigarette end; since there is no control over this aspect, this filter should be protected and isolated from explosions. Other hazardous filters are those that capture dust from several points, for example from various machines, since the likelihood of an ignition source rises exponentially. These should ideally be isolated and protected.

Likewise, if the filters are used for cleaning purposes, they also run the risk of picking up foreign bodies, including the forbidden cigarette ends. The protection should also be fitted outside and far from points of use since there are usually very small suction lines (DN 80 – 50) and they work under a strong vacuum. If they are fitted far from their use points the explosion is very unlikely to be propagated to the personnel using the machine.

Silos pose a big problem if they are old, since we do not know their resistance, a crucial factor in sizing the venting panels. We therefore need to work towards the prevention of ignition sources; all work should be carried out only with special work permits, in particular if welding work is involved. Likewise we need to isolate a potential explosion of the filling mechanism, typically an elevator, which should be isolated against explosions.

As we see, the criteria are based on knowledge of how the plant and equipment works, without forgetting worker training.

2. Another very different example is coal milling. Coal, being an ore, does not come in a pure state and the accompanying grit may well spark off an explosion in the milling process. Given that the presence of this grit is inevitable, we are bound to inert the process on a continual basis. How should this be done? Ideally by using the burner’s own combustion gases. Inerting means
reducing the oxygen percentage from the figure of 21% in the air to the 12% that serves as the limiting oxygen concentration (LOC).

In this milling process the sparks of a mechanical origin are not the only ignition source. Another would be the self-combustion of the finely milled coal, which tends to oxidise, resulting in an "oxygen poor" environment and generating carbon monoxide (CO). Should this process-generated CO exceed the limit of 1500 ppm, we should activate emergency inerting with CO₂. Another indicator of this self-combustion process is temperature increase; if this rises above 80ºC we would again activate CO₂ to pre-empt the fire and/or explosion risk.

Even so the mills and bag filters of the process are protected by means of venting doors. In the event of any explosion these would relieve the initial pressure and close again, since in this case the solid is highly combustible and it is crucial to prevent outside air from entering.

In sum, we should:

- **Ascertain the explosiveness of the substance** or substances. If there are several, we will take the most hazardous as reference.

- **Identify risk-prone equipment**, prioritising prevention and protection in light of the probability of failure and coexistence with an ATEX.

- **Evaluate economically** the cost of the measures taken (investment set against the safety improvement).

- **In view of all the above, DEFINE THE PRIORITIES**.

Following these 4 steps will enable us to set up an explosion prevention and protection criterion on our site.

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