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Two Different Methods of Risk Assessment for Combustible Dust Hazardous Areas – A Case Study

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Abstract

This case study reviews two methods for determining process risk for two different combustible dust handling systems. The methods used were applied to existing installations. The first method using the guidance of draft IEC/ISO 80079 standards for Non electrical equipment in hazardous areas was applied to a coal handling system. The second method uses HAZID analysis to prioritise risk reducing measures for a dairy spray dryer. Comments are given about the pros and cons of each technique, and the challenges in using hazardous area zoning techniques originally designed for ensuring electrical safety in a wider risk assessment context.

Introduction

Industrial dust explosions occur regularly in New Zealand. The worst NZ incident occurred some time ago, in a plastics factory in 1965, killing four people and injured a further six [1]. In more recent times, anecdotal media reports indicate that a dust explosion within a dust handling system at a joinery factory in 2011 injured two people [2]. There are many incidents that go unreported, generally because (luckily) no was injured. In the past six months there have been numerous incidents in industries such as dairy spray dryers, grain handling plant, saw mills, bio fuels and coal processing plant.

It is also common in industrial plant handling combustible dust to experience combustible dust fires. A dust explosion even with appropriate explosion mitigation in place usually causes significant fire damage along with lost production and other recovery costs.

The key philosophy in the protection of people and assets in industries handling combustible dust is to apply the hierarchy of controls [3], being: inherent safety, engineered controls, followed finally by procedural controls. These should be used to ensure ignition sources are avoided, or where they can’t be avoided then they must be appropriately controlled. If the ignition source controls cannot be relied on then providing explosion effect mitigations that vent flame and pressure away from people, or suppress the development of an explosion, may be necessary. A question often raised is, when is it necessary to increase the protection measures? At what point has a plant been adequately protected for fire and explosion hazards?

In New Zealand the person who controls a place of work has a particular responsibility under Section 16 of the Act to take ‘all practicable steps’ to ensure that harm from hazards does not occur. By working through a risk
assessment process the hazards can be systematically identified and, where practicable, additional controls can be proposed to minimize the risk.

To minimise the risk posed by handling combustible dust there are several measures that can be taken. This process involves:

- If possible the plant should be designed to be inherently safe [3], if this is not possible or practical then;
- Minimise ignition sources, and;
- Reduce the prevalence of dust in air mixtures (includes ‘housekeeping’ measures to prevent the buildup of dust layers)

In practice these measures often are not able to be fully applied due to the nature of existing processes. The process design has threats that can cause ignition risk of one sort or another. Once all controls to prevent the hazardous event are exhausted then mitigation measures must be considered to form barriers to the potential harm caused by a serious fire or dust explosion. In the situation of new plants the earlier the concept of eliminating or avoiding hazards (rather than controlling them) is adopted the more inherently safe a plant design can be.

This case study looks at two different methods for using risk based methods for identifying the degree of protection required in existing plant handling combustible dust.

**Methodology 1 - Standards Based Methods**

The first case, where Standards-based assessment has been applied, was a coal handling bin used as short term storage delivering fuel to a heat plant. The client’s question was simple: Is the bin design appropriately protected?

To determine this, guidance from both the code of practice for combustible dust [4], the hazardous area classification standards [5], and the ignition assessment table from the draft ISO/IEC standards for Non electrical equipment in hazardous areas [6] were applied.

This methodology can be simply described as follows;

1. A multi-disciplined team with the right skills, experience and plant knowledge is assembled to work together in a workshop format.

2. The occurrence of combustible dust clouds is defined on an equipment item basis, using standards guidelines [5]. This is essentially assigning the correct classification of hazardous areas (eg zone 20,21, or 22) for the plant as a first step.

3. For each part of the plant determine the potential ignition sources that are presented by the equipment from a fixed list of known possible ignition hazards. [4]

4. Determine whether any of the potential ignition sources can become effective in either normal operation, foreseeable malfunction or rare malfunction. This is determining the occurrence of the ignition source against qualitative guidelines.

5. For each situation apply the rules set out in section 7 of the Code of Practice [6]. These can basically be summarized as
Equipment installed in a Zone 22 area – Effective ignition sources shall not be present during normal operation.

Equipment installed in a Zone 21 area – Effective ignition sources shall not be present during normal operation or during foreseeable malfunctions.

Equipment installed in a Zone 20 area – Effective ignition sources shall not be present during normal operation, foreseeable malfunctions or in rare malfunctions.

6. Where the equipment doesn’t meet these requirements then independent protection measures are considered in the following order.

   a) Minimise the likelihood that ignition sources arise.
   b) Minimise the likelihood that ignition sources become effective.
   c) Minimise the likelihood of the explosive atmosphere reaching the ignition sources.
   d) Minimise the explosion effects and minimise the likelihood of flame propagation.

Application of the method

The first step of getting the hazardous areas classified correctly is done by following the qualitative guidance from AS/NZS60079.10.2. The coal bin in this case contained a relatively reactive coal, for the purposes of this case study published data is used [7,8,9].

<table>
<thead>
<tr>
<th>Airborne dust</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosible/non explosive</td>
<td>na</td>
<td>Yes</td>
</tr>
<tr>
<td>Maximum explosion pressure</td>
<td>Barg</td>
<td>10</td>
</tr>
<tr>
<td>Maximum rate of pressure rise</td>
<td>Bar/s</td>
<td>-</td>
</tr>
<tr>
<td>Lower explosion Limit</td>
<td>g/m³</td>
<td>35-49</td>
</tr>
<tr>
<td>Limiting oxygen concentration</td>
<td>%</td>
<td>-</td>
</tr>
<tr>
<td>Minimum ignition energy</td>
<td>mJ</td>
<td>&gt;30mJ</td>
</tr>
<tr>
<td>Minimum ignition temperature (BAM)</td>
<td>ºC</td>
<td>425 - 555</td>
</tr>
<tr>
<td>Minimum ignition temperature (C,G)</td>
<td>ºC</td>
<td>425 - 555</td>
</tr>
<tr>
<td>Electrical Resistivity</td>
<td>ohms.m</td>
<td>Unknown</td>
</tr>
<tr>
<td>Kst Value (maximum)</td>
<td>m.bar/s</td>
<td>129 - 151</td>
</tr>
</tbody>
</table>

Dust Layers

| Minimum ignition temperature (glow temp) | ºC | 225-250 |
| Electrical Resistivity                  | ohms.m | Unknown |

The following is a commentary of what the various test parameters are used for when assessing ignition source risk.

<table>
<thead>
<tr>
<th>Test and Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum ignition energy (without)</td>
</tr>
<tr>
<td>Test and Use</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Minimum ignition temperature – layer</td>
</tr>
<tr>
<td>Minimum ignition temperature – Cloud</td>
</tr>
<tr>
<td>Explosive limits</td>
</tr>
<tr>
<td>Electrical resistivity</td>
</tr>
<tr>
<td>Moisture content</td>
</tr>
<tr>
<td>Particle size</td>
</tr>
<tr>
<td>Kst – Explosion Constant</td>
</tr>
<tr>
<td>Pmax – Maximum explosion overpressure</td>
</tr>
</tbody>
</table>

A site visit was carried out to investigate the bin in question and to understand the processes leading up to the bin for generation of dust and possible release locations.

The material being fed into the bin was “run of mine”, as such it is relatively coarse with a small proportion of finer material. It wouldn’t immediately be associated with being a dusty product however the process of handling the coal and the environmental conditions had led to fine layers building on the internal structures of the bin.

When calculated, the volume of dust held in layers within the bin was more than sufficient to create an explosive atmosphere if disbursed into a cloud. Other contributing factors to the bin classification were the use of a direct coupled dust collector which ran continuously and returned fines directly to the bin.

Whilst filling, a combustible cloud can be expected to be continuous although local to the filing point. When not filling there is an uncontrollable dust layer on the internal structures of the hopper which if disturbed would cause a combustible cloud that could linger for some time due to the dry powder like nature of the separated dust.

The classification made for the enclosed hopper was Zone 20. The extent of this zone must include all the internal volume of the vessel even though the dust clouds would have been local to the filling opening.
Following this, the second step of the methodology is applied. The ignition sources within the bin are identified, in the case of a reactive coal:

- Exothermic reactions, including self-ignition of dusts
- Flames and hot gases
- Electrical Apparatus
- Hot surfaces

For the purpose of this paper, just one line of that assessment is taken as an example of the ignition hazard assessment format.

<table>
<thead>
<tr>
<th>Potential Ignition Source</th>
<th>Description of the basic cause</th>
<th>During normal operation</th>
<th>During unforeseen malfunction</th>
<th>Hz Risk</th>
<th>Reason for assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flames/Hot Gases</td>
<td>Burnback event from the boiler</td>
<td></td>
<td>X</td>
<td></td>
<td>Burning or run down procedure requires the slide gate to be shut, so burnback cannot occur</td>
</tr>
</tbody>
</table>

In this case the basic cause occurred during a foreseeable malfunction during a run down or hold procedure for the furnace of the heat plant. An operator missing a step of shutting off the coal bin from the feeder chute potentially could lead to exposure of hot gases from the furnace to a zone 20 area.

Location A shows the location of the slide gate at the top of the chute supplying the furnace.

For a zone 20 area, according to the rules in section 7 of the code of practice [4] this ignition source is not allowable and two independent means of preventing it occurring are required.

In this situation to meet the requirements two independent forms of control were required to prevent the foreseeable malfunction.

The proposed additional measures where;

- An interlock on hopper level to ensure a product plug remains in place, preventing exposure of the zone 20 dust cloud, whilst high gas temperatures are in the furnace. Once the temperature is at a safe
level the remaining coal can feed out of the chute leaving an open path to the bin.

- Monitoring of the temperature inside the chute and shut slide gates based on a temperature interlock.

By applying these two measures the occurrence can be revisited with the controls in place.

<table>
<thead>
<tr>
<th>Description of the measure</th>
<th>ROI</th>
<th>Technical documentation</th>
<th>During normal operation</th>
<th>During foreseeable malfunction</th>
<th>During severe malfunction</th>
<th>Not relevant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure based protection method to ensure that the food chutes are full so the prevents dust cloud exposure</td>
<td>ASA1Z84745 clause 7.2</td>
<td>Specification of detection system</td>
<td>×</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consider installing a minimum level requirement to prevent exposure of hot gases to zone 20 area</td>
<td>ASA1Z84745 clause 7.2</td>
<td></td>
<td></td>
<td></td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>Consider close plug sensors to close slide gates</td>
<td>ASA1Z84745 clause 7.2</td>
<td></td>
<td></td>
<td></td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>Ensure existing temperature sensors act quickly and automatically shut the slide gates on high temp detection</td>
<td>ASA1Z84745 clause 7.2</td>
<td></td>
<td></td>
<td></td>
<td>×</td>
<td></td>
</tr>
</tbody>
</table>

By using the tabulated format and a multi-disciplined team in a workshop setting the ignition risks can be identified relatively easily. The application of the rules from the code of practice allows the team to effectively make decisions on addressing ignition sources within hazardous areas by applying control measures.

**Methodology 2 – Process Hazard Analysis**

In this second case a HAZID workshop study format was used for the purpose of identifying and focusing in on the major fire and explosion risks for a spray drying plant. The objective of the study being to assist the client to identify and close the gaps between the current installation and good practice.

A key objective and strength of this methodology is to allow the workshop team to focus at a high level identifying both the occurrence and the consequence of various scenarios. Within a short period all the potential scenarios can be identified and documented.

The methodology followed in this situation was;

1. A multi-disciplined team with the right skills, experience and plant knowledge is assembled to work together in a workshop format.
2. Define the clients risk tolerance by establishing a risk assessment matrix
3. Identify fire & explosion scenarios using a structured tabular HAZID format. This step is performed by a team in a workshop setting looking at where the hazardous inventories are stored and processed, and what the likely ignition sources are.

4. Make an assessment of the consequences of the fire and explosion scenario

5. Assess what the existing risk reduction controls are.

6. Gather data on the efficacy of existing controls and emergency response.

7. Use good practice, codes and standards, analysis of process threats on the highest risk scenarios to make recommendations around possible risk reduction measures.

**Application of the method**

The multidiscipline team formed to apply this methodology first established the consequence matrix from which a qualitative ranking of consequence could be made.

<table>
<thead>
<tr>
<th>Consequence</th>
<th>People</th>
<th>Physical Assets</th>
<th>Reputation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Insignificant</td>
<td>Minor first aid (cut or graze)</td>
<td>Shut down for clean up - less than 72hrs no damage, spares on site.</td>
<td>Negligible impact</td>
</tr>
<tr>
<td>1 Slight</td>
<td>Minor medical attention</td>
<td>Minor plant damage,</td>
<td>Adverse local media</td>
</tr>
<tr>
<td>2 minor</td>
<td>Major incident needing hospitalisation</td>
<td>Week down time to repair items.</td>
<td>Adverse capital city media coverage</td>
</tr>
<tr>
<td>3 moderate</td>
<td>Hospitalisation required, one fatality</td>
<td>Replace large sections of chamber/piece of equipment</td>
<td>Adverse and extended national coverage</td>
</tr>
<tr>
<td>4 major</td>
<td>3 or more fatalities</td>
<td>Inability to process 24months</td>
<td>Adverse International media coverage</td>
</tr>
</tbody>
</table>

The next step was to agree the way frequency of event occurrence would be assessed.

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Rare</td>
</tr>
<tr>
<td>B</td>
<td>Unlikely</td>
</tr>
<tr>
<td>C</td>
<td>Moderate</td>
</tr>
<tr>
<td>D</td>
<td>Likely</td>
</tr>
<tr>
<td>E</td>
<td>Often</td>
</tr>
</tbody>
</table>

Finally a risk assessment table was drawn up. This table was then used as the basis for the HAZID analysis.
The HAZID technique was then applied to the spray dryer and associated process equipment. Hazards are identified with reference to either fire or explosion hazards and evaluated in terms of potential hazards and effects, threats (or causes in this case the ignition source), and safeguards/controls.

The focus of the workshop is primarily on identification and framing of hazards.

The following diagram shows the basic arrangement of the dryer.

The team systematically works through the plant identifying threats (ignition sources), consequences, applying risk scores and recording the controls and recovery measures that exist. The following table shows four lines from the HAZID analysis.
Major hazards for fire and explosion scenarios can then be prioritised for further analysis. In this particular case the following scenario’s ranked as the highest risk scores

Explosion Scenarios
- Ingredient bin
- Lactose and calcium carbonate (other products such as permeate) bin
- Dryer fluidised bed
- Dryer Powder cone mill
- Dry Cyclones

Fire Scenarios
- Dryer chamber
- Dryer fluidised bed

Additional analysis was then under-taken by using standards and codes of practices, specialist advice for particular plant areas with a score of 6 or higher to determine if prevention or mitigation controls would be appropriate to reduce the risk score.

For example in the dryer fire scenario – “Dryer Chamber” when a more in depth look at the threats is made it is clear there are numerous potential threats that could result in a smouldering fire within the dryer chamber, considered a zone 20 area.

For example - Process threats
- product formulation susceptible to thermal decomposition (eg high fat/protein)
- Air cooling systems failure
- Powder layer removal systems failure
- Incorrect setup of nozzle system
- Fines return system blockages
- Temperature control failure

Existing controls that were already in place are focused on mitigation of the effects of a smoulder such as;
- CO detection – automated response to picking up the gases of thermal decomposition.
- Dryer Deluge system – automated response to increases in air stream temperature (above normal) or levels of CO.

From the detailed analysis of the threats it was clear that a focus on preventative measures could reduce the occurrence and overall risk score of the fire scenario. However the plant should also have confidence in the existing mitigation measures also.

The final recommendations for this specific scenario where therefore a combination of:
• a risk based approach to identification of new preventative controls, such as setting of time bound process alarms, feedback from failed systems,
• the verification of existing systems design, such as deluge valve failure modes, methods to increase the robustness of the system, and
• the validation of control measures, such as instrumented alarms, analysers, deluge systems, are installed and operate as designed, are robust, and are proven regularly.

Discussion of methods – pros and cons
The two methodologies presented here for analysing process hazards in combustible dust handling plants follow two different avenues.

Method 1 uses the methods from codes and standards for handling combustible dust, and relies on accurate assessment of hazardous areas. It follows a set of guiding rules for determining if controls applied are suitable. It doesn’t differentiate between high hazard scenarios and lower hazard scenarios as it treats all ignition sources with equal weighting.

Pros of method 1
• A defined set of rules for determining the acceptability of equipment ignition hazards
• A simple qualitative method to apply to individual equipment items or to an number of equipment items joined together to form a process.
• It provides a systematic method for identifying potential ignition sources
• In the future non electrical equipment possibly will be assessed prior to the point of sale and equipment suitable and certified for the various zones will be available.
• It encourages addressing all ignition sources in processes with classified hazardous areas, not just electrical sources of ignition.

Cons of method 1
• It can be completed in a workshop session however requires a considerable amount of participant training by the facilitator during the sessions to bring them up to speed with the code of practice rules
• Determining if a potential ignition source can become effective is difficult and requires specialist knowledge.
• The tendency to over classify process plant or conservatively classify large areas will have huge impacts on the cost and complexity of non-mechanical equipment.
• Decisions regarding the zoning of items may be incorrectly governed by the type of equipment to be installed in the area rather than the correct process of determining the occurrence of the cloud or layer. An example of this could be a high speed mill where ignition sources are present in normal operation within what would normally be zone 20 area. Under the rules in the code of practice this is not allowable, and therefore such equipment cannot be installed.
Method 1 doesn’t take consequence of ignition into account, this is separately done by the application of Equipment Protection Levels (EPL’s) rather than zones. The consequences of ignition may lead to different decisions being made especially regarding the explosion protection measures.

Method 2 follows a risk based approach to identifying hazards and quantifying risk based on occurrence and consequence of certain scenarios occurring. It is a method applied to allow focus areas to be prioritised for further analysis.

Pros of Method 2
- A large number of scenarios can be explored in a relatively short time, maximising the output from relatively expensive risk workshops.
- Draws on the experience of the team to identify realistic scenarios
- Provides a short list of areas for further analysis into threats to the process causing ignition, configuration of controls based on risk score. Most companies have a limited amount of resources and budget so the focus is very important.

Cons of Method 2
- Unless considerable work is done beforehand in determining the combustible dust characteristics and the interpretation of these then the group will tend to consider all combustible dusts in a similar way and focus on consequence more than occurrence.
- Occurrence of the scenarios is “gut feel consensus” when using only qualitative methods and, depending on the team makeup and experience, the results can be vastly different.
- Determining the top event leading to the worst consequence is often difficult or not easily differentiated in this analysis.
- Individual threats can be missed due to the high level nature of the method.

In summary both methods work for identifying hazards within plants handling combustible dust. The methods developed for electrical safety such as classifying hazardous areas has laid the basis for qualitatively determining the occurrence of clouds and layers that could pose an explosion risk.

By using a systematic method for assessing the equipment ignition risks and implementing changes to control the risk a plant can be shown to be “taking all practicable steps” to ensure harm doesn’t occur.

To meet our obligations under the Health and Safety in Employment Act as employers, employees or designers, all ignition sources must be considered in the process plants we work in not just electrical ignition sources.
References

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6. ISO80039:36 – Committee Draft - Non-electrical equipment for explosive atmospheres - Basic method and requirements


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9. Clete R. S. “Coal dust explosion hazards”, mine safety and health administration