Hazard Analysis

In the previous article [Dust Explosion Characterization and Hazard Assessment (Part 1)] the concept of dust explosion risk was discussed. The risk of a dust explosion is the product of two factors, the probability of occurrence and the severity of the consequence. These two factors can be estimated, in part, by conducting standard tests to characterize the dust in question. Standardized tests to determine the minimum exploisible concentration (MEC), the minimum ignition energy (MIE), the auto-ignition temperature of a dust cloud \( \text{MAIT}_{\text{dust-cloud}} \) or layer \( \text{MAIT}_{\text{dust-layer}} \) and the limiting oxygen concentration (LOC) can be used to ascertain the probability of dust explosion occurrence. The standard tests to determine the peak explosion overpressure and rate of pressure rise can be used to estimate the severity of a dust explosion.

Once the powder / dust / hybrid materials are characterized, a five-stage hazard analysis can be started in many situations. The materials’ reactivities may not be well defined prior to the hazard analysis, or safety audits. In these cases, process / facility evaluations can begin, but cannot be concluded until appropriate material reactivity is determined. A list of steps, which should be taken to evaluate fire / explosion hazards in process, is listed in Figure 1. The steps will facilitate an organized review of the dust explosion hazards present.

As an integral part of the investigation, two different formal analysis tools should be used for the task. Some of these tools are FMEA, FTA, and HAZOP. It is beyond the scope of this article to discuss the details of these methodologies, however, each of them approach process safety uniquely and can complement each other. Additionally, they can act as a crosscheck for each other where one approach may even point out oversights made in the second.

Dust explosion hazards can be identified according to a specific process and equipment. A summary of explosion propagation, and initiation potential for various processes / equipment, are shown in Table 1.

<table>
<thead>
<tr>
<th>Process Equipment Type</th>
<th>Explosion Potential</th>
<th>Propagation Potential</th>
<th>Initiation Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Transport (e.g. Air Conveying, Belt Conveyors, Elevators)</td>
<td>High</td>
<td>High</td>
<td>ESD, Metal Sparks, Friction, Heat</td>
</tr>
<tr>
<td>II. Transfer (e.g. Separators, Cyclones, Baghouse, Silos &amp; Bins, FIBC)</td>
<td>Moderate to High</td>
<td>Moderate to High</td>
<td>ESD, Heat, Metal Spark, Hot Embers</td>
</tr>
<tr>
<td>III. Grinding</td>
<td>Very High</td>
<td>Very High</td>
<td>Metal Sparks, Heat</td>
</tr>
<tr>
<td>IV. Blending</td>
<td>Very High</td>
<td>High</td>
<td>ESD, Metal Spark, Heat</td>
</tr>
<tr>
<td>V. Dryers (e.g. Fluid Bed, Spray, Flash Belt)</td>
<td>Very High</td>
<td>High</td>
<td>Heat, ESD, Hot Embers, Friction</td>
</tr>
<tr>
<td>VI. Screening</td>
<td>Moderate</td>
<td>Very High</td>
<td>ESD, Friction, Hot Embers, Metal Spark</td>
</tr>
<tr>
<td>VII. Granulating</td>
<td>High</td>
<td>Moderate</td>
<td>ESD, Friction, Heat, Hot Embers</td>
</tr>
<tr>
<td>VIII. Dust Collecting Receivers</td>
<td>Very High</td>
<td>Very High</td>
<td>ESD, Heat, Metal Spak, Hot Embers</td>
</tr>
<tr>
<td>IX. Mixing into Reactors</td>
<td>Very High</td>
<td>Very High</td>
<td>ESD, Metal Spark, Heat</td>
</tr>
<tr>
<td>X. Bagging &amp; Filling FIBCs</td>
<td>High</td>
<td>High</td>
<td>ESD, Hot Embers, Metal Spark, Heat</td>
</tr>
<tr>
<td>XI. Emptying Bags/FIBCs</td>
<td>High</td>
<td>High</td>
<td>ESD, Hot Embers, Metal Spark, Heat</td>
</tr>
</tbody>
</table>

The first step is to “Collect Relevant Data”. This is primarily a collection of “book keeping” tasks where data on Material Properties (reactivity & ignitability), Process Flow Diagrams, and Facilities & Equipment Layout are obtained. The collection phase can also include data about the Equipment Specifications and Designs, Process & Instrumentation Diagrams, Material & Energy Flow Rates, and Utility Locations. Additionally, often neglected components of the collection stage are Documenting Standard Operating Procedures and Documenting Personnel Training Levels.

The next step is to “Conduct Facility Walk-Through”. This step is primarily for existing facilities but a “virtual walk-through” is also possible for facilities and/or process units that are still on the drawing board. The walk-through should focus on establishing the condition of existing Fire / Explosion Suppression Protection equipment. The reviewers should take many photographs / video and notes of the walk-through.

Figure 1. Five Stage Dust Explosion Hazard Analysis

Table 1. Process and Equipment Dust Explosion Hazards
been established then re-evaluate the hazards analysis and risk assessment for quantitative changes. A number of safety codes now address the dust / vapor explosion potential depending on the type of industry or operations. Codes of a general nature are listed as follows:

**NFPA Codes:**
- NFPA 65, 480, 481 for Combustible Metals and Metal Dusts
- NFPA 68, 69 for Explosion Protection Systems
- NFPA 91, 650, 654, 655 for Handling and Conveying of Dusts, Vapors and Gases
- NFPA 5000

**Universal Building Codes:**
- Requirements for Group H
- Occupancy, Section 307.1

Noting locations for dust cloud or layer hazards, unusual situations or conditions (on-the-ground realities that are not in the paper blueprint plans). Also, note areas where material upsets and dust accumulation tend to occur. Inclusion of utility locations and equipment conditions will help formulate future mitigation strategies or point to current explosion hazards. In addition to dust explosion hazards scrutinizing solvent storage and processing can identify hybrid mixture (dust and vapor) explosion hazards. The walk-through should also include the personnel and equipment in the location and traffic patterns near the process area. This provides a scope to establish personnel interactions with the process / facility (an often over looked safety component).

Now that the pertinent information has been collected, one can **Start the Hazard Evaluation**. Initially the team should first review the applicable safety codes (NFPA, OSHA etc). The team should then draft potential process upset & failure mode scenarios and then theorize potential effects of failure or upset. It is very important to include all identifiable potential ignition sources even though they may have a very low probability of occurrence. For dust explosion hazard analysis it is necessary to keep the focus on factors that comprise the explosion pentagon - Fuel / Oxidant / Ignition / Source / Confinement / Dispersion.

Once the evaluation is completed and the accident scenarios for the dust explosion have been established, the **Risk Assessment** of the scenarios can be made. The assessment can rely on the data obtained from laboratory tests conducted on the dust sample. The key factors to include would be the probability of initiation (ignition source present and sensitivity of the dust to ignition [minimum ignition energy]), probability that reactive material is present (fuel source or minimum exploisable concentration) and the probability of the potential failure occurring. The consequence of a potential dust explosion can be examined by focusing on the severity of the failure mode event to humans and to the facility. An indicator to the magnitude of the severity is from the explosion overpressure of the dust and the rate of pressure rise. Then for each hazard scenario a quantitative value to the potential dust explosion scenario should be assigned. This quantitative value can be in the form of money lost due to the explosion event, direct and indirect costs should be used.

Once the risk of the potential dust explosion event has been quantitatively established it is important to **Devise and Implement Hazard Mitigation Plan**. The plan should detail the dust explosion hazard mitigation strategy and document any procedural changes and equipment modifications. Once the mitigation plan has

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**Criteria for a Successful Hazards Analysis**

A successful hazards analysis is when all the hazards have been identified. We know that we have identified all the hazards when the level of effort, knowledge and experience of the hazards analysts dictate the level of hazard identification. Another factor is related to the ease of getting process information and the level of openness or availability of plant personnel. This also relates to the conceived degree of hazard by management and plant personnel.

To be successful, the hazard analysis should include hazards associated with the following: mechanical items, electrical or electro-mechanical items, electronic and computer control items, hydraulics and pneumatics, chemical reactions, or lack of them, sequences of operations, procedures, or lack of such procedures, utility losses, facility conditions, process conditions, startup sequence(s), shutdown sequence(s), emergency shutdown, and maintenance functions.

The success of the hazard analysis can also be measured by whether the identified hazards are realistic and credible and the consequences are realistic.
Many times, plant personnel do not understand or accept the identified consequences. Recent plant incidents investigated at FAI indicated that a lack of thorough knowledge of the ignition and explosion behavior of dust-air mixtures permitted an explosion to occur. In one case, the ignition behavior and the explosion hazard of dust accumulation on ledges of trusses was not identified. The knowledge of a dust’s minimum ignition energy, particle size distribution, electrostatic chargeability and resistivity would have allowed them to define the potential for a dust explosion. Once the potential was understood the necessary protective measures for their industrial operations could have been implemented.

Summary

Methods have been presented to evaluate the dust and hybrid explosion hazards in plants and process operations. Ways to evaluate hazards have been presented relative to material reactivity, ignitability and explosion output. Criteria for successful engineering hazards analysis have been identified. In powder operations, dust and hybrid fires and explosions can be minimized so that the potential is never near the operational conditions including startup, shutdown and emergency shutdown. Safety codes and testing have also been presented.

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