How to prevent or mitigate a dust explosion in your bucket elevator

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A bucket elevator’s unique characteristics make it both more vulnerable to and more difficult to protect from dust explosions than other mechanical conveyor types. However, testing can determine your material’s explosivity characteristics, and prevention and mitigation measures can help reduce the risk for a dust explosion and minimize the damage if one occurs. This article discusses material testing and explosion prevention and mitigation measures you can take to protect your bucket elevator.

The bucket elevator is one of the most commonly used mechanical conveyors for vertically transporting bulk solid materials. The way a bucket elevator receives, conveys, and discharges material, however, can create an ideal environment for a dust explosion.

A dust explosion requires that all five elements of the dust explosion pentagon are present: combustible dust, a sufficiently concentrated suspended cloud, an enclosure, an oxidant (usually oxygen in the air), and an ignition source. During an explosion, the ignition source ignites nearby dust particles starting a chain reaction during which the suspended dust particles rapidly combust, generating enough heat and gas expansion to breach the enclosure.

If you’re conveying combustible dust in your bucket elevator, you should always assume that all five dust-explosion elements could be present because completely preventing an explosible atmosphere or the introduction of an ignition source usually isn’t possible. I’ve personally investigated bucket elevator dust explosions that occurred when the elevator wasn’t even operating. Generally, any bucket elevator handling small particles (≤500 microns) of agricultural materials (such as grain or sugar), fuels (such as coal or lignite), wood products, textiles, specialty chemicals and precursors, or certain unoxidized metals is potentially at risk for a dust explosion or fire.

You can reduce the risk by knowing your bucket elevator’s hazards and your material’s combustion characteristics and by minimizing potential ignition sources and dust. You can also employ mitigation measures to reduce the damage caused by an explosion. Before discussing explosion prevention and mitigation measures, however, knowing some bucket elevator basics is important.

Bucket elevator basics

A typical bucket elevator, as shown in Figure 1, consists of a boot section at the bottom with a material inlet and a boot pulley, a head section at the top with a material discharge and a head pulley, one or more intermediate housing sections, a belt or chain that travels around the two pulleys (or sprockets if a chain is used), an electric motor, and numerous plastic or steel buckets mounted on the belt or chain. In operation, the motor turns the head pulley and moves the belt or chain. The attached buckets collect material from the inlet in the boot, carry it up to the head, and dump it out through the discharge.
The elevator’s intermediate housing sections can be either a single shaft containing both the up and down sides of the belt, or they can be separate, with an up leg and a down leg. While most applications require an enclosed bucket elevator to contain dust or protect the material from the weather, an open bucket elevator can be used for some indoor applications where the material doesn’t generate dust. Also, some bucket elevators, such as a Z conveyor, which typically has horizontal loading and discharge sections and a vertical intermediate section, are designed to handle fragile materials more gently and create minimal dust and spillage but tend to operate at a lower material throughput rate than a standard bucket elevator.

Know your bucket elevator’s hazards
Recent full-scale tests at two internationally recognized, independent labs\(^1\)\(^2\) demonstrated higher maximum reduced pressures (\(P_{\text{red}}\)) during an ignition event than were previously assumed. \(P_{\text{red}}\) is the maximum pressure that occurs during an ignition event where mitigation measures have been taken to reduce the ignition’s effects. Relatively high turbulence and dust loading inside the bucket elevator housing contributed to the higher \(P_{\text{red}}\) values, which were observed both in elevators with explosion suppression systems and in those with explosion venting. [Editor’s note: More findings of these tests, along with explosion suppression and venting, are discussed later in this article.]

The elevator’s buckets typically generate some fines and dust from turbulence and spillage when they pick up the material in or near the boot and from jostling or bumping as the buckets rise. Depending on a material’s nature, its particles can become statically charged as they fall. Most of the spilled material accumulates in the boot, but some fines can cling to the elevator housing’s inside wall and can then become re-entrained if the wall is bumped or otherwise disturbed — if the drive belt becomes misaligned, for example, and a bucket impacts the wall. Airflow from an attached dust collector can actually help to entrain fines dislodged from the housing wall during an impact.

Even without an impact, fines clinging to the housing wall can fuel a combustion event that begins lower in the housing or in the boot. A bucket elevator is often very tall, and an ignition near its boot can create a chimney effect, resulting in increased turbulence as the heated air rises through the shaft and flows around the buckets. This turbulence can re-entrain the dust clinging to the housing walls, adding fuel to the fire.

Determine your material’s combustion characteristics
Having your dust tested will help you determine how much protection your bucket elevator needs. Per NFPA 68 and 69,\(^3\) the end user of the equipment is responsible for testing the materials being handled. Many bulk solids equipment suppliers and independent consultants operate labs where you can submit a sample of your material for testing.\(^4\)

Certain testing parameters are critical. Your dust’s \(K_s\) value is a measure of the rate of pressure rise in a standardized test and is indicative of how severe an explosion the dust will generate. Your dust’s \(P_{\text{max}}\) value is the maximum pressure the dust generated during the standardized test and is indicative of the pressure a deflagration could generate without mitigation measures. These values will help you determine your elevator’s required protection device configuration and housing strength. Your dust’s minimum explosive concentration (MEC) can be useful where part of your protection strategy is to minimize fines in the elevator. Your dust’s air and layer minimum ignition temperatures can be useful if your material is being dried or otherwise exposed to elevated temperatures prior to entering the elevator.

Your material’s capacity to self-heat is also important. A self-heating material can degrade and spontaneously combust if left undisturbed long enough. Examples of self-heating materials include low-order coal, wood from evergreen species, and sewage sludge. You should
consider inerting your bucket elevator if you’re handling a material that’s susceptible to reaching its ignition temperature spontaneously. Inerting involves sealing the elevator’s housing and introducing an inert gas such as nitrogen or exhaust gas from a gas burner to reduce the oxygen concentration to a safe level for your material, which can be determined by testing.

Eliminate ignition sources
Preventing predictable ignition sources from entering your bucket elevator should be your first step for avoiding a dust explosion. Most ignition sources in bucket elevator explosions come from upstream process equipment, such as a drier or mill. Carefully monitor and control your upstream process to prevent tramp metal, sparks, or other ignition sources from entering your bucket elevator. Monitor the material inlet where possible using temperature sensors, metal detection, or spark or infrared detection, and ensure that rapid, preferably automatic, prevention steps occur at predetermined setpoints. For example, metal, spark, or infrared detectors can shut down the process or activate a fire-suppression system if an ignition source is detected.

An ignition can also come from inside the bucket elevator. A misaligned or slipping belt can generate heat and should be automatically monitored, as shown in Figure 2. Failed internal bearings can pose a particular hazard. You can use external bearings or monitor internal bearings at the elevator’s boot and head ends with thermocouples (Figure 2). If the belt goes out of its control parameters or if the bearings begin to overheat, the bucket elevator should automatically shut down to prevent ignition.

Electrical equipment should all be Class II, either Division 1 or 2 (as appropriate) in accordance with the National Electric Code (NFPA 70®). Also pay careful attention to electrical bonding and grounding as outlined in NFPA 77.

Review all administrative controls to ensure safe work practices. Pay particular attention to hot work permit procedures and be vigilant when employing outside contractors who may not be familiar with your plant’s safety requirements and procedures.

Minimize dust
Even though you should assume that your bucket elevator will always contain enough dust to support an explosion, you should still do what you can to minimize dust.

Configure your elevator’s material inlet to minimize turbulence at the boot. If your application allows, using a Z conveyor and metering the material feed can provide a more controlled filling and reduce fines to a safe level.

Use a dust collector to minimize entrained fines and fine deposits on the bucket elevator’s housing walls. Regularly inspect and clean inside the boot and housing to remove fine buildup.

Employ mitigation measures
Even if you’ve minimized ignition sources and dust in your bucket elevator, an ignition could still occur. To mitigate the effects of an explosion:

- Locate your bucket elevator outdoors if possible.
- Ensure that the bucket elevator’s housing is strongly built. However, building the housing strong enough to withstand a dust explosion’s high $P_{\text{red}}$ even in conjunction with suppressant discharge devices (discussed next), may not be practical.
- Use an active suppression system triggered by optical or pressure detectors, or both, to lower the $P_{\text{red}}$ and minimize the effects of an explosion. The independent lab tests previously mentioned demonstrated that suppressant discharge devices were most effective when mounted in the boot, the head, and the legs, as shown in Figure 1. Partly because the boot and head sections are relatively small and the legs are typically long, flames from an ignition starting in the boot or head section can accelerate up or down the legs ahead of pressure buildup. As a
result, pressure detection when used alone resulted in quite high $P_{rel}$ values (upward of 2.4 bar). The lowest $P_{rel}$ value ($\leq 0.3$ bar) was achieved using optical detectors. Many factors affect this value, including the dust’s $K_s$, the bucket construction material, the distance between buckets, and the detector locations and set points.1,2

• Vent your bucket elevator. NFPA 68: Standard on Explosion Protection by Deflagration Venting now has a section (paragraph 8.8) devoted to bucket elevators. This level of detail concerning bucket elevators has never before been included in NFPA consensus standards and is based on full-scale tests conducted by the United Kingdom’s Health and Safety Executive. The standards include required vent sizes, distances between vents for various $K_s$ values, and required housing strengths.

The standards state that venting can be achieved using flameless vents as well as conventional vent panels. A conventional vent located indoors must be ducted to a safe discharge area outside the building, but a flameless vent is made to absorb the explosion without exterior discharge. This solves the problem of protecting the elevator’s boot section, which is typically located inside the building, often in a restricted, below-grade location, making a conventional vent impractical.

• Use isolation devices to stop the spread of an explosion. An explosion in a bucket elevator can spread through any and all openings and in all directions. A rotary valve, double flap-gate valve, gate valve, pinch valve, or suppressant discharge device triggered by a detection device can isolate an ignition event and keep it from spreading outside the elevator. Provide isolation at the material discharge coming off the elevator’s head, at the material inlet leading into the boot, and on any connected dust collection ducts.

For further reading

Find more information on combustible dust hazards and dust explosion prevention and mitigation in articles listed under “Safety” and “Dust collection and dust control” in Powder and Bulk Engineering’s comprehensive article index in the December 2014 issue or the Article Archive on PBE’s website, www.powderbulk.com. Find more information on bucket elevators in articles listed under “Mechanical conveying.” (All articles listed in the archive are available for free download to registered users.)

References


4. For a list of companies that offer material testing, see Powder and Bulk Engineering’s current Reference & Buyer’s Resource, available at www.powderbulk.com.

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