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Processes for Drying Powders – Hazards and Solutions

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This paper will provide an overview of the various processes for drying combustible powders with particular emphasis on spray, fluidized bed and ring dryers. FM Global, an industrial property insurance company, has seen numerous explosion and fire losses in these units that have caused extensive equipment damage with a serious impact on production and loss of sales. A number of large incidents have occurred in Europe and the UK.
The paper will review the loss history accumulated by FM Global over the last 25 years and point out overall causal factors as well as specific factors in the major processes. This also includes some information on incidents provided by a major manufacturer of process dryers.
There will be an overview of the processes with emphasis on operational parameters that can impact the hazard created by processing combustible dusts. While the systems can be quite different in size, function and operating conditions, a number of common hazards are present.
With the review of each major process type there will be a discussion of process hazards, key controls, alarms and interlocks and description of the protection and mitigation features that can be implemented to minimize the effects of fire and explosion events. This will emphasize FM Global loss prevention guidelines but will also indicate applicable NFPA and EU codes.

1. General overview of drying operations

There are a number of dryer types that can be used in industry for processing solids (Mujumdar 2006). Dryers can be of the continuous or batch type. Heating can be provided by combustion of a fuel directly into the drying chamber or indirectly by using another media to carry heat to the drying chamber. The indirect heating may be provided by air, steam, hot water or organic heat transfer fluids. Direct heated dryers also present the potential for a fuel explosion.
Most dryers operate at approximately atmospheric pressures but some sensitive materials are dried under vacuum and at lower temperatures and these are most often small batch processes.
The material handled can be combustible or non- combustible which has a significant impact on the hazards that need to be dealt with. For this paper, the focus will be on dryers handling combustible solids as these present both fire and explosion hazards.
Small quantities of materials are often dried in batch tray dryers and these present little or no explosion hazard from the solids being processed but can present vapor explosion hazards if the fluid being removed is an ignitable liquid. *(Ignitable Liquid:* Any liquid or liquid mixture that will burn. A liquid will burn if it has a measurable fire point. Ignitable liquids include flammable liquids, combustible liquids, inflammable liquids, or any other term for a liquid that will burn.) They can also present fire hazards if overheated or spilled solids remain in the dryer for extended periods.
Large quantity operations require the use of continuous dryers and with the large rates of solid dry product create the potential for both explosion and fire. The most common types of continuous dryers include the following:

- Belt or band dryers
- Rotating drum dryers
- Flash or ring dryers
- Spray dryers
- Fluidized bed dryers

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1.1 Drying operation hazards

Dying operations present many hazards both from an operational standpoint to insure quality product is produced and from the safety aspect to insure there are no accidents that interrupt operations and harm employees. Equipment that is well controlled to produce quality product often has reduced the kinds of malfunction that result in damage to property or exposure to personnel. (Process control & alarms are usually considered the first layer of protection in a layer of protection analysis LOPA).

Some of the common hazards of drying operations include:

- Fuel explosions
- Release of flammable vapors/solvents and organic heat transfer fluids
- Accumulations of material
- Overheating leading to spontaneous heating and autoignition of the solid being processed
- Sparks – electrostatic, friction or electrical
- Dust fire or explosion
- Discharge of hot product to downstream processes or storage

Fuel explosions are usually addressed early in the project due to the impact on product quality. Proper design of the fuel firing control system and application of standard codes of installation will limit the risk from this exposure. Example codes include FM Global Loss Prevention Data Sheet 6-9, *Industrial Ovens and Dryers*, NFPA 86 *Standard for Ovens and Furnaces* and BS 5410, part 3, *Code of practice for oil firing. Installations for furnaces, kilns, ovens and other industrial purposes*

The hazard produced by the removal of flammable solvents from the solid product is usually recognized but the hazards presented by the use of organic heat transfer fluids (HTF) are often overlooked. They can be misunderstood by both the user and installer because most HTF have high flash and boiling points. This misunderstanding has caused many fire and explosion losses in industry. HTF are often handled above their flash or boiling points and therefore are quite easily ignited and once ignited burn as hot as any low flash point liquid. HTF used at elevated pressure can also create a flammable mist when released and result in a combustion explosion. In a recent 10 year period FM Global recorded 111 events involving HTF of which 73 were fires and 7 were explosions with the remainder having other causes.

To control the hazards of HTF, details can be found in FM Global Loss Prevention Data Sheet 7-99, *Heat Transfer by Organic and Synthetic Fluids.*

To control the potential of overheating, spontaneous heating and fire/explosion hazards of the combustible powders being handled, proper understanding of the material properties is needed. Some of the more common properties that may be needed include:

- Kst, Pmax (ASTM 1226 or EN14034-1, 2)
- Minimum ignition energy, MIE (ASTM E2019 or EN13821)
- Minimum explosible concentration, MEC (ASTM E1515 or EN14034-3)
- Thermal stability
  - DSC (Differential scanning calorimetry)
  - DTA (Differential thermal analysis)
- Isothermal stability test
  - Spontaneous ignition test (UN Division 4.2)
- Layer ignition test (ASTM E2021 or EN50281-2-1)
- Cloud ignition test (ASTM E1491 or EN50281-2-1)
- Limiting oxidant concentration, LOC (EN14756)
- Resistivity, conductivity, chargeability
- Toxicity

Once the material properties are understood, control of material flow in the process by measuring flow or physical observation is needed to prevent unexpected accumulations or extended heating beyond that normally expected.

Direct flame ignition from the heating system is a hazard that can be reduced or prevented by indirect heating.

Hot work exposures are common in industry and the hazard can be reduced or prevented by implementing a hot work permit system (see FM Global Loss Prevention Data Sheet 10-3, *Hot Work Management*)

Finally relative to controlling the fire and explosion hazards associated with these operations a number of steps are possible. For large dryers, outside locations minimize the peripheral damage from fires or explosions. Where they need to be located indoors they should be isolated from other operations in a separate building or an attached structure on the outside wall of an existing building with at least 1 hour fire-rated construction. Explosion venting of most of these dryers will be needed where clouds of dust or flammable vapor can be present. Finally, automatic fixed fire protection systems (sprinklers) will be needed where combustible product is present in quantities sufficient to cause damage.

2. Loss History

To understand the exposures that can be presented by drying operations it is useful to review loss history. In a recent 25 year period, FM Global experienced 260 explosions involving dusts and within those incidents 14 involved dryers including 5 incidents in spray dryers, 7 in rotary dryers and 2 in flash dryers. Analyzing the causes of these losses we find that burner flame, overheating, hot surface, chemical action, sparks and static were the causes identified.

In a different period, both fire and explosion losses involving only spray dryers were studied. Here 18 incidents were found with ½ fires and ½ explosions. Of these, 13 were in the food industry. We have noted a growing number of incidents involving the processing of milk and infant formula type products. The cause of spray dryer incidents include the same ignition sources as from the larger review but here, 8 of the losses were associated with overheating.

One of the problems with insurance data is small incidents or those below the deductible go unreported skewing the data to larger losses and making the frequency look lower than reality.

GEA – Niro, a major manufacturer of industrial spray dryers shared some of their incident data information. The data is based on an estimated 4,500 – 5,000 dryers in service in a period of over 40 years. They indicate 285 fires and 56 explosions. Of those, they classified 174 of them as ‘major’ and noted that at least 28 started in the fluidized bed dryer. They identified the following as major contributing factors:

- Explosion vents welded shut or not ducted outside
- Fire extinguishing systems inoperable

While this data gives a much clearer picture of the frequency of incidents in these units there is only limited detail on the industry involved, the causes or scale of the events (monetary loss or downtime).

3. Review of dryer types

The next several sections will address specific dryer types and the typical process features related to operating safety as well as features controlling dust hazard and effects.

3.1 Belt or band dryers

This is the type of dryer that normally comes to mind when speaking of dryers and might be called conventional dryers. They typically consist of a horizontally mounted sheet metal enclosure with a belt/band moving the product through the dryer. Heating is often direct firing of gaseous fuel. Indirect heating by air or steam would also be common.

Typically the product is sheet materials like cloth, carpet and particle board but other possibilities include grain, wood chips, etc. The former materials would not present a dust hazard but the latter could. In these types of dryers the main hazard would be where solvent liquid/vapors are being removed with the result being a potential for a flammable vapor-air explosion.

Process controls for both types of product would be temperature control for the heating and air circulation systems and monitoring/controlling product flow to prevent overheating and maintaining the belt /band system.

From the safety side there would be a need for safety ventilation where flammable vapors are being removed, temperature controls where excess temperatures can cause ignition of the product and fire protection systems, usually automatic sprinklers, to protect the largely inaccessible portions of the dyer where fires can grow undetected.

Maintenance issues could include regular inspections of moving parts looking for rubbing parts (friction) and spilled combustible material which could ignite by spontaneous ignition from sitting too long at elevated temperatures or by the friction of the moving parts.

3.2 Rotary drum dryers

Rotary dryers (Figure 1) are used in many operations with two common occupancies being wood chips for particle board plants or the grain waste at fuel ethanol facilities. They are often large because of the amount of materials that need to be processed. The process material and the hot gases usually come in one end and out at the other. They are usually slightly inclined to move the material from one end to the other and the rotation tumbles the material and has the potential to create dust clouds. In other cases the wall of the dryer has metal baffles or “flights” which lift and advance material through the drum. The process has the potential to create hot embers either from direct heating or where material accumulates in the dryer, overheats and eventually re-enters the process stream.

From an operations standpoint the basic loss prevention features related to fuel fired equipment should be applied with the added complication that there are gears, bearings and alignment issues to insure the equipment operates properly and material doesn’t accumulate, overheat and ignite. The nature of the

Figure 1: Rotary Drum Dryer

vessel makes active protection for the fire hazard somewhat problematic and they are usually heavy construction so somewhat resistant to small events. The nature of the equipment makes direct explosion venting impractical since it could be installed only on the ends. Some venting is possible through the inlet and outlet openings. Down stream equipment may include cyclone or bag type dust collectors which may need explosion venting.

The following additional features are recommended to minimize the damage from a fire or explosion:

1. Do not exceed operating capacity without careful study (management of change). Increased capacity is often achieved by higher processing temperatures increasing the potential for overheating and development of hot embers.
2. Monitor temperature of the air at the inlet and outlet of the dryer and the discharged product itself and provide interlocks to shutdown heating and dump product to a safe location, not moving it to the process line or storage.
3. Provide systems for spark detection and extinguishing both in the heated air and product lines. Spark or ember detection in the product stream may require diversion of the product and deluge water spray to control a potential fire in downstream equipment.

For examples of detection and diversion systems suggested for a wood particle process see FM Global Loss Prevention Data Sheet 7-10 *Wood Processing and Woodworking Facilities*, Figure 17 and 18.

3.3 Flash and ring dryers

Flash dryers (Figure 2) are little more then pneumatic transport systems with an enlarged heated section which serves to increase dwell time to dry the product being processed. Ring dryers are a close cousin and becoming especially popular in the fuel ethanol industry. Downstream processing can include cyclones and bag dust collectors and possibly fluidized beds to further dry or cool the product before discharge to use or storage. They may be either direct or indirect heated. They present many of the same process hazards of the rotary dryer system.

Loss prevention precautions include preventing accumulation of dusts and particulate in the ducts which can overheat with the potential for creating hot embers. Operating beyond design capacity and associated higher operating temperatures can exacerbate both of these problems.

Protection features include temperature monitoring throughout the system, spark detection and extinguishing systems and explosion venting including the fluidized bed portion. Ring dryers create added complication in providing explosion venting for the ring section with a large L/D. The solution to providing adequate venting is providing venting for 'virtual sections' with manageable L/D.

Figure 1 Flash Dryer

3.4 Spray dryers

Spray dryers are very common in the food and pharmaceutical industry with fluidized beds for finish drying and cooling. Heating is most often but not always indirect. Solid/liquid slurry is pumped thorough an atomizer with high pressure or air to create a fine spray of slurry. The heated air drives off the fluid (water or solvent) resulting in fine to moderately coarse particles falling to the bottom. It is understood that for the most part, in the upper part of the dryer the product is too wet and the concentration of material too low to present a dust explosion. At the bottom there is now dry product and increased concentration with a greater potential for an explosion. The hazard is recognized in VDI 2263, part 7 where the body of the dryer is classed as zone 20, continuously hazardous. The system has associated dust and product separation and transfer, both pneumatically and by mechanical means with belt or screw conveyor components. Unique process hazards include the following:

- Powder accumulations near the atomizer and elsewhere
- Peripheral equipment hazards
    - Hot bearing/surfaces
    - Fans/blowers with mechanical sparks

To deal with these process hazards a number of features need to be provided. For the heating system, appropriate fuel and combustion controls as well as monitors and interlocks between heating and the feed and product systems are needed. Install vibration detection where there are large fans, especially those in the dust stream. Temperature supervision is important for the inlet and outlet of both spray and fluid bed dryers and the product outlet. It is not uncommon to have video observation inside the spray dryer to watch for accumulation near the atomizer. A number of explosions have been caused by spontaneous heating of the accumulated material which breaks loose and causes ignition in the bottom of the dryer where the driest material can be above the MEC. Finally, a relatively recent addition is to monitor for carbon monoxide (CO), an indicator of spontaneous heating.
Because of the inherent dust hazard in much of the system a key prevention feature is ignition control. Unique ignition sources and controls are noted below:

- Overheated materials especially near atomizer where hot air usually enters can be prevented by
    - Control accumulations by proper operating limits for atomizer
    - Temperature limits both for incoming hot air and within the dryer
    - Video monitoring
    - Maintenance (lubrication, alignment, cleaning)
    - Regular cleaning of the interior using an air broom or wash down
- Static ignition is usually not an issue unless the powder has an MIE less than 10 – 25 mJ
    - Control static by grounding, bonding and inerting (sometimes the latter can be accomplished with direct heating systems where the combustion off-gas is low in oxygen)
- Mechanical sparks are usually related to fans in the dust stream which should be prohibited but where this is not possible control of sparking can achieved by
    - Fans of type A or B construction per AMCA 99-0401-86, *Classifications for Spark Resistant Construction*
    - Vibration monitoring by detection or physical checks
    - Maintenance (lubrication, alignment, clean)
- Friction sources can be controlled by
    - Monitoring & maintenance

Even where there is high level attention to control (reduce frequency) of ignition sources, we know from extensive loss experience in this and other occupancies that ‘ignition sources are free’. There always seems to be one at the worst possible time. The result is the need for mitigation features.
The most common explosion mitigation is venting. For most operations, calculations assume the full volume of the vessel is used for vent sizing. However based on studies, losses and knowledge of the process some adjustment is permitted. FM Global Loss Prevention Data Sheet 7-76 and NFPA 68 permit sizing on a partial volume approach assuming that the conical section is where the explosive volume will occur. VDI 3673 and EN 14491 use full volume & Kst but adjustment is permitted “based on published or experimental data from representative venting trials”. A major spray dryer manufacturer, GEA Niro uses a Radandt adjustment to VDI/EN equations based on testing at moderate scale along with a filling factor to adjust for the cloud dispersion method. In addition they use a K and Pmax based on a test at reduced dust concentration accounting for the typically lower the concentration in the spray dryer compared to the value developed using the standard test methods (ASTM 1226 or EN14034).
Based on a past comparison for an FM Global client, the FM Global, NFPA and GEA Niro methods used without consideration for an individual case can come up with different vent requirements. A few adjustments within the allowances of the methods permitted a vent area that all parties agreed was acceptable.
Other mitigation approaches can use explosion suppression systems or containment design where the vessel is designed to be strong enough to either prevent deformation (pressure resistant) or allow limited deformation but not rupture (pressure shock resistant). Containment is likely the most costly of the three mitigation methods.

3.5 Fluidized bed dryers

Fluidized bed dryers are often used along with spray or flash dryers or can be operated independently. These are typically horizontal cylinders in design with a perforated air distributor plate. Flow of air through the plate and the bed fluidizes the particles and allows removal of any moisture (water, solvent, etc). The wet material typically enters one end and the dry material finds it way to the discharge outlet. Some of the unique hazards of fluidized bed dryers are as follows:

- Spontaneous heating from material spilling off the bed, not moving freely or accumulating in low flow areas
- Maintain fluidizing medium (air) flow
- Product thermal stability and temperature control
- Hot bearings/surfaces
- Sparks – electrostatic, friction or electrical
- Flexible connections that can blow out in an explosion exposing the surroundings

There is always some lifting of the product fines into the space above the bed (elutriation) that presents a continuous or intermittent dust explosion potential. VDI 2263, part 7 classifies the space above the bed as zone 21 (occasionally in normal operation) while the plenum below is zone 22 (seldom, short term hazard). To control the hazard of these operations a number of process interlocks and alarms are suggested:

- Loss of fluidizing medium (air) flow should cause shut down of the heating system
- Temperature should be monitored and shut down interlocks considered on the following
    - Fluidizing medium inlet & outlet
    - Product outlet
    - Heating system
    - Key bearings – mechanical components, blowers, etc.
- LEL monitoring where solvent may be present
- Carbon monoxide (CO) as an indicator of spontaneous heating

Finally explosion mitigation will be needed to minimize the damage to equipment from an explosion. As with spray dryers, eliminating oxygen, containment, venting, explosion suppression and isolation are all appropriate. The most common solution would be suppression or venting. Unlike the case of spray dryers, design for the full volume of the dryer is suggested.

4. Conclusions

Drying systems processing combustible particulates and powders present inherent explosion hazards. Each type of system has its own operation & design features that prove valuable to process different types of materials and these differences present issues in developing appropriate prevention and mitigation strategies. Even with the differences, there are commonalities that can apply throughout the industries using these systems. Attention to the small details and differences on individual systems are needed to insure that each operates in the safest manner possible.

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