FPRF Combustible Dust Symposium

**NFPA Combustible Dust Hazard Codes and Standards**
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NFPA voluntary, consensus standards form the most complete basis currently available for establishing combustible dust hazard process safe practices. No comprehensive federal regulation exists; in fact, only grain handling facilities are specifically covered by a US Department of Labor – Occupational Safety and Health Administration (OSHA) 1987 regulation. NFPA, on the other hand, maintains seven NFPA documents applicable to the dust-hazard specific requirements for agricultural and food processing dusts, combustible metal dusts and powders, wood processing and woodworking dusts, sulfur dust, coal dust, and all other combustible dusts.

These NFPA documents begin with a hazard assessment that considers the facility, the process, and the associated fire and explosion hazards. Once identified by the process hazards analysis, specific hazards are evaluated in order to determine the specific type and level of control measure required.

## Background

While the West Pharmaceutical, CTA Acoustics, and Hayes-Lemmerz incidents of 2003 served as a catalyst for the US Chemical Safety and Hazard Investigation Board (also known as Chemical Safety Board or CSB) to initiate the Combustible Dust Hazard Study, the February 7, 2008 explosion and fire that struck the Imperial Sugar refinery in Port Wentworth, GA reignited industry and government attention on the hazards of combustible dusts. The CSB highlighted the hazards of combustible dusts much earlier in its 2006 report, *Combustible Dust Hazard Study*. The Executive Summary reads, "The CSB has concluded that combustible dust explosions are a serious hazard in American industry, and that existing efforts inadequately address this hazard (1)." The Imperial Sugar incident served as another reminder of the accuracy of this conclusion. The CSB study highlights 281 incidents that occurred in 44 states, in many different industries, and involved a variety of different materials.

The CSB issued several recommendations with their final report, including a recommendation that OSHA develop and issue a comprehensive combustible dust standard for general industry that addresses hazard assessment, engineering controls, housekeeping, and worker training. According to CSB, the OSHA standard should be based on the NFPA voluntary consensus standards. OSHA responded by establishing the Combustible Dust National Emphasis Program (NEP) (Directive CPL 03-00-008 updated March 2008). "The purpose of this NEP is to inspect facilities that generate or handle combustible dusts which pose a deflagration or other fire hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape; deflagrations can lead to explosions (2)."

OSHA's Director of Enforcement Programs, Richard Fairfax, reported that under the NEP, OSHA had conducted 813 inspections during the period November 1, 2007 through March 6,

2009, coinciding with the initial implementation of the NEP (3). Those inspections resulted in a total of 3662 violations, with paragraph 5(a)(1) General Duty Clause, Housekeeping, and Electrical topping the list in terms of most frequently cited provisions of OSHA regulations. OSHA is not permitted to cite workplace hazards based upon NFPA consensus standards provisions. However, the NEP states that the NFPA standards are used to identify known hazards resulting from combustible dust hazard process operations. If, upon inspection by OSHA, those known hazards are not addressed, OSHA is able to cite for failure to abate the specific hazard to either the General Duty clause or to a specific OSHA standard.

The House of Representatives also took notice and passed H.R. 5522, the Worker Protection Against Combustible Dust Explosions and Fire Act in March 2008. The bill, when signed into law, would direct OSHA to issue an interim standard followed by a final rule according to a specific and accelerated timetable. NFPA and other recognized industry standards were to be the basis for OSHA's regulatory action under the provisions of this law. No final action was taken by the Senate at the conclusion of the previous Congressional session, so the process has resumed with the new Congress. The House Committee on Education and Labor reintroduced the bill (H.R. 849) on February 4, 2009.

As noted in the CSB study, combustible dust explosions can occur in any industry handling combustible dusts; however, it is important to point out that four industry sectors account for over half of the incidents – food products, lumber and wood products, chemicals, and primary metals) (1).

So, even without a federal standard making the NFPA standards mandatory, these standards are frequently used as the basis for inspection guidance and upgrading process hazard control for combustible dust hazard processes in a wide range of industries. What do these documents require and how do they apply to the various industries? We will begin with a discussion of NFPA 654.

## NFPA 654 – Combustible Dust Hazard Process Safety Building Block

NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids* was initiated by the Committee on Dust Explosion Hazards in 1943 and originally applied only to the prevention of dust explosions in the plastics industry. By 1982, the scope had been expanded to include chemical, dye, and pharmaceutical dusts, since the fire and explosion hazards of those dusts were deemed to be generally the same as for plastic dusts. The current edition of NFPA 654 applies to the manufacturing, processing, blending, conveying, repackaging, and handling of combustible particulate solids and their dusts (4). It covers all combustible dusts, except those specifically addressed in other NFPA standards, and is one of the most cited documents for control measures for combustible dust hazards. OSHA and CSB reference NFPA 654 in their respective documents alerting industry to the hazard potential from combustible dusts and their potential for fire and explosion ((1), (2), and (5)).

In summary, NFPA 654 recognizes the fire and life safety hazards posed by combustible dusts and applies building construction requirements and equipment isolation methods to mitigate the consequences of fires and explosions. The standard also addresses selection and design of protective systems by referencing other NFPA standards (such as NFPA 68 and 69) in order to meet the goal – "to provide safety measures to prevent and mitigate fires and dust explosions in facilities that handle combustible particulate solids (4)."

The standard also requires that facilities implement management systems to prevent dust explosions by addressing:

- Hazard evaluation
- Change management
- Inspection and maintenance
- Housekeeping
- Training and procedures

NFPA 654 defines a *combustible particulate solid* as,

> "Any combustible solid material, composed of distinct particles or pieces, regardless of size, shape, or chemical composition (4)."

This term addresses the change that the solid material undergoes as it moves within the process equipment, where actions such as particle abrasion, grinding, or pulverizing break the material down and produce a mixture of large and small particulates, some of which could be small enough to be classified as dusts. For this reason, we have the first key point regarding the material – the presence of dusts should be anticipated in the solids handling process stream, regardless of the starting particle size of the material.

Combustible dusts are a subset of the combustible particulate solid; likely by testing, it has been determined that the material will undergo combustion at some temperature or when exposed to some determined strength of ignition source. However, because combustible dust explosions require additional elements beyond the fundamental fuel, oxygen, and ignition source in the traditional fire triangle, a combustible dust must also be dispersed in air and suspended and there must be confinement in order to realize the pressure increase associated with the explosion. That means that the particulate must be capable of being suspended in air. NFPA 654 defines *combustible dust* as,

> "A combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape (4)."

Dusts traditionally have been defined as a material 420 micron or smaller (capable of passing through a U.S. No. 40 standard sieve), but that criterion means particulates of atypical shape and size might be excluded. The annex of NFPA 654 recommends that combustible particulates with an effective diameter of less than 420 micron should be considered as meeting the criterion of the definition. The annex also highlights that even though flat platelet-shaped particles, flakes, or particles of fibers with lengths that are large compared to their diameter usually do not pass

through a 420 micron sieve the particles might still pose a deflagration hazard. Other complicating aspects of defining the dust solely on the 420 micron basis include the tendency for particulates to agglomerate due to accumulated electrostatic charge. The agglomerates behave as if they were larger particles, yet when they are dispersed they present a significant hazard. The precautionary message from this discussion is that any particle that has a surface area to volume ratio greater than that of a 420 micron diameter sphere should also be deemed a combustible dust.

The final unique term found in NFPA 654, *hybrid mixture* indicates "a mixture of a flammable gas with either a combustible dust or a combustible mist (4)." A key aspect of hybrid mixtures is that even when the flammable gas or vapor is present in the mixture at concentrations less than the lower flammable limit (LFL) for the gas or vapor, the violence of a dust–air combustion is enhanced. NFPA 654 also warns that in certain circumstances, hybrid mixtures can be deflagrable, even if the dust is below the MEC and the gas or vapor concentration is below the LFL. Examples of hybrid mixtures are a mixture of methane, coal dust, and air or a mixture of gasoline vapor and gasoline droplets in air.

Chapter 4 expresses the philosophy of the Committee and establishes a framework followed more or less by all the NFPA documents that apply to combustible dust hazard processes. As noted by the CSB in its conclusions, lack of awareness appears as a common factor throughout the hallmark cases investigated by the CSB and others in the past 10 to 15 years. Thus, it is not surprising in the era of Process Safety Management that NFPA 654 requires a hazard analysis. Resources to assist in the hazard analysis include *Guidelines for Hazard Evaluation Procedures* developed by the AIChE Center for Chemical Process Safety (6). A recent article describing process hazard analysis for dust handling operations is found in Perry, et.al. (7).

Another key feature of process safety is change management and NFPA 654 includes requirements that are applicable on a retroactive basis. This is not standard for the provisions of most NFPA voluntary, consensus documents – normally, it is the practice that the requirements are not intended to be applied retroactively. In this case, however, the Committee recognizes the evidence presented in the CSB report which demonstrates that changes in process contributed significantly to a number of the incidents investigated. For example, the Hayes-Lemmerz explosion in October 2003 involved dust collection equipment that had been added to the facility along with the recycling equipment without an evaluation of this change in process. The management-of-change procedures in NFPA 654 require the following issues to be addressed prior to any change:

(1) The technical basis for the proposed change

(2) The safety and health implications

(3) Whether the change is permanent or temporary

(4) Modifications to operating and maintenance procedures

(5) Employee training requirements

(6) Authorization requirements for the proposed change

Within the inventory of dust hazard process documents, two of the NFPA documents provide an alternative to the typical prescriptive requirements found in consensus standards. Both NFPA 654 and NFPA 664, *Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities*, offer a performance-based or prescriptive approach to safeguarding dust hazard process operations from fires and explosions and providing both fire and life safety. The inclusion of the performance-based approach means that a facility operator could utilize alternative measures of protection not provided for in the standard as long as the performance-based criteria are satisfied.

The performance-based process requires that specific objectives be established so that the strategies used to achieve objectives can be developed. NFPA 654 defines four objectives – life safety, structural integrity, mission continuity, and mitigation of fire spread and explosions. Simply stated, the life safety objective means the facility must be designed to protect occupants not in the immediate proximity of the ignition from the effects of fire, deflagration, and explosion for the time needed to evacuate, relocate, or take refuge. In addition, the structure is required to be located or constructed to minimize the propagation of fire or explosion to adjacent properties and to avoid injury to the public within those adjacent properties.

As outlined in the objectives, there are both structural and life safety objectives which distinguishes the NFPA approach from the protections embodied in the current OSHA standards or in any potential new OSHA regulation. The OSHA act restricts OSHA to addressing protection of the health and safety of the worker and that often does not include concern with structural protection. Because of both the fire and explosion events and the potential for the explosion to impact workers beyond the area of initiation, some of the structural objective within NFPA 654 would need to be included in any OSHA regulation.

Chapter 5 of NFPA 654 provides the details for the performance-based design option by establishing performance criteria for each objective. For example, the life safety objective is satisfied if either ignition has been prevented or if no person, other than those in the immediate proximity of the ignition, is exposed to untenable conditions due to the fire, and no critical structural element of the building is damaged so that it impacts occupants during evacuation. The criteria are evaluated against both design fire and explosion scenarios.

Chapter 6 of the standard defines the protective measures required as part of the facility and systems design. All NFPA dust standards limit the recycling of exhaust air into a system. The standard requires that areas where combustible dusts are produced, process, handled, or collected are to be designed as either: segregated, separated, or detached. Segregated applies to situations where physical barriers are installed to isolate combustible particulate solid processes and other operations within a facility or area. Separation imposes a distance between hazardous areas and surrounding exposures, and the standard sets the minimum separation distance at 30 ft (9 m). In

detached construction, the combustible particulate solid process is located in the open or in a separate building.

Dust explosion hazardous area

NFPA 654 applies the requirements throughout the standard to those areas where either a fire or an explosion hazard exists. The fire or dust explosion hazardous area exists wherever dust accumulations exceed some layer thickness. In NFPA 654, the layer thickness has been specified as either (4):

(1) Areas where dust accumulates to a thickness of 1/32 in (0.8 mm)

(2) Areas where dust clouds of a hazardous concentration exist

This specified thickness can be approximated by the thickness of a US dime or a paper clip, but the dust cloud that has reached a hazardous concentration (i.e. the Minimum Explosible Concentration (MEC)) is more difficult to quantify in the field. Eckhoff and others have suggested that such a concentration within a dust cloud would obscure visibility across a relatively small distance, 6 to 10 feet (2 to 3 m) (8).

Interestingly, NFPA 664 describes the dust hazardous area for wood processing and woodworking operations based upon a layer thickness of 1/8 in (3.2 mm) (9). FM Global publishes in their data sheet, FM 7-76, that a layer thickness of 1/16 in (1.6 mm) represents the point at which cleaning of the accumulated dust layer should begin (10). So, who is right in this dust layer discussion?

If one looks more closely at each of the sources above, there is another factor to be considered and that is something called bulk density. Where dusts of different bulk densities are involved, the layer thickness for the equivalent mass represented by the 1/32 in (0.8mm) layer is inversely proportional to the bulk densities for the other dusts. NFPA 654 provides this relationship as a formula in the standard:

$$\text{Allowable thickness (in)} = [(1/32)(75)]/\text{bulk density (lb/ft}^3\text{)} \qquad \text{Equation 1}$$

A review of NFPA 664 and FM 7-76 reveals that both use wood dust as the basis for the stated layer thicknesses, but NFPA 664 cites a bulk density of 20 lb/ft$^3$ (320 kg/m$^3$) while FM cites a bulk density of 36 lb/ft$^3$ (580 kg/m$^3$) By working through the relationship in Equation 1, it can be shown that all three sources described here in this paper have arrived at essentially the same equivalent layer thickness based upon the chosen bulk density for the dust as noted. So, one conclusion that needs to be stated is that these sources are not in conflict with each other by citing differing values of layer thickness to be used to trigger the need for cleanup. What each source has established is that a very small accumulated layer of different types of dusts can be sufficient to pose a potential for a dust explosion hazard.

Another way to view the bulk density property is to describe its effect as being analogous to various types of snowfall. In humid environments, such as the Northeast, it is typical to produce heavy, wet snowfalls – i.e., higher bulk density and thus more compacted, accumulating layers. While in the West or Rockies, the snow tends to be light, fluffy, "powder" due to the drier climate prevalent in that region. Consequently, the bulk density represented would be a much lower value and produces a thicker, less compacted layer of snow. An industrial facility manufacturing facial tissue works with a solids process that yields values of bulk density that are quite low and thus typically would be experiencing thicker layers. Another facility working with sulfur would expect more compacted layers due to sulfur having a higher relative bulk density to that of the tissue. One can also consider the accumulating layer in terms of a mass per unit area – when the nominal values found in the sources above are examined, a value of 0.2 $lb/ft^2$ results.

This is an important concept as much of the focus coming from the CSB and OSHA, particularly with the increased inspections through the NEP, is just on the 1/32 in (0.8 mm) dust layer thickness.

NFPA 654 provides specific requirements for fire and explosion protection for specific equipment. To determine the level of protection necessary, the standard requires that a risk evaluation be conducted and then documented. Based upon the risk evaluation, explosion protection for equipment may be required and can incorporate one or more of the following methods:

1. Oxidant concentration reduction
2. Deflagration venting
3. Deflagration pressure containment
4. Deflagration suppression systems
5. Dilution with noncombustible dust
6. Deflagration venting through a listed dust retention and flame-arresting device

These methods are based upon the requirements found in NFPA 68 and 69 for the design and installation, inspection, and maintenance of these systems. NFPA 654 also requires that equipment that is connected by ductwork be protected from deflagration propagation by isolation devices; design and installation of these devices would also be based upon provisions found in NFPA 69.

Chapter 7 of NFPA 654 provides requirements for specific equipment – bulk storage enclosures, material transfer systems, duct systems, material feeding devices, bucket elevators, enclosed conveyors, air-material separators, air-moving devices, abort gates/abort dampers, mixers and blenders, and dryers.

NFPA 654 provides a basis for safety that offers a 3-pronged approach:

1. Prevent or limit formation of hazardous atmosphere

2. Prevent ignition of the hazardous atmosphere
3. Limit the consequences of a deflagration to acceptable levels (mitigation or control)
    a. Includes secondary explosion protection

With that basis for safety in mind, the remainder of the document includes housekeeping, control of ignition sources, training and procedures, and inspection and maintenance.

Housekeeping is another of the retroactively applied segments of the standard. As commonly observed in the various investigation reports, the apparent lack of sound housekeeping regimens contributed significantly to many of the noted incidents. The debate over what layer thickness to apply and when that accumulated layer should trigger cleanup has been conspicuously absent in many of the most significant losses reported. The housekeeping hierarchy intended by the standard is that blowing down of areas should be avoided, except where it is the only means for cleanup. If done improperly, blowing down can spread the accumulated layer and disperse it into the air (the exact opposite of what is intended). Continuous suction systems represent the ideal when exhausted to a properly designed and installed dust collection system. It is important to also recognize the need for equipment that is suitable for the electrical area classification.

The standard also applies the requirements for training and procedures and inspection and maintenance retroactively.

Annex D of the standard provides some examples of dust layer characterization and precautions. In addition to further discussion of the application for the 1/32 in (0.8 mm) dust layer thickness, guidelines for use in establishing a cleaning frequency are also provided in this annex.

Review of safe practices

Regardless of the dust type – grain, metal, coal, or plastic – several questions are asked for each NFPA standard when evaluating the explosion potential for a dust hazard process. Let's examine them each as they occur in the sequence most related to the hazard analysis. Remember the philosophy outlined by NFPA 654 as a basis for safety.

Is my solid or particulate combustible and is it able to form a combustible dust? What governs that?

Evaluation of a combustible dust explosion hazard and the attendant prevention techniques should be based on actual test data. A list of the essential tests and data needed is contained in the NFPA standards.

Once the presence of a combustible dust has been confirmed, the previously stated basis for safety found in the NFPA standards can be applied – prevent or limit formation of a hazardous atmosphere, prevent ignition, and limit the consequences through mitigation or control measures.

When considering the formation of the solid or dust, total elimination of the dust product is not often practicable as materials must be handled as part of the manufacturing and process stage. A common element found in many of the case histories cited by OSHA and CSB (e.g., West Pharmaceutical, Jahn Foundry, and Imperial Sugar) is the persistent importance of housekeeping in facilities handling or processing combustible particulate solids. Poor housekeeping is often recognized as an essential factor in defining the conditions leading to secondary explosions, whereby the number of exposed personnel becomes increased as the fire and explosion effect zone grows.

The recent incidents investigated by the CSB, OSHA, and others reinforce the importance of housekeeping in the safe operation of facilities handling combustible particulate solids. Guidance provided in the NFPA standards establishes requirements for housekeeping programs to limit the accumulation of flammable dust in facilities. NFPA 654 provides the most detailed requirements in the mandatory portions of the document and supports those requirements with supplemental information in the annex to those requirements. It is important to understand that none of the NFPA standards currently establish a requirement for housekeeping programs that are tied to a specified minimum dust layer thickness. However, the minimum dust layer thickness defines the dust explosion hazard area, which then triggers specific protective measures.

What practices can be observed to improve overall housekeeping success? Facilities can be designed to promote and facilitate cleaning. In Chapter 6 of NFPA 654, physical barriers are permitted to be used to limit dust migration in order to minimize the extent of the housekeeping zone (segregation). The standard also requires all penetrations of floors, walls, ceilings, and partitions defining such barriers to be dust tight. Housekeeping programs must recognize and address all areas where combustible dust may accumulate, which includes personnel-occupied areas as well as concealed areas. As noted in the CSB report, the housekeeping program at West Pharmaceuticals rigorously addressed the personnel-occupied areas of the facility, but overlooked the area above the false ceiling.

NFPA 654 and the other dust-type specific standards require all surfaces where dust might accumulate be designed and constructed to minimize dust accumulations and to facilitate cleaning. This typically means that interior window ledges are sloped, beams or girders are boxed, and concrete walls are painted to limit dust adherence. Localized dust collection systems may also be used to limit dust migration, provided such systems are designed, operated, and maintained to control their own inherent dust explosion hazards. One of the most effective ways of limiting the spread of dust through a facility is to keep it inside the equipment. Proper design, maintenance, and operation of equipment to minimize dust emissions should be a priority.

As noted in the overview of NFPA 654, the standard provides specific requirements for the safe conduct of housekeeping operations. Several of the case histories demonstrate how housekeeping in dusty areas introduces the potential for the formation of combustible dust clouds. The preferred method for cleaning would incorporate a fixed-pipe vacuum system with a remotely located exhauster and dust collector meeting the requirements for hazardous locations. In some applications where sweeping or blowing down must be used, NFPA 654 establishes

specific safeguards to ensure blowing down with steam or compressed air can be completed safely. Some of the commodity specific standards incorporate more restrictive requirements for the housekeeping practices. As an example, combustible metals, found in NFPA 484, *Standard for Combustible Metals*, requires use of nonsparking scoops and soft brooms for cleanup and restricts the use of water when aluminum dust or powder is involved.

What other lessons can be taken away from the case histories described in the CSB report?

Limit the production of dust clouds during housekeeping by using methods other than blowdown first where possible and control ignition sources in the area by either deenergizing equipment or removing all ignition sources – CSB found that a dust cloud generated during cleaning operations at CTA Acoustics was likely ignited at the open door of a hot oven. NFPA 654 also requires that air moving devices (fans and blowers) be shut down during maintenance as a precaution against additional ignition sources.

NFPA 654 requires regular cleaning frequencies be established for walls, floors, and other horizontal surfaces (including concealed or less accessible areas). The standard also provides guidance to evaluate when conditions might necessitate more frequent cleaning – factors contributing to the Jahn Foundry explosion in Springfield, MA in 1999 included heavy accumulations of combustible resin dust left uncontrolled due to inadequate housekeeping and cleaning program.

NFPA 654 also requires that buildings and structures utilize construction safeguards (segregation, separation, or detachment) to limit the effects from any fire or explosion event – the explosions at CTA Acoustics and Jahn Foundry illustrate the effect of inadequate design of structures for the purpose of preventing or limiting propagation of an explosion event.

## Conclusion

Preliminary results from OSHA inspections conducted under the Combustible Dust NEP indicate that the specific deficiencies include many of the same causes highlighted in this paper – equipment not properly designed, installed, or maintained; excessive accumulations of dust; and equipment not provided with proper or adequate deflagration isolation systems or explosion venting. NFPA standards address hazard evaluation of the dust hazard process, characterization of the dust properties, measures for capturing and collecting the dust, requirements for dust explosion prevention and protection, and housekeeping program elements. The results from the OSHA NEP suggest that many in industry are still not adequately aware of the problem. It is likely that Congress will act to further accelerate the learning curve for those industries not yet aware of the hazards of combustible dusts and the solutions that are readily available in the form of the NFPA standards.

## A Request for Assistance

NFPA 654 is currently undergoing a review and revision according to the normal NFPA procedures. NFPA codes and standards are voluntary, consensus documents that should reflect the recognized and generally accepted practices of the industry to which it applies. The NFPA Technical Committee on Handling and Conveying of Dusts, Vapors, and Gases invites those

affected by the standard to provide any comments you have on the content of the standard during this revision cycle. The Committee has completed the first step in the process – review and action on Public Proposals and approval of its Report on Proposals (ROP). The ROP will be published June 26, 2009 on the NFPA 654 document web page: (http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=654) and Public Comments can be submitted based upon a review of the ROP until September 4, 2009. Public Comments to the ROP actions can be submitted to NFPA using the form available at: http://www.nfpa.org/categoryList.asp?categoryID=124&URL=Codes%20and%20Standards

Please contact the author of this paper (NFPA Staff Liaison to the Technical Committee) with questions regarding the revision process or the work of the Committee.

References


(1) U.S. Chemical Safety and Hazard Investigation Board, "Combustible Dust Hazard Study," Investigation Report 2006-H-1, CSB, Washington, DC (November 2006).
(2) U.S. Department of Labor, Occupational Safety and Health Administration, "Combustible Dust National Emphasis Program," CPL-03-00-008 OSHA, Washington, DC, (March 11, 2008).
(3) Fairfax, Richard E., "OSHA and Combustible Dust," OSHA Region V Combustible Dust Conference, Naperville, IL, (March 20, 2009).
(4) National Fire Protection Association, "Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids," NFPA 654, NFPA, Quincy, MA (2006).
(5) U.S. Department of Labor, Occupational Safety and Health Administration, "Combustible Dust in Industry: Preventing and Mitigating the Effects of Fire and Explosions," Safety and Health Information Bulletin 07-31-2005, OSHA, Washington, DC (2005).
(6) Center for Chemical Process Safety, *Guidelines for Hazard Evaluation Procedures*, 3rd edition, AIChE, New York, NY (2008).
(7) Perry, Judy A., Henry Ozog, Michelle Murphy, R. Peter Stickles; "Conducting Process Hazard Analyses for Dust-Handling Operations," Chem. Eng. Progress, 105 (2), pp. 28 – 35, February 2009.
(8) Eckhoff, R. K., "Dust Explosions in the Process Industries," 3rd. edition, Gulf Professional Publishing, Houston, TX (2003).
(9) National Fire Protection Association, "NFPA 664, Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities," NFPA 664, NFPA, Quincy, MA (2007).
(10) FM Global, "Prevention and Mitigation of Combustible Dust Explosion and Fire," Data Sheet 7-76, FM Global, Norwood, MA (May 2008).