Comparison Between 2006 and 2013 Editions of NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*

An ioMosaic Corporation Whitepaper

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1. Introduction

After much anticipation, the new 2013 Edition of NFPA 654[1], *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing and Handling of Combustible Particulate Solids*, has finally been issued. This is one of the key standards utilized for safe handling of combustible solids. Several important updates and additions were incorporated into this edition of the standard, including:

- Updated definition of a combustible dust
- Added determination method for a dust flash fire or explosion hazard area
- Added housekeeping frequency specification and cleaning methods
- Updated recommendations for separation, segregation, or detachment
- Updated usage specifics for flexible and rigid intermediate bulk containers
- Strengthening of included safety management systems (SMSs)
- Added contractor and subcontractor management system

2. Definition of a Combustible Dust

Subtle changes were made to the definitions for "combustible dust" and "combustible particulate solid." These definitions make a distinction between materials that pose a fire hazard from those that pose a flash fire or explosion hazard when suspended in air.

The actual definitions clearly specify that these combustible particulate solids can be any size, shape, or chemical composition. There is additional clarification included in Annex A of the standard. Historically, in order to define a combustible dust, the particle size criterion was 420 microns or smaller in diameter. With the aim to harmonize with other standards, a particle size of 500 microns or lower is now considered appropriate. However as the annex points out, there are some exceptions that can present a deflagration hazard even though the particle size is larger than 500 microns, such as fibers, flakes, and agglomerates. The determination of whether a particulate solid poses a flash fire or explosion hazard should be determined using a standardized test method. ASTM has included a screening test in their most recent version of their *Standard Test Method for Minimum Explosible Concentration of Combustible Dusts*, E 1226.

3. Determination of a Dust Flash Fire or Explosion Hazard Area

New specific criteria have been added for the determination of the dust flash fire or explosion hazard area. Four methods are described in the new standard: (1) Layer Depth Criterion Method, (2) Mass Method A, (3) Mass Method B, and (4) Risk Evaluation Method. The first three methods are quantitative assessments of the amount of fugitive dust to determine if a hazard exists. The Risk Evaluation Method is a performance-based option in which a risk evaluation can be completed to assess the existence of a flash fire or explosion hazard. The risk evaluation must be acceptable to the authority having jurisdiction (AHJ).

[1] NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing Processing, and Handling of Combustible Particulate Solids, 2013 Edition*

3.1 Layer Depth Criterion Method

This is the easiest method and can be used for any application. This method elaborates on the 1/32" criteria from the 2006 Edition of the NFPA 654 standard.[2] The new criterion adjusts for the particular bulk density of a dust, using the following equation from NFPA 654 Section 6.1.3.1 [Eq. 1]:

$$\mathrm{LD\ (in)} = \frac{(\frac{1}{32}\mathrm{in})(75\frac{\mathrm{lb}}{\mathrm{ft}^3})}{\mathrm{BD}} \qquad \text{[Eq. 1]}$$

where,

LD: layer depth (in)

BD: bulk density (lb/ft^3)

If the bulk density is 75 lb/ft^3, then the layer depth criteria (1/32") from the 2006 Edition can be applied. A dust explosion and flash fire hazard is deemed to exist when any of the following conditions exist:

- More than 5% of the footprint area is above the layer depth criterion
- An area bigger than 1,000 ft^2 (92.9 m^2) is above the layer depth criterion
- The total volume of accumulated dust is greater than 5% of the footprint area multiplied by the layer depth criterion
- The total volume of accumulated dust is greater than 1,000 ft^2 (92.9 m^2) multiplied by the layer depth criterion

3.2 Mass Method A

Mass Method A is intended to estimate the mass of dust accumulation, external to the process equipment, to determine if there is a flash fire or explosion hazard. This is a simplified method that does not require detailed information about the building or the combustible dust.

Two equations from NFPA 654 Section 6.1.4 [Eq.2 and Eq.3] apply to this method, one for the dust explosion hazard and the other for the dust flash fire hazard. When the mass of fugitive dust exceeds the calculated threshold, a dust explosion or flash fire hazard exists in the area. Due to the assumptions about the dust characteristics and building construction that are incorporated in these equations, there are limits placed on the applicable floor area and ceiling heights when performing these calculations.

3.2.1 Dust Explosion Hazard

$$\mathrm{M_{basic-exp}} = 0.004 \cdot \mathrm{A_{floor}} \cdot \mathrm{H} \qquad \text{[Eq. 2]}$$

where,

$M_{basic\text{-}exp}$: threshold dust mass (kg) based on building damage criterion

A_{floor}: lesser of enclosure floor area (m^2) or 2,000 m^2

H: lesser of enclosure ceiling height (m) or 12 m

[2] NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing Processing, and Handling of Combustible Particulate Solids, 2006 Edition*

3.2.2 Dust Flash Fire Hazard

$$M_{basic-fire} = 0.02 \cdot A_{floor} \quad \text{[Eq. 3]}$$

where,

$M_{basic-fire}$: threshold dust mass (kg) based on personnel fire exposure criterion

A_{floor}: lesser of enclosure floor area (m^2) or 2,000 m^2

H: lesser of enclosure ceiling height (m) or 12 m

3.3 Mass Method B

As with Mass Method A, Mass Method B is intended to estimate the mass of dust accumulation external to the process equipment to determine if there is a flash fire or explosion hazard. Mass Method B requires more detailed information concerning the material properties of the dust and the building. Equations 4 and 5 from NFPA 654 Section 6.1.5 apply to this method, one for the dust explosion hazard and the other for the dust flash fire hazard. When the mass of fugitive dust exceeds the calculated threshold, a dust explosion or flash fire hazard exists in the area. Because there are fewer assumptions associated with these equations, there are no limits on the applicable floor area or ceiling height with this method.

3.3.1 Dust Explosion Hazard

$$M_{exp} = \left[\frac{P_{es}}{DLF}\right] \cdot \left[\frac{C_\omega}{P_{max}}\right] \cdot \frac{A_{floor} \cdot H}{\eta_D} \quad \text{[Eq. 4]}$$

where,

M_{exp}: threshold dust mass (kg) based on building damage criterion

P_{es}: enclosure strength evaluated based on static pressure calculations for the weakest building structural element not intended to vent or fail (bar g) per NFPA 68[3].

DLF: dynamic load factor, the ratio of maximum dynamic deflection to static deflection per NFPA 68 (DLF = 1.5 for worst-case value)

C_ω: worst-case dust concentration (kg/m^3) at which the maximum rate-of-pressure-rise results in tests conducted per ASTM E 1226

P_{max}: maximum pressure (bar g) developed in ASTM E 1226 tests with the accumulated dust sample

A_{floor}: enclosure floor area (m^2)

H: enclosure ceiling height (m)

η_D: entrainment fraction = 0.25 (alternative value can be used based on the risk 3

[3] NFPA 68, *Standard on Explosion Protection by Deflagration Venting, 2007 Edition*

3.3.2 Dust Flash Fire Hazardous Area

$$M_{\text{fire}} = \rho \cdot C_{\omega} \cdot \left[\frac{P_{initial}}{P_{initial} + P_{max}}\right] \cdot \frac{A_{floor} \cdot D}{\eta_D} \qquad \text{[Eq. 5]}$$

where,

M_{fire}: threshold dust mass (kg) based on personnel fire-exposure criterion

ρ: probability of flame impingement on a person, not to exceed 0.05 (5% probability)

C_{ω}: worst-case dust concentration (kg/m^3) at which the maximum rate-of-pressure-rise results in tests conducted per ASTM E 1226

$P_{initial}$: 1 bar absolute

P_{max}: maximum pressure (bar g) developed in ASTM E 1226 tests with the accumulated dust sample

A_{floor}: enclosure floor area (m^2)

D: nominal height of a person (2 m)

η_D: entrainment fraction = 0.25 (alternative value can be used based on the risk evaluation)

3.4 Risk Evaluation Method

This is a performance-based option for evaluating whether an explosion or flash fire hazard exists. This option is subject to approval by the AHJ. This option is an extension of the required process hazard analysis (PHA) that focuses on the material properties and inherent design and operating features of the equipment and facility. This provides an opportunity to consider unique characteristics such as the minimum ignition energy (MIE) or the difficulty in suspending the dust in air that could impact the presence of an explosion or flash fire hazard.

4. Housekeeping and Cleaning Methods

Although housekeeping was discussed in the NFPA 654 2006 Edition, the 2013 Edition emphasizes the importance of the frequency of cleaning and the cleaning methods. All of the housekeeping provisions in the 2013 Edition are to be applied retroactively.

Housekeeping is critical for facilities that are intended to be operated with fugitive dust deposits less than the dust accumulation thresholds defined using one of the four approved methods discussed above. In these situations, the facility is probably not equipped with deflagration protection features or classified electrical equipment and additional personal protection from dust deflagration hazards may not be provided. In these cases, the facility and personnel are not equipped to safely handle a secondary explosion or flash fire that could result from excessive amounts of fugitive combustible dust in the area. For these reasons, strict housekeeping plans must be established using the Tables (Tables 1 and 2 below) from NFPA 654, Annex A, Section A.8.2.1.3. An inspection program must also be implemented to ensure that the housekeeping conforms to these requirements.

Table 1: Unscheduled Housekeeping Frequency

Accumulation on the Worst Single Square Meter of Surface	Longest Time to Complete Unscheduled Local Cleaning of Floor-Accessible Surfaces	Longest Time to Complete Unscheduled Local Cleaning of Remote Surfaces
> 12 times threshold dust mass/accumulation	8 hours	24 hours
> 2–4 times threshold dust mass/accumulation	4 hours	12 hours
> 4 times threshold dust mass/accumulation	1 hour	3 hour

Table 2: Housekeeping Equivalent Depths

Accumulation on the Worst Single Square Meter of Surface	Average Depth at 75 lb/ft^3 (1200 kg/m^3)	Average Depth at 30 lb/ft^3 (481 kg/m^3)
> 0.2 – 0.4 lb/ft^2 (> 1–2 kg/m^2)	> $^1/_{32}$ – $^1/_{16}$ in (0.8 –1.7 mm)	> $^5/_{64}$ – $^5/_{32}$ in (2.1 – 4.2 mm)
> 0.4 – 0.8 lb/ft^2 (> 2 – 4 kg/m^2)	> $^1/_{16}$ – $^1/_8$ in (1.7 – 3.3 mm)	> $^5/_{32}$ – $^5/_{16}$ in (4.2 – 8.3 mm)
> 0.8 lb/ft^2 (> 4 kg/m^2)	> $^1/_8$ in (> 3.3 mm)	> $^5/_{16}$ in (> 8.3 mm)

Cleaning methods are also important to avoid dust hazards caused by the formation of dust clouds. The NFPA 654 2013 Edition establishes a clear hierarchy for cleaning methods: (1) vacuum, (2) water wash-down or sweeping, and (3) use of compressed air. If using blow-downs with compressed air, some precautions must be followed:

- Vacuuming, sweeping, or water wash-down must be used prior to the compressed air method for all accessible dust deposits
- The remaining dust accumulation in the area must be below the dust accumulation threshold (described in Table 2)
- Use a maximum discharge pressure of the compressed air of 30 psi (270 kPa) in accordance with OSHA requirements
- Electrical equipment potentially exposed to airborne dust should meet the requirements of NFPA 70[4], National Electric Code, NEMA 12, or equivalent

[4] NFPA 70, *National Electrical Code, 2011 Edition*

- All the ignition sources and hot work surfaces capable of igniting a dust cloud shall be shut down or removed from the area

The NFPA 654 2013 Edition also clarifies the requirements for portable vacuum cleaners. They do not need to be listed for use in Class II hazardous locations if they meet certain other criteria.

5. Separation, Segregation, or Detachment

The NFPA 654 2006 Edition describes the need for separation, segregation, or detachment of a process area to minimize the damage from a fire or explosion. The 2013 Edition of NFPA 654 provides additional details regarding these requirements.

The physical barriers designed for segregation shall have a one (1) hour fire resistance rating and should follow the requirements of NFPA 68. If a separation distance is used to limit the dust flash fire or explosion hazard area, the minimum distance is 35 ft (11 m), consistent with NFPA 51B[5], *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*.

6. Flexible and Rigid Intermediate Bulk Containers

Although the 2006 Edition already includes information regarding the use of flexible and rigid intermediate bulk containers, the 2013 Edition provides more detailed information concerning which type to use depending on the operating and atmospheric conditions. For instance, flexible intermediate bulk containers (FIBCs) are allowed to be used for carrying combustible particulate solids following specific requirements. These requirements depend on the MIE and the nature of the surrounding atmosphere. Table 3 from NFPA 654, Annex A, Section A.9.4.3.6 shows the use of different types of FIBCs depending on the MIE and the surroundings:

Table 3: Use of Flexible Intermediate Bulk Containers (FIBCs)[6]

Bulk Product in FIBC	Surroundings		
MIE of Solids	Nonflammable Atmosphere (1,000 mJ > MIE)	Class II, Divisions 1 and 2 (1,000 mJ ≥ MIE > 3mJ)	Class I, Divisions 1 and 2 (Gas Group C and D) or Class II, Divisions 1 and 2 (MIE ≤ 3mJ)
MIE > 1,000 mJ	A, B, C, D	B, C, D	C, D[b]
1,000 mJ ≥ MIE > 3mJ	B, C, D	B, C, D	C, D[b]
MIE ≤ 3mJ	C, D	C, D	C, D[b]

a. MIE measured following the requirements of ASTM E 2019

b. Use of types C and D is limited to Gas Groups C and D with MIE ≥ 0.14 mJ

[5] NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work, 2009 Edition*

[6] NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing Processing, and Handling of Combustible Particulate Solids, 2013 Edition*

Additional details are also included in the 2013 Edition, such as the following:

- Special precautions are necessary when a flammable gas or vapor atmosphere is present inside the FBIC
- For conductive combustible particulate solids, the use of types A, B, and D is not recommended

If dusts are going to be charged manually into a rigid container with a flammable atmosphere, the 2013 Edition includes additional precautions that must be taken to perform this task safely. These requirements include:

- Conductive or static-dissipative components must be grounded
- Direct emptying of powders from nonconductive plastic bags into a vessel that contains a flammable atmosphere is strictly prohibited
- The use of nonconductive liners in grounded conductive or static dissipative outer containers is permitted, provided that the liner thickness is < 0.08" (2 mm) and the liner can't become detached
- Loading chutes, receiving vessels, and auxiliary devices must be conductive and grounded
- Personnel in the vicinity of the vessel openings that contain flammable atmospheres are grounded
- Operators shall wear flame-resistant garments as specified in NFPA 2113[7], *Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Flash Fire*
- A risk assessment is conducted to determine additional engineering and administrative controls necessary to protect against ignition of the flammable atmosphere

7. Safety Management Systems (SMS)

The 2013 Edition of the standard enhances some of the existing SMS features in the previous version (e.g., training) and also adds new elements (e.g., incident investigation, contractors, subcontractors).

7.1 Training and Procedures

The NFPA 654 2013 Edition emphasizes that the operating and maintenance procedures must address personal protective equipment (PPE), including flame-resistant garments. Additional details are also spelled out for the emergency response plan (ERP). NFPA 654 2013 Edition requires that these procedures should be reviewed at least once per year or more frequently if changes occur.

7.2 Incident Investigation

Incident investigation is very important in safety management, as it can help prevent future incidents or accidents (lessons learned). This new section in the standard covers

[7] NFPA 2113, *Standard on Selection, Care, Use, and Maintenance of Flame – Resistance Garments for Protection of Industrial Personnel Against Flash Fire, 2012 Edition*

some key issues necessary to perform a good incident investigation. These include when an investigation is necessary, who should lead the investigation, and what needs to be documented.

An investigation is required when the fire or explosion incident results in property damage, production shutdown time, or injury. “Near misses” (significant events without consequences) should also be investigated.

A person with a working knowledge of the facility and the process should lead the investigation.

The written incident investigation report should include the following:

- Date of the incident
- Location of the incident and equipment/process affected
- Description of the incident, contributing factors, and the suspected cause
- Operation of the automatic/manual fire protection systems and emergency response
- Recommendations and corrective actions taken, or to be taken, to prevent a reoccurrence
- Lessons learned from the investigation

This report and the lessons learned from the incident must be shared with all affected personnel operating, maintaining, and supervising the facility.

7.3 Contractors and Sub-Contractors

The 2013 Edition of NFPA 654 includes an entirely new section regarding contractors and subcontractors. Contractors and subcontractors must be qualified and have the requisite skills for the jobs they are hired to do. Contractors involved in the commissioning, repair, or modification of explosion protection systems must also be qualified as specified in Chapter 15 of NFPA 19, *Standard for Explosion Prevention Systems*[8]. Owner/operator training of contractors must be documented. This training must include qualification for operation of any owner/operator equipment, the potential hazards from fires, explosion and toxic releases, the site-specific safe work practices, and the facility’s ERP.

8. Conclusions

This new 2013 edition of NFPA 654 provides a number of key changes which have been under review for quite some time. One of the main changes is a clarification of what constitutes a flash fire and/or explosion hazard using one of four methods. This is a key point needed to determine the type of hazard present and therefore the appropriate safeguards. Additional clarification has been provided on housekeeping methods and the importance of this task. This update also reconciled some of the management systems with other related combustible dust standards to provide some consistency with regard to expectations regardless of the type of facility or dust being handled. NFPA 654

[8] NFPA 69, *Standard on Explosion Prevention Systems, 2008 Edition*

is an important combustible dust handling standard that covers a wide variety of dusts and facility types and it is critically important to understand these recognized and generally accepted good engineering practices in order to keep the people in your facility safe when working with or around combustible dusts.

9. About ioMosaic Combustible Dust Services

Managing hazards associated with handling combustible dusts requires an understanding of dust characteristics coupled with a thorough knowledge of evolving combustible dust management standards and practices.

ioMosaic has the tools to help you:

- Characterize your dust
- Conduct PHAs
- Develop programs (management of change)
- Design dust deflagration vents

ioMosaic consultants can help develop your program from inception through execution or address specific aspects of combustible dust hazard management.

9.1 Key Services Available

- Dust characterization testing and analysis
- Initial assessment
- PHA
- Deflagration vent sizing
- NFPA 654 compliance audit
- Employee training
- Standard development
- Software solutions for PHAs, management of change, and data management
- Incident investigation