

# CHEMICAL PROCESSING

LEADERSHIP | EXPERTISE | INNOVATION

## Understanding Dust Explosion Dangers



Sponsored by

**Fike**®



# ARE YOU FLIRTING WITH DISASTER?

**DON'T IGNORE POTENTIAL HAZARDS IN YOUR FACILITY.**

***TRUST FIKE*** for expert testing  
in addition to a full range of  
explosion protection solutions.

# **Fike®**

***To arrange for your no-obligation hazard analysis,  
Call 877-814-3453 or email [IndustrialProtection@Fike.com](mailto:IndustrialProtection@Fike.com)***

# Table of Contents

## **Dust Explosion Standard Gets Significant Revisions** 4

Major changes to NFPA 654 include new administrative requirements

## **Defuse Dust Dangers** 7

Carefully consider and then counter risks of fire and explosion

## **Demystify Dust Explosion Propagation** 8

Five common misconceptions can lead to a false sense of security

# Dust Explosion Standard Gets Significant Revisions

Major changes to NFPA 654 include new administrative requirements

By Steven J. Luzik, Chilworth Technology, Inc.

**THE STANDARDS** Council of the National Fire Protection Association (NFPA), Quincy, Mass., has issued the 2013 revision of the NFPA 654 “Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids.” This standard applies to all combustible particulate solids or hybrid mixtures, regardless of concentration or particle size, where the materials present a fire or explosion hazard. The owners or operators of affected facilities are responsible for implementing the requirements.

The 2013 edition, which now is in effect, incorporates several significant changes, most notably in the areas of housekeeping and establishing whether or not a flash fire or explosion hazard exists within a facility. These changes are particularly important because incident history and statistics clearly indicate that secondary dust explosions, caused by inadequate housekeeping and excessive dust accumulations, have been responsible for much of the damage and casualties experienced in major industrial dust explosions. Other important areas that have been revised or where new requirements have been added include safety management practices such as hazard analysis, management of change, training, emergency procedures, and contractor and subcontractor safety.

This article will focus on the changes in administrative requirements.

## INCIDENT INVESTIGATIONS

There now are requirements for investigating incidents that result in a fire or explosion of a magnitude that

causes property damage, production downtime or injury. Section 4.4 of the revised standard mandates preparing a written report that describes the incident, lists what has been learned, and includes recommendations to prevent future occurrences. Additionally, the summary of the report must be shared with affected personnel operating, maintaining and supervising the facility.

## HOUSEKEEPING PROGRAM

Section 8.2 outlines requirements for a formal housekeeping plan; these are tied into the methodologies outlined in Chapter 6 that can be implemented to determine if a dust flash fire or explosion hazard exists inside a plant. Chapter 6 provides four different methods for assessing these hazards.

- *The Layer Depth Criterion Method.* This establishes a baseline combustible dust accumulation based on the dust’s bulk density. It adjusts the previous benchmark dust accumulation level (2006 Edition) of 1/32 in., which was based on a dust with a bulk density of 75 lb/ft<sup>3</sup>, by multiplying 1/32 in. by 75 lb/ft<sup>3</sup> and dividing the number by the bulk density of the site’s dust to establish a new threshold accumulation thickness. (Thicker layers are allowed for lower density materials.) The total area of nonseparated dust accumulation can’t exceed 5% of the footprint area and the total volume in the footprint area can’t surpass the layer depth criterion multiplied by 5% of this area. (For areas greater than 20,000 ft<sup>2</sup>, the maximum accumulations and total volumes are based on a footprint

area of 1,000 ft<sup>2</sup>.) For example, in a room with an area of 1,000 ft<sup>2</sup> where dust having a bulk density of 37.5 lb/ft<sup>3</sup> has accumulated, the layer depth criteria is 1/16 in. and the accumulation of dust in the room can't surpass 1/16 in. over 50 ft<sup>2</sup>. Additionally, the total volume of dust in this room can't exceed (1/16 in.)/12 in./ft×50 ft<sup>2</sup> = 0.26 ft<sup>3</sup> or 9.77 lb.

- *Mass Methods A and B.* Method A relies on an equation to calculate the threshold dust mass accumulation based on floor area and room height. Method B provides a number of parameters, including room area and height, room or enclosure design strength, dust explosibility and entrainment factor. Method B has been adapted from the NFPA 68 “Standard on Explosion Prevention by Deflagration Venting,” which adjusts the amount of venting needed when the combustible mixture only fills part of the room and also considers explosion dynamics based on the properties of the dust of interest.
- *A risk evaluation method acceptable to the authority having jurisdiction.* This method affords increased flexibility to an evaluator when assessing the hazard, and supplements the process hazard analysis outlined in Chapter 4. The risk assessment, which must be performed by a competent professional, must show that the proposed strategy will achieve the same result as prescriptive methods. It's based on scientific facts and test data generated on the combustible dust(s). This approach can be a very important alternative to the first three methods for industries that generate significant amounts of combustible dusts due to the inherent nature of their manufacturing operations or where dust control or cleanup may present substantial challenges. The risk-based approach considers the physical, chemical, explosibility and ignitibility properties of a dust as part of the overall risk assessment — for example: Is the combustible dust very difficult to ignite? Does it have very weak explosibility properties? Does the nature of

the dust particle (size and shape) make generation of a combustible atmosphere improbable? Is an incandive ignition source likely? These are some of the factors that are considered in determining whether an explosion hazard exists in a plant.

Section 8.2 requires implementing a planned inspection process to evaluate dust accumulation rates and housekeeping frequencies to prevent threshold accumulation levels from developing on walls, floors, horizontal surfaces such as equipment, ducts, pipes, ledges, beams, above suspended ceilings and other concealed surfaces, for example, electrical enclosures.

The plan also must include requirements establishing time to clean local spills or short-term accumulations, and to allow for the elimination of the spilled mass or accumulations derived from implementation of the Section 6.1 methodologies. Tables in Annex A provide guidance on the time allowed for such cleanup activities.

Section 8.2.1.4 mandates performing a documented risk assessment to determine the level of housekeeping consistent with any flash fire or dust explosion protection measures in Section 6.4, Deflagration Venting of the Room, and Section 11.22, Personal Protective Equipment (PPE), if the facility is operated at dust levels that exceed the chosen criterion in Section 6.1. (Chapter 11 includes new requirements for PPE where a room or building is judged to present a dust flash fire or explosion hazard.)

## TRAINING AND PROCEDURES

Three specific areas have received important revisions:

- *Written emergency response plan.* There is a new requirement to develop a written emergency response plan for preventing, preparing for, and responding to work-related emergencies, which include fires and explosions. This plan must be reviewed annually or as required by process changes.
- *Contractors and subcontractors certification.* A significant number of incidents have been attributed to

### RELATED CONTENT ON CHEMICALPROCESSING.COM

"CP On-Demand Webinar: "Dust Control: How to Identify & Manage Explosion Hazards," accessible via <http://webcast.streamlogics.com/audience/index.asp?eventid=60911195>.

"Dust Removal Gets A Rethink," [www.ChemicalProcessing.com/articles/2012/dust-removal-gets-a-rethink/](http://www.ChemicalProcessing.com/articles/2012/dust-removal-gets-a-rethink/)

"Dust Gets Its Due," [www.ChemicalProcessing.com/articles/2011/dust-explosion-gets-its-due/](http://www.ChemicalProcessing.com/articles/2011/dust-explosion-gets-its-due/)

"Understand the Shocking Truth," [www.ChemicalProcessing.com/articles/2010/192/](http://www.ChemicalProcessing.com/articles/2010/192/)

"Get Up-to-Date on Explosion Venting Requirements," [www.ChemicalProcessing.com/articles/2009/047/](http://www.ChemicalProcessing.com/articles/2009/047/)

inadequate training of contractors or subcontractors. The owner of the facility ultimately is responsible for the actions of personnel performing activities on its site. The standard now mandates employing only qualified contractors possessing the requisite craft skills for work involving the installation, repair or modification of buildings (interior and exterior), machinery and fire protection equipment. Examples of the skill sets required are provided in the Annex and include applicable American Society of Mechanical Engineers (ASME) stamps and professional licenses.

In addition, contractors involved in the commissioning, repair or modification of explosion protection equipment must be qualified as specified in Chapter 15 of NFPA 69, "Standard on Explosion Protection Systems." Basically this requirement includes both training and authorization by the specific explosion-protection-system manufacturer.

- **Contractor training.** The standard now requires that contractors operating owner/operator equipment be trained and qualified to operate the equipment and perform the work. Written documentation must be maintained on the training provided and the individuals trained. In addition, any contractor working on or near a given process must be made aware of potential hazards from exposures to fire, explosion or toxic releases. That individual also must comply with the facility's safe work practices and policies,

including (but not limited to) equipment lockout/tagout permitting, hot work permitting, fire system impairment handling, smoking, housekeeping and use of PPE. Contractors also must be trained on the facility's emergency response and evacuation plan, including (but not limited to) emergency reporting procedures, safe egress points and evacuation areas.

### SIGNIFICANT CHANGES

The 2013 revision of NFPA 654 imposes several new administrative requirements designed to improve safety, including:

1. reporting of incidents;
2. providing PPE for employees working in areas where a flash fire or explosion hazard exists;
3. implementing a housekeeping program designed to prevent dust flash fire or explosion hazards in buildings or rooms;
4. developing an emergency response plan; and
5. establishing contractor qualification and training.

Familiarity and understanding of these requirements will enable an operator/owner to take the steps necessary to comply with the revised standard. Expert help may be required in some cases. ●

**STEVEN J. LUZIK**, PE, CFEI, is senior process safety specialist for Chilworth Technology, Inc., Princeton, N.J. E-mail him at [sluzik@chilworth.com](mailto:sluzik@chilworth.com).

## Defuse Dust Dangers

Carefully consider and then counter risks of fire and explosion

**WHEN THE** West Fertilizer Company in West, Texas, blew up on April 17, 2013, killing 14 people, it must have taken Donald Adair, the owner of the plant, by surprise. In his 2011 emergency plan, Adair described the worst-case scenario for his plant as a 10-minute release of gas! Perhaps we chemical engineers don't appreciate the risks posed by dust as well as we do those of flammable fluids.

One way to bolster your understanding of dust's risks is to check out *Chemical Processing's* free on-demand webinar "Dust Control: How to Identify & Manage Explosion Hazards," accessible via <http://webcast.streamlogics.com/audience/index.asp?eventid=60911195>.

You must estimate the severity of the risk and then its probability. NFPA 499, "Recommended Practice for the Classification of Combustible Dusts and of Hazardous Locations for Electrical Installations in Chemical Process Areas," lists many compounds that produce combustible dusts. If yours isn't on the list, test according to ASTM E1226, "Standard Test Method for Explosibility of Dust Clouds."

In simplified terms, ASTM E1226 involves disturbing a small volume of dust with a pulse of air, followed, after a prescribed time delay, by ignition with a small electrical charge. The dust must contain < 5% moisture by weight and have particles smaller than 420 microns in diameter (i.e., ones that pass through a U.S. No. 40 standard sieve). The test takes place in a bomb of at least 20 liters at ranges of dust concentrations, fuel/air ratios, and electric charges. The goal of this test is to estimate the maximum pressure, the rate of pressure rise with time, and the dust deflagration index,  $K_{st}$ , a measure of relative explosive severity; these parameters also are useful in designing deflagration vents. OSHA defines a dust as a hazard if its  $K_{st}$  exceeds zero; this definition won't protect you if your process produces fines, especially those smaller than 15 microns, which easily are converted to an aerosol. A  $K_{st}$  between 0 and 200 (when measured in bar-meters/sec) indicates a weak explosive risk typical of sugar.

ASTM E1226 can pose several problems: measuring the dust density accurately; accounting for the pressure spike from the igniters; maintaining a dry sample; mixing issues affecting dust and air combustion; and, perhaps, comparisons between bombs of different volumes. So, get as much data as you can on dust properties, do more bomb runs, evaluate the equipment and procedure for systemic faults, and compare your test data against a known standard.

With the severity estimated, it's time to consider the probability that a spark or heat could initiate a fire or explosion. Probability tests involve measurement of the minimum ignition energy (MIE), the minimum explosible concentration (MEC), the auto-ignition temperature (AIT), and the limiting  $O_2$  content (LOC). Except for the AIT, tests are for dust clouds. ASTM E2019 covers measuring the MIE of a dust cloud; ASTM E1515 the MEC of a cloud; ASTM E1491 the AIT of a cloud; and ASTM E 2021 the AIT of layered dust. No LOC test is approved in the US; ASTM has WK41004 in the works but Europe has DIN EN 14034-4:2004.

The spark risk is measured in millijoules (mJ). OSHA states that "materials that ignite above 0.50 joules (500 mJ) are not considered sensitive to ignition by electrostatic discharge." Between 500 and 100 mJ, equipment and people must be grounded to reduce the risk of ignition. An MIE less than 25 mJ is extremely hazardous, posing a risk during bulk operations, e.g., pneumatic conveying, silo storage, etc.

German data from 1965–1985 show that electrical discharge represents only 10% of the ignition sources in 426 accidents. Unfortunately, it's not as easy to assess the danger from heat. Fire caused by grinding or another physical action, drying or even self-heating represents the greatest potential, and is poorly understood. I couldn't find any correlation directly connecting MIE and fire risk; it's more of an article of faith that a low MIE is a fire risk.

So, let's move on to mitigation. Here're some ideas: 1) keep surface temperatures 170°F below the AIT; 2) avoid rubbing of rotating parts; 3) reduce rotating speed; 4) maintain strict grounding policy (see: "Move Against Static Electricity," [www.ChemicalProcessing.com/articles/2013/move-against-static-electricity/](http://www.ChemicalProcessing.com/articles/2013/move-against-static-electricity/)); 5) measure and decrease available oxygen; and 6) cut the quantity of dust by good housekeeping. Also, read the article on p. 27, "Dust Explosion Standard Gets Significant Revisions," [www.chemicalprocessing.com/articles/2013/dust-explosion-standard-gets-significant-revisions/](http://www.chemicalprocessing.com/articles/2013/dust-explosion-standard-gets-significant-revisions/), which highlights important revisions to that standard for prevention of fire and dust explosions.

Hopefully, by focusing on temperature as well as electricity we can avoid more surprises for plant managers. ●

**DIRK WILLARD**, Contributing Editor  
dwillard@putman.net

# Demystify Dust Explosion Propagation

Five common misconceptions can lead to a false sense of security

By Jérôme Taveau, Fike Corporation, USA

**THE UNFORTUNATE** propensity of dust explosions to destroy facilities and claim lives has been reported in numerous past incidents. A recent illustration is the massive explosion that occurred on February 7th, 2008 at the Imperial Sugar Company in Port Wentworth, Ga., where 14 people were killed and 36 people were injured.

Powder handling processes often are comprised of interconnected enclosures and equipment. Flame and pressure resulting from a dust explosion can therefore propagate through piping, across galleries, and reach other pieces of equipment or enclosures, leading to extensive damage.

Inspired by Paul Amyotte's book "An Introduction to Dust Explosions" [1], this article will enumerate, illustrate and unravel five common myths about explosion propagation.

## MYTH #1: A LARGE AMOUNT OF DUST IS NEEDED FOR AN EXPLOSION TO PROPAGATE

Dust explosions don't need large amounts of fuel to propagate. In his book [2], Eckhoff underlines that even a 1 mm layer can create a dust explosion hazard in a typical room. This has been confirmed experimentally by Tamanini [3], who carried out a series of cornstarch explosion tests in a full-scale gallery equipped with several vent panels. The explosion only needed a 1/100 inch layer of dust on the ground to fully propagate.

During a vented explosion, unburned fuel is ejected outside the primary enclosure and is able to create a secondary explosion. The same phenomenon happens when a

dust explosion occurs in a vessel connected to pipes

Valiulis et al. [4] studied the flame propagation into an 89-ft-long clean air duct connected to a 0.64 m<sup>3</sup> initiating enclosure containing cornstarch or phenolic dust. Tests conducted have resulted in flame propagation distances in the range of 22–89 ft, even in a clean air duct.

Recent findings from Fike Corporation's research on dust explosion propagation [5, 6] have shown that a flame propagates even more easily when dust concentration into the pipes is low (50 g/m<sup>3</sup> compared to 500 g/m<sup>3</sup>), both for low reactivity (wood flour) and high reactivity (phenolic dust) fuels; this was attributed to the increased inertia of richer dust-air mixtures.

## MYTH #2: A DUST EXPLOSION STARTING IN A VENTED VESSEL CAN'T PROPAGATE THROUGH CONNECTED PIPES

It is a common belief that protecting an enclosure (by means of venting or suppression) will affect explosion propagation in such a manner that no explosion isolation is needed at all.

In the early 1990's, Chatrathi et al. [7] performed gas explosion experiments using a 2.6-m<sup>3</sup> vessel connected to pipes, and were able to provide evidence that "[...] although venting protects a vessel from the high pressures generated by an explosion, it does not necessarily prevent the explosion from being propagated through piping into other vessels." This statement is also fully valid for dust explosions.

## TEST: INTERCONNECTED VENTED VESSELS



Figure 1. Explosion test is conducted using interconnected vented vessels. Source: Health and Safety Laboratory, Harper Hill, Buxton, U.K.

van Wingerden et al. [8] carried out a series of tests with maize starch, peat and wheat dusts to study explosion propagation in a 5.8-m<sup>3</sup> vented bag filter connected to a 2-m<sup>3</sup> vessel by a 72-ft long duct. Experiments with maize starch resulted in explosion propagation through the entire system.

Holbrow et al. [9] conducted explosions tests with coal, toner and anthraquinone dusts using a combination of vented vessels (2-m<sup>3</sup>, 6.3-m<sup>3</sup>, 20-m<sup>3</sup>) connected by a pipe up to 49-ft long. They showed that an explosion in a primary vented vessel can propagate to a secondary vented vessel (Figure 1).

Fike Corporation routinely performs demonstration tests at its remote testing facility. One of these tests involves a vented dust collector equipped with two pipes. On Figure 2, one can see that even though the dust collector is vented, flame can propagate through these pipes. Ultimately, chemical isolation with sodium bicarbonate (blue cloud on the right of the figure) is needed to extinguish the resulting flame.

The fact that a dust explosion from a vented vessel can propagate through pipes over long distances is also well illustrated by the incident that occurred on October 29th, 2003 in Huntington, Ind., (Figure 3). In this plant manufacturing automotive wheels, an aluminum dust explosion started in a dust collector protected by a vent panel and propagated through pipes to the entire facility, resulting in one fatality and seven injuries [10].

## MYTH #3: A DUST EXPLOSION CAN'T PROPAGATE AGAINST PROCESS FLOW

An argument also often heard is that a dust explosion can't propagate against pneumatic process flow.

To challenge this statement, Vogl [11] conducted explosion propagation tests in a pneumatic conveying system consisting of a dust feeder, a 131-ft (or 157-ft) conveying pipe, a cyclone and a suction fan. Maize starch, lycopodium, and wheat flour were used as fuels. Dust concentration into the pipe was varied in the range 75–450 g/m<sup>3</sup>. Further work by the same author [12] included a vented initiating vessel. Both experimental programs clearly demonstrated that an explosion is capable of traveling both with and against process flow (Figure 4), even over long distances.

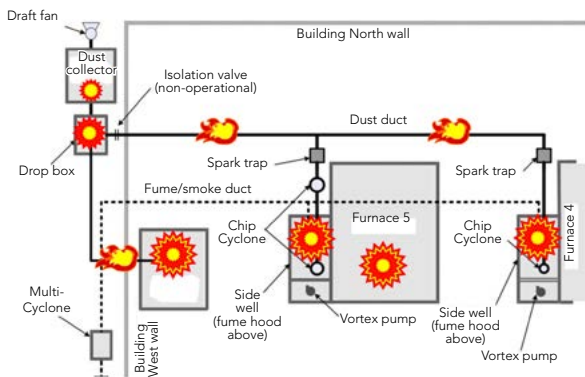
More recently [5, 6], Fike Corporation conducted an extensive experimental program to study dust explosion propagation in industrial conveyance systems.

## TEST: VENTED DUST COLLECTOR



Figure 2. In this demonstration test at Fike Corporation, a flame propagates through a vented dust collector equipped with two pipes. Source: Fike Corporation

## ACCIDENT 1: HUNTINGTON, IN (2003)



1. Furnace No. 5 Wall
2. Fume Hood over Side Well
3. Side Well
4. Aluminum Ingots
5. Dry Chip Hopper
6. Dust Duct
7. Fume Duct
8. Reject Wheels for Remelting

Figure 3. View of the dust collector (outside) and the facility (inside) after a dust explosion at a manufacturing plant in Huntington, Ind., in 2003. Source: U.S. Chemical Safety and Hazard Investigation Board.

## TEST: PROPAGATION AGAINST PROCESS FLOW



Figure 4. Dust explosion propagation tests demonstrate that an explosion is capable of traveling both with and against process flow. Source: FSA Germany.

For that purpose, a large-scale test rig comprising of a vented vessel connected to two pipelines was erected at Fike Corporation's remote testing facility. By means of a fan, different flow conditions were established (from 15 m/s to 30 m/s). Among other findings, research ultimately showed that explosion propagation from a conveyed vented vessel is possible both with and against process flow (Figure 5).

## MYTH #4: A DUST EXPLOSION WEAKENS AS IT PROPAGATES

Literature includes numerous discussions about explosion behavior in interconnected vessels. Experimental evidence has shown that explosions not only propagate, but become increasingly more damaging due to three phenomena [13]:

- **Flame acceleration:** gas flow created by the primary explosion in a vessel will stretch the propagating flame into the pipes, increasing its surface area, its rate of combustion, and thus leading to higher flame speeds and pressure. Eventually, the initial deflagration (subsonic) can become a detonation (supersonic), resulting in much higher explosion pressures.
- **Flame jet ignition:** when the large and fast flame coming from the primary vessel will reach the secondary enclosure, it will ignite the remaining unburned material more violently and lead to higher explosion pressures and rates of pressure rise.

## VESSEL-TO-VESSEL PROPAGATION

Primary Vessel (m <sup>3</sup> )	Secondary Vessel (m <sup>3</sup> )	Maximum Explosion Pressure (bar)
2	20	8.4
20	20	11.4
2	2	14.7
20	4	19.7

Table 1. An explosion in the primary vessel can cause propagation resulting in a much more violent explosion in the secondary vessel. Source: Health and Safety Laboratory, U.K.

- Pressure piling: gas expansion from the primary explosion will increase pressure into the pipes and the secondary enclosure (“pre-compression”) prior to the passage of the flame, leading to a more violent explosion than for ambient conditions.

Lunn et al. [14] carried out coal and toner dust explosions using combinations of two contained vessels (2 m<sup>3</sup>, 4 m<sup>3</sup>, 20 m<sup>3</sup>) connected by a pipe up to 16-ft long. It was shown that an explosion in the primary vessel can result in explosion propagation and cause a much more violent explosion in the secondary vessel (both in terms of maximum rate of pressure rise and maximum explosion pressure, see Table 1). The same effect was shown, although to a lesser extent, for interconnected vented vessels by Holbrow et al. [9].

This aspect is also well illustrated by some of the worst dust explosions that ever occurred in grain elevators [15]:

- In 1982 (Metz, France), a dust explosion originated in a headhouse, spread throughout the upper gallery and spaces between silos (Figure 6).
- In 1997 (Blaye, France), a dust explosion occurred in the northern headhouse before propagating into the upper gallery up to the southern end of the gallery (Figure 7).
- In 1998 (Wichita, Kansas, USA), dust was ignited in the east tunnel of the south array of silos and propagated through the entire grain elevator (Figure 8).

In all cases, a minor primary event quickly developed into a major explosion involving an entire facility, leading to partial or entire collapse of reinforced concrete structures.

## TEST: FLAME PROPAGATION DEMONSTRATION



Figure 5. This series of pictures illustrates how an explosion propagation from a conveyed vented vessel is possible both with and against process flow. Source: Fike Corporation.

## ACCIDENT 2: METZ, FRANCE (1982)

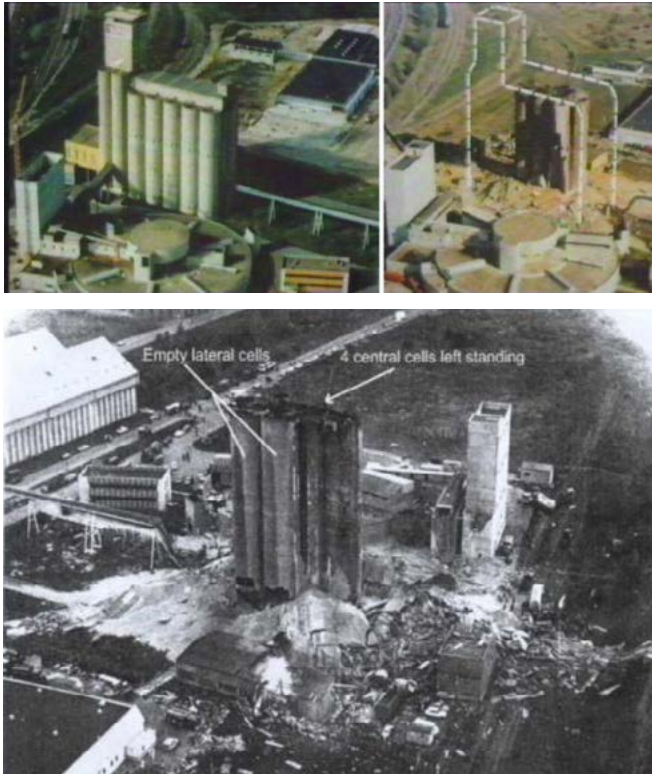


Figure 6. In this before and after picture, a dust explosion in Metz, France originated in a headhouse and spread throughout the grain elevator, reducing it to rubble. Source: French Ministry of Environment

### MYTH #5: SMALL DIAMETER PIPES DON'T SUPPORT DUST EXPLOSION PROPAGATION

Dust explosion propagation in small pipes has always been a controversial topic. The primary argument being that flame propagation is challenged due to heat loss to the pipe walls.

In some of the experiments previously mentioned [11], Vogl used a 4-in. pipe and observed full propagation.

van Wingerden et al. [8] observed different explosion propagation behaviors in 6-in. pipes, depending on the reactivity of the dust, while no propagation occurred with wheat dust ( $K_{St} = 55 \text{ bar.m/s}$ ), maize starch ( $K_{St} = 145 \text{ bar.m/s}$ ) was able to sustain full propagation in nearly all cases. They concluded that “the more reactive a dust is the higher the

## ACCIDENT 3: BLAYE, FRANCE (1997)

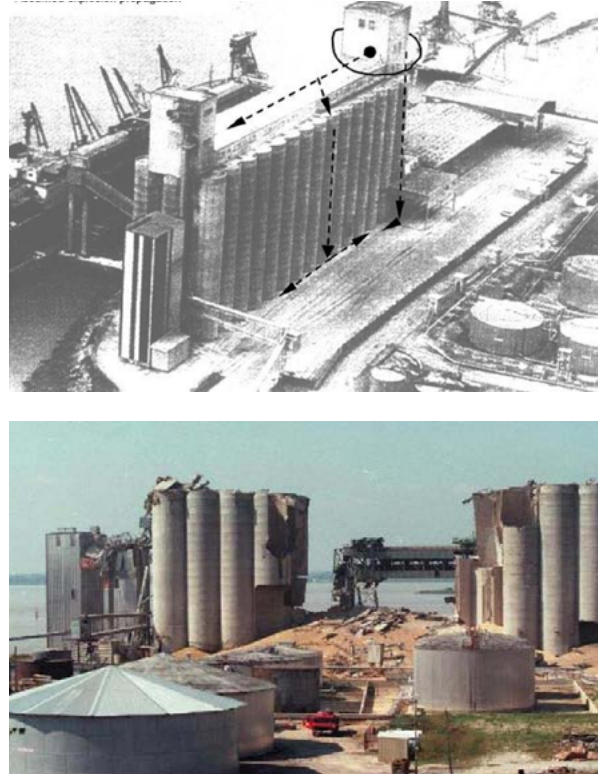


Figure 7. The schematic depicts the supposed explosion (top) and view of the damage (bottom) caused by a dust explosion in Blaye, France. Source: French Ministry of Environment.

chance of flame propagation throughout the entire system is and the stronger the effect may be.” However, they also observed that “Dusts with similar  $K_{St}$  values do not always show similar behavior when propagating through ducts.”

Andrews [16] conducted a comprehensive experimental program related to flame jet ignition of dust clouds. He investigated the effects of different parameters (primary vessel size and venting arrangement, dust, pipe diameter, pipe length, presence of obstacles) on the likelihood for a flame to propagate from a primary vessel and ignite a dust cloud in a secondary vessel. He alternatively used one 2-m<sup>3</sup> vessel and one 20-m<sup>3</sup> vessel connected by a 16-ft long pipe (6-in., 10-in., 20-in. diameter) to an 18.25 m<sup>3</sup>-vessel (flame jet ignition vessel). While no flame

### ACCIDENT 4: WICHITA, KS (1998)



Figure 8. Dust ignited in the east tunnel of the south array of silos propagated through the entire grain elevator. Source: DeBruce Grain Elevator Explosion Report, GEEIT.



transmission occurred using 6-in. pipe attached to the 2-m<sup>3</sup> vessel, flame propagated in nearly all cases when using the 20-m<sup>3</sup> vessel.

According to the Fike Corporation's research conducted with different fuels [5, 6], explosion propagation is more influenced by the reduced pressure and impulse developed in the primary vessel (whether generated by

changes in  $K_{st}$ , dust concentration or venting area), rather than pipe diameter. Recent tests in Fike Corporation's 5-m<sup>3</sup>-vessel pipelines system using 6-in. pipes showed full propagation with and against process flow.

While conditions for dust explosions to propagate in relatively small diameter pipes aren't yet fully established, their ability to propagate has been clearly demonstrated by several researchers.

## CONCLUSION

A review of past incidents and experiments reveals that dust explosion propagation in industrial-scale piping is a reality, and not a myth. History has shown that most devastating dust explosions occurred when the initial deflagration propagated and strengthened, causing widespread damage and numerous deaths.

While explosion protection techniques, such as venting and suppression, are generally applied to enclosures and equipment, the need for explosion isolation is underestimated because some

## ACKNOWLEDGMENTS

The author acknowledges the invaluable efforts of Fike Corporation's Explosion Protection team in conducting the flame propagation research. In addition, the author acknowledges the support of the Fike Corporation for providing the resources and funding necessary to pursue this program and their permission to publish this work.

myths about dust explosion propagation still remain.

Explosion propagation is affected by many parameters. Therefore, specific knowledge is primarily important to determine the conditions under which explosions do or do not propagate. ●

**JÉRÔME TAVEAU** is Scientific Advisor at Fike Corporation, Industrial Protection Group. He is a member of ASTM E27 and NFPA combustible dust committees. He can be reached at [jerome.taveau@fike.com](mailto:jerome.taveau@fike.com).

## REFERENCES

1. Amyotte, P.R., "An Introduction to Dust Explosions: Understanding the Myths and Realities of Dust Explosions for a Safer Workplace", IChemE, 2013
2. Eckhoff, R.K., "Dust Explosion in the Process Industries", 3rd edition, Elsevier, 2003
3. Tamanini, F., "Dust Explosion Propagation in Simulated Grain Conveyor Galleries", Technical Report FMRC J.I. OFIR2.RK. National Grain and Feed Association, Washington, D.C., 1983
4. Valiulis, J. V., Zalosh, R. G., Tamanini, F., "Experiments on the Propagation of Vented Dust Explosions to Connected Equipment", Process Safety Progress, Volume 18, Issue 2, 99-106, 1999
5. Farrell, T., Vingerhoets, J., Snoeys, J., Going, J., "Dust Flame Propagation in Industrial Scale Piping - Part 1: Empirical Study in a Conveying Vessel-Pipeline System", 9th Global Congress on Process Safety, San Antonio, Texas, 2013
6. Vingerhoets, J., Farrell, T., Snoeys, J., "Dust Flame Propagation in Industrial Scale Piping - Part 2: CFD Study of a Conveying Vessel-Pipeline System", 9th Global Congress on Process Safety, San Antonio, Texas, 2013
7. Chatrathi, K., DeGood, R., "Explosion Isolation Systems Used in Conjunction with Explosion Vents", Process Safety Progress, Volume 10, Issue 3, 159-163, 1991
8. van Wingerden, K., Alfert, F., "Dust Explosion Propagation in Connected Vessels", VDI Berichte 975, 1992
9. Holbrow, P., Andrews, S., Lunn, G.A., "Dust Explosions in Interconnected Vented Vessels", Journal of Loss Prevention in the Process Industries, Volume 9, Issue 1, 91-103, 1996
10. Chemical Safety Board, "Aluminum Dust Explosion and Fire, Hayes Lemmerz International, Inc., Huntington, Indiana, October 29, 2003", Report n°2004-03-I-IN, 2005
11. Vogl, A., "Flame Propagation in Pipes of Pneumatic Conveying Systems and Exhaust Equipment", Process Safety Progress, Volume 15, Issue 4, 219-226, 1996
12. Vogl, A., "Explosionsübertragung aus Behältern in Rohrleitungen pneumatischer Anlagen", VDI Berichte 1272, 1996
13. Bjerketvedt, D., Bakke, J.R., van Wingerden, K., "Gas Explosion Handbook", Journal of Hazardous Materials, Volume 52, Issue 1, 1-150, 1997
14. Lunn, G.A., Holbrow, P., Andrews, S., Gummer, J., "Dust Explosions in Totally Enclosed Interconnected Vessel Systems", Journal of Loss Prevention in the Process Industries, Volume 9, Issue 1, 45-58, 1996
15. Taveau, J., "Secondary Dust Explosions: How to Prevent them or Mitigate their Effects?", Process Safety Progress, Volume 31, Issue 1, 36-50, 2012
16. Andrews, S.P., "Jet Ignition of Dust Clouds", Health and Safety Laboratory, 1998