OSHA’S COMBUSTIBLE DUST NATIONAL EMPHASIS PROGRAM AND
COMBUSTIBILITY CHARACTERISTICS TESTING OF PVC RESINS
AND PVC DUSTS

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Abstract

This paper provides an overview of the current and potential regulation of the hazards of combustible dust (CD) by the Occupational Safety and Health Administration (OSHA) and the influence of National Fire Protection Association (NFPA) standards and U.S. Chemical Safety Board (CSB) investigations on OSHA enforcement and rulemaking activities. This paper also presents the results of recent laboratory testing performed to determine the explosibility and other combustibility characteristics1 of samples of a variety of polyvinyl chloride (PVC) resin grades provided by resin producers. Explosibility testing was performed on samples of PVC dispersion resins, PVC copolymer resins, PVC suspension resins, and PVC dust particles sampled from a baghouse serving a PVC suspension resin production line. All test results fell into Class St 1, described as a weak explosion risk, when evaluated in a 20 liter test chamber. Because PVC resins by themselves do not have a known history of incidents where explosions occurred, this suggested the possibility that the test results from the 20 liter chamber test vessel reflected a false positive (or “overdriven”) situation caused by the ignition of the PVC particles as they passed through the flame of the ignition source rather than through the self-propagating deflagration that represents explosibility. As-received suspension resin samples from producers were retested for explosibility in a 1 cubic meter test chamber and the results indicated no explosion risk, falling into Class St 0. This suggests that, at least for the tested suspension resins, the test results from the 20 liter chamber test vessel reflected a false positive (or “overdriven”) situation and that the samples were not explosible. This paper was prepared for presentation at the SPE ANTEC on April 2, 2012.

Introduction

1 The term “explosible,” with respect to a dust, means that a cloud of the dust dispersed in air is capable of propagating a deflagration when airborne in an explosible concentration in the presence of a low energy ignition source at or above the minimum ignition energy for that cloud of dust. The potential explosion hazard of a dust cloud is characterized by the following dust explosibility parameters: maximum explosion pressure, Pmax; maximum rate of pressure rise, (dP/dt)max; and explosibility index, Kst. The broader term “combustible,” with respect to a dust, means that the dust is capable of igniting and burning, but may not be explosible. The dust could be in a cloud or in a solid layer accumulation. The additional combustibility parameters include: minimum ignition temperature of a dust cloud or dust layer from a hot surface.

Fires and explosions fueled by combustible dusts (CD) have long been recognized as a major industrial hazard. [1] In November of 2006, the CSB issued a combustible dust hazard investigation report (the “2006 CSB Report”) that described the occurrence of 281 dust fires and explosions in U.S. industrial facilities during the period from 1980 to 2005, resulting in 119 fatalities and 718 injuries.[2] A review of the data based assembled by the CSB for this 2006 report indicates that PVC resin was not implicated in any of these incidents. [3] A review of the data on 466 explosive dust incidents compiled by the OSHA for the period from January 24, 1980 through December 31, 2010 indicates that PVC resin was not implicated in any of these incidents. [4]

In its 2006 report, the CSB stated that NFPA has issued comprehensive standards to prevent and mitigate CD explosions, and that the standards are widely recognized by experts as effective and authoritative. The NFPA CD standards are frequently referenced in OSHA citations issued under the General Duty Clause of the OSH Act (as evidence of both recognition of the hazard and a feasible means of eliminating or reducing the risk of exposure to the hazard). The NFPA CD standards are also incorporated by reference into the International Fire Code, and are referenced by authoritative publications on CD hazards. Although these NFPA CD standards are generally incorporated directly or by reference into fire regulations of state and local jurisdictions, the CSB found that their adoption and enforcement is inconsistent and largely ineffective. Not all states have adopted fire codes that clearly reference NFPA standards, and jurisdictions within states often amend the state-adopted codes or adopt different codes. [5] The 2006 CSB Report called for:

- A comprehensive OSHA regulatory standard to prevent dust explosions in general industry;
- Improved training of OSHA inspectors to recognize dust hazards;
- Improvements to Material Safety Data Sheets to better communicate CD hazards to workers;
- Action by the International Code Council to revise the International Fire Code to mandate compliance with CD safety requirements as set forth by NFPA.

OSHA initially concluded that the requirements of its existing standards and the General Duty Clause were

2 OSH Act Section 5(a)1, 29 U.S.C. § 654.
adequate to address the hazards of CD, but that a National Emphasis Program was necessary to increase the level of awareness and resources being devoted to this hazard. A massive and catastrophic sugar explosion at Imperial Sugar's Port Wentworth Georgia facility on February 7, 2008, killed 14 workers, injured many more and led to an outcry from the CSB and Congress for a new OSHA regulation to address CD [6].

**OSHA Combustible Dust NEP**

OSHA initiated its Combustible Dust National Emphasis Program (CD NEP) (CPL 03-00-006) on October 18, 2007, to inspect facilities that generate or handle combustible dusts that pose a deflagration/explosion or other fire hazard. [7] Following the Imperial Sugar incident, OSHA revised the CD NEP to focus on industries with more frequent and high consequence dust incidents, and to include more inspections. The revised CD NEP targets 64 types of industries and encourages OSHA compliance personnel to look for CD issues in connection with every on-site inspection, regardless of whether the site is in one of the industries targeted by the CD NEP.

Section 18 of the Occupational Safety and Health Act encourages States to assume responsibility for developing and enforcing workplace safety and health requirements through state programs approved by OSHA. OSHA has approved 26 State-Plan Programs. OSHA strongly recommended that all State Plans participate in the CD NEP. Since the inception of the CD NEP, more than 1,000 combustible dust inspections have been conducted, including inspections conducted by State Plan States. To date, 11 states have adopted OSHA's CD NEP and an additional four states have plans to adopt the program. [8] It is worth noting that the California Division of Occupational Safety and Health (DOSH) (Cal-OSHA) adopted a general CD standard in 1985 [9] when OSHA adopted a CD standard limited to the grain industry. [10] The Insurance and Safety Fire Commissioner for the State of Georgia adopted two CD rules in 2008, although Georgia is not a State Plan state. [11]

Although OSHA does not have a comprehensive standard on combustible dust hazards, there are ten existing OSHA standards that, in one way or another, address some aspect of the hazards of combustible dust. The CD NEP focuses on these standards, as well as the General Duty Clause.[12]

The CD NEP, along with an OSHA training institute course, trains OSHA inspectors in combustible dust hazards and how to conduct a combustible dust inspection. Inspectors are directed to determine whether a plant has a history of fires, whether the site has material safety data sheets (MSDS) that address CD issues, the presence of CD accumulations and other sources of data. In locations where the layer of accumulated dust is as at least as thick as a standard paperclip (0.8 mm, or 1/32 inch) and covers some meaningful area, inspectors are directed to take a sample of the dust and photograph and document their findings.

The conditions under which a CD accumulation presents a combustible dust hazard remain the subject of controversy. Because of the complexity involved in assessing risk, NFPA standards provide for two approaches. The conservative approach, also referred to as the “specification-based approach,” is to focus solely on whether a threshold amount of CD is present, and to assume that the dust will somehow become airborne, at or above the minimum explosible concentration, in the same time frame that an ignition source having the minimum ignition energy for that dust is present. The alternative, performance-based approach is generally described as having an expert determination as to whether that is a credible risk for which protective measures are required.

**Evolving Criteria for Determining a Dust Accumulation Hazard**

The most generally applicable NFPA combustible dust standard is NFPA 654-2006, “Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids,” as modified by Tentative Interim Amendment (TIA) 06-1. [13] It applies to all combustible dusts not covered by one of the other four NFPA combustible dust standards. The text of NFPA 654-2006 states what measures should be taken when a combustible dust hazard is present, but, prior to TIA 06-1, did not define the conditions that present a combustible dust hazard.

Prior to TIA 06-1, non-mandatory Annex D to NFPA 654 was used as a reference for establishing guidelines on the frequency of cleaning. It stated that an accumulation of 0.8 mm (1/32 inch) of CD, with a bulk density of 1,202.4 kg/m^3 (75 lbs/ft^3), over more than five percent of a floor area “is a moderate hazard,” “is about as much coverage as should be allowed in any plant,” and “is capable of creating a hazardous condition.” In other words, under NFPA 654-2006, prior to TIA 06-1, a 0.8 mm (1/32 inch) layer of CD with a bulk density of 1,202.4 kg/m^3 (75 lbs/ft^3) was of potential concern (because it was \( \geq \) “the layer depth criterion”) and a layer that dust of less than 0.8 mm (1/32 inch) was ignored (because it was \(< \) “the layer depth criterion”). Reflecting the fact that the magnitude of the hazard is based on the mass of fuel (CD) present rather than its layer thickness, NFPA 654-2006 contains a linear bulk density equation that permits the “layer depth
“criterion” to be adjusted\(^3\) to reflect the actual bulk density of the CD. As a practical matter, many organizations had been using the 5% coverage area as a rule of thumb for all areas at or above the layer depth criterion without regard to the actual thickness of the dust layer. The NFPA 654 Committee determined that this approach did not accurately reflect the existence or magnitude of the combustible dust hazard, which it determined was related to the mass of CD and not the layer thickness. Based on that determination, the NFPA 654 Committee proceeded to amend the standard with an approach that, for all practical purposes, eliminates any consideration of layer thickness, except that a layer of 0.4 mm (1/64 inch) or less can be ignored.

Based on a superficial read, it may appear that TIA 06-1 “simply” converted the non-mandatory layer thickness guideline into a mandatory requirement, adjusted for bulk density, but it actually did far more than that. Except for the fact that a layer of 0.4 mm (1/64 inch) or less can be ignored, TIA 06-1 actually eliminated the layer thickness guideline and replaced it with a volume threshold requirement. Yes the layer thickness requirement is listed in Sub-paragraph 6.1.1.3(1)(a), but Sub-paragraph 6.1.1.3(1)(b) renders it meaningless because the language of Sub-paragraph 6.1.1.3(1)(b) is always more restrictive than Sub-paragraph 6.1.1.3(1)(a), and the introductory language of Paragraph 6.1.1.3 states that a combustible dust hazard is deemed to exist when “any of the following conditions exist” – meaning either the condition in Sub-paragraph 6.1.1.3(1)(a) or the condition in Sub-paragraph 6.1.1.3(1)(b).

TIA 06-1 includes the following language:

6.1.1.3* A dust deflagration hazard shall be deemed to exist where … any of the following conditions exist [emphasis added]:

(1) For buildings or rooms with footprint areas smaller than 1860 m\(^2\) (20,000 ft\(^2\))

(a) the area of dust accumulations exceeding the layer depth criterion is greater than 5% of the footprint area, or

(b) the total volume of dust accumulations is greater than the layer depth criterion multiplied by 5% of the footprint area.

Under TIA 06-1, the volume of all layers of CD in excess of 0.4 mm (1/64 inch) present in a single room, except those that meet the criteria for separation by distance,\(^4\) are aggregated in determining whether a threshold quantity of CD is present.

These changes are most readily understood by example. For simplicity, we will assume a CD with a bulk density of 1,202.4 kg/m\(^3\) (75 lbs/ft\(^3\)) layered on the floor of a 930 m\(^2\) (10,000 ft\(^2\)) room with no other surfaces on which CD may collect. Therefore the layer depth criterion is 0.8 mm (1/32 inch). If 5% of the floor 46.5 m\(^2\) (500 sq. ft.) has a uniform 0.8 mm (1/32 inch) layer of CD, the volume of the dust would be 0.037 m\(^3\) (1.3 cubic feet). Under Sub-paragraph 6.1.1.3(1)(b) of TIA 06-1, that would be the maximum amount of non-separated CD that could be present in the room without meeting the threshold quantity trigger (“the Maximum Permissible Unprotected Volume”). Under Sub-paragraph 6.1.1.3(1)(a) of TIA 06-1, the threshold quantity trigger is not met, regardless of how many feet high the CD is piled on the 46.5 m\(^2\) (500 sq. ft.) of area, as long as no more than 5% of the floor (46.5 m\(^2\) or 500 sq. ft.) is covered with CD at or above the layer depth criterion. For an extreme example, assume that a pile of CD that is 3.1 m (10 feet) wide x 15.2 m (50 feet) long x 0.3 m (1 foot) deep is placed on the 46.5 m\(^2\) (500 sq. ft.) area. The volume would be 14.2 m\(^3\) (500 cubic feet). That condition does not meet the trigger in Sub-paragraph 6.1.1.3(1)(a), but it does exceed the alternate trigger of 0.037 m\(^3\) (1.3 cubic feet) (“the Maximum Permissible Unprotected Volume”) in Sub-paragraph 6.1.1.3(1)(b) by more than two orders of magnitude. That is clearly an extreme example and the dust would need to be contained in some way to achieve that configuration. At the other extreme, assume 5% of the floor is covered with a 0.8 mm layer, which equals the Maximum Permissible Unprotected Volume. The addition of a minimal volume of CD that would barely raise the aggregate volume of CD in the room above the Maximum Permissible Unprotected Volume would also trigger Sub-paragraph 6.1.1.3(1)(b). In theory, one need simply add a thimble full of dust that produces a layer of CD that exceeds 0.4 mm (1/64 inch) and is placed on top of or within 9.14 m (30 feet) of the contiguous layer of CD that is 0.8 mm (1/32 inch) and covers 46.5 m\(^2\) (500

\(^3\) The adjustment is a simple linear equation. The adjusted trigger layer thickness equals 0.8 mm (1/32 inch) multiplied by a factor equal to 1,202.4 kg/m\(^3\) (75 lbs/ft\(^3\)) divided by the bulk density of the actual material. For example, the trigger layer depth would be 4 mm (5/32 inch) for dust with a bulk density of 240.5 kg/m\(^3\) (15 lb/ft\(^3\)). \[0.8 \times (1,202.4/240.5) = 4.\]

\(^4\) Section 6.2.3, as revised by TIA 1020, provides:

6.2.3.1 Separation shall be permitted to be used to limit the fire or dust explosion hazardous area, that separation area shall be free of dust to the extent that dust accumulations on any surfaces do not exceed 0.4 mm (1/64 in.) or surface colors are readily discernible. The required separation distance between the hazardous area identified in 6.1.1.3 and surrounding exposures shall be determined by the following:

(1) Engineering evaluation that addresses the properties of the materials
(2) Type of operation
(3) Amount of material likely to be present outside the process equipment
(4) Building design
(5) Nature of surrounding exposures

6.2.3.2 In no case shall the distance be less than 9 m (30 ft).
square ft.). Being within 9.14 m (30 feet) of the main layer, it would not meet the criteria for separation and would be aggregated with the main (46.5 m² or 500 square feet layer) volume. The addition of that thimble of CD would meet the criteria of Sub-paragraph 6.1.1.3(1)(b), and the room would be deemed a combustible dust hazard.

NFPA 654-2006 is in the final stages of an accelerated revision cycle. The revised standard is expected to retain the criteria established by TIA 06-1 as one basis for determining whether a dust accumulation poses a combustible dust hazard. It is also expected to offer an alternative approach that is reported to be less conservative, but would require the use of complex formulas with numerous variables that could only be populated by the results of the costly testing needed to determine the characteristics and combustion properties of the CD.

OSHA has issued numerous citations under its General Industry housekeeping standard on the basis that excessive CD accumulations pose a fire or explosion hazard. While the agency has intentionally refrained from announcing quantitative criteria for determining when an accumulation of CD is deemed excessive, we would not be surprised if OSHA attempted to use the criteria from TIA 06-1 for that purpose.

OSHA Citations

According to OSHA, the most frequently cited standard under the CD NEP is the OSHA Hazard Communication Standard (HCS), 29 C.F.R. 1910.1200. The HCS citations, generally based on the alleged failure to provide the required training to employees on the hazards of CD, account for 27% of the alleged violations cited in the course of OSHA’s CD NEP inspections. The second most frequently cited standard under the CD NEP is OSHA’s Housekeeping Standard, 29 C.F.R. 1910.22. Section 1910.22 citations, representing 20% of the alleged violations are based on allegedly excessive and hazardous accumulations of CD. As with the HCS, the Housekeeping Standard was not adopted for the purpose of regulating combustible dusts.

During CD NEP inspections, employers were also cited for alleged violations of requirements covering personal protective equipment, electrical equipment, first aid, powered industrial trucks, and fire extinguishers. OSHA compliance officers also found that, contrary to the generally applicable rule, compressed air in excess of 207 kPa (30 psi) was being used for cleaning purposes in situations where a higher pressure was not needed. The use of compressed air to clean accumulated dust is likely to create a dust cloud and can result in deflagration or explosion if the dust is combustible and airborne at the minimum explosive concentration, and an ignition source generating the minimum ignition energy is present. NFPA 654 bars the use of air blowdowns except under limited conditions, and, under those limited conditions, limits the pressure of blowdown air to a gauge pressure of 103 kPa (15 psi). OSHA issued citations under the General Duty Clause, Section 5(a)(1) of the OSH Act, to eliminate or minimize the use of air blowdowns.

In the absence of an applicable OSHA standard, OSHA can cite the General Duty Clause, to address recognized fire and explosion hazards for which there are feasible means of eliminating or abating exposure to the hazard. In its 2009 report, OSHA lists 32 separate examples of General Duty Clause citations under the CD NEP. Some examples of the alleged violative hazards cited under the General Duty Clause are listed below:

1. Dust collectors were located inside buildings without proper explosion protection systems, such as explosion venting or explosion suppression systems.
2. Deflagration isolation systems were not provided to prevent deflagration propagation from dust handling equipment to other parts of the plant.
3. The rooms with excessive dust accumulations were not equipped with explosion relief venting distributed over the exterior walls and roofs of the buildings.
4. The horizontal surfaces such as beams, ledges and screw conveyors at elevated surfaces were not minimized to prevent accumulation of dust on surfaces.
5. The ductwork for the dust collection system did not maintain a velocity of at least 4500 ft/min to ensure transport of both coarse and fine particles and to ensure re-entrainment.
6. Flexible hoses used for transferring reground plastics were not conductive, bonded or grounded to minimize generation and accumulation of static electricity.
7. A nonconductive PVC piping was used as.

5 OSHA’s housekeeping standard, 29 CFR 1910.22, was adopted under the special provision in Section 6(a) of the OSH Act that, for a period of two years, authorized OSHA to adopt National Consensus Standards as OSHA standards without the traditional rulemaking. To avoid an improper delegation of Congressional power, OSHA was required to adopt the national consensus standards without substantive change. There is a persuasive legal argument that OSHA improperly amended the national consensus standard, which was the source of its housekeeping standard, when it adopted Section 1910.22. That rule is the subject of a pending OSHA rulemaking on walking-working surfaces and fall protection. If OSHA is unable to retain or rescind Section 1910.22, we would expect the agency to rely on the General Duty Clause to cite what it deems to be hazardous accumulations of CD.

6 While OSHA continues to issue HCS citations in connection with CD, there is a persuasive legal argument that the HCS does not apply to CD.

7 See 29 CFR 1910.242(b) and Section 1926.302(b)(4).
ductwork. Ductwork from the dust collection system to other areas of the plant was not constructed of metal.

8. All components of dust collection system were not constructed of noncombustible materials in that cardboard boxes were being used as collection hoppers.

9. Equipment such as grinders, shakers, mixers and ductwork were not maintained to minimize escape of dust into the surrounding work area. Employer did not prevent the escape of dust from the packaging equipment, creating a dust cloud in the work area.

OSHA also referenced NFPA 499 in recommending safe practices for electrical equipment used in Class II locations, and NFPA 68 and 69 for explosion venting and suppression techniques.

**Combustible Dust Class II Electrical Classification Determination**

When an area within a site is classified as a hazardous location, as defined in Section 1910.399(a), because of the presence of CD, Section 1910.307 of OSHA’s electrical standards requires the employer to use electrical equipment approved for use in that hazardous (classified) location. Section 1910.399(a) defines a Class II, Division 2 location as a location where:

(i) Combustible dust will not normally be in suspension in the air in quantities sufficient to produce explosive or ignitable mixtures, and dust accumulations will normally be insufficient to interfere with the normal operation of electric equipment or other apparatus, but combustible dust may be in suspension in the air as a result of infrequent malfunctioning of handling or processing equipment; and

(ii) Resulting combustible dust accumulations on, in, or in the vicinity of the electric equipment may be sufficient to interfere with the safe dissipation of heat from electric equipment or may be ignitable by abnormal operation or failure of electric equipment.

Sections 1910.307 and 1910.399 do not provide any quantitative guidance as to when an accumulation of dust triggers classification. Our understanding is that OSHA has been using 3.2 mm (1/8 inch) as the trigger for requiring a Class II, Division 2 electrical classification. However, the classification diagrams in NFPA 499-2008, “Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas”, generally treat a layer of dust that obscures the color of the underlying surface as Class II, Division 2, and a layer of dust in excess of 3.2 mm (1/8 inch) as Class II, Division 1. Table 4.5.2 of NFPA 499 contains a fairly extensive list of combustible dusts. There is no listing for PVC.

As explained in the CD NEP (OSHA CPL 03-00-008), for Class II locations—those made hazardous by the presence of CD—polymeric dusts are included in Group G (atmospheres containing other combustible dusts, including flour, grain, wood flour, plastic and chemicals) — OSHA uses a special test procedure to determine whether a dust is a CD for purposes of electrical classification. The Class II determination is based on tests performed according to ASTM E1226 in a 20 liter chamber on a sample screened to <75 microns. “National Materials Advisory Board (NMAB) 353-3-80, Classification of Combustible Dusts in Accordance with the National Electrical Code, defines dusts having ignition sensitivity greater than or equal to 0.2 or explosion severity greater than or equal to 0.5 to be appreciable explosion hazards requiring electrical equipment suitable for Class II locations.”[17] According to OSHA, dusts whose explosibility parameters fall below these limits are generally considered weak explosion hazards. In addition to determining the appropriate electrical classification, ignition sensitivity and explosion severity are important criteria for sizing and designing deflagration vents and other safety relief devices in order to prevent or control a primary explosion.

**Determining Combustibility for Purposes Other than Electrical Classification**

To determine if a dust is a CD, OSHA collects samples and sends them to its Salt Lake City Laboratory where they are tested on an “as-received” basis using standard ASTM methods for determining characteristics related to dust combustibility and explosion hazards. The term “as-received” generally means samples are tested without screening out larger particles, but after reducing the moisture content below 5%. In situations where large chunks would be present, they would be removed because they would interfere with the test and it is highly unlikely they would become airborne in any initial event.

In addition to moisture content, literature suggests that the explosion properties of a CD relate significantly to the particle size involved, making it necessary to study the particle size distribution of dusts. Finer particles can reach increased concentrations for prolonged periods in head spaces inside vessels and equipment where air flow is minimal during certain operating periods. Finer particles can also become airborne within a facility during handling or from transfer line or vessel leaks and eventually accumulate as a dust layer on all sorts of obscure surfaces - horizontal, inclined and vertical -- throughout a work environment.
In performing explosibility testing, ASTM E1226-10 conservatively recommends\(^5\) that material be screened to below 75 microns (pass through 200 mesh screen) in order to assess potential worst case scenarios for combustibility. It is a conservative approach that generally may be used when the person performing the analysis is not in a position to make a more accurate determination as to the relevant particle size for analysis. Whenever testing is performed, it is important to document the test protocol.

OSHA recognizes the generally accepted categories shown in Table 1 for combustible dusts based on Kst value, determined by testing of sampled dust accumulations. The Kst value represents the maximum rate of pressure rise generated when dust is tested in an explosion chamber. It is generally viewed as providing the best “single number” estimate of the anticipated behavior of a dust deflagration, if one occurs.\(^{[18]}\)

**Combustibility Determinations**

When determining whether a powder is a CD, there are many important factors as listed in Table 2 that need to be measured in assessing the risk associated with a dust cloud or layer of a particular material.

The Minimum Ignition Energy (MIE) is the lowest energy of a spark that is capable of igniting the most sensitive dust/air mixture (dust cloud) with sustained combustion. Generally, this energy is released over a very short period of time and would not typically cause ignition of an intact dust layer. MIE is a function of: A) Physical and chemical properties of the dust including particle size distribution, chemical composition, and moisture content; B) Specific concentration of dust in the dust/air mixture; C) Initial temperature of the dust/air mixture; D) Dynamic conditions such as turbulence, instantaneous velocities; and E) Type of ignition source. Determining the minimum ignition energy of a CD is necessary to be able to determine whether a dust cloud of a particular material is capable of being ignited by a static discharge event or whether more energy such as from an electric arc of an electrical fault to ground or from a source such as an open flame might be needed. The lower the energy required to ignite a dust cloud, the greater the concern becomes that the material could experience a primary explosion, which normally occurs within the confines of a vessel, from a small static discharge event.

The Minimum Ignition Temperature (MIT) is the temperature of a hot surface which would cause ignition (initiation of an explosion) of a dust cloud or ignition of a dust layer. The MIT for dispersed dust is principally used to ensure that plant surface temperatures cannot cause the ignition of the dispersed dust. The MIT measurements, therefore, find particular use in drying operations where dust dispersion/accumulation is present at elevated temperatures (e.g. spray dryers, flash dryers, and fluid bed dryers). Furthermore, if dust accumulations remain in a dryer for an extended period of time, oxidative self-heating can raise the temperature of the dust to the MIT. According to the National Electrical Code, the surface temperature of any equipment must be less than the ignition temperature of the specific dust to be encountered reduced by a safety factor.

Kst value and Pmax are needed to determine plant explosion relief and suppression system requirements, and explosion containment design. NFPA 68, “Standard for Explosion Prevention by Deflagrations Venting,” provides more understanding of explosion severity test results and includes equations for sizing explosion relief vents based on Kst.\(^{[19]}\) The Maximum Explosion Pressure and the Maximum Rate of Pressure Rise are also used to calculate Explosion Severity and Ignition Sensitivity for the electrical classification determinations.

The Minimum Explosible Concentration (MEC) is the minimum concentration of material (g/m³) that must be present in a dust cloud for the material/air mixture to be considered exploitable. The MEC is sometimes used to design plants with sufficient air throughput to keep dust levels below the exploisible limit. Care is required in using this approach because, in practice, dust clouds are rarely uniform, and settlement or unforeseen circumstances can easily arise to create locally exploisible concentrations even though mean concentration levels may be below the MEC.

**PVC Resins Combustibility Study**

The Vinyl Institute and its members undertook a resin testing program to assess the combustible characteristics of various PVC resin samples. The primary types of PVC resin are suspension and dispersion, based on the method used for polymerization. Suspension resins are the most widely used, representing some 95% of the PVC resin produced in the U.S. Suspension resins are used in extrusion and injection molding applications. The typical particle size for suspension resins can be from 120 to 200 microns, and the resins have substantial porosity and pore structure. In contrast, the particle size of dispersion resins typically ranges from 0.4 to 2 microns and the particles have very little porosity or pore structure. Dispersion resins are used in plastisols, and film calendaring operations. The results for the test program are shown in Table 3.

\(^{5}\) Section 9.2 states that tests may be run on an as-received sample, but recommends that the test be run on a sample with 95% of the particles less than 200 mesh (75 μm) to represent a theoretical worst case scenario of an accumulation of fines at some location in a processing system,
**Interpreting the Results**

The results of these tests can be used as a basis for determining precautions to exclude possible ignition sources and otherwise prevent or protect against potential dust explosion incidents.

- The minimum ignition energy (MIE) results show that practically all the PVC samples are difficult to ignite. Dusts with MIE >1000 milli-Joules are considered difficult to ignite from any credible ignition source. Only the baghouse dust sample from Facility C is below this level. Through the use of the baghouse, the more combustible dust fraction is removed from the PVC resin product and handled at the producing plant. These MIE results show that the samples are less susceptible to low energy ignition sources such as a static discharge event and would need a high energy source to ignite such as from an open flame or electrical arc from a fault to ground.

- Both dispersion and copolymer type resins have minimum ignition energies over 10 Joules, which mean they are very hard to ignite. Both of these resins are very small particle sizes (typically in the 0.4 to 2 micron average particle size range), a characteristic of PVC resins produced with the dispersion process.

- When tested in a 20 liter spherical test chamber, the sampled PVC resins and baghouse dusts exhibit combustible dust characteristics that correspond to Class St 1, which is a weak explosion category. The 20 liter sphere simulates a closed process vessel where a high dust concentrations may be found, possibly as a result of dust accumulations being loosen (e.g., during the blowback cycle in a baghouse), and a primary explosion might occur. Because the heat of the ignition source in a 20 liter sphere can combust particles close to it, a phenomenon known as overdriving occurs. In those circumstances, ASTM (E1226-10 and E1515-07) recommends that the sample be retested in a 1 m³ test chamber to determine whether it is actually explosible.

- When tested in a 1 m³ sphere test chamber, the as-received suspension resins samples displayed no explosibility characteristics and would be classified as Class ST 0. The larger 1 m³ test chamber more closely simulates conditions associated with a secondary explosion where concentrations of dust in a more open environment outside of a vessel, but within the confines of a building, are subjected to ignition sources.

- Finer particle fractions (<75 microns) found in suspension resin samples exhibit higher combustibility characteristics than the resin itself. Because the typical particle size for suspension resins is 120 to 200 microns, significantly smaller particles are a very minor component of suspension grade resins. There are several reasons for this. Suspension resin polymerization employs suspending agents and highly engineered reactor agitation to tightly control monomer droplet size. Once polymerized, the resin is dried using direct contact with flowing warm air which essentially de-dusts the resin, and the fine particles are collected in a baghouse. Customers who use suspension resins would not expect to find a significant amount of particles in the < 75 micron particle size range in these grades. Indeed, the first samples of commercially sold suspension resins provided to the testing laboratory contained such a small quantity (typically <3% wt. below 75 microns) of fine particles that it became impractical for the laboratory to screen and collect enough small-particle material to produce the ASTM-recommended test sample with 95% of the particles less than 200 mesh (75 μm). For this reason, testing was performed on baghouse dust samples that had a higher concentration of small particles. Attempts by the testing laboratories used in this study to screen the samples for particle size distribution analysis gave erroneous results because the screens blinded with electrostatic charged particles.

- Low moisture content does not appear to be a factor that correlates to increasing explosibility of the PVC samples. PVC resin characteristically does not absorb much moisture as evidenced by the low moisture content of the as-received samples. With other types of materials, literature reports more sensitivity to moisture content that what PVC displays.

**Applying Dust Combustibility Risk Assessment to the Vinyl Industry**

The PVC industry has been tightly regulated since 1975 when the first OSHA standard for workplace exposure was developed for vinyl chloride. Since that time, the PVC industry has made numerous improvements in the manufacturing process, control of particle size, and limits on workplace exposure to employees. Today’s current OSHA permissible exposure limit (PEL) 8 hour time weighted average (TWA) for particles not otherwise regulated (PNOR) is 15 mg/m³ (5 mg/ m³ for respirable fractions) [20] and this assures that workplace exposure is safe. The PVC resin industry has a demonstrated record of compliance which is reflected by its low illness and injury rate. OSHA’s PNOR PEL is a factor of some 5,000 times lower than the most sensitive minimum exploisable concentration for PVC resin; this provides an additional measure of safety against a deflagration incident. These detailed regulations not only limit employee exposure to levels believed to be safe for chronic exposure but also require stringent controls and technology for preventing workplace dusts hazards.

**Conclusions and Recommendations**
The results of this study show the evaluated samples of PVC powders had weak to no explosibility characteristics depending, at least to a significant degree, on how they were tested. Those results are consistent with industry experience and the absence of any documented combustible dust incidents involving pure PVC in the CSB or OSHA databases. A similar conclusion is reached in The European Council of Vinyl Manufacturers (ECVM) guidance document on the EU “ATEX Directive”, which also states there are no PVC dust explosions reported by insurance brokers for ECVM members. These results should not be considered as a substitute for testing dust accumulations for a specific facility. While the risk of a combustible dust incident during normal transportation and handling of suspension or dispersion grade PVC resins appears to be low, due to the high minimum ignition energy required, we would not interpret the test results to imply there is no risk. Good housekeeping, adequate ventilation, appropriate mechanical and electrical design of the installation, and proper handling and mixing procedures are key work practices that have successfully controlled the hazards of dust in the PVC industry.

Both the 20 liter and 1 m³ test chambers were utilized to characterize the explosibility of suspension grade PVC resins sampled for this study. The CSB addresses both types of testing in Section 4.1.1.4 of the Hoeganaes Corporation Case Study [22]:

“Both the 20-L and 1-m³ tests are accepted methods that can characterize dust explosibility; however results from the two tests may differ. There are several factors that can contribute to varying results among the dust test methods. Dust characteristics, such as particle size, moisture content, and degree of oxidation (for metals) can affect the ignitability of the sample in the test chamber.

The 20-L and 1-m³ test chambers were designed to simulate dust explosions in facility settings, but each test has limitations. The main difference between the two tests is the chamber size and the dust dispersion mechanism. Since the 1-m³ test is larger, theoretically it can better simulate an open-space dust cloud explosion. However, that larger volume also makes it harder to create a uniform distribution of dust within the testing chamber. In the smaller 20-L test chamber it is easier to create a uniform distribution; however, it is possible that the smaller chamber also creates an “overdriving” effect. Since the 20-L chamber is smaller, the energy exerted by the igniters may combust enough dust creating the appearance of ignition — a situation that would not occur in a facility setting (citations omitted).

NFPA revised the 2012 edition of NFPA 484 to state that explosibility screening tests shall be performed in accordance to the 20-L test standard, E1226(-10). However, NFPA added to the standard annex that the results of the 20-L test can be conservative and an owner or operator of a facility may elect to use a 1-m³ test for dust explosibility testing as the 20-L test may result in false positives for dusts with lower KSt values.”

It should be noted that both tests are for explosibility screening, and alone may not convey the full combustibility hazard. It appears that the CSB undertook the Hoeganaes Case Study because it presented a unique situation involving iron dust particles (primarily in the 45-150 micron range). The explosibility test in the 20 liter sphere indicated a weak explosion hazard, the explosibility test in the 1-m³ enclosure indicated no explosion hazard, and the CSB found that the facility’s history of metal dust “flash fires became normalized,” prior to the fatal incident on January 31, 2011, “since they did not result in any serious injuries” prior to that date. The flash fire characteristic of the iron dust demonstrates that it presents a potential deflagration hazard, whereas the lab tests measured its potential explosibility, a more rapid type of deflagration. Unlike the metal industry experience with iron dust flash fires, the plastics industry has no known history of flash fires involving pure PVC resin.

Typically, PVC resin is blended with other additives such as impact modifiers, lubricants, process aids, and fillers that can be expected to alter the combustibility characteristics of the PVC resin. Both the additives and the blended material should be evaluated through the appropriate application of the referenced ASTM test methods. For samples taken as part of an OSHA CD NEP inspection, it is a good idea to split the sample with the inspector and submit your sample to a test lab for characterization. Knowing the combustibility characteristics of all materials handled at a facility is one factor in assessing combustibility risk as part of a comprehensive facility program. Related good practices include:

A) Assuring adequate grounding of processing equipment, storage vessels, transfer lines, and structures;
B) Minimizing combustible dust accumulations, particularly in obscure locations; 10

9 Annex A (Section A.4.3.2) to NFPA 484-2012 indicates that the results of the 20-L test may be false positives and states that an owner or operator of a facility may elect to rely on dust explosibility screening tests performed in an enclosure with a volume of at least 1-m³, “which [according to Section A.4.3.2] is less susceptible to over-driving and thus will provide more realistic results.”

10 Annex D and Chapter 8 of NFPA 654 list recommended procedures for routine housekeeping to minimize risks from fugitive dust accumulations.
C) Attentive repair of any leaks in fluidizing lines and equipment;
D) Consulting with experts to provide appropriate deflagration venting in equipment;
E) Effectively communicating to employees and contractors about the hazards and locations of combustible dust and appropriate protective measures; and
F) Planning and training for a well-coordinated emergency response.

Acknowledgements

The authors thank The Vinyl Institute and its members for their review and significant comments, and for their permission to prepare and present this paper. Combustibility testing was contracted with Chilworth Laboratories in New Jersey and Fike Laboratories in Missouri.

References

11. Rules And Regulations Of The Safety Fire Commissioner, Chapter 120-3-24 Rules And Regulations For Loss Prevention Due To Combustible Dust Explosions And Fire, and Chapter 120-3-3 Rules And Regulations For The State Minimum Fire Safety Standards.

Key Words: Dust, OSHA Combustible Dust National Emphasis Program, Explosion, Explosible, Polyvinyl Chloride, PVC resin, NFPA, NEC
<table>
<thead>
<tr>
<th>Dust Explosion Class</th>
<th>Kst (bar.m/s)</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>St 0</td>
<td>0</td>
<td>No explosion</td>
</tr>
<tr>
<td>St 1</td>
<td>&gt;0 and &lt;= 200</td>
<td>Weak explosion</td>
</tr>
<tr>
<td>St 2</td>
<td>&gt;200 and &lt;= 300</td>
<td>Strong explosion</td>
</tr>
<tr>
<td>St 3</td>
<td>&gt;300</td>
<td>Very strong explosion</td>
</tr>
</tbody>
</table>

**Table 2: Combustible Dust Tests**

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Test Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Minimum Ignition Temperature of Dust Layer</td>
<td>Measure of a dust layer sensitivity to ignition by hot surfaces</td>
<td>ASTM E-2021, IEC Document 31H</td>
</tr>
<tr>
<td>3. Minimum Ignition Temperature of Dust Cloud (MIT), also known as MAIT</td>
<td>Measure of dust cloud sensitivity to auto ignition by hot surfaces and mechanical/frictional sparks</td>
<td>ASTM E1491, IEC 61241-2-1 BS EN 50281-2</td>
</tr>
<tr>
<td>4. Explosion Severity (20-Litre Sphere)</td>
<td>Explosion severity data (Pmax, dP/dtmax, Kst, St Class) used for explosion protection and risk assessment</td>
<td>ASTM E1226 BS EN 14034</td>
</tr>
<tr>
<td>5. Explosion Severity (1 m³ Sphere)</td>
<td>Explosion severity data (Pmax, dP/dtmax, Kst, St Class) used for explosion protection and risk assessment</td>
<td>ASTM E1226 BS EN 14034 ISO 6184-1</td>
</tr>
<tr>
<td>6. Minimum Explosible Concentration (MEC)</td>
<td>Measures explosible limit of the powder</td>
<td>ASTM E1515 ISO 6184-1</td>
</tr>
<tr>
<td>7. Moisture Content</td>
<td>Weight loss after oven drying for 6 hours at 50 °C, or moisture analyzer</td>
<td>None Specified</td>
</tr>
<tr>
<td>8. Particle Size Distribution</td>
<td>Measures the distribution of various particle sizes in a sample</td>
<td>Gilson Sieve Shaker, 40, 50, 100, 140, 170, 200 mesh screens with antistat</td>
</tr>
<tr>
<td>PVC Resin Sample</td>
<td>GP Dispersion</td>
<td>VA Copolymer</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Type of Polymerization Process</td>
<td>Emulsion</td>
<td>Emulsion</td>
</tr>
<tr>
<td>Designator for Plant Providing Sample Test</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>2. Minimum Ignition Temperature of Dust Layer, deg. C</td>
<td>390 - 400</td>
<td>390 - 400</td>
</tr>
<tr>
<td>4a. Explosion Severity, Kst (bar.m/s), 20 liter test chamber</td>
<td>91</td>
<td>68</td>
</tr>
<tr>
<td>4b. Dust Explosion Class in 20 liter test chamber</td>
<td>ST 1</td>
<td>ST 1</td>
</tr>
<tr>
<td>4c. Maximum Explosion Pressure, bar, 20 liter test chamber</td>
<td>8.7</td>
<td>6</td>
</tr>
<tr>
<td>4d. Explosion Maximum Rate of Pressure Rise, bar/sec., 20 liter test chamber</td>
<td>336</td>
<td>252</td>
</tr>
<tr>
<td>4e. NEC Dust Class II</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5a. Explosion Severity, Kst (bar.m/s), 1 m³ test chamber</td>
<td>Not Tested</td>
<td>Not Tested</td>
</tr>
<tr>
<td>5b. Dust Explosion Class in 1 m³ test chamber</td>
<td>Not Tested</td>
<td>Not Tested</td>
</tr>
<tr>
<td>6. Minimum Explosible Concentration (MEC), gm/m³</td>
<td>80 - 90</td>
<td>180 - 200</td>
</tr>
<tr>
<td>7. Moisture Content, wt. %</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>8a. Particle Size, Avg (microns)</td>
<td>1 (typ)</td>
<td>N.A.</td>
</tr>
<tr>
<td>8a. Dust Fraction (&lt;150 micron, %)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>8c. Dust Fraction (&lt;75 micron, %)</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

[1] Data for MIE and 20 liter test were performed on sample screened to <150 micron, and data for 1 m³ test was performed on "as-received" sample.

GP--General Purpose, VA--Vinyl Acetate