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Comparative Case Study Analysis of Combustible Dust Explosions: Determining the Need for an OSHA Combustible Dust Standard

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Comparative Case Study Analysis of Combustible Dust Explosions: Determining the Need for an OSHA Combustible Dust Standard

A Thesis Presented

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DEDICATION

This document is dedicated to all the workers who have lost their lives as a result of a combustible dust explosion.

ACKNOWLEDGMENTS

I would like to give thanks to my thesis committee chair, Dr. Scotty Dunlap, for his continued patience, encouragement, and uncanny knack from pulling me back from the ledge during my research process. Without his reassurance and grounding I would have never saw this through to the end.

I would also like to thank my thesis committee members Dr. Carolyn Harvey and Dr. D.Gary Brown. I stumbled into Dr. Harvey’s office ten years ago to ask for directions to another professor’s office. I came to visit Eastern Kentucky University intending to pursue another course of study. If it was not for that chance occurrence she would not have persuaded me to change my undergraduate major to Environmental Health Science and I wouldn’t be in the profession I am today. Dr. Brown provided me with real world industry knowledge so when I began my career I was running before I hit the ground. By busting my chops often and hard he toughened me up enough to succeed in a male-dominated field.

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Last but not least I want to also give a special thanks to my family who has had to endure my absence, frustrations, shenanigans, malarkey, and mini-meltdowns while working on this research project.

ABSTRACT

This study examines the hazards associated with combustible dust, the need for an OSHA standard to assist in the prevention of combustible dust explosions, and the influence such a standard would have on employers in industries where combustible dust is used. The framework of this study is to compare and evaluate the performance of two companies that experienced a combustible dust explosion. Past Kentucky Occupational Safety and Health (KYOSH) inspection history was reviewed as well as all data collected prior-to and after the explosions. This information was reviewed as well as: OSHA industry standards, OSHA Compliance Directives, NFPA codes and standards, additional consensus standards, and peer-reviewed journal articles. This study found that the most effective method of preventing a combustible dust explosion is implementing a combustible dust management program including emphasis on housekeeping and management of change. An OSHA combustible dust General Industry Standard would provide the knowledge and additional motivation to implement the necessary mitigation procedures to prevent a combustible dust explosion. However, a standard would be difficult to develop one single standard to cover combustible dust in every industry. One solution is that industries that are covered by additional industry consensus standards be exempt from the standard. An example would be a woodworking facility that is covered by NFPA 664, Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities. Special care would have to be taken by OSHA with regards to how combustible dust is defined, if the standard is performance-based or specification-based, small v. large businesses, and economic concern.

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BACKGROUND

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History of Combustible Dust Incidents

I have been working as an Industrial Hygienist for the past eight years. Imagine handing out safety equipment on The Discovery Channel's "How It's Made." I have been given the opportunity to view a colorful mix of industries both inside and out in various states of organization or disorganization, depending-on where you look. Every facility's safety culture is unique. Although combustible dusts have always been a problem, a trending safety issue is the lack of knowledge on the hazards of combustible dusts.

Combustible dust explosions have been a significant concern in industry for centuries. One of the most quoted combustible dust explosions occurred at a flour warehouse at the rear of a bakery in Turin, Italy, in 1785 (Eckhoff, Dust Explosions in the Process Industries, 2003). A boy who worked at the bakery was moving flour by the light of a lantern when the explosion occurred. The investigation conducted by Count Morozzo following the "Spontaneous Inflammation" correlated the amount of moisture in the flour to the frequency of dust explosions. The same study also provided information concluding the entrapment of dust deposits in different areas of Mr. Giaocomelli's bakery contributed to secondary explosions. Dust explosions have continued to occur. Often those in high-risk industries wonder why there are so many of these explosions. Regulatory agencies and other experts seem to wonder why there are so few. There was only one explosion in Mr. Giacomelli's Bakery, yet the activities at fault were performed on a daily basis.

The Chemical Safety Board (CSB) identified 281 combustible dust incidents between 1980 and 2005 that killed 119 workers and injured 718 and extensively damaged industrial facilities. This is not including primary grain handling or underground coal dust explosions. The incidents occurred in 44 states, in many different industries, and involved a variety of different materials (BOARD, 2004). Although research began over two hundred years ago, the Occupational Safety and Health Administration (OSHA) does not have a standard on combustible dust beyond addressing it in specific regulations targeted at high hazard operations, such as 29 CFR 1910.272 in the grain handling industry.

One of my more memorable inspections was at a steel mill in Northern Kentucky. The facility had dust accumulations on pipes and other surfaces over three inches in depth. These were housed in a small enclosed room. To obtain a dust sample for analysis, I climbed atop a mezzanine that was home to a large screw conveyer. The conveyer delivered small pellet-type beads to a machine below. This machine shot the pellets at stainless steel axles for commercial trucks at high speed to clean off any residual oil and to smooth out the overall product. I was amazed when I reached the top of the platform. There was a dust/pellet mixture several inches thick. The dust was so slippery I almost fell. I was at this location on a referral to investigate a recent duct work fire. I requested the housekeeping procedures to control the dust in the area. In response to my request, the foreman laughed and said, “Baby, this is a steel mill. It’s going to be dirty.” He had a very valid point. Steel mills are dirty by trade. As I left that facility, my appearance bordered a worker leaving the coal mines, or the Tin Man from the Wizard of Oz. Several weeks later the lab results concluded the dust was combustible.

In spite of a more in-depth understanding of risks associated with combustible dust explosions, many facilities do not identify dust as a hazard, leading to a false sense of security. The facility I inspected had a working safety program with weekly toolbox meetings. The safety manager's office had an "open-door policy" pertaining to any concerns of employee safety. Yet, with all the history listing the dangers of combustible dust, it was not a concern. A situation that could have taken the lives of all who were employed was considered a minor nuisance.

There is a great deal of knowledge to gain from reviewing the history of combustible dust explosions. One of the most important topics is housekeeping in facilities, including how that facility processes its combustible particulate solids. Accumulations of dust throughout a facility can potentially intensify the dust explosion, thereby increasing the number of personnel exposed. Such exposure would involve extreme temperatures, the burning dust cloud, along with the pressure wave accompanying the subsequent explosions. This added mass of additional fuel in suspended particulates can lengthen the duration of the explosion by increasing the explosion impulse. Ultimately, the facility's personnel, structures, and equipment sustain heavier damage because the force of these blasts can cause a structure to collapse.

Recent Case Studies

1. **<u>Malden Mills Industries, Methuen, Massachusetts, December 11, 1995</u>**. This explosion and fire in a textile products manufacturing facility injured more than 20 workers. Fortunately, there were no fatalities. Property damage was estimated at $500 million (at the time, the ninth largest fire loss in U.S. history, based on NFPA data). The explosion originated when employees used high-pressure air

hoses to clean flock (short nylon fibers) from the manufacturing equipment (BOARD, 2006).

2. **Ford Motor Company, Rouge Complex, Dearborn, Michigan, February 1, 1999.**7 This powerhouse explosion resulted in the deaths of six workers and serious injuries to 14 others. The powerhouse building and related facilities were extensively damaged, with estimated costs exceeding $1 billion, making this one of the most expensive industrial accidents in U.S. history. Investigators determined the cause of the explosion was a natural gas buildup in a boiler that was being isolated for maintenance. Zalosh, in his review of the incident, suggests that much of the damage in the powerhouse and adjacent buildings was due to secondary coal dust explosions. Inspections after the explosion revealed dust accumulations ranging from light dustings to deposits of up to an inch thick on some surfaces, with dust accumulations in the range of 800 to 3,800 g/m2 on floors and overhead beams (BOARD, 2006).
3. **Jahn Foundry, Springfield, Massachusetts, February 25, 1999**. This explosion in a foundry shell mold fabrication building sent 12 employees to the hospital, with burns covering from 40 to 100% of their bodies. Three of the injured subsequently died. While the cause of the initial explosion could not be conclusively identified, there were two plausible theories. The first involved the ignition of a natural gas/air mixture in a curing oven. The second included an airborne cloud of combustible phenol formaldehyde resin external to an oven being where significant accumulations of combustible resin dust were ignited. As an explosion propagated through the ductwork, vibrations shook loose resin dust

accumulations from the exterior duct surfaces and from adjacent building surfaces, leading to devastating secondary explosions (BOARD, 2006).

4. **Rouse Polymerics International, Inc., Vicksburg, Mississippi, May 16, 2002**. An explosion in this rubber recycling plant injured 11 workers (six critically), five of whom later died from severe burns. The plant was reported to be "a total loss." The process recycled elastomeric materials, producing a very fine powdered rubber product. Investigators believed that sparks from an oven exited an exhaust pipe, landed on the building roof, and started a fire. The fire is believed to have spread to an adjacent piece of equipment where it caused an initial explosion that prompted a secondary explosion involving accumulations of dust in the building (BOARD, 2006).

5. **West Pharmaceuticals, Kingston, North Carolina, January 29th, 2003.** This explosion resulted in six fatalities and injured dozens of additional employees. The facility was extensively damaged and was ultimately destroyed. An investigation by the U.S. CSB determined that significant quantities of combustible polyethylene dust had accumulated above a false ceiling in a manufacturing area. An initiating event suspended this dust in the air, where it subsequently contacted an ignition source, resulting in an extremely energetic explosion (BOARD, 2006).

6. **CTA Acoustics, Corbin, Kentucky, February 20, 2003**. This explosion injured 44 employees, 12 of whom were flown to hospital burn units; 7 later died. The initial explosion and fire occurred in a production line that was partially shut down for cleaning. A thick cloud of dust dispersed by the cleaning activities was

ignited by the flames in an oven door that had been left open. Secondary explosions propagated throughout the facility, as combustible phenol formaldehyde resin dust was dislodged from surfaces, adding to the airborne fuel loading (BOARD, 2006).

7. **Imperial Sugar, Port Wentworth, Georgia, February 7, 2008**. This explosion in a sugar refinery injured nearly 40 employees and contractors, 14 of whom died from their injuries; some after extended periods in a hospital burn unit. Damage to the refinery was extensive. OSHA's investigation determined an initial explosion, likely occurring in a bucket elevator, suspended sugar dust accumulations in the processing building, leading to secondary explosions. Preliminary results of on an-going CSB investigation indicate that dust accumulations in the sugar refinery were feet deep in some locations. OSHA has proposed citations with fines totaling near $5.1 million (BOARD, 2006).

Most-workers, and many process safety professionals for that matter-will likely go through their career without being personally exposed to the aftermath of a devastating dust explosion. The skeptic might conclude, based upon personal experience, that dust explosions are unlikely and, therefore, low-risk events.

In the late 1970s, a series of devastating grain dust explosions in grain elevators left 59 people dead and 49 injured. In response to these catastrophic events, OSHA issued a "Grain Elevator Industry Hazard Alert" to provide employers, employees, and other officials with information on the safety and health hazards associated with the storage and distribution of grain. In 1987, OSHA promulgated the Grain Handling Facilities standard (29 CFR 1910.272), which remains in effect. This standard, other OSHA standards such as Emergency Action Plans (29 CFR 1910.38), and updated industry consensus standards all played important roles in reducing the occurrence of explosions in this industry, as well as mitigating their effects. The lessons learned in the grain industry can be applied to other industries producing, generating, or using combustible dust.

The topic of dust explosions has certainly not escaped regulatory and legislative attention. OSHA is currently implementing a national emphasis program (NEP), examining conditions and safety controls in facilities handling combustible dusts. Under this program, state and federal agencies have conducted over 800 inspections since November 2007, resulting in the citation of over 3500 violations. In addition, Congress is considering legislation that would mandate the promulgation of an OSHA combustible dust regulation.

Industry experience has indeed shown that poor housekeeping standards in facilities handling combustible dusts heighten the risks of facility operations; including risks to facility personnel, to business continuity, and to company reputation. Far too many facilities would appear to be-either wittingly or unwittingly trusting to luck rather than skill in regards to prevention of damaging dust explosions within their facilities.

This experience prompted me to be more aware of the levels of combustible dust in the facilities I visit and to take note of how different facilities manage a combustible dust program. I wondered if certain industries would find it more difficult to implement a culture change where combustible dust is concerned. I was able to witness how one location corrected their deficiencies involving combustible dusts. I had the opportunity to review the safety program of CTA Acoustics after their explosion in 2003 and compare it with my visit to their location in 2011.

Types of Combustible Dust

A dust explosion has the following four elements: a combustible dust, dust dispersion in the air or other oxidant at or exceeding the minimum exposable concentration (MEC), an ignition source such as:

1. An electrostatic discharge
2. An electric current arc
3. A glowing ember
4. A hot surface
5. Welding slag
6. Fractional heat or direct flame

As well as some means of confinement. The requirements of a dust explosion are fuel, ignition, dispersion, oxygen, and confinement. A combustible dust is a substance which can be oxidized. This includes carbonaceous and metallic materials. This definition includes all solid combustible materials. The particle size of the material will determine how easily that substance will ignite and how fast the explosion occurs. Mineral deposits, in contrast, will not explode. These include mineral particulates such as sand, kaolin, gravel (limestone dust), inorganic pigments, table salt, or certain substances treated with a fire retardant (OSHAa, 2009).

Combustible dusts are solids ground into fine particles, fibers, chips, chunks or flakes that can cause a fire or explosion when suspended in air under certain conditions. A variety of dusts can be combustible; some include metal (aluminum and magnesium), wood, plastic or rubber, coal, flour, sugar, and paper. Any combustible material, along with a few materials normally considered noncombustible, can burn rapidly when reduced to a very small size, thereby creating a dust. When enough of this dust is suspended in air, it can become explosive.

For any dust materials having a specific chemical composition, the chance of a combustible dust explosion or deflagration depends on many variables, including:

1. Size of particles
2. Shape of particles
3. Particle surface-area-to-volume ratio (the smaller the particle, the larger the more surface area found in the dust cloud)
4. Agglomeration (how well particles stick together)
5. Impurities present in the material
6. Moisture content of the material
7. The location and depth of dust before a cloud is formed
8. The concentration of particles in a dust cloud, the variation in concentration throughout a dust cloud (if there are uniform amounts of dust throughout the cloud)
9. Oxygen concentration
10. Turbulence in the area containing the cloud
11. Characteristics of the ignition source (how much energy and for how long)
12. The location of the ignition source in relation to the dust cloud.

Data indicates that mineral dusts (such as silicates, sulphates, nitrates, carbonates, phosphates, cement, salt, gypsum, sand, and limestone) are not explosable (OSHAb, 2009)

Combustible dust explosions do not occur at random. The environment needed for a deflagration is very specific. Five elements are needed for a combustible dust explosion to occur. The first three elements are the three items needed for a fire: fuel, heat, and an oxidizer. These three elements form what is often called the ``fire triangle." The dust fulfills the fire triangle in being the fuel, an ignition source represents heat, and oxygen present in air is an oxidizer. The fourth element is dust dispersion. An event must occur to make the dust airborne. The dust must also be in an appropriate concentration. These four conditions are necessary for the deflagration, a violent combustion accompanied by a pressure wave. The combustion is rapid but spreads at a speed less than the speed of sound. The final element is confinement which is necessary for an explosion. Confinement can be in many forms. These can include a building, room, duct, or a piece of equipment. A storage area is another good example. An explosion occurs when the pressure developed by a deflagration becomes too great for the structure and causes the enclosure to rip open. Collectively, all five of these elements are given two extra sides to form the ``dust explosion pentagon."

Secondary explosions occur when pressure waves from an initial (also called primary) deflagration or explosion scatter a concentration of dust into the air. The dispersion is paired with an ignition source. This ignition source ignites the dust cloud along with any remaining dust that has built up on various surfaces in the enclosure. These surfaces can include little-seen areas such as the tops of equipment and rafters. The height of the accumulation area is directly correlated with the size of dust. In these areas the small particle size actually increases their surface area making them more hazardous. Secondary explosions are frequently more devastating than the initial primary explosion. This is due to the increased amount of fuel and the size of the ignition source (dust that was dispersed during the initial deflagration). In some places, explosions have a domino effect and continue to cascade throughout a facility. NFPA 654 clarifies the definition of explosible powders to include any combustible particulate having a surface to volume ratio greater than a 420 micron "spherical" particle (NFPAa, 2013).

Brief Overview of Materials and Equipment Involved in Combustible Dust Incidents

Table 1
PARTICULATE MATERIALS INVOLVED IN REPORTED DUST EXPLOSIONS

Material	FM Global # Incidents	UK HSE # Incidents	Germany # Incidents
Wood/Paper	56	69	120
Coal	27	24	33
Metals	19	55	47
Plastics	8	10	46
Food/Grain	??	94	88
Pharma Products	??	27	??
Other/Unknown	4	24	23
Totals	150	303	23

Source: Eckhoff, Rolf K., Dust Explosions in the Process Industries, 2nd ed., Butterworth-Heinemann, 1997.

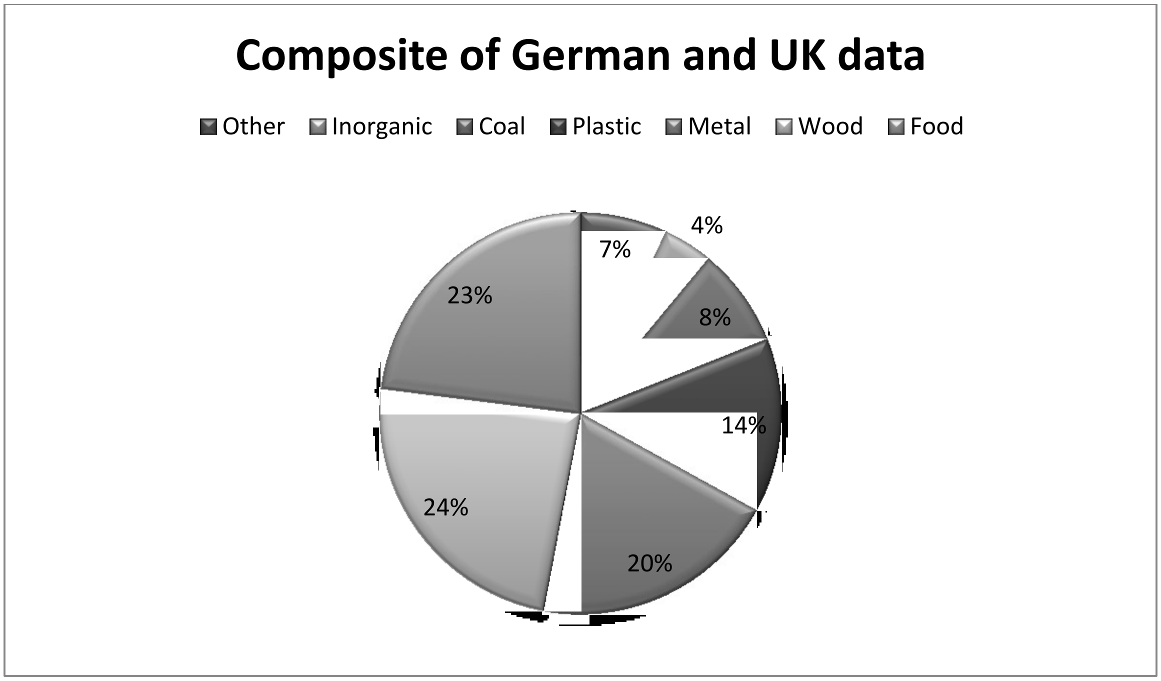

Figure 1: TYPES OF DUST INVOLVED IN INCIDENTS

Source: Eckhoff, Rolf K., Dust Explosions in the Process Industries, 2nd ed., Butterworth-Heinemann, 1997.

Table 2

EQUIPMENT INVOLVED IN REPORTED DUST EXPLOSIONS

Equipment	FM Global # incidents	UK HSE # incidents	Germany # incidents
Dust Collectors	156	55	73
Grinders/Crushers	35	51	56
Silos/Hoppers/et.al	27	19	86
Conveying Equipment	32	33	43
Dryers/Ovens	22	43	34
Mixers/Blenders	12	7	20
Other/Unknown	84	95	114
Totals	372	303	426

Source: Eckhoff, Rolf K., Dust Explosions in the Process Industries, 2nd ed., Butterworth-Heinemann, 1997.

Testing Standards that Apply to Combustible Dust issues

Several factors are used in quantifying the explosion hazard associated with different types of combustible dust. Typically these are reviewed in a two-step process. The first set includes the Maximum Explosion Pressure (P_{max}) at optimum concentration, K_{st} (normalized rate of pressure rise) as defined by ASTM E 1226, Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts (ASTM, 2000), Minimum Ignition Energy (MIE), Particle Size Distribution (PSD), and Minimum Explosible Concentration (MEC). These are most important in hazard evaluation.

Next are Limiting Oxidant Concentration (LOC) to prevent ignition by inerting, Layer Ignition Temperature (LIT) for hot spots, dust cloud ignition temperature, electrical volume resistivity, charge relaxation time, and chargeability. To evaluate a facility, often both the NFPA and OSHA standards are referenced. If the type of dust is known, the characteristics can be referenced in various publications, such as NFPA 68 and Annex F (NFPA, 2013), Eckhoff (Eckhoff, Dust Explosions in the Process Industries, 2003), or BGIA GESTIS-DUST-EX (IFA, 2013). If the substance or characteristics are unknown, then particle size distribution must be determined. Next tests must be conducted to determine the K_{st} and P_{max} in determining the severity of a potential explosion.

PSD is a simple process using a sieve of a known size to separate the particles of dust. The dust is placed on screens and the amount of particles of each size is determined. This process is important because as the particle size increases, the minimum explosive concentration also increases. The testing used to assess a dust explosion can be separated into two categories:

1. The likelihood of an explosion, called ignition sensitivity
2. The consequences of the dust explosion or explosion severity.

The Minimum Explosible Concentration test determines the lowest concentration of dust in the air that can be ignited. This information determines how easily an explosible cloud of dust may be formed.

The Limiting Oxidant Concentration (LOC) test determines the concentration of oxygen that is necessary for an explosion. The results from this test are used to develop methods to prevent and/or reduce the severity of an explosion. The need for controls such as oxygen concentration sensors or the use of gases that deter combustion can be obtained from this test (British Standards Institution, 2004).

The Minimum Ignition Temperature of a Dust Cloud (MIT-Cloud) test determines the lowest temperature that would ignite the dust cloud. This test is important when evaluating what could ignite the dust in a facility. Processes that use electrical devices, create friction, heat, static or sparks. The moisture content and particle size of the dust directly correlate with the MIT value (ASTMa, 2012).

The Minimum Ignition Temperature of a dust layer (MIT-Layer) test determines the lowest temperature capable of igniting a dust layer of a standard thickness, 5 to 12.7mm. This test is used to determine how easily the dust will ignite from contact with a hot surface (ASTM, ASTM E2021, Standard Test Method for Hot-Surface Ignition Temperature Dust Layers). The National Electric Code has specific standards concerning surface temperatures of electrical devices in hazardous Class II areas.

The Minimum Ignition Energy (MIE) test determines the lowest electrostatic or mechanical spark energy that is capable of igniting a dust cloud (ASTMa, 2012). The information obtained from this test is used to evaluate how easily a dust cloud can ignite via electrostatic discharge. Sparks of a predetermined energy are used in an attempt to ignite dust samples of varying shapes and sizes in a 1.2 liter vertical tube. Two different types of sparks are used both: capacitive (used to evaluate electrostatic discharge sensitivity) and inductive (used to evaluate mechanical discharge sensitivity).

The 20-liter Sphere Explosion Test (ASTM, 2000) is an introductory test which will determine whether or not the dust is explosible and, if so, will determine the severity of an explosion. The dust is dispersed in the chamber and ignited. If an explosion occurs, the pressure data is recorded. This includes the maximum explosion pressure and the maximum rate of pressure rise. These numbers are used to calculate the Deflagration

Index (K_{st}). This information determines how bad an explosion would be if it happened. The K_{st} is useful in determining proper engineering controls to prevent dust explosions or lessen the impact they cause. This can include explosion containment, pressure relief venting, and suppression.

STATEMENT OF THE PROBLEM

A combustible dust explosion is a catastrophic event often resulting in loss of life and property. Many employers and employees are unaware of the hazards associated with combustible dusts. As a result, many companies do not take the steps necessary to determine if a dust present is a combustible dust. Without an appropriate mitigation strategy for a combustible dust it can accumulate and result in a combustible dust explosion. The lack of an OSHA General Industry standard addressing the recognition, training, evaluation, and control of combustible dust increases the risks of a combustible dust explosion.

PURPOSE OF THE STUDY

The purpose of this study is to examine the hazards associated with combustible dust, the need for an OSHA standard to assist in the prevention of combustible dust explosions, and the influence such a standard would have on employers in industries where combustible dust is used. Using two case studies involving recent combustible dust explosions in the state of Kentucky, I will review previous KYOSH citations issued to each company and analyze the management of change of each facility. This investigation will allow me to determine the necessity of an OSHA standard after reviewing each facility history pre-and post-combustible dust explosion.

POTENTIAL SIGNIFICANCE

This study will provide an in-depth overview of the concepts relating to the prevention of combustible dust explosions. The need for a regulatory standard to ensure employers use due diligence in the prevention of combustible dust explosions will be addressed including how such a standard would influence the probability of future combustible dust instances.

DEFINITION OF TERMS

Key Terminology Relating to Combustible dust

Combustible Dust. A finely divided combustible particulate solid that presents a flash fire hazard or explosion hazard when suspended in air or the process-specific oxidizing medium over a range of concentrations (NFPAa, 2013).

Combustible Particulate Solid. Any solid material composed of distinct particles or pieces, regardless of size, shape, or chemical composition that presents a fire hazard (NFPAa, 2013).

Deflagration. Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium (NFPAa, 2013).

Explosion. The bursting or rupture of an enclosure or a container due to the development of internal pressure from a deflagration (NFPAa, 2013).

Fugitive Grain Dust. Combustible dust particles, emitted from the stock handling system, of such size as will pass through a U.S. Standard 40 mesh sieve (425 microns or less) (OSHAc, 2014).

Hybrid Mixture. A mixture of a flammable gas at greater than 10 percent of its lower flammable limit with either a combustible dust or a combustible mist (NFPAa, 2013).

Lower Flammable Limit (LFL). The lowest concentration of material that will propagate a flame from an ignition source through a mixture of flammable gas or combustible dust dispersion with a gaseous oxidizer (NFPAa, 2013).

Minimum Explosible Concentration (MEC). The minimum concentration of a combustible dust suspended in air, measured in mass per unit volume, that will support a deflagration (NFPAa, 2013).

Minimum Ignition Energy (MIE). The lowest capacitive spark energy capable of igniting the most ignition-sensitive concentration of a flammable vapor-air mixture or a combustible dust-air mixture as determined by a standard test procedure (NFPAa, 2013).

Combustible Dust per OSHA National Emphasis Program

On March 26, 2012, OSHA amended the HCS to align with the Globally Harmonized System for the Classification and Labeling of Chemicals (GHS). However, the GHS does not contain a classification for combustible dust hazards, and to maintain coverage of this hazard under the HCS, OSHA amended the standard's definition of "hazardous chemical" to include "combustible dust." Noting ongoing efforts at the United Nations (UN) and in the agency's own combustible dust rulemaking, OSHA did not adopt a definition of the term combustible dust in the final rule. Rather, as an interim measure, OSHA stated that it had already provided guidance on combustible dust, including the Combustible Dust National Emphasis Program (NEP), which "includes an operative definition." (77 FR 17705). OSHA also noted that a number of voluntary consensus standards exist, "particularly those of the NFPA," which provide further guidance (OSHAd, 2013)

Combustible Dust per NFPA 654

Previously, NFPA 654: “Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids” defined combustible dust as a "finely divided solid material 420 microns or smaller in diameter (material passing a U.S. No. 40 Standard Sieve) that presents a fire or explosion hazard when dispersed and ignited in air."

However, the 2013 version of NFPA 654 defines a combustible dust as “A finely divided combustible particulate solid that presents a flash fire hazard or explosion hazard when suspended in air or the process-specific oxidizing medium over a range of concentrations.”

This was changed because although the size of the dust particle plays a significant factor in its combustibility, other contributing elements could increase a dust’s combustibility, even though it is too large to pass through a U.S. No. 40 Standard Sieve. The standards that have removed the size criteria from their definitions include additional notes discussing the new size of <500 microns, passing through a U.S. Sieve No. 35. The shape or grouping of particles may prevent them from passing through the smaller sieve, but the surface to area volume ratio still poses a deflagration hazard. The smaller particles could be held together as a result of the process or even a static charge.

Some NFPA standards still use the size of <420 microns in the combustible dust definition. These include “NFPA 61: Standard for the Prevention of Fires and Dust

Explosions in Agricultural and Food Processing Facilities” and “NFPA 704: Standard System for the Identification of Hazardous Materials for Emergency Response.”

Deflagration Versus Explosion

An explosion is the bursting or rupture of an enclosure or container due to the development of internal pressure. Explosions can be separated into two different classifications: detonations and deflagrations. A deflagration is the propagation of a combustion zone at a speed that is less than the speed of sound in the unreached medium. A detonation is the propagation of a combustion zone at a velocity that is greater than the speed of sound in the unreached medium.

Deflagration is subsonic combustion that usually spreads through the process of thermal conductivity. This means that a sample of hot burning material will heat neighboring cold material to the point of ignition. Detonation is different in that it spreads through shock compression at much greater speed than deflagration.

Concepts of Combustible Dust Fires

Five things must be present for a combustible dust fire: an ignition source, confinement, dispersion, combustible dust, and oxygen. For the explosion to occur, additional conditions must be in place. The dust must be combustible and fine enough to be airborne. The dust cloud must be between the lower explosive limit and the upper explosive limit for that particular dust. The dust must be dry, although some dust can be explosive and contain a specific percent of moisture. There must be sufficient oxygen in the atmosphere to support combustion. The dust must be in a confined area. Finally, there must be a source of ignition.

A dust explosion occurs when a combustible dust is suspended and then ignited in air. This rapid burning of material and release of gaseous product causes a successive rise in pressure. This pressure results in an explosive force that can damage property, as well as result in multiple fatalities. These explosions begin with a “primary explosion.” This explosion happens in a confined area, such as a storage silo, enclosed transport system (conveyer), cyclone, or other process vessel. This type of explosion will often rupture the containment area which allows heat, flame, and dust to be released into the surrounding areas. This will disperse dust that has settled on surfaces in the areas of the facility. Such distribution will cause a “secondary explosion.” As the surface dust becomes suspended in the air, subsequent explosions will occur as it ignites. These explosions will cause dust to shake loose from other areas of a facility leading to a chain reaction forming multiple explosions in a facility.

Differences between MEC and LFL

The minimum explosible concentration (MEC) is the minimum concentration of combustible dust suspended in air, measured in mass per unit of volume that will support a deflagration. The lower flammable limit (LFL) is the lowest concentration of a combustible substance in an oxidizing medium. The upper flammable limit (UFL) is the highest concentration of a combustible substance in an oxidizing medium that will propagate a flame.

The Minimum Ignition Temperature (MIT) is the lowest temperature at which ignition occurs. The particle size and moisture content is directly correlated with the MIT. This means the lower the particle size and the lower the moisture content, the lower the MIT. The Minimum Ignition Energy (MIE) is the lowest electrostatic spark energy (in milijoules) that is capable of igniting a dust cloud. The particle size and moisture content also directly correlate with the MIE. The lower the particle size and lower the moisture content the lower the MIE. The MIE is also lower the higher the temperature in the atmosphere of the dust cloud.

- $(dP/dt)_{max}$ = maximum rate of pressure rise
- Deflagration index, K_{st} = maximum rate of pressure rise $(dP/dt)_{max}$ normalized to 1.0 m^3 volume
- P_{max} = maximum pressure reached during the course of a deflagration

Deflagration index - K_{st}

$Kst = (dP/dt)_{max} V^{1/3}$ (bar m/s) where: $(dP/dt)_{max}$ = the maximum rate of pressure rise (bar/s)

V= the volume of the testing chamber (m^3)

Table 3

DUST EXPLOSION CLASSES

Dust Explosion Class	K_{st} (bar m/s)	Characteristic
St 0	0	No explosion
St 1	>0 and >/= 200	Weak explosion
St 2	> 200 and >/= 300	Strong explosion
St 3	> 300	Very strong explosion

ASSUMPTIONS

All data utilized in this study are accurate as it was obtained from credible sources. Two themes are often associated with combustible dust explosions. These are the lack of knowledge of the hazards associated with combustible dust and an employer's mismanagement of the hazard once it has been identified. An OSHA general industry standard including the recognition, training, evaluation, and control of combustible dust will decrease the number of combustible dust explosions.

LIMITATIONS

This study will provide insight into the general hazards associated with combustible dust. As this research is qualitative, the individual characteristics from a facility and/or industry may not be generalizable to a population. The data for the case studies involve two facilities in Kentucky and was acquired from the KYOSH inspection reports which were obtained via an open records request. As a result, the accuracy of the case study analysis is dependent upon the information contained within those reports. This will also create a limitation in the research presented.

ORGANIZATION OF THE STUDY

This study will include five sections: background, literature review, methodology, research findings and analysis, and discussion and implications. The background discusses the history of combustible dust, the different types of combustible dust, types of industries involved in combustible dust incidents, testing standards that apply to combustible dust, the problems associated with no OSHA General Industry standard addressing combustible dust, the purpose for this research, the significance of a regulatory standards effect on the number of combustible dust explosions, the assumptions for data collection, terms used in the study, and the limitations of the research. The literature review includes consensus standards accepted by OSHA that are typically incorporated by reference. The methodology section discusses how this study was conducted, what the research entailed, and how it was used to determine the need for a regulatory standard for combustible dust. Research findings and analysis include an in depth analysis of dust explosion hazard management, conditions which create primary and secondary combustible dust explosion hazards, and the current protocol for the issuance of OSHA citations. The discussion and implications section contains the end analysis of the research questions along with how the promulgation of a regulatory standard would effect different types of employers.

CHAPTER II

LITERATURE REVIEW

COMBUSTIBLE DUST CONCENSUS STANDARDS

The NFPA, FM Global, and ASTM are the top three consensus standards used for an OSHA General Duty citation. Other industry specific organization may also serve as a basis for this type of citation or as proof of employer knowledge.

NFPA 61 Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities (2013 edition) applies to all facilities that "receive, handle, process, dry, blend, use, mill, package, store, or ship dry agricultural bulk materials, their by-products, or dusts that include grains, oilseeds, agricultural seeds, legumes, sugar, flour, spices, feeds, and other related materials." This standard also covers "facilities designed for manufacturing and handling starch, including drying, grinding, conveying, processing, packaging, and storing dry or modified starch, and dry products and dusts generated from these processes. Those seed preparation and meal-handling systems of oilseed processing plants not covered by NFPA 36, Standard for Solvent Extraction Plants." In this edition the definitions pertaining to the handling, conveying, and the dust collection of agricultural products have been updated. The requirements of bucket elevators have been revised to reflect current industry practice. A requirement of a written housekeeping program was included as well as requirements for pneumatic conveying system designs.

NFPA 68 Standard on Explosion Protection by Deflagration Venting (2013 Edition) applies to "the design, location, installation, maintenance, and use of devices and systems that vent the combustion gases and pressures resulting from a deflagration within an enclosure so that structural and mechanical damage is minimized.” This edition (2013) includes a revised method for calculation of the venting of deflagrations of gas mixtures. The chapter on “venting of deflagrations in dust mixtures has been revised to address differences between translating vent panels and hinged vent panels, to permit sub-atmospheric initial pressures, and to incorporate new research on the entrainment of accumulated dust in a building. New sections address bucket elevators and grain silos, and new annex material provides guidance on designing vent ducts and estimating the fundamental burning velocity of a fuel.”

NFPA 69 Standard on Explosion Prevention Systems (2014 Edition) provides information on the “design, installation, operation, maintenance, and testing of systems for the prevention of explosions by means of the following methods: control of oxidant concentration, control of combustible concentration, pre-deflagration detection and control of ignition sources, explosion suppression, active isolation, passive isolation, deflagration pressure containment, and passive explosion suppression.” This edition (2014) underwent an update to improve the overall clarity of the document.

NFPA 70 National Electrical Code® (2014 Edition) covers the “installation of electrical conductors, equipment, and raceways; signaling and communications conductors, equipment, and raceways; and optical fiber cables and raceways.”

NFPA 77 Recommended Practice on Static Electricity (2014 Edition) recommends practices pertaining to the “identification, assessment, and control of static electricity for purposes of preventing fires and explosions.” This edition became more user-friendly in that the entire chapter was reorganized to make it easier to read.

NFPA 85 Boiler and Combustion Systems Hazards Code (2015 Edition) applies to the following: "Single burner boilers, multiple burner boilers, stokers, and atmospheric fluidized bed boilers with a fuel input rating of 3.7 MWt (12.5 million Btu/hr), Pulverized fuel systems at any heat input rate, and fired or unfired steam generators used to recover heat from combustion turbines [heat recovery steam generators (HRSGs)] and other combustion turbine exhaust systems at any heat input rate." The purpose of this code is to contribute to operating safety and to prevent uncontrolled fires, explosions and implosions in equipment. Although this is not supposed to be used as a design handbook, it establishes the minimum requirements for the design installation, operation training, and maintenance of these types of systems.

NFPA 86 Standard for Ovens and Furnaces (2015 Edition) applies to "Class A, Class B, Class C, and Class D ovens, dryers, and furnaces; thermal oxidizers; and any other heated enclosure used for processing of materials and related equipment." This standard also applies to other heated enclosures used for the processing of materials.

NFPA 91 Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids (2013 Edition) provides the minimum requirements for "the design, construction, installation, operation, testing, and maintenance of exhaust systems for air conveying of vapors, gases, mists, and particulate solids as they relate to fire and/or explosion prevention, except as modified or amplified by other applicable NFPA standards." This standard is referenced by other NFPA standards such as: NFPA 69, 70, 86, 484, 654, and 664. The 2015 Edition now applies to particulate solids, both combustible and non-combustible.

NFPA 120 Standard for Fire Prevention and Control in Coal Mines (2015 Edition) covers the minimum requirements for “reducing loss of life and property from fire and explosion in the following: Underground bituminous coal mines, Coal preparation plants designed to prepare coal for shipment, Surface building and facilities associated with coal mining and preparation, Surface coal and lignite mines.”

NFPA 484 Standard for Combustible Metals (2015 Edition) applies “to the production, processing, finishing, handling, recycling, storage, and use of all metals and alloys that are in a form that is capable of combustion or explosion.” This edition includes revised procedures for determining the combustibility and explosibility of metal dust, allowing the use of historical data. Systems management requirements are also included.

NFPA 499 Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas (2013 Edition) recommended practices to provide information on “the classification of combustible dusts and of hazardous (classified) locations for electrical installations in chemical process areas and other areas where combustible dusts are produced or handled.” This document also provides information on “combustible dusts as it relates to the proper selection of electrical equipment in hazardous (classified) locations in accordance with NFPA 70, National Electrical Code.” This edition contains a general criterion to assess the combustibility of a dust including their ignition characteristics.

NFPA 654 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids (2013

Edition) applies to “all phases of the manufacturing, processing, blending, conveying, repackaging, and handling of combustible particulate solids or hybrid mixtures, regardless of concentration or particle size, where the materials present a fire or explosion hazard.” This edition includes changes to the housekeeping requirements with regard to the determination of a cleaning frequency based on the nature of the dust and the establishment of a hierarchy for methods used to clean the areas containing combustible dust. This edition also includes information on best practices in a safety management system when dealing with combustible dusts.

NFPA 664 Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities (2012 Edition) establishes the “minimum requirements for fire and explosion prevention and protection of industrial, commercial, or institutional facilities that process wood or manufacture wood products, using wood or other cellulosic fiber as a substitute for or additive to wood fiber, and that process wood, creating wood chips, particles, or dust.” This edition includes a new methodology for assessing a deflagration hazard using the settled bulk density as a determining factor for allowable thickness for combustible wood dust. This also contains a section with detailed dust collection instructions for the previously mentioned methodology.

NFPA 2113 Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire (2015 Edition) specifies the “minimum selection, care, use, and maintenance requirements for flame-resistant garments for use by industrial personnel in areas at risk from short-duration thermal exposures from industrial fires that are compliant with NFPA 2112, Standard on Flame-Resistant Garments for Protection of Industrial Personnel Against Flash Fire."

ASTM E1515-14 Standard Test Method for Minimum Explosible Concentration of Combustible Dusts covers the "determination of the minimum concentration of a dust-air mixture that will propagate a deflagration in a near-spherical closed vessel of 20 L or greater volume. Data obtained from this test method provide a relative measure of the deflagration characteristics of dust clouds. This test method should be used to measure and describe the properties of materials in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment that take into account all of the factors that are pertinent to an assessment of the fire hazard of a particular end use."

ASTM E1515-14 Standard Test Method for Minimum Explosible Concentration of Combustible Dusts "covers the determination of the minimum concentration of a dust-air mixture that will propagate a deflagration in a near-spherical closed vessel of 20 L or greater volume. Data obtained from this test method provide a relative measure of the deflagration characteristics of dust clouds. This test method should be used to measure and describe the properties of materials in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment that take into account all of the factors that are pertinent to an assessment of the fire hazard of a particular end use."

FM Global, Data Sheet No. 7-76 Prevention and Mitigation of Combustible Dust Explosions and Fire (2006 Edition. This document describes the recommended preventative measures to reduce the frequency of combustible dust explosions and protection features to minimize damage from a combustible dust explosion.

OSHA NEP INSPECTION GUIDELINES

Compliance Safety and Health Officers (CSHO) are required to use appropriate personal protective equipment and other equipment when they are in areas that have the potential to contain combustible dusts. Personal protective equipment includes-but is not limited-to cotton clothing, fire resistant clothing, static dissipating footwear or straps. Equipment such as cameras, flashlights, and air monitoring equipment must be intrinsically safe. Dust samples must be collected using natural bristle hand brushes, non-sparking, conductive dust pans, non-spark producing sample container, non-spark producing funnel for filling sampling containers, and non-spark producing scoops for removing dust from collection equipment.

CSHOs must recognize the criteria for a deflagration to occur: a combustible dust, the dust must be dispersed in an oxidant above the minimum explosible concentration, and there is an ignition source. Once these have been satisfied the CSHO must recognize the following criteria as being present for an explosion to occur; the above criteria for a deflagration, and the combustible mixture is dispersed in an enclosed environment.

Combustible dust sampling is conducted when there is a potential for a combustible dust explosion due to an accumulation of dust. CSHOs are instructed to collect dust from areas where greater than 5% of the floor in any area is covered in a thickness of dust greater than $1/32^{th}$ of an inch. This factor of 5% does not apply if the floor area is greater than 20,000 ft^2 as the 1,000 ft^2 is the upper limit. Assessments shall include areas other than the floor of a facility. Overhead beams, joists, ducts, and both vertical, such as walls, and horizontal surfaces, such as on equipment. The OSHA Combustible Dust National Emphasis Program cites Annex D of NFPA 654, which contains guidance on dust layer characterization and precautions. The OSHA NEP states, "Rough calculations show that the available surface area of bar joists is approximately 5 % of the floor area and the equivalent surface area for steel beams can be as high as 10%. The material in Annex D is an idealized approach based on certain assumptions, including uniformity of the dust layer covering the surfaces, a bulk density of 75 lb/ ft^3, a dust concentration of 0.35 oz/ ft^3, and a dust cloud height of 10 ft."

ADDITIONAL RESEARCH

The type of combustible dust will affect the type and size of an explosion. A list of dusts could be evaluated and the results could be catalogued for an easy-access database for employers. However, employers would have to possess specialized knowledge on what other components are present in their facilities. It was found that mixing dust can cause a decrease in self-ignition temperature (Benjamin Binkau, 2014). A great resource to model a combustible dust database is CHEMSAFE. This database includes safety characteristics used by the EU explosion protective directives. It is extensive and has a great deal of data that can be used to identify the material used and/or created in a process to determine the combustibility of that material (Maria Molnarnea, 2014).

Along with the products that facilities use and produce, an employer must also carefully consider the equipment that is present in an area that contains combustible dust.

Electrical standards specific to combustible dust should be developed because standards addressing other combustibility issues are very different from the hazards associated with combustible dust. Design concepts do not take into account the elements needed for a combustible dust explosion and how equipment can be designed to prevent an explosion. Standards should be developed that address how equipment must be constructed to keep dust out of their enclosures and designed so that the surface temperature is maintained within a reasonable level (Eckhoff, 2000).

Maintaining a successful combustible dust program can be expensive. A facility should have a strong risk-based evaluation system when addressing any hazard relating to preventing a combustible dust explosion. An article from Safety Science utilizes a risk-based methodology based on a Bayesian Network to help determine a facility's risk along with evaluating the performances of the safety measures used. This method can aid in streamlining the allocation of resources and is particularly useful when a facility has a limited budget (Zhi Yuana, 2015).

In areas that contain combustible dust, it is imperative that both preventative and protective measures exist. In a perfect world, the preventative measures would stop any combustible dust explosion. Unfortunately, that is impossible. The preventative measures lower the risk of an explosion but are not perfect. Protective measures must also be implemented to safeguard both employees and property. Not every type of protective measures will be effective in every facility. Most enclosures that can withstand the maximum pressure of deflagration can help to isolate an explosion. If not, different means of protection should be considered such as explosion venting, flameless explosion venting, and/or explosion suppression (Taveau, 2014).

CHAPTER III

METHODOLOGY

CONTEXT OF STUDY

The framework of this study is to compare and evaluate the performance of two companies that experienced a combustible dust explosion. The first, Polymer Partners, LLC., had a combustible dust explosion on December 7, 2011 which resulted in one fatality. The second, CTA Acoustics INC., had a combustible dust explosion on February 20, 2003 which resulted in seven fatalities. Past Kentucky Occupational Safety and Health (KYOSH) inspection history was reviewed as well as all data collected after the explosions.

The research theory used in this study is interpretivism. A researcher using interpretivism relies upon the “participant’s views of the situation being studied” (Creswell, 2003). This research study used past experiences of two different facilities to understand how each facility mitigated hazards associated with combustible dust explosions. One facility was very proactive and the other very reactive.

The two different approaches used by each facility in managing these hazards created the basis for my research questions. Specifically, that if a facility is not required through an OSHA standard to take certain mitigation steps when working with combustible dusts, will that facility take appropriate steps to prevent an explosion? Also, would an OSHA combustible dust standard provide the knowledge to assist an employer in preventing a combustible dust explosion?

RESEARCH QUESTIONS

This research is seeking to answer the following questions:

1. Are there particular types of equipment that present an increased risk in relation to combustible dust explosions?
2. What types of equipment are most involved in dust explosions?
3. What are the mitigation techniques of dust hazards for equipment?
4. What conditions create primary and secondary combustible dust explosion hazards?
5. What are possible ignition sources for combustible dust explosions?
6. What are characteristics of dangerous dust concentrations?
7. What are the dangers of dust accumulation?
8. Are dust control programs effective at preventing combustible dust explosions?
9. With all the documentation provided by the NFPA, how would an OSHA standard lessen the number of combustible dust explosions?

DATA COLLECTION

The following archival documents were reviewed for this study to determine themes on best management practices related to dust explosion prevention:

1. Occupational Safety and Health Association General Industry Standards
2. Occupational Safety and Health Association Compliance Directives
3. Occupational Safety and Health Association Publications
4. Kentucky Occupational Safety and Health Division of Compliance Inspection reports

5. NFPA 61 Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities (2013 edition)
6. NFPA 68 Standard on Explosion Protection by Deflagration Venting (2013 Edition)
7. NFPA 69 Standard on Explosion Prevention Systems (2014 Edition)
8. NFPA 70 National Electrical Code® (2014 Edition)
9. NFPA 77 Recommended Practice on Static Electricity (2014 Edition)
10. NFPA 85 Boiler and Combustion Systems Hazards Code (2015 Edition)
11. NFPA 86 Standard for Ovens and Furnaces (2015 Edition)
12. NFPA 91 Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids (2013 Edition)
13. NFPA 120 Standard for Fire Prevention and Control in Coal Mines (2015 Edition)
14. NFPA 484 Standard for Combustible Metals (2015 Edition)
15. NFPA 499 Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas (2013 Edition)
16. NFPA 654 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids (2013 Edition)
17. NFPA 664 Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities (2012 Edition)

18. NFPA 2113 Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire (2015 Edition)
19. ASTM E1515-14 Standard Test Method for Minimum Explosible Concentration of Combustible Dusts
20. FM Global, Data Sheet No. 7-76 Prevention and Mitigation of Combustible Dust Explosions and Fire (2006 Edition.
21. U.S. Chemical safety Board Combustible Dust Hazard Investigation
22. News reports
23. Peer reviewed Journal articles

DATA ANALYSIS

The data were organized and reviewed to obtain a general overall view of the information. From this information common themes were identified and connected. (Creswell, 2003). The data containing these themes were derived from the following:

1. Information found in the KYOSH inspection reports
2. Information found in the OSHA industry standards
3. Information found in the OSHA Compliance Directives
4. Information found in the NFPA codes and standards
5. Information found in the consensus standards
6. Information found in journal articles

SUBJECTIVITIES

As a Compliance Safety and Health Officer, I have completed a variety of combustible-dust related inspections. I have interacted with employers who know the hazards of combustible dust and risk utilizing inadequate safety and health programs. I have also interacted with employers who do not have the knowledge necessary to manage a successful combustible dust program. In my profession, each completed inspection can alter an employer's view on a particular subject. This has both good and bad properties. It gives the Compliance Officer a better understanding and a greater knowledge of the topic. It can also affect future judgments depending on how an individual case is settled. To curb any underlying biases from my personal experience, I have taken two different cases involving combustible dust explosions and relied on the facts and figures stated in each report. I also looked at the topic from the view of a regulatory agency, but also from the view of the average employer.

CHAPTER IV

RESEARCH FINDINGS AND ANALYSIS

DUST EXPLOSION HAZARD MANAGEMENT

Certain types of equipment are more prone to be involved in a combustible dust explosion.

Types of Dust Handling Equipment

- Bag Openers /Slitters
- Blenders/Mixers
- Dryers
- Dust Collectors
- Pneumatic Conveyors
- Size Reduction Equipment /Grinders
- Silos and Hoppers
- Hoses, Loading Spouts, Flexible Boots

Equipment Involved in Dust Explosions

Table 4

EQUIPMENT INVOLVED IN DUST EXPLOSIONS

Material	**US (1985 – 1995)**		**UK (1979 – 1988)**		**Germany (1965 – 1980)**	
	Number of Incidents	%	Number of Incidents	%	Number of Incidents	%
Dust Collectors	156	42	55	18	73	17

Table 4 (continued)

Material	US (1985 – 1995)		UK (1979 – 1988)		Germany (1965 – 1980)	
Grinders	35	9	51	17	56	13
Silos	27	7	19	6	86	13
Conveying systems	32	9	33	11	43	10
Dryer/Oven	22	6	43	14	34	8
Mixers/Blenders	>12	>3	7	2	20	5
Other or Unknown	84	23	95	31	114	27
Total	372	100	303	100	426	100

These are the most common types of equipment involved in combustible dust explosions in processing industry from 1965 until 1995. *Source*: Eckhoff, Rolf K., Dust Explosions in the Process Industries, 2nd ed., Butterworth-Heinemann, 1997.

Equipment that May Create or Contain Dust Hazards

Bag openers and slitters have the potential to create dust clouds either from opening the packing of a material or disturbing the material itself as a part of the process. When a powder is emptied from a container, there is a potential for the electrostatic charging of those solids. The powder moves against the container and can become electrostatically charged. This is also a concern in the process that carries the powder away from the area. Whenever two surfaces come into contact with one another, electrostatic charges can be produced and serve as an ignition source for a combustible dust explosion.

Blenders and mixers have the potential to produce an electrostatic charging of solids. Dust clouds may form not only in the area of the equipment but also inside the machine. Other ignition sources can include the friction of parts or solids inside the machine.

A facility may have multiple types of dryers onsite. Direct-heat dryers use a convective drying system. The heat is generated by heated air or gas. Indirect-heat dryers use a conduction drying system. This type of dryer removes moisture produced via a vacuum system. Dryers present a variety of hazards. If the product feed rate is too slow, the material can become overheated and ignite. A stored dried product has the potential to self-heat. The motions of a dryer can cause the electrostatic charging of solids resulting in an electrostatic discharge. Material being dried can be heated beyond its own auto-ignition temperature. Equipment failure or malfunction can cause the overheating of product. Also, the minimum ignition energy is greatly reduced as the temperature is increased.

There are a variety of dust collector styles. A cyclone separator is a centrifugal separator. Air enters one area of the cyclone and is forced into a spiral stream where the heavier dust particles are spun out and fall to the bottom. The cleaner air is forced into an internal spiral which exits the cyclone on the side opposite the entry. Dust is collected in containers below the cyclone and removed. Cyclones are less susceptible to fires and explosion than fabric filters.

Electrostatic precipitators are dust collectors that utilize static electricity to remove particles from the air. Dust containing air is forced over a highly negative charged electrode. The particles pick up the negative charge. Next, the particles are passed over an electrode with a high positive charge. As opposite charges are attracted to one another and the particles “stick” to the positive electrode. These particles are removed either manually (someone brushing the electrodes clean) or automatically (the electrodes automatically shake or have an automatic internal brushing system). Electrostatic precipitators have an increased risk of fire due to the electrical discharges from the dust accumulations reducing the clearance distance to below the voltage breakdown distance. The risk can also be caused from dust particles being ignited outside and then collecting inside the unit.

Fabric filters are another type of dust collector (baghouses). Air containing dust is pulled through a fabric filter using suction. The filters remove the particles as the air passes through. Depending on the system design the dust may be collected on the exterior or interior of the fabric filter. Fabric filter dust collection systems have risks. For instance, there is the presence of easily ignitable fine dust in a turbulent atmosphere and broken, full, faulty, or overcapacity filters. Ignition sources can include electrostatic discharges and/or the introduction of heated particles into the baghouse.

Wet scrubbers separate the dust particles using a water vortex. This stream of water saturates the incoming air and this mixture is forced through a series of baffles. The water is moved to a storage container and the dust particles settle to the bottom via gravity. Wet scrubbers do not usually pose a great risk of fire by nature, unless the flow of water is interrupted.

Pneumatic conveying systems located downstream from the central process have a high rate for fire and explosion. Static electricity is generated from particle to particle contact or from particle to duct wall contact. These charged particles may leak from joints into the atmosphere and electrostatic sparking can occur, resulting in an explosion. Grinding or drying can create heated particles. These particles may be carried into the pneumatic conveying system creating embers by the high gas velocity. Tramp metal (metal dust/filings, nuts, bolts, broken machinery parts) traveling through the pneumatic system can potentially be a heat sources via friction.

Grinders/size reduction equipment often produces dust. This type of equipment is an ignition source due to the friction. Tramp metal introduced into the system can cause a frictional heat source. Also, if the feed rate is too slow, the increase of product can increase the risk of a fire and/or explosion.

Silos and hoppers contain dust, and with the nature of the organic material contained within, fires may occur. Aerobic bacterial growth can cause heat or if the material is dry and loosely packed, spontaneous fires may occur.

Flexible hoses, loading spouts, and boots/socks are at an increased risk of explosion. The powder being transferred through the hoses generates a greater rate of static charge when compared to a liquid.

Mitigation of Dust Hazards for Equipment

Methods used to prevent an explosion include controlling the air, fuel, or ignition source. Mitigation techniques can control one of these items or a combination thereof.

Construction is also an important consideration in explosion prevention. Facilities should invest in damage-limiting construction. This type of design can minimize the damage from a deflagration in equipment or building. This can be pressure resistive, pressure relieving, or a combination of the two. The most common are venting panels on enclosures, whether buildings or equipment. These panels release at a pressure below the strength of the enclosure.

Once an explosion occurs, the damage can be lessened through isolation. This is where a system or device is designed so that it prevents the propagation of the explosion effects from moving from one area to another area. The strength of the vessel is also a factor. An example would be a vessel that can withstand an explosion pressure in excess of 0.2 barg (3 psig) without being damaged or destroyed.

Bag openers and slitters should contain a suppression system along with a rupture disk capable of venting all of the materials of the process upstream. Careful attention should be paid to the entrance hood as the very act of cutting the bag and emptying the contents often forms a dust cloud. Any fugitive dust should be cleaned from floors, surfaces, and equipment within a reasonable time and not be allowed to accumulate.

Fires and explosions can be prevented in dryers by carefully maintaining the concentration of the combustible dust outside the explosible range, maintaining the oxygen concentration below limiting oxidant concentration, and excluding ignition sources. Explosion protection in dryers includes deflagration venting, explosion suppression, and explosion containment.

Mitigating techniques can vary from one dust collection system to another. Protective measures to use with cyclones can consist of venting, suppression, along with proper grounding and bonding. The latter is critical to prevent the buildup of static electricity. An electrostatic precipitator should be equipped with an automatic sprinkler system, along with an interlock to automatically de-energize the electrostatic precipitator if the sprinkler system becomes active. Baghouses and fabric filters should also have an automatic sprinkler system. This system should include an interlock rotary valve at the hopper bottom that stops whenever the sprinkler system is activated to prevent the transfer of dust into another part of the process. Special care should be taken when evaluating process duct work, with additional attention given to detection methods within the duct itself. The installation of an infrared fire detector placed in the duct between the dust collector, a spark arrestor or settling chamber in the duct between the process and the collector, and deflagration isolation in the duct between the processes upstream of the bag house are all good practices. The deflagration isolation will prevent a flame from traveling from the baghouse back through the duct work to the process. Precautions taken with the baghouse itself include properly grounding and bonding fabric filter components to dissipate electrostatic charges, the installation of a ruptured/broken bag alarm, and a high-temperature sensor with alarm.

Pneumatic conveying systems mitigation methods include venting, suppression, pressure containment, deflagration insolation, spark detection and extinguishing system, and the use of inert conveying gas. Size reduction equipment, grinders and pulverizers, will also benefit from those methods with the addition of the prevention and removal of tramp metal, metal that has be inadvertently introduced, in the system. Silos and hoppers should be located outside to lower the risk to employees and property. Devices such as air cannons should not be used to break bridges in silos since they cause the further dispersement of air within the enclosed structure. Spontaneous fire due to the breakdown of organic material can be detected with methane and carbon monoxide detectors.

Silos and hoppers should be equipped with pressure containment, inerting, and suppression systems to protect against explosions. Venting is the most common protection method. All flexible hoses should be bonded and grounded.

CONDITIONS WHICH CREATE PRIMARY AND SECONDARY COMBUSTIBLE DUST EXPLOSION HAZARDS

Ignition Sources

Controlling ignition sources in areas where combustible dust is present is one of the most effective means of mitigating the risk of a combustible dust explosion. Ignition sources vary from facility to facility, depending on the nature of the process being used. Housekeeping and preventive maintenance are vital in managing a combustible dust program.

Static electricity is the electrical charging of materials through physical contact and separation and the positive and negative electrical charges formed by this process. When there is a potential for static electricity, the process must be properly grounded. If it is not, a static charge may develop with enough energy to discharge a static arc. This arc may provide an ignition source to an adjacent mixture of dust in the ambient air.

A hot surface is considered any surface that has exceeded the minimum auto-ignition temperature. A layer of surface dust upon a hot surface is a high risk as the surface itself becomes a potential point of ignition. If the hot surface is a machine, equipment oils and lubricants may exacerbate the risk as these materials are combustible.

Open flames or glowing embers are not always obvious. These include-but are not limited to-candles, smoking, furnaces, lighters, matches, flares, and portable heaters.

Both electric arcs (a continuous discharge of a current when a strong current jumps a gap in a circuit or between two electrodes) and sparks (a momentary discharge) are ignition sources. The use of electrical equipment not rated for use in hazardous locations (NEC Class II) is a high risk factor.

Powered industrial trucks can create sparks when their engines are engaged. This can originate from the vehicle starter, combustion, or a backfire.

Biological or chemical reactions may cause spontaneous ignition. Stored organic material can decompose creating smolder spots. These spots are ignition sources producing heat and gas.

Equipment friction can become an ignition source via mechanical impact. Bearings, gears, and blades can strike surrounding metal causing a spark, while the friction can cause heat.

Characteristics of Dangerous Concentrations

There are a variety of factors to consider when evaluating the hazards of a combustible dust. Different conditions can cause the dust to reach an explosive concentration, along with varying physical characteristics. These characteristics include particle size, shape, chemical properties, and moisture content. An example is the smaller the particle size and the lower the moisture content of a combustible dust, the lower the minimum ignition temperature. The larger the surface area of a particle of dust the stronger the explosion. Considerations other than the dust particle also include ambient humidity, amount of oxygen in the area, and concentration of dust in the area.

Identifying the characteristics of these dusts may prove to be difficult. The material may change at different points in a system, so a material that is of no concern at the beginning of a process may become an explosion risk midway through the same process.

Danger of Dust Accumulation

The danger of an accumulation of combustible dust is that when the dust is disturbed, there is a potential for a serious explosion. The best practice is to keep the workplace as dust free as possible. This includes routine inspection of known areas where dust accumulation may occur, as well as hidden or infrequently visited areas. These locations include above false ceilings, inside ventilation or conveyor equipment, adhering to uneven walls and/or ceilings, rafters, or in ducts. These “hidden” areas often pose a greater risk of explosion because they may collect dust for years before being noticed. In the event of a dust deflagration, the percussion will shake loose this material and cause subsequent explosions throughout the facility.

Equipment that handles and/or process materials that have a large surface area has the highest risk of a combustible dust incident. These include dust collection units and machines that pulverize or grind materials. Mitigation techniques for each piece of equipment will vary but the control of accumulating dust and the management of ignition sources are the best methods to prevent a combustible dust explosion. A good housekeeping program will decrease the risk of both primary and secondary events. Fugitive dust should be kept to a minimum and special care should be taken to ensure all areas are clean. An example is a cleaning schedule that will remove the dust from the surfaces and floors including rafters, walls, and other harder to reach areas.

Combustible dust ignition sources can be heat (including the breakdown of organic material), friction, static charge and equipment not correctly rated for a specific electrical hazard class. Characteristics that are found in dangerous dust concentrations include particle size, shape, chemical properties, and moisture content. When dusts of a particular set of characteristics are allowed to accumulate past a certain concentration a combustible dust explosion can occur. A great means of prevention includes a management of change program and a good housekeeping program can decrease the risk of a combustible dust explosion. Even though there are many documents available from OSHA, NFPA, and other sources a combustible dust program would both hold employers accountable in managing a combustible dust program and give employers the knowledge needed to develop such a program.

CASE STUDY I: POLYMER PARTNERS, LLC.

Introduction

Polymer Partners, LLC. (Polymer) produces black resin concentrates and other specialty compounds for use in other manufacturing industries. On December 7, 2011, a flash fire occurred at Polymer located in Henderson, Kentucky. As a result, three employees were engulfed and one later died as a result of the injuries. Employees operated the machines over three shifts during a typical work week. Employees were exposed to the hazards of combustible dust during these times. The risk of a combustible dust event was increased when the employees were servicing or performing maintenance on the machines and equipment.

Facility Description

Polymer manufactures different shades of plastic pellets. Carbon black is used in various amounts depending on the particular color desired. The Polymer process ensures equal dispersion within the resin to produce a uniform color. The mixture varies depending on customer request. The two most common proportions are 25% carbon black, 2% additives, 73% resin or a more basic 50% carbon black and 50% resin. The plastic pellets are then sold to other companies for use in industries, such as the automotive industry.

Manufacturing the black pellets occurs through a line system that contains nine different stages. In the Production Room there are three lines that fabricate the black pellet: lines 45, 68, and 9. Each line has a dump area, a receiving area, a conveyor system, a Farrel Continuous mixer, an extruder, a pelletizer, a water bath, a classifier, and a boxing area. The lines vary in size depending on each Farral Continuous mixer. The larger the mixer, the more pellet product that line can produce. The extruder, pelletizer, water bath, and classifier are located on the first level. The feeders, conveyor system, and Farrel Continuous Mixer are located on the second level. The receivers for the carbon black, resin, and additives are located on the third level. The dust collection systems are located throughout each area, such as behind the feeders and the dump areas.

Process Description

Line 45 is located along the back wall in the Production Room. This is the first line system which uses an average of 600 pounds of carbon black, additives, and resin combination per hour. The Farrel Continuous mixer utilizes rotors with a radius of four inches and a screw conveyor with a radius of five inches. This line system produces an average of 600 pounds of carbon black pellets per hour. A maximum of 1,500 pounds of carbon black and 900 pounds of resin are used per eight-hour shift.

Line 68 is located in between lines 45 and 9. This system's Farrel Continuous mixer utilizes rotors with a radius of six inches and a screw conveyor with a radius of eight inches. This line produces 2,000 pounds of carbon black pellets per hour. A maximum of 25,000 pounds of carbon black and 7,500 pounds of resin are used per eight-hour shift.

Line 9 is located adjacent to the breakroom. The Farrel Continuous mixer of this system utilizes rotors with a radius of nine inches and a screw conveyor with a radius of eight inches. This line produces 8,000 pounds of carbon black pellets per hour. A maximum of 20,000 pounds of carbon black and 20,000 pounds of resin are used per eight-hour shift.

Each line has a dedicated dump station with a fifty horsepower motor. Carbon black, resins, and additives are dumped into their corresponding dump stations and are then fed into the receiver by a programmable logic-controlled piping system. The bags of carbon black, resins, and additives range in size from 50 pound bags to 550 pound bags. Employees hand-pour the 50-pound bags into the system. The larger bags require a mechanical lift to empty the product into the dump station.

The receiver for the carbon black delivers the product to the Farrel Continuous mixer. Carbon black has a particulate size ranging from 75 nm to 11 nm. It is delivered pneumatically from the dump station into the receiver via the programmable logic-controlled computer system.

The receiver for the resin works the same as the receiver for the carbon black. Various resins are used at the facility and are customer driven. A couple of resins used are nylon and polyethylene. The resin receiver can hold approximately 2,800-3,200 pounds of material while the receiver for carbon black can hold approximately 1,200 to 1,800 pounds.

The Farrel Continuous Mixer (FCM) will mix substances including carbon black, additives, and resin. The FCM is powered by an electric motor. The ingredients for each batch of pellets are dropped into a mixing chamber via a piping system and are then mixed by the rotors and emptied through the orifice. Heat is produced by both the rotors and the chamber itself.

Polymer falls down into the extruder from the FCM. When the material leaves the extruder it is in a thin spaghetti shape. The pelletizer cuts those strands of polymer into small black pellets. The water bath rinses the pellets to remove any residue. The finished product is then boxed in various sized boxes and prepared for shipping.

A dust collection system, Torit Environmental Control Dust Collector ECB-3, is used in this facility. Dust collection booths are located near the FCMs and the dump stations. The dust collection system pulls the dust into a bag house located outside of the building. The bag house is changed out one time per week to minimize dust buildup. Maintenance employees change the filters in the Torit booths on an as-needed basis. The dust collection system contains a cleaning purge in which every 10 seconds the solid-stage timer energizes a solenoid valve which causes the corresponding diaphragm valve to send a pulse of compressed air through the filter cartridge from inside outward. This removes the collected dust from the outside surface of the filter cartridge. Two are cleaned per pulse. The dust falls into a dust drawer for removal.

Incident Description

Three employees of Polymer Partners, LLC. (Polymer) were working on and in the area of the Line 9 in the production area. A flash fire occurred at approximately 1:31pm on the #9 Farrel Continuous Mixer. Three employees were engulfed and another was injured while assisting the other three engulfed employees. All four were transported to the local hospital. The three who were engulfed had to be moved to facilities specializing in burns. One employee was flown to the Vanderbilt University Burn Unit while two others were flown to the University of Louisville Burn Unit. The employee who was injured trying to aid the other three was admitted to the local hospital ICU for observation. The employee flown to the Vanderbilt University Burn unit passed away from injuries several days later.

Pre-Incident Events

Line 9 was running a 50% carbon and 50% resin mixture on the day of the accident. Employees stated the carbon running that day was “real fine, nasty, would buildup.”

Dust Explosion

The KYOSH inspection following the explosion was unable to determine the one event that lead to the accident. The only eye-witness statement was that “the orifice blew open.” This was from an employee to a member of management in an ambulance. It is likely that the heat generated within the FCM caused an increase in pressure greater than the orifice could withstand. The force of the flames exiting the equipment could have dispersed the layers of carbon black on the surfaces and floors which lead to the subsequent ignition. The prevailing factors appear to be either one of the following factors or a combination of the factors located in the following section.

Contributing Factors

1. Carbon Shot - Carbon black would often contain moisture and form bridges. A bridge is when the particles stick together forming a stiff layer of material. The FCM delivery system would not recognize the bridge and continue to load the material. The machine would not have time to adjust once the bridge collapsed and a higher level/percentage of carbon black would be introduced into the machine, referred to as a "Carbon Shot." As a result, a higher amount of heat would be generated allowing the resin to reach the temperature of degradation. Once this superheated mixture reached the air, the introduction of oxygen could result in a self-ignition and a subsequent fireball.
2. Blocked Vent Hole - Line 9 FCM is equipped with vent holes to allow the release of gas as a means of pressure relief. According to employee interviews, a blocked vent hole is the most likely cause for the flash fire that occurred on the day of the accident. Employees stated there was no set procedure for checking these vents.
3. Broken Orifice Gate Cylinder - After the explosion, the Line 9 FCM was taken apart to determine the extent of any damage to the machine. It was found that the hydraulic cylinder shaft was attached to the clevis of the orifice gate was broken. Investigators were unable to determine exactly

when this occurred. If this condition was present prior to the explosion, the mixer would have continued to build up pressure and heat until the mixture found a way to escape.

4. Lack of Adequate Preventive Maintenance - According to employee interviews, the preventive maintenance procedure was not completed in a uniform or timely fashion. This coincides with information obtained from earlier KYOSH inspections. Most of the machines leaked hydraulic fluid and/or oil. The equipment known to KYOSH to have leaks were the mixers, extruders, oil heaters, mixer cylinder pumps, and orifice cylinder pumps. According to the employee interviews, the Line 9 FCM orifice leaked oil/hydraulic fluid whenever it was opened or closed. A lack of proper fluid levels could cause the hydraulic cylinder controlling the orifice gate to not function properly, if at all. Employees also stated members of management were aware of the leaking equipment. Management stated to KYOSH during post-incident interview that the preventive maintenance schedule consisted of a daily checklist being filled out. When performing the daily checklist, the oil/hydraulic fluid levels were checked. However, the source of the leaks or cause of the fluid loss was never determined. The solution was to add more oil/hydraulic fluid so the machines would run.
5. Lack of Adequate Employee Training in Start-Up Procedures - Employees stated the machine operators were never really trained how to operate the

machines. Approximately two weeks prior to the explosion a Carbon Shot occurred on Line 9.

6. The operator did not turn down the rotors, and a Carbon Shot caused a fire beneath the electrical panel. This fire reached the operator on Line 68.

KYOSH Inspection History Data

KYOSH conducted an investigation (Federal Inspection # 307557306) in 2004 at this location. A history of fire was noted at the facility. The employer was issued a citation pertaining to the presence of Class II explosive dust in which lack of operator training, along with equipment maintenance, inspection, and testing were included. Citations were also issued with regard to housekeeping and accumulations of carbon black, a Class II combustible dust. It was also found that the use of Powered Industrial Trucks used in these areas were not rated for a Class II environment.

Another investigation (Federal inspection # 310656426) was conducted in 2007 that reported a continuing pattern of fire. The facility was again cited for housekeeping due to the carbon black dust, but this time further citations were added for oil and water on the floors. The facility was also cited for not training employees to use handheld fire extinguishers provided for their use.

In 2007 KYOSH conducted an investigation one month following the previous inspection and issued a citation pertaining to accumulations of carbon black dust on the facility surfaces. The Safety Data Sheet (SDS) at the time for the product stated it was a Class II explosive dust according to the KYOSH Federal Inspection # 310658372.

In June of 2010 KYOSH issued several repeat violations (Federal Inspection # 313811820). The first was a repeat of a General Duty Clause violation. It was found that the employers' housekeeping measures were insufficient to maintain accumulations of Class II combustible dust below hazardous levels. Accumulations were observed by the CSHO at depths up to 2.5 inches in the Production Room. The employer also revealed to the CSHO that the facility had no preventive maintenance program. The Line 9 FCM was observed "operating in a state of disrepair or malfunction during production activities on 29JUL10 where seals were ...releasing significant amounts of material in the air in the Production Room." This area had a history of incipient stage fires. The second repeat citation involved the accumulations of dust on the surfaces of the facility. The third repeat citation pertained to the accumulations of dust on the floors of the facility. The fourth repeat citation was related to the use of Powered Industrial Trucks used in Class II environments that were not rated for operation around explosive dusts. A citation was also issued because employees were not trained in the physical and health hazards of carbon black dust, resin, and other additives. The employer was also cited for not visually inspecting portable fire extinguishers monthly.

Following the explosion in 2011, Polymer was cited for ten safety violations (KYOSH Inspection #314601188). These included the following: lack of lock-out tag-out procedures, failing to annually review lock-out tag-out procedures, not providing electrical protective equipment appropriate for the specific parts of the body to be protected and for the work being performed (flame-resistant outer clothing, voltage-rated gloves, and protective clothing for the face and neck area), not providing electrically insulated tools, recordkeeping (not recording an injury), failing to perform hazard assessments, not providing fit-test for the voluntary use of respirators, an electrical violation for industrial use of relocatable power taps, an electrical violation for a control panel having openings not effectively closed, and electrical junction box with exposed wires.

Polymer received two hazard communication citations in February of 2012 (KYOSH Inspection #314601410) concerning a potential carcinogen used in the facility. The company did not list the chemical in the Hazard Communication Program nor did it maintain a Safety Data Sheet on the chemical. Later that year in June, twelve additional citations were issued to Polymer (KYOSH Inspection #316393503). These include the following; steps for shutting down, isolating, blocking and securing machines or equipment to control hazardous energy, employees were not required to affix personal lockout devices to machines when working on these machines, failing to provide proper machine guarding, another guarding violation where a grinding wheel did not have an appropriate guard and exposed employees to flying chips or exploding wheels, an unguarded horizontal shaft, an electrical citation for uncovered circuit breaker spaces, not providing annual bloodborne pathogen training, multiple recordkeeping violations, compressed air used for cleaning not less than 30 psi, unlabeled electrical disconnect, and not maintaining 3 feet of clear space in front of a circuit breaker panel and three electrical disconnects.

Additional Agency Standards

The General Duty citation (Federal Inspection # 307557306) issued in 2004 referenced National Fire Protection Association (NFPA 654 Standard for the Prevention of Fire and Dust Explosion from the Manufacturing, Processing, and Handling of Combustible Particulate Solids 2000 Edition). One feasible and acceptable abatement method to correct this hazard is to establish and enforce an inspection, testing, and maintenance program in sections 8.1.1, 8.1.2, 8.1.3, and Appendix M, which address essential elements of the inspection, testing, and maintenance program. In addition, sections 7.1.2 and 7.1.3 apply, which include the initial and refresher training to be provided to employees who are involved in operating, maintaining, and supervising facilities that handle combustible particulate solids.

The citations in the 2010 inspection include feasible abatement measures set forth in NFPA 654 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids 2000 Edition, Appendix A - Explanatory Material, Section A.2.2.3.1. Those include the following: (a) Dust layer 1/32 in. (0.8mm) thick can be sufficient to warrant immediate cleaning of the area (b) The dust layer is capable of creating a hazardous condition if it exceeds 5 percent of the building floor area. (c) Dust accumulation on overhead beams and joists contributes significantly to the secondary dust cloud and is approximately equivalent to 5 percent of the floor area. Other surfaces, such as the tops of ducts and large equipment, can also contribute significantly to the dust cloud potential. (d) The 5 percent factor should not be used if the floor area exceeds 20,000 feet squared. In such cases, a 1,000 feet squared layer of dust is the upper limit. (e) Due consideration should be given to dust that adheres to walls since it is easily dislodged. (f) Attention and consideration should also be given to other projections such as light fixtures, which can provide surfaces for dust accumulations. (g) Dust collection equipment should be monitored to ensure it is operating effectively.

Management of Change

A proper management of change program begins with a full assessment of a process to determine what factors affect the safety and health of the employees. In this evaluation, an employer will determine all risks associated with each task and determine appropriate policies and procedures to ensure the workplace safety and health. Once these policies and procedures are established any variance from the original assessment is reviewed and communicated to the employees. This method provides a stable and reliable work environment.

The SDS for the Carbon Black used at Polymer states “Dusts at sufficient concentrations can form explosive mixtures with air.” This document also lists this product as a Class II explosive dust. This facility had a history of excess accumulations of Carbon Black dust. KYOSH issued citations related to these dust accumulations in 2004, 2007, and 2010. The excessive black dust was also found present following the 2011 dust explosion. Information that included means of abatement when working with combustible dust was provided to the employer.

From these observations, Polymer did not practice reasonable diligence for this facility. Polymer received a General Duty citation in 2004 and made no effort to implement any protocols or procedures to ensure the amounts of dust were kept within a manageable level according to the NFPA (OSHA had not published the Combustible Dust NEP at this time). The facility was issued a repeat General Duty citation in 2010 for the exact same condition. If Polymer had implemented a dust control program, the 2011 explosion may not have occurred.

CASE STUDY II: CTA ACOUSTICS INC.

Introduction

On February 20, 2003 a fire triggering subsequent explosions occurred at CTA Acoustics, a manufacturing plant located in Corbin, Kentucky. A total of thirty-seven injuries occurred, as well as seven fatalities. CTA Acoustics, Inc. (CTA) is a manufacturer of thermal and acoustic insulation primarily used in the automotive industry, although a lesser amount is used in building materials. At the time of the explosion, the company employed approximately 560 people. The facility operated seven days per week and 24 hours per day. The employees performed shift work ranging from 8 to 12 hours at one time. The variable hours could be on a rotating or a swing shift for a total of four shifts each day. CTA representatives stated approximately 120 employees were in the building at the time of the explosion.

Due to the nature of the incident, an investigation was conducted by the Kentucky Division of Occupational Health and Safety Compliance (KYOSH). The investigation utilized root cause analysis to determine possible ignition sources. These included the oven located directly adjacent to the forming area, electrical sparking/arcing, employee smoking, and/or sparks from moving machinery or tools. A variety of causal factors were discovered in the course of the inspection. Factors identified involved both housekeeping and ventilation.

Facility Description

The building housing the operation was approximately 302,000 ft^2 and was constructed of a steel frame with steel siding, a flat tar and gravel roof, and concrete floors. The facility was separated into two different production areas. The first was the

Materials Processing lines, located on the south side of the building. The second was the Mold Department, located in the northeast area of the facility. The Materials Processing lines processed and formed fiber and phenolitic resin blend insulation. The Mold Department both molded and blended mats. The facility had an open floor plan equipped with concrete fire walls sectioning off additional areas from the operations space. These areas included the maintenance department, shipping/receiving department, and office area. A variety of equipment was utilized at the time of the explosion. These included, but were not limited to, process mold presses, blending and forming machinery, slitters, ovens, forklifts, and general maintenance equipment.

Process Description

CTA Acoustics manufactures acoustical and thermal insulation. A variety of materials were used in the processes at CTA. These included an assortment of fiberglass, natural, and synthetic fibers. These materials were dependent on which product was being produced at any particular time. A natural resin (identified as "yellow" in the KYOSH report) was used to make duct liner while the black resin was used to make the automotive acoustic insulation. Phenol formaldehyde resin powder was also utilized as a major component of the process. Phenol formaldehyde resin was utilized as a binding agent that both strengthens the insulation and provides thermal protection.

The CTA processing area was composed of four lines identified by number: Line 401, Line 402, Line 403, and Line 405. The equipment for each line was configured for the specific product produced, but the process was the same for all four lines. All lines were overseen by one-line supervisor and each individual line was run by five employees which included a crew leader, line inspector, oven tender, and two blend room operators.

Lines 403 and 405 were also called “mat forming lines” and were utilized to fabricate fiberglass insulation material.

The processing lines contained a system of conveyors in which the product ran through feeders, pickers, formers, an oven, and slitters. Most of the process equipment is contained in what is known as the Blend Room (also known as the Garnett Room), which was a steel wall enclosure with large doors that normally remained open.

Employees initiated the process by manually feeding fibers that are either natural, fiberglass, or synthetic-into the blend line feeders. Each blend line contained a conveyor that transported the fiber to a section called the mixing picker. This section was equipped with rotating bars affixed with long teeth. These teeth separated and mixed the fibers concurrently. The rotating cylinder of the mixing picker pushed the fibers forward into the direct feeder hopper. The fibers were carried away from the direct feeder by way of an incline conveyor, also affixed with long teeth. Next, a prescribed amount of binding material, phenolic resin powder, was deposited onto a mat of fiber which had been formed onto a residue feeder. CTA purchased and utilized large quantities of phenolic resin. Each package of phenolic resin weighed approximately 2,000 pounds. Due to the size and weight of the containers, employees had to use a hoist to lift the powder and subsequently dump the resin into a hopper attached to an inclined auger system. The material was opened with a high-speed roller, which also loosened the resin, before being transported to the mat forming area.

This section was equipped with a chain conveyor and a downdraft ventilation system. This type of ventilation drew air horizontally across a surface as opposed to drawing it vertically into a hood. This ventilation system aided in drawing the fiber/resin blend onto a chain conveyor used to transport the mixture into the forming area. The ventilation system was also designed to remove any dust, residue, or fiber that would otherwise accumulate in the work area. The underside of the forming chain conveyer was equipped with four exhaust ducts that carried any material to the roof, which housed a bag-house dust collection system. Any collected resin was mechanically released from the bag house via vibration. Any released resin powder was conveyed to the vertical line equipped with a rotary air locking mechanism so the material could be returned to the Blend Room for reuse.

The fiber binder pack, or "mat", was formed and cured with heat. The uncured fiber binder pack was moved to the lower oven conveyor. In this process, heat was applied as the fiber binder pack was transported between the upper and lower oven conveyors. The heat set the phenol formaldehyde resin-the binding agent, by partial melting. This process gave the product dimensional stability while allowing the binder to retain much of its original properties. At the conclusion, the product exited the oven and moved to a section to cool. Lastly, the product is measured and sectioned into different lengths, cured into its final shape, and packaged for shipment.

Incident Description

The explosion occurred on February 20, 2003, at approximately 7:33am. A new shift, working 7:00am to 7:00pm had just begun for Lines 401, 402, 403, and 405. The concussive force of the explosions raised the roof off the building and blew out several walls. The walls were constructed of concrete block and metal sheeting. The fire resulted in damage to raw materials, finished and semi-finished products, and other combustible materials located in and near the area. According to the KYOSH investigation, employees on all lines stated that "the lines were not in operation at the time of the explosion and the lines were being prepared to run product or were being cleaned." Employee accounts of the accident revealed "a loud boom was heard and immediately followed by a large flash of fire and a black dust cloud." Employee accounts of the explosion varied slightly in the exact number of booms and fire flashes. Some employees indicated that there "may have been multiple explosions." Of the 120 employees in the building at the time of the explosion, 18 employees were hospitalized and 27 others were treated at the local hospital and released. The highest numbers of injuries were from burns and smoke inhalation. Of the eighteen hospitalized, seven received injuries that were fatal. All of the fatalities were attributable to second and third degree burns. Other injuries included lacerations, smoke inhalation, and one knee injury.

Pre-Incident Events

CTA had a ventilation study conducted at the facility in 2002. The study found the units used for makeup air (the air drawn into the system) were routinely turned on or off depending on the temperature. As a result, when units were turned off a substantial quantity of air was being removed, yet a lesser quantity was being replaced creating a negative pressure throughout the building which caused "the exhaust equipment to work at a much lower rate." This allowed a larger amount of dust to be released in the production areas rather than being eliminated through the dust collection units. Both employees and management stated the airflow would move the fiberglass throughout the building. Additional air patterns between machines would result in resin dust, along with the fiberglass, to move freely throughout the facility.

Dust Explosion

From employee accounts and observations of the accident site of the KYOSH report, it appeared that the explosion "began in the area of Line 405 oven and mat former and traveled west along Lines 403, 402, and 401." The most seriously injured were working in or around the Blend Rooms. Two of the injured employees were working on the roof performing routine maintenance on the baghouse for Line 405. Those employees reported a blast came through the roof followed by explosions or fires in succession on the baghouses for lines 403, 402, and 401. The explosion damaged all lines with the most significant damage on Lines 405 and 403. Damage to the facility included "blown out roof decking, fire and blast damage to the dust collection systems, the collapse and cracking of concrete block walls, material fires, and fire damage to production equipment."

Employee interviews revealed there was no serious difficulty in evacuating the building and rescue operations were not required by the fire departments (KYOSH). According to employees and management officials, sprinkler systems and alarm systems activated properly following the explosion. The Laurel County Director of Public Safety served as the Incident Commander following the explosion. At approximately 7:34am Kentucky Utilities and Delta gas were informed of the incident and were instructed to turn off the facility utilities. Four different firefighting services responded to the scene: West Knox County Fire Department, Keavy Fire Department, Laurel County Fire Department, and Whitley County Fire Department. One crew utilized an aerial truck in an attempt to suppress the fire located on the exterior portion of the roof. All employees were able to egress from the structure and received medical treatment via local

Emergency Medical Services. A safe zone was established outside a one-half mile radius from the facility. An Incident Command Center and all associated operations were established. Only fire and rescue personnel had access to the facility at that time. Local law enforcement stopped all traffic on north and south bound Interstate I-75 for approximately one hour. Another concern was a railway in close proximity to the incident. CSX was contacted and all rail traffic was ceased for approximately four hours. After the threat from fire was controlled, the Kentucky National Guard Civil Service Team was dispatched to conduct air monitoring inside and outside the building. CTA regained control of the building on February 21, 2003 (KYOSH, 2003).

Contributing Factors

1. The process of making the insulation creates a large amount of dust. Dust was often observed wafting throughout the processing area. Dust accumulations were not addressed throughout the facility. The area above the Garnet Room only received only annual cleaning. Employees stated there were often up to six inches of dust in the garnet room during operation. No housekeeping program was in place.
2. The 405-line oven had a history of malfunction and fire. The temperature regulation unit was not working properly, forcing the employees to manually control the oven. Fires were commonplace in and around the opening of the 405 oven. Management stated the fires were "usually the result of a spark from the conveyer chains igniting the buildup of resin." On the day of the explosions, Line 405 was down for cleaning. During this time, employees were cleaning out the oven and forming hood.

3. Baghouses in the area of Lines 403 and 405 were found to be designed for lower actual volumes of air than the amount of air being pulled through the units. As a result, these units often became clogged with dust. When this occurred, one of two methods was used to dislodge the dust from the bags. The first was a high-pressure blast of air which was used to "shake" the dust to the bottom of the baghouse. The second involved the employees manually striking the bags with sticks. This material was manually removed via a chute ending in a cardboard box located on the floor of the blending room.

KYOSH Inspection History Data

In 2002, CTA received a machine guarding citation. In this KYOSH report (Inspection #304697097), the CSHO mentioned that employees were concerned with the breathing air quality because of the large quantity of dust in the air. CTA hired a company to perform an indoor air quality study. This report did not address the combustibility of the dust present.

In 2003, KYOSH cited CTA for multiple health violations (Inspection #305916579) following the explosion. This included a General Duty violation for "workplace conditions that are likely to result in fire or explosion from a class II explosive dust", as well as the following conditions: inefficient ventilation system caused the capture ventilation hoods to be unable to remove enough dust from the air, fire door (located in the 405 duct work adjacent to the transition) was incapable of closing due to the build-up of resin-containing materials on the walls of the duct work, a management of change program was not implemented for the production lines which used the phenol-formaldehyde resin, and oven doors were left open during normal operations as a method of controlling the temperature. There were additional citations: a housekeeping violation pertaining to the floors and surfaces covered in dust and a Hazard Communication violation because the employees were not trained in the hazards of the phenolic resin.

CTA also received multiple safety violations (Inspection #305910440) following the explosion. These included an electrical violation for the thermal control module not properly regulating the oven temperatures, an electrical violation for industrial use of relocatable power taps (surge protectors), a pilot light relay in an oven temperature control cabinet had been blocked with a paper to bypass the safety time out, an electrical violation because flexible cords (extension cords) were used as a substitute for fixed wiring and flexible cords were run through holes in the walls and attached to building surfaces, and electrical equipment/wiring methods/installations of equipment were used in a Class II Division I location which were not intrinsically safe nor approved for that hazardous (classified) location.

Additional Agency Standards

National Fire Protection Association (NFPA) 499, Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas states that, "if a dust cloud is likely to be present under normal conditions, the area should be classified as Division 1, and If a dust layer greater than 1/8-inch-thick is present under normal conditions, the area should be classified as Division 1". This classification for electrical installations is to prevent the explosion of combustible dust. In addition, NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of

Combustible Particulate Solids, 2000 edition states that when combustible dusts are produced, processed, handled, or collected shall be detached, segregated, or separated from other occupancies in order to minimize damage from a fire or explosion. It states that when separation is used to limit the fire or dust explosion hazardous area, the area shall include areas where dust accumulations exceed 1/32 inch.

NFPA 654 (appendix A.2.3.1) also establishes guidelines for dust accumulations as follows: Dust layers 1/32 in thick can be sufficient to warrant cleaning of the area [1/32 in is about the diameter of a paper clip wire or the thickness of the lead in a mechanical pencil]. The dust layer is capable of creating a hazardous condition if it exceeds 5 percent of the building floor area. Dust accumulation on overhead beams and joists contributes significantly to the secondary dust cloud and is approximately equivalent to 5 percent of the floor area. Other surfaces, such as the tops of ducts and large equipment, can also contribute significantly to the dust cloud potential. The 5 percent factor should not be used if the floor area exceeds 20,000 ft^2 (1860 m^2). In such cases, a 1,000 ft^2 (93-m^2) layer of dust is the upper limit. Due consideration should be given to dust that adheres to walls, since it is easily dislodged. Attention and consideration should also be given to other projections such as light fixtures, which can provide surfaces for dust accumulation. Dust collection equipment should be monitored to ensure it is operating effectively. For example, dust collectors using bags operate most effectively between limited pressure drops of 3 inches to 5 inches (0.74 kPa to 1.24 kPa) of water. An excessive decrease or low drop in pressure indicates insufficient coating to trap dust. Guidelines (a) through (g) serve to establish a cleaning frequency.

Factory Mutual 7-76, Prevention and Mitigation of Combustible Dust Explosions and Fires (1996, revised September 1998) states, "Housekeeping; in some areas fugitive dust escape is inevitable. Establish a comprehensive and conscientious housekeeping program to keep dust accumulations to less than 1/16 inch. For very light materials having a bulk density of approximately 16 lbs. ft^3 such as wood dust, keep accumulations to 1/8 inch or less". Also **"**Regardless of the housekeeping methods used, pay particular attention to eliminating accumulations above floor levels, such as equipment tops or building structural members. Dust accumulated at higher locations is far more hazardous than dust at floor level, because dust is more likely to become suspended (airborne) and create an explosible cloud if it is distributed."

Management of Change

After the 2003 explosion, CTA moved its facility to a different location. At the new location, CTA made many changes. CTA began requiring all of the processing line equipment to be designed as Electrical Class I Division 1 or Class II Division 2 as the combustible dust was present in those areas. Special care was taken in making the new lines as fire-proof as possible. The process line rooms were designated as regulated areas. An employee had to be certified to enter any of these rooms. This certification included training in NFPA 77 (Recommended Practice on Static Electricity) and NFPA 654 (Standard for the Prevention of Fires and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids). Employees were also required to wear static resistant clothing and static dissipating footwear. The plant, as well as each of the processing lines-including the ductwork-was fitted with fire sprinklers. The main ductwork was also equipped with a fire suppression system (triggered by photo receptive sensors) that would discharge if a fluctuation in pressure was detected. The processing rooms were equipped with an adequate ventilation system along with humidifiers. These actions were taken to lessen the combustibility of any dust in the air and to reduce accidental static build-up. All equipment was grounded and any equipment that was brought into the facility had to be bonded. The ovens were also equipped with a magnetic locking system that could not be accessed without shutting down the entire system.

Housekeeping was performed regularly as CTA implemented a Process Housekeeping Program. This program provides guidance to both employees and management. The program includes provisions for routine safety inspections and regular housekeeping inspections. Equipment must be maintained and operated in a manner that lessens the escape of fugitive dust, regular cleaning frequencies were established for floor and horizontal surfaces (such as ducts, pipes, hoods, ledges, and beams) to minimize dust accumulations. A Fugitive Dust Program was also implemented that rated the dust levels on a scale. Each point on the scale (ranging from 1 to 6) had a definition and coinciding action associated with that point.

CTA made numerous changes between the 2003 fatality inspection following the dust explosion and the 2011 follow-up inspection. This facility managed the risks associated with combustible dust and maintained an efficient management of change process. As a result, CTA has now operated 12 years without an explosion.

OSHA STANDARDS

How New OSHA Standards Are Created

An OSHA standard can begin in a variety of ways. OSHA itself can initiate procedures themselves or different agencies can petition for a new standard including, but not limited to, these: "Secretary of Health and Human Services (HHS); the National Institute for Occupational Safety and Health (NIOSH); state and local governments; any nationally-recognized standards-producing organization; employer or labor representatives; or any other interested person" (OSHAe, 2015). If OSHA determines there is a sufficient foundation for the development of a new standard, then advisory committees are used to review the petitions so they can make recommendations for a new standard. These advisory committees include the National Advisory Committee on Occupational Safety and Health (NACOSH), which advises, consults with, and makes recommendations to the Secretary of HHS and to the Secretary of Labor on matters regarding administration of the Act. Also included is the Advisory Committee on Construction Safety and Health which advises the Secretary of Labor on formulation of construction safety and health standards and other regulations (OSHAe, 2015).

If there is enough need for a new standard, OSHA will publish the plans for the standard in the "Notice of Proposed Rulemaking" section of the Federal Register. Next, there is a period for public feedback where written oppositions, along with evidence, are submitted to OSHA for review. There may also be public hearings where groups can speak. Following these steps, OSHA will publish its final rule in the Federal Register. If a new standard will be adopted by the agency, OSHA will also publish the standard in its entirety, including the effective date and the purpose for the adoption of that standard.

All employers covered within the scope of the standard are required to follow the new standard. Although OSHA publishes the new standard immediately, employers are usually given a grace period where different parts of the standard are implemented at different times.

The 2012 update to the OSHA Hazard Communication Standard is an example of the graduated implementation of a standard. The updated standard went into effect in 2012 and employers, chemical manufacturers, importers, and distributors must comply with different sections at different times over a period of four years (OSHA, 2015). Although rare, if OSHA determines that employees are in grave danger due to the presence of a particular hazard, the agency can implement a temporary emergency standard. These standards will go into effect as soon as they are published. The publication of the emergency standard itself will serve as a notice of a proposed permanent standard. In this instance, any interested party may challenge the OSHA temporary emergency standard before a United States Court of Appeals. The decision made by the court will be the determining factor in whether or not the temporary standard will remain in effect for the duration of the appeals process.

Combustible Dust Related Citations by OSHA

The safety practices of industry are routinely built on a foundation of regulatory standards. The type of industry will determine which standards will be utilized. The safety culture will determine how the company will comply with the standards. The challenge remains as to how an industry can struggle with safety when the directions are simply stated in a concise and easy to understand format within a given regulation.

For each section in 29 CFR 1910 (OSHA standards for General Industry) there are numerous letters of interpretation describing how easily standards are misunderstood. As Compliance Safety and Health Officers, we often turn to standard Compliance Guides, documents providing the CSHO with specific information on how to cite a standard violation, in determining how to cite a particular violation of a standard.

The base of a working safety program is regulatory standards. Compliance and understanding rest on the standards. Any shift from either element may result in employee injury. As the diversity of industry is measureless, such items of reference must maintain their generality. This allows each standard to remain applicable yet malleable to meet the capabilities of an individual establishment. One example is a company obtaining a variance when a process cannot be fulfilled according to items required to meet a standard. Alternative safeguards can be approved as a substitute method of compliance.

OSHA does not currently have a standard for every hazard. One example is combustible dust, although the hazards of grain dust were included in the grain handling standard on December 31, 1987, which came subsequent to a number of deadly grain elevator explosions. OSHA decided to issue this grain handling standard in an effort to protect the 155,000 workers in the grain industry who must deal with both the risk of fire and explosion from highly combustible grain dust on a daily basis (OSHA, 1987).

Citations for combustible dust are currently issued under the standards that have provisions included to address the dust. There are multiple standards that are currently cited for combustible dust hazards. The actual citation will be dependent mostly on where the dust is found. For violations at grain handling facilities, citations are issued under

1910.272. The grain handling standard specifically addresses “fugitive grain dust”, which means combustible dust particles.

If the area of a hazard is covered by OSHA’s ventilation standard (1910.94), then those violations shall be cited according to that standard. The ventilation standard has paragraphs that involve abrasive blasting, grinding, polishing, and buffing operations. This standard does not specifically address the combustibility of the dust. It does, however, incorporate NFPA 68, which addresses explosion venting. This document includes information on combustible dust.

If the dust collects on the surfaces or floors, then 1910.22 (the housekeeping standard) is cited. Two different citations may be issued if combustible dust is found on both the floors and surfaces under the standard. Because of the similar nature of these violations, they are often grouped as one citation. Unfortunately, this standard does not address combustible dust specifically.

Housekeeping violations in storage areas are found under 1910.176(c). This standard states, “Storage areas shall be kept free from accumulation of materials that constitute hazards from tripping, fire, explosion, or pest harborage.” There is a mention of explosion, but nothing is particular to dust.

If there is an accumulation of dust greater than 1/32 of an inch per the OSHA Combustible Dust NEP that is not at a grain handling facility, covered under the ventilation activities according to that standard, on the floor or on a surface, or in a storage room, then a General Duty violation may be issued. The General Duty Clause is used for combustible dust hazards “within a dust collection system, or other containers, such as mixers” (OSHA, 2015). A General Duty citation can also be issued for deflagration and explosion hazards if SLTC (Salt Lake Technical Center) determines that the dust is combustible.

Housekeeping violations at coal-handling operations are cited under 1910.269. This standard regards electric power generation, transmission, and distribution. It states that where operations may produce a combustible atmosphere, any sources of ignition shall be eliminated or controlled to prevent ignition of the combustible atmosphere. Dust is included in the description.

If employees could be exposed to combustible dust flash fire hazards, then those employees must be provided proper personal protective equipment to mitigate the risk of burn injuries. These citations would fall under the OSHA personal protective equipment standards, in particular 1910.132(a). The OSHA standard regarding process safety management has a list of Highly Hazardous Chemicals in Appendix A of 1910.119. If the dust is included in that list and is present in a quantity greater than or equal to those listed, then a citation under 1910.119 will be issued.

Dust samples, when possible, are collected for analysis. If the results reveal the dust is a Class II dust and the location where the dust was found is defined as an electrical Class II area, then a citation under 1910.307 will be issued. Areas where combustible dust is present and identified as a Class II dust must follow very stringent electrical guidelines to prevent the ignition of the dust. Any equipment used in that area and wiring must be intrinsically safe, rated for that hazard class, and otherwise safe for working in that location class.

The hazard communication standard, 1910.1200, requires all employers to provide information relating to the combustibility or explosibility of any dust to the employees exposed. This must be provided in the Hazard Communication Program itself, labels, as well as safety data sheets, and training. The inclusion of combustible dust in the Hazard Communication Program is relatively new. This provision was adopted in the 2012 revision of the Hazard Communication Standard.

Bakeries that utilize sugar and spice pulverizers may be cited under 1910.263. This standard incorporates NFPA guidance by reference which states, "all pulverizing of sugar and of sugar or spice grinding shall be done in accordance with NFPA 62-1967 (Standard for Dust Hazards of Sugar and Cocoa) and NFPA 656-1959 (Standard for Dust Hazards in Spice Grinding Plants)" (OSHA, 2015).

Systems of Control

Controlling the levels of combustible dust in a facility begins with the management of that facility. A program to address the levels of combustible dust used and/or created in a process must be written and implemented prior to the start of that process. This program should be created in a manner that the intended audience can understand. For example, if the program is in English, all employees must be able to understand English. This includes spoken words as well as written material. Some employees can understand a different language when it is spoken but cannot read that language. This presents specific barriers in the use of policies, procedures, and signage used in the facility.

Along with creating policies and procedures, the employer should also institute safe work rules that address working with, around, and on any operations that involve combustible dusts. This will include employees who normally run the machines, any janitorial and/or housekeeping employees, and any maintenance employees who will service this equipment. Special provisions should also be provided to address visitors to the facility, including outside contractors.

The employer should also develop a means of identifying any combustible dust hazards, thereby maintaining safe operating conditions. This includes the prevention, control, and mitigation of combustible dust fires and explosions. A program should include inspection procedures for both the work areas, individual pieces of equipment, dust control and/or capturing equipment, fire detection and suppression devices, housekeeping, procedural reviews, and a management of change system. A maintenance program for the above listed items should also be a part of the program. It is also a good practice to solicit input from employees on how things are running with a particular system or process. There are times when an employee will bypass a safe work rule to make a job easier. When things like this occur, the employer should reevaluate the system or procedure to determine if either needs to be updated. An employee who works with a particular process every day for the duration of their shift will usually have more knowledge on what it means to work in that position than a member of management. It is much easier to work with employees than to work against them especially, if there are more employees than management.

There should also be a corrective action process for any item found deficient on an inspection. CTA has a very good system where different items were ranked from 1 to 6. For example, a dust level of 1 would indicate little to no amount of fugitive dust in the area. No corrective action would be warranted. A level of 3 would indicate a level of dust that requires immediate action. An employee would be tasked with removing the dust from the surfaces in the area, as well as doing a check of the dust collection systems to ensure they were working properly. A level of 6 would indicate the dust being at a depth greater than or equal to 1/32 of an inch, which is above the NFPA 654 guidelines. In this instance, the work process would be shut down until the cause of the dust was identified. If it were employee misconduct, the employee(s) would receive appropriate disciplinary action. If it were a mechanical failure, the process could not resume until that equipment was repaired.

Training is an imperative portion of any dust control program. Any persons that would be in the area of the process that produces and/or uses combustible dust should be trained in the hazards associated with combustible dusts, safety awareness, and safe work rules prior to any exposure to combustible dusts or their process and at least annually thereafter. More in-depth job specific or task specific training should be mandated as different jobs may have different hazards in relation to combustible dusts. The program should also address how outside vendors and contractors will be trained. Contractors may be unfamiliar with the layout of the facility so they should be trained in the company's emergency action plan. In the event a combustible dust event occurs, a current emergency action plan should be in place so employees, visitors, and outside contractors are aware of assembly points, evacuation procedures, means of safe egress, and methods of accounting for the evacuees.

There must be a defined management of change procedure to be used in evaluating any proposed change to the facility, product, process, or any other factor that alters the current policy. This evaluation should be implemented prior to the change so the effects of said change can be evaluated. If changes are to be made, the management should review the necessity of the change, how long the change will be in affect (permanent or temporary), training requirements, hazard assessment, and how this change will affect other systems, such as planned maintenance.

The Need for an OSHA Standard

Multiple OSHA standards have very specific requirements addressing combustible dusts since it is a known hazard. Having an OSHA standard to address all of general industry, as well as construction, which implements a defined program to include the management of change would greatly reduce the number of fatalities due to combustible dust explosions. The NFPA provides valuable tools necessary to assist employers on recognizing, evaluating, controlling, and anticipating combustible dust fires and explosions. With all this material available, an OSHA standard specific to combustible dusts could help prevent devastating combustible dust events. OSHA has already proven that a provision including combustible dust decreased the number of dust explosions when the grain handling standard was promulgated.

In 2003 OSHA reviewed the grain handling standard. During that review union representatives stated, "…since its promulgation, grain explosions were down 42 percent, and injuries and deaths from grain explosions were reduced by 60 percent and 70 percent respectively. For the ten years prior to the standard (1978-1987), the average number of explosions per year was 20.5. This average decreased to 10.3 explosions per year from 1988 to 1997 and further decreased to 6.3 per year from 1998 to 2007. OSHA gathered this data from the Regulatory Review of OSHA's Grain Handling Standard, Kansas State University in cooperation with USDA Federal Grain Inspection Service, and USDA Grain Inspection, Packers, and Stockyards Administration." (OSHAf, 2009).

Unfortunately, this standard covers only grain handling facilities. The U.S. Chemical Safety Board (CSB) conducted a study after investigating three combustible dust related fatalities in a period of two years. The CSB found "281 combustible dust incidents between 1980 and 2005 that killed 119 workers, injured 718, and extensively damaged industrial facilities" (Board, 2015). OSHA has already established in its pre-rule stage that many other industries are experiencing multiple fatalities during combustible dust explosions.

The case studies presented earlier in this document provide an example that a good combustible dust control program can decrease the chance that a combustible dust explosion will occur. CTA worked to maintain adequate indoor air quality but did not assess the hazards associated with the combustible dust in their facility. The combustible dust explosion was in direct correlation to the facility's lack of proper planning. After the explosion, CTA developed a dust control program, and it has been explosion free for the past twelve years.

Polymer, on the other hand, did not address their dust problem on multiple occasions. This facility was issued the same General Duty citation relating to combustible dust twice. If this company had implemented a dust control program similar to that of CTA after the initial 2004 combustible dust General-Duty citation, or even after the 2010 repeat combustible dust citation- the combustible dust explosion of 2011 could have been prevented. Of course, it could be argued that any implemented control program could mitigate these types of events, so having a standard would serve no purpose for the companies who are already participating in these types of dust control programs.

OSHA standards serve more than one purpose. The first is to ensure a safe working environment for all employees. In addition, the standards are invaluable educational tools. If a dust control program is required by an OSHA standard, a list of items to be included in this program is also included. The OSHA standard will delineate what is needed in a dust control program. Even the most well-intentioned dust control program could prove disastrous if all necessary elements are not included. The Kentucky Labor Cabinet contains a Division of Education and Training (E&T). An employer can contact KYOSH to schedule a site visit with E&T. A consultant will look at any area or item requested by the employer, including any industrial hygiene monitoring or sampling. This is a free service to any employer in Kentucky. After the inspection, the employer is presented with a list of violations similar to a citation received by the Division of Compliance. There is no penalty associated with an E&T citation, but the employer is required to correct all violations found. Because there is no OSHA standard for combustible dust, E&T only recommends that the employer abide by NFPA 654. In addition, E&T also does not do combustible dust sampling. An employer is not required to correct anything that is recommended. For these reasons, many educational opportunities are missed.

Also, in my experience, I have found that the majority of employers are either not eager to correct a “recommendation” or they may believe a recommendation is not important. For example, I was assigned an inspection at a woodworking facility that produced a large amount of wood dust. The dust was a Class II combustible dust and a General Duty citation was issued related to the combustible dust in that facility. This location did not realize after the consultation visit from the Kentucky E&T Division, they needed to correct any recommended items. This was a very unfortunate situation, but it happens all too often. I provided the employer with the OSHA NEP and several links to example combustible dust programs. A combustible dust standard would not only ensure the safety of our workforce by preventing the number of workplace fatalities due to combustible dust explosions, but it would also provide educational material to the employer.

CHAPTER V

DISCUSSION AND IMPLICAITONS

COMBUSTIBLE DUST DEFINITION

Easy to understand language is very important in regulatory standards. Instead of a technical document, a combustible dust standard would be more beneficial if it read as a regulatory instruction manual. There are questions on what is truly considered a combustible dust. This question must be considered to determine which industries are covered under the scope of the standard. For example, some mineral dusts, such as limestone, silica, and sulfates, are non-combustible. Industries that use and/or produce these dusts can be an exclusion to the standard unless, of course if these dusts have been treated with something that is flammable or combustible. Another example is if an industry is covered by a more vertical standard, that industry should be excluded from complying with a new combustible dust standard, for instance, employers in the grain handling industry.

There has also been discussion as to defining combustible dust based on the dust's explosibility. In an OSHA Combustible Dust Expert Form there was discussion on which testing method could be used to determine if a dust should be included in the standard. One expert stated that "combustible dust is any dust that can support flame propagation, and the American Society for Testing and Materials (ASTM) has already developed a testing methodology (ASTM E-1226) that can be used to determine if a dust meets that criterion" (Eastern Research Group, pg 7, 2011). This individual felt that if a dust supports flame propagation as defined by the ASTM methodology, then that dust should be covered by the standard. The Kst has been a long-standing indicator of combustibility.

Some argue that the lower Kst (1-100 bar-meters/second) values should be excluded because the dusts scoring in that range would not produce a significant event. For example, sugar has a Kst of 56 bar-meters/seconds. For this reason the Kst does not seem like a very good criterion to limit the scope of the standard.

Another expert brought up a good point in saying that “OSHA should distinguish between prevention and protection in its consideration of explosibility. Ignition sensitivity is useful for determining what preventive measures might be required (e.g., monitoring bearing temperature in a hammer mill). In contrast, Kst is an engineering parameter that is used to design protective measures” (Eastern Research Group, pg 10, 2011). This would allow for multiple criteria to define a combustible dust depending on the characteristics of a facility.

PERFORMANCE-BASED OR SPECIFICATION-BASED

A performance-based standard would state what an employer must achieve, but would not define how it must be accomplished. A specification-based standard presents a defined manner in which all items must be completed. Some of the NFPA standards use performance-based methods such as hazard analysis. These standards allow a great degree of flexibility in the manner in which an employer can abate a hazard. The Hazard Communication Standard is an example of a performance-based standard. The standard requires the employer to provide training to their employees on the chemicals they use. It does not state how that training should be presented. The employer can decide what is best for their facility as long as the performance-based goals are achieved. This is a good plan when a program is needed to include a broad range of industries.

A specification-based standard has more specific scope and is limited in flexibility. The grain handling standard is an example of a specification-based standard. This standard covers a span of industry that has a limited range of dusts and hazards. For these reasons, a specification-based standard includes very specific housekeeping requirements. Grain handling injuries have declined since the promulgation of the standard, so OSHA decided in its last review of the standard to keep that standard in its current state.

For a combustible dust standard, it would be very difficult to create a specification-based standard due to the varying types of dusts and all the different industries that would be covered under the standard. A performance-based standard would be better suited. Perhaps OSHA could have a provision listed in the standard that if the employer is abiding by a more vertical industry standard, such as a NFPA standard relating to that specific dust or process, then that employer would also be exempt from the OSHA combustible dust standard.

ECONOMIC CONCERN

Some facilities were built prior to any dust control standards or a facility may have complied with the dust control measures at the time of construction, but with new technology, its current system is now outdated or obsolete. OSHA must take into consideration the cost to employers in upgrading existing facilities. The OSHA Hearing Conservation Standard takes into consideration economic feasibility when assessing engineering controls. A CSHO will look at the cost of a Hearing Conservation Program per worker per year and the cost of the engineering control. If the cost of the Hearing Conservation Program is less expensive than the engineering control, then the company is allowed to move straight to controlling exposure by personal protective equipment. This example is not exactly how a combustible dust standard implementation would work, but there could be other ways an employer could meet the standard. If it was economically infeasible for an employer to install a device to prevent dust escape from a process, another option would be to ensure the facility had a very strict housekeeping program to ensure the dust levels remain in a safe range. "Grandfathering" in facilities with regard to safety protocols is not favored because it requires the regulatory agency and the industry to place a value on human life.

There are administrative controls that an employer could implement while working toward compliance. These include-but are not limited to-housekeeping, a management of change program, training, inspection, and preventive maintenance. The time frame for compliance with a new combustible dust standard could also be extended for those employers having economic difficulty. The 2012 Hazard Communication Program changes were implemented over the course of four years. Higher hazard industries could be required to comply in four years while the lower hazard industries could take up to eight or ten years for full compliance.

There is also concern for the cost associated with testing to determine whether or not a dust is combustible. ASTM E1226 screening to determine if a material is explosive can cost $525.00. If the dust is considered explosive, the sample analysis will be automatically be upgraded to "Explosion Severity Testing" with a cost of $1,470.00 (EMSL Analytical, 2016). Depending on the number of dusts used and/or produced by a company, the testing itself can be expensive. There are also questions as to the frequency of testing. A partial solution would be the development of an OSHA Combustible Dust

Database. Employers could access this database and locate known values for assessing the combustibility of dusts. Employers could develop management plans and engineering controls based on these figures rather than complete the testing themselves. When using a mixture, the Combustible Dust Standard could have a section similar to the Hazard Communication Standard in that the employer would rely on the most hazardous ingredient in the mix to complete the hazard assessment. An example of an exception would be if the components of the mixture have a synergistic effect on one another. This would make the combination a greater hazard than the individual components.

SMALL BUSINESS V. LARGE BUSINESS

Another question derived from this research involves size exclusions for small versus large businesses. A large 350,000 ft^2 facility producing wood veneers would be working with and producing very different quantities of dust compared to a small 1,000 ft^2 woodworking facility. NFPA 664, the Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities, limits the scope to "woodworking operations that occupy areas of more than 465 m^2 (5000 ft^2) or where dust producing equipment requires an aggregate dust collection flow rate of more than 2549 m^3/hr (1500 ft^3/min)" (NFPAb, pg. 8, 2012). Facilities that do not fall into this range are excluded from the standard. This is another instance where a facility could use a NFPA standard that is more vertical than a horizontal combustible dust standard that is designed to cover a wide variety of industries.

Annex D of NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids, is referenced in the OSHA Compliance Directive for combustible dusts. NFPA 654 Annex

D, Dust Layer Characterization and Precautions, provides information to help determine precautions to take with different dusts and their depths. This document states "For rooms or buildings where dust accumulations are limited to a small area, one way to determine if the actual dust accumulation is sufficient to result in a dust deflagration hazard is to ratio the actual dust accumulation to the permissible dust accumulation. If the ratio exceeds 1, then a dust deflagration hazard exists in the subject building or room" (NFPAa, pg 53, 2013)." This document also states that "immediate cleaning is warranted whenever a dust layer of 1/32- inch thickness accumulates over a surface area of at least 5% of the floor area of the facility or any given room. The 5% factor should not be used if the floor area exceeds 20,000 ft^2 , in which case a 1,000 ft^2 layer of dust is the upper limit" (NFPAa, pg 53, 2013). OSHA could have the option of incorporating sections of the NFPA documents as a means for limiting the scope of the standard.

One expert in the Combustible Dust Expert Forum (Eastern Research Group, pg 11, 2011), however, raised the point that "a facility using smaller quantities of material will have a more localized hazard" and that "workers at these smaller facilities are also often in closer proximity to the hazard." In this instance it was discussed that administrative controls such as housekeeping and a Management of Change Program would be a better fit for the smaller facilities because the cost of engineering controls would be costly and economically unfeasible for smaller employers. It does not take a lot of dust to make a detrimental explosion especially when confined to a small area. So the argument for size exclusions to the scope of the standard needs additional research to make the best determination.

The following lists future research opportunities that could be complementary to this thesis:

1. In-depth analysis of the training provided by the Federal OSHA Education and Training programs compared to their State equivalent.
2. Evaluate how inspectors are trained with regard to combustible dust in other agencies (for example, federal and insurance agencies) and compare.
3. Analysis of industry-specific training programs and educational materials used by employers in high hazard industries in relation to combustible dust.
4. Local as well as State Combustible Dust Emphasis Programs in comparison with the Federal OSHA Combustible Dust National Emphasis Program.
5. Evaluate the follow-up inspections with facilities covered under State managed Occupational Safety and Health Plans and compare the recurrence of citations in Federally managed states vs State managed plans.
6. Analysis of OSHA versus NFPA inspection procedures in relation to combustible dust.

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