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Lechleitner, Anthony, D. ***Combustible Dust Hazard Assessment for Company XYZ***

Abstract

In order to determine if Company XYZ's packaging facility was at significant risk of a coal dust explosion a review of existing dust analyses were reviewed, equipment, practices, and accumulation was assessed and compared to identified best practices. Methods used to determine whether or not a risk was presented include reference tables that summarized the best practices from industry experts for dust handling equipment and allowable personnel behaviors. This data was analyzed and recommendations have been identified. Each recommendation was associated with a level of significance and prioritized in order to assist Company XYZ towards reaching the elimination of this significant hazard. The most significant issues identified include the lack of appropriate explosion ventilation on the coal bucket elevator, the lack of an isolation device separating the dust collector from the rest of the building, and alarm systems to notify operating personnel when a malfunction occurs. Overall, it was determined that Company XYZ is at risk of experiencing significant loss due to a dust-based explosion within the coal handling process of the facility.

Table of Contents

List of Tables

Chapter I: Introduction

Since the industrial revolution, heavy manufacturing has been woven into the rural and urban framework of America and has provided many individuals with the means to provide for their families. Heavy manufacturing brings not only jobs and business development to an area, but also a number of personnel and environmental risks to the employees and communities affected by the business (Adams, 1982). Over the last 40 years, there has been increased pressure on business and industry to work in conjunction with government agencies to develop standards, tools, and practices to reduce these risks and preserve the personnel and environment affected. (Fleming, 2001)

The Occupational Safety and Health Administration (OSHA) began identifying risks that have been determined to require extra emphasis in 1985 with the implementation of the first National Emphasis Program (NEP). Since 1985, a number of NEP's have been introduced including programs that led to increased enforcement and focus on silica exposure, lead exposure, hazardous machinery and combustible dust. These NEP's allow OSHA to increase its activities in outreach, training, as well as the creation and dissemination of guidance and educational materials and cooperative ventures with stakeholders (OSHA, 2008). The Combustible Dust National Emphasis Program was initially released in October of 2007, however a catastrophe at a Georgia sugar plant the following year compelled OSHA to place additional resources towards this NEP in March of 2008 (Conn, 2010). This NEP covers a multitude of different industries and numerous materials including metal dust, wood dust, coal and other carbon dusts, plastic and additives, biosolids, organic dusts (sugar, flour, paper, soap, dried blood), and certain textiles.

According to the Wisconsin Historical Society paper production has been part of Wisconsin history since the state's first paper mill began production near Milwaukee in 1848. Paper production has continued to be a major contributor for the Wisconsin economy in over the next 150 years although this process creates a number of significant risks (Hall, Ragsdale, Arthurs, Ikoma, Borton, & Cook, 2009). One significant risk present in all paper mills is combustible dust, which not only creates a significant fire risk, but also has the potential to accumulate on overhead horizontal surfaces which lead to it becoming airborne and create an explosion. Examples of combustible dust that are common in paper mills include coal dust, fly ash, and paper dust (Jones, 2007).

Company XYZ is a medium sized paper mill with a 450 acre facility that employs approximately 430 individuals. The mill manufactures approximately 1500 tons of corrugated medium per day and to produce this amount of paper, the plant requires an extraordinary amount of fuel and raw materials. The primary steam boiler fuel for the mill is coal, with other fuels such as biogas, bark, and natural gas being used as supplemental sources. The coal is delivered to the plant via rail car and released through a door on the underside of the rail container. This coal then traverses a 500-foot inclined conveyor where it is separated into two lines for crushing, storage, and eventually feeding the boiler. Each time coal is transported or transferred through a particular system there is a potential for dust to be released. These dust releases can be significant, and at times release airborne concentrations that are visible and surface based accumulations which exceed 1/4 inch by the time the Power Area Cleaner returns to remove this fuel source by vacuuming the dust where it is accessible.

Statement of the Problem

The presence of significant coal dust accumulations in and around the coal handling equipment and structures within the power and steam generation areas at Packaging Company XYZ's Paper Mill is placing the organization at significant risk of experiencing a catastrophic explosion and is exposing employees to coal dust inhalation hazards while controlling the accumulations.

Purpose of the Study

The purpose of this study is to determine and document the magnitude of the coal dust accumulation, determine the risk associated with coal dust accumulation, determine and identify control measures to minimize dust release, and develop methods to mitigate the severity or prevent a significant coal dust explosion at the mill.

Goals of the Study

The following goals are presented below which indicate the specific forms of data that will be collected to ascertain the significance of the exposure and the limits of the current means to prevent and control an explosion.

- Assess coal dust accumulations throughout the primary coal storage and distribution system.
- Analyze existing dust test reports that have determined the explosivity, auto-ignition temperature, and minimum concentration required for an explosion.
- Analyze coal handling equipment design to identify sources of dust release and potential ignition sources.
- Compare company equipment and handling and clean-up practices against industry best practices and government-based regulations.
- Analyze the current methods and equipment used to mitigate a coal dust explosion.

Background and Significance

While coal is in its lump form, this fuel source requires time and extreme heat to combust. Crushed coal, on the other hand is highly combustible and presents an explosion hazard when such is either handled improperly or allowed accumulate on horizontal surfaces. The risk associated with a coal dust explosion includes the loss of the coal handling and power generation plant which would potentially require a replacement cost of $42.5 million for an entire power generation plant. An explosion within the coal handling area and the steam generation plant also presents the risk of loss of life, which OSHA estimates the direct and indirect costs to equate to $8.7 million per fatality. Without power plant-generated steam, the paper machines are inoperable resulting in the loss of business continuity which is an estimated profit of $432,000 per day. These paper machines would remain inoperable until a series of rental boilers could be ordered and made operational. This paper mill currently requires an around-the-clock position to prevent an explosion by controlling the coal dust resulting in a cost of $24.52 per hour or $215,000 per year in wages. Each of these employees are required to remove the accumulated coal dust and are routinely exposed to potential inhalation of the associated particulates and thus are at risk of developing black lung.

Assumption of the Study

This study will be performed under the assumption that the coal dust release varies depending on the source of coal, the season it is transported to the site, and the amount of water which is applied during the pre-transport phase in order to minimize dust aerosolization during rail transport. This study was performed during the winter and spring which assumedly results in less dust being released than during the late summer and fall due to the moisture content of the coal. The moisture content of the coal is dictated by the delicate balance of controlling coal dust and maintaining a coal product that remains readily combustible when it reaches the boilers.

Limitations of the Study

This study will be limited to the Packaging Company XYZ's Mill coal handling and steam generation process. This study will utilize data obtained by the mill and records generated for mill use. Confidential business information may limit the detail of some information used in the study.

Definition of Terms

Bituminous Coal. A relatively soft coal containing a tarlike substance called bitumen.

Black Lung. "Coal worker's pneumoconiosis is a lung disease that results from breathing in dust from coal, graphite, or man-made carbon over a long period of time." (Dugdale III, Hadjiliadis, & Zieve, 2011para. 1).

Deflagration. "Rapid heat generation and oxidation of the fine particulate creates a flame front. If that flame front moves at less than the speed of sound it generally is considered to be a deflagration." (Maxwell, 2009 para. 9)

FM. FM Global is a worldwide insurance company that provides commercial and industrial property insurance which create datasheets, best practices, and approves equipment.

NEP. National Emphasis Program for OSHA.

Phlegamatization. A term used when an explosive has an agent added to it that stabilizes it.

OSHA. Occupational Health and Safety Administration.

Chapter II: Literature Review

The purpose of this study was to determine and document the magnitude of the coal dust accumulation, determine the risk associated with coal dust accumulation, determine and identify control measures to minimize dust release, and develop methods to mitigate the severity or prevent a significant coal dust explosion at Company XYZ's paper mill. This chapter will begin with a history of dust explosions with a focus on three recent catastrophic dust events. The chapter will then move towards the elements required to exist for a dust explosion potential, how to measure dust explosiveness and dust explosion theory. This will conclude with accumulation control as well as ignition source control and approaches to minimize the damage resulting from a dust explosion.

History of Dust Explosions

The analysis of combustible dust explosions which have occurred in recent years can shed some light on the magnitude of this problem. In February, 1999, a foundry in Massachusetts experienced a dust explosion that killed three employees and injured nine more (OSHA, 1999). As a result of this explosion, the foundry was cited for 40 health and safety violations and agreed to pay $148,500 in penalties. It should be noted, however, that only two of these violations were directly related to the explosion (O'Brien, 1999). According to OSHA, a small deflagration occurred within the ductwork which dislodged settled dust. This dislodged dust then became fuel for a secondary explosion. A joint investigation that was conducted with state and local officials discovered inadequacies of housekeeping, ventilations system design, the maintenance of ovens, and other equipment safety devices.

A notable fatal dust explosion occurred in January of 2003 at a North Carolina pharmaceutical plant that manufactured rubber drug-delivery components (Occupational Safety and Health Administration, 2005). After the CSB concluded its full investigation, the event that dispersed the dust and the ignition source remained undetermined due to the extent of the damage. The CSB did determine that the plant did not perform an adequate engineering assessment on the use of powdered materials, the engineering management systems did not ensure that relevant industrial fire safety standards were consulted, the material safety data sheets did not identify combustible dust hazards, and the plant hazard communication program did not identify combustible dust hazards or make the workforce aware of the hazard (U.S. Chemical Safety Board, 2006).

One of the most devastating industrial dust explosions occurred at a sugar refinery in Georgia. This explosion killed 14 people, injured many more, and resulted in increased regulatory focus from OSHA (Occupational Health and Safety Administration, 2009). The explosion likely began inside of a sugar conveyor that was recently enclosed, creating a confined, unventilated space where the dust was allowed to accumulate. The CSB believes that the ignition source of this explosion was an overheated bearing which led to the primary explosion within the confined conveyor area. This primary explosion promulgated the dust in the surrounding area and created the dust suspension that is required for a continuing explosion. The CSB identified several causes including that the conveying equipment was not designed or maintained to minimize the release of sugar dust, inadequate housekeeping practices allowed the escaped dust to accumulate, and that the refinery's emergency evacuation plans were inadequate. As a result of this incident, the CSB recommended that OSHA formalize regulations to address combustible dust hazards in the workplace (U.S. Chemical Safety Board, 2009).

In 2006, the Chemical Safety Board (CSB) performed a comprehensive study on the history of dust fires and explosions in the United States. The CSB performed this study after investigations of three fatal explosions in 2003, including explosions of aluminum dust, fiberglass resin dust, and fine plastic powder. This study identified the occurrence of 281 combustible dust fires and explosions between 1980 and 2005 that killed 119 workers and injured 718 (U.S. CSB, 2006). This study concluded that American industry and regulatory bodies are inadequately addressing the explosion based risks that accumulated dust presents (U.S. CSB, 2006). Shortly after the conclusion of this study, the CSB recommended that OSHA develop a comprehensive regulatory standard for combustible dust. As a response to the CSB recommendation, OSHA released a National Emphasis Program on combustible dust in October of 2007 and amended the program shortly after an explosion at a Georgia sugar factory in 2008 (OSHA, 2008).

The Dust Pentagon

It is conceivable that the accumulation of combustible dust would be a serious concern for American business owners, and many types of materials which are used, generated, transported or stored throughout various industries would fit within this type of fire hazard. According to the CSB, many solid organic, metal, and some nonmetallic inorganic materials will burn or explode if such are finely divided and dispersed in sufficient concentrations (U.S. CSB, 2006). However, combustible dust is not the only entity which is required for a dust explosion to occur. According to OSHA and the dust fire and explosion pentagon, five elements are necessary for a combustible dust explosion. The elements required include the combustible dust (fuel), an ignition source, oxygen in the air, dispersion of dust particles in sufficient quantity and concentration, and confinement of the dust cloud. Types of ignition sources include sparks from hot work, arcing from electrical equipment, and hot surfaces which may exist on mechanical equipment. Accumulated dust does not present an explosion hazard until it is dispersed into the air. When this dust is dispersed into the air at sufficient quantities, it presents as dangerous of a situation as an explosive concentration of petroleum vapors (CSB, 2006). This explosive concentration is defined as the minimum explosive concentration (MEC) and corresponds to the smallest concentration of airborne dust that produces a pressure at least twice as large as the initial pressure at ignition (Zalosh, 2011). This value is determined in the U.S. per the American Society for Testing and Materials (ASTM) per the test procedure with dusts in various concentrations and a pyrotechnic igniter in a 20-liter sphere (Zalosh, 2011). Without an enclosure, the rapid combustion process would be described as a fireball or a flame front although, the confinement required for a dust explosion is usually a process equipment enclosure. At times, a process equipment enclosure serves as the confinement for the primary explosion, which then propagates surrounding dust into the surrounding environment/building and serves to promote the occurrence of the secondary explosion. As presented in Table 1, the ASTM is developing a standardized test to determine the limiting oxygen concentration or the minimum amount of oxygen required to propagate an explosion through a dust cloud. This information will be useful for determining the amount of inert gases required to prevent an explosion.

Measuring Dust Explosiveness

The combustibility of dust particles depends on a number of factors including the type of material as well as its moisture content and particle size. According to the NFPA, combustible dust is any finely divided solid material that is 420 microns or smaller in diameter and presents a fire or explosion hazard when such is dispersed and ignited in air (NFPA, 2013). The CSB believes that the ease of ignition and severity of combustion is influenced by particle size due to the smaller particle sizes having greater surface area when compared to their weight (CSB, 2006). While the size of the particle is relatively easy to understand, there are many factors that are not easily measured. The American Society of Testing and Materials (ASTM) recognized this challenge and developed standard tests that can be used to compare the properties of dust-based materials. The dust properties that have standardized tests include the dust deflagration index (K_{st}), maximum explosion overpressure generated (P_{max}), the maximum rate of pressure rise (dp/dt_{max}), the minimum ignition energy (MIE) and the minimum explosible concentration (MEC), which are listed in Table 1.

Table 1

Measured properties of combustible dusts.

Property	Definition	ASTM Test Method	Application
K_{st}	Dust Deflagration Index	ATSM E 1226	Measures the relative explosion severity compared to other dusts.
P_{max}	Maximum explosion overpressure generated in the test chamber	ASTM E 1226	Used to design enclosures and predict the severity of the consequence.
$(dp/dt)_{max}$	Maximum rate of pressure rise	ASTM E 1226	Predicts the violence of the explosion. Used to calculate $K_{st.}$
MIE	Minimum ignition energy	ASTM E 2019	Predicts the ease and likelihood of ignition of a dispersed dust cloud.
MEC	Minimum explosible concentration	ASTM E 1515	Measures the minimum amount of dust, dispersed in air, required to spread an explosion. Analogous to the lower explosive limit for air/gas mixtures.

Property	Definition	ASTM Test Method	Application
LOC	Limiting oxygen concentration	ASTM standard under development	Determines the least amount of oxygen required for explosion propagation through the dust cloud.
ECT	Electrostatic charging tendency	No ASTM standards	Predicts the likelihood of the material to develop and discharge sufficient static electricity to ignite a dispersed dust cloud.

(CSB, 2012)

The ASTM is developing a standard test to determine the limiting oxygen content (LOC) which is the least amount of oxygen required for explosion propagation through the dust cloud. OSHA has created a classification system for combustible dusts based on the information ascertained in the by the ASTM K_{st} value. This classification system is based entirely on the relative explosivity of the dust and separates the dust into four classes. The first class (St 0) is not explosive and has a K_{st} rating of 0 bar m/s. An example of this form of dust would be silica. The second class (St 1) is explosive and will cause a weak explosion according to the K_{st} value which is less than 200 bar m/s. Examples of this form of dust include powdered milk, charcoal, sulfur, sugar and zinc. The third dust explosion class is (St 2), which has a K_{st} value between 200 and 300 bar m/s and will cause a strong explosion. Examples listed in Class St 2 include cellulose, wood flour, and poly methyl acrylate. The most explosive dust class is St 3, which has a K_{st} greater than 300 bar m/s. Examples within this dust class include aluminum and magnesium. The previously described classification system can be found in Table 2. It should be noted that coal dust is classified as St 2 whether it is either bituminous or subbituminous, with K_{st} values ranging from 80 to 200 bar m/s (Rahm and Merritt, 2000). Another characteristic of dust that is crucial for determining the potential for an explosion is the minimum explosible concentration (MEC). The MEC of dust is the measurement of the concentration of dust dispersed in the air that is required to foster an explosion. According to OSHA the MEC of dust is analogous to the lower explosive limit used to determine the level of explosive vapors or gases in air required to spread an explosion (OSHA, 2009).

Table 2

Examples of K_{st} Values for Different Types of Dusts

Dust explosion class	K_{st} (bar.m/s)	Characteristic	Typical Material
St 0	0	No Explosion	Silica
St 1	>0 and ≤ 200	Weak Explosion	Powdered Milk, charcoal, sulfur, sugar, zinc, coal
St 2	>200 and ≤ 300	Strong Explosion	Cellulose, wood flour, and poly methyl acrylate
St 3	>300	Very Strong Explosion	Anthraquinone, aluminum, and magnesium

(OSHA, 2009)

Dust Explosion Theory

Dust explosions are classified along a timeline as being either a primary or secondary event. After investigations of several dust explosions, the CSB released a document that described how secondary dust explosions, due to inadequate housekeeping and excessive dust accumulations, caused much of the damage and casualties in recent catastrophic incidents. It is common that an initial explosion which may or may not be a dust explosion takes place on a smaller scale and consequently creates a shockwave that disturbs accumulated dust on floors or overhead surfaces. This dispersed dust is the fuel for the secondary and latter explosions which are responsible for a majority of the damage. According to an OSHA Safety and Health Bulletin

(2005), employers need to focus on removing three of the five elements of the dust explosion pentagon, which includes the dust, the ignition source, and dispersion of the dust cloud.

Dust Accumulation Limits

Controlling the accumulation of dust is critical in order to avoid a combustible dust explosion. It is estimated by the NFPA that more than 1/32 of an inch of dust over 5 percent of a room's surface area is enough to present a significant explosion hazard. According to the U.S. Chemical Safety Board (2006), the accumulations at the North Carolina pharmaceutical plant in 2003 were generally less than 0.25 inches deep, although this was enough dust to create an explosion that left six employees dead. NFPA 654 and FM Global both have released information that may be used a guide to limit dust release and accumulation. Factory Mutual (FM) recommends that accumulations of combustible dust do not exceed 1/16 of an inch over more that 5% of the room floor area and the surface area of the building does not exceed 1,000 ft^2 (FM Global, 2012).

Dust Accumulation Control

The recommendations for dust accumulation control can be separated into two groups which include housekeeping practices and point source control. Several key concepts to consider regarding housekeeping practices include providing access to all hidden areas to permit inspection and cleaning, using cleaning methods that do not generate dust clouds, and developing and implementing a hazardous dust inspection, testing, housekeeping, and control program. OSHA's datasheet 7-76 titled, "Prevention and Mitigation of Combustible Dust Explosions and Fires" also provides recommendations for housekeeping and dust accumulation control. The FM data sheet specifies that the fugitive-dust-control program requires recordkeeping of housekeeping activities, a periodic review of the maintenance schedule, and a focus to eliminate accumulations above the floor level. FM suggests that combustible dust accumulations of 1/16" requires clean up and uses the analogy of about the thickness of a quarter. The FM data sheet and OSHA Outreach Training suggest vacuuming whenever possible with equipment rated for dust control, and where such is impractical, to utilize sweeping or water wash-down methods. The datasheet describes compressed air cleaning as being acceptable, but only in areas where any electrical equipment that is not properly rated for the hazardous environment can be shut down before the dust removal process is initiated (Downs, 2009). The NFPA suggests that if compressed air or steam is to be used for housekeeping, such shall be performed only after vacuuming has been performed and the dust accumulation is under the threshold limit determined by the facility (NFPA, 2013).

The FM Datasheet 7-76 contains descriptive practices for controlling dust releases from process equipment. The practices described in the datasheet include applying a liquid suppressant at a point in the process that involves substantial turbulence of the product to ensure that the suppressant is thoroughly mixed in with the material stream. NFPA 654 titled, "Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids" suggest having continuous vacuum over areas that regularly produce dust (NFPA, 2013). FM also recommends that an interlocking device be used to shut the dust generating process down if the suppressant spray-system malfunctions (if such is being relied upon as the only means of dust control) and that a maintenance and inspection program exists to ensure that the equipment is performing as expected. Another option for hazard control is to inert the combustible dust by mixing it with a noncombustible dust or other substance (known as phlegmatization). FM recognizes this control and offers recommendations to ensure that the mixed substance is found to be noncombustible per the

ASTM E1515 and to ensure that there is not separation of the mixture in later parts of the handling process (FM Global, 2012)

Ignition Source Control

Another element which is required to create a combustible dust explosion is an ignition source. Ignition sources may include friction, static electricity, electrical arcs and high temperature objects. The National Electric Code has created a hazardous location coding system that divides hazardous environments into three categories. Class 1 locations include areas where the presence of gases or vapors in the air creates the potential for an explosive atmosphere. Class 2 locations are areas made hazardous by the presence of combustible dust which can cause powerful explosions. Class 3 locations are likely to contain easily-ignitable fibers or filings and while these materials may not create an explosion risk, they do create a fire hazard (OSHA Office of Training and Education, 1996). Electrical equipment is not only classified by what type of hazard is present, but also how often the situation exists. The condition is classified differently if the hazard is normal or abnormally present. If the hazard is always present, then the condition is considered normal, whereas if the hazard is infrequent or will be present through accidental failure or unusual operation, the situation would be considered being abnormal. These conditions are classified as either normal – Division 1, or abnormal – Division 2 (OSHA Office of Training and Education, 1996). FM Global recommends that all electrical equipment involved in areas where combustible dust is present should meet the Class II, Division 1 or 2 requirements (FM Global, 2012).

Electrical equipment is not the only potential ignition source that can initiate an explosion, since other sources of ignition may include hot work, smoking, open flames, and static electricity (FM Global, 2012). OSHA defines hot work as riveting, welding, flame cutting or other fire or spark-producing operations while FM Global defines hot work as any temporary or permanent operation involving open flames or producing heat and/or sparks. An effective hot work program requires that the facility has control of every job involving hot work. Effective hot work process/activity control includes defining the expectations, training/communicating, permitting, timely hot work checks, and continuous auditing of the management system (FM Global, 2006). The permitting process allows the owners and operators of the building to place control over when and where hot work is performed at the facility. A proper permitting process also creates a system of accountability for employees, contractors, and operators and requires that routine follow up occurs three hours after the hot work is complete to ensure that the area is free of fire or smoldering materials (Liberty Mutual Insurance, 2004).

All moving equipment involved in a dust-producing environment has the potential to create an ignition source due to the presence of friction. FM Global identifies specific equipment that is considered hazardous to include dust collectors, cyclones, and bucket elevators. Dust collectors are imperative to control the release and accumulation of the dust but can also pose a hazard if such are not operated properly. FM recommends that an organization inspect and maintain the bags inside of dust collectors and also ensure that the straps which are used to ground various components within the collector are well secured to the structure to minimize the generation of static electricity. According to FM's loss history, dust collectors accounted for 66 of the 166 losses with regard to the type of equipment which is lost (FM Global, 2012). Bucket elevators consist of various moving mechanical parts, product transfer areas, and an enclosure, which makes this equipment a candidate for a dust explosion event. To minimize the potential for a bucket elevator to create the ignition source and thus cause the primary explosion, FM Global has identified specific recommendations. The first recommendation is to ensure that belt-driven elevators are provided with a device that will cut the power to the drive system if the belt slows down more than 20% (possibly due to plugged unit or else another form of equipment malfunction). Other recommendations include locating bearings outside of the elevator casing, installing devices of equipment to shut down the elevator if the belt misaligns, and limiting the use of combustible linings to only areas that require such.

Explosion Minimization

While preventing dust explosions is the overall goal, safeguards can be installed to minimize the loss or damage in the event of such a catastrophic event. Isolating equipment can be used to separate dust producing equipment to limit the explosion to one piece of equipment or a portion of the facility (FM Global, 2012). Types of isolating equipment include rotary air locks, chokes, rapid action valves, and high speed abort gates. Rotary air locks and chokes prevent the propagation of the explosion by separating or choking the equipment with a structure, paddle, or the product itself to stop the travel of the flame front (FM Global, 2012). Rapid action valves and high speed abort gates are actuated by the presence of either a pressure change or through infrared explosion detection within the vessel upstream. When these devices close, they essentially stop the travel of the flame front and therefore prevent the propagation of the explosion (FM Global, 2012).

If a dust-based explosion occurs, the damage and loss can also be limited by the proper installation of explosion relief (blast) doors and flame front diverters. Generic recommendations for proper installation of explosion venting are well documented in FM data sheet 7-76. Recommendations included within this datasheet include not using explosion vents through the roof, utilization of a device to maintain the vents in the open position if an event occurs, providing tethering cables to limit movement, and also not to attach a fire suppression system to the vent or a rupture plate which are used for over pressurization release purposes (FM Global, 2012). Specific recommendations and calculations for explosion relief venting can be determined by using FM Globals DustCalc software. Determining appropriate relief venting can be difficult through the use of calculations due to the number of variables involved, and therefore the readily available DustCalc software is a proprietary system that utilizes information ascertained by FM Global after years of research (FM Global, 2012). DustCalc takes into consideration variables that include vessel volume (V), dust explosibility (K_{st}), maximum unvented pressure (P_{max}), explosion-vent area (A_v), explosion-vent relief pressure (P_{stat}), explosion-vent panel mass and orientation, explosion-vent duct length (L_d), and area (A_d), the fraction of the vessel volume containing an explosive mixture, and a pre-explosion equipment pressure (P_o) to determine appropriate venting requirements (FM Global, 2012). A flame front diverter is defined by the Center for Chemical Process Safety as a device that opens in response to the pressure wave preceding the flame front of the deflagration, therefore venting out the flame front and pressure. The FM datasheet on the prevention and mitigation of combustible dust explosion and fire includes recommendations for flame front diverters whether such are constructed in-house or are purchased from another company (FM Global, 2012). This datasheet describes that flame front diverters are not to be used upstream of an air-moving fan because an explosion originating upstream of the diverter will propagate past the diverter, or when air streams have significant loading of abrasive dust that would erode the pressure relieving diverter cover, or work environments contain mixtures of flammable vapors or gases that exceed the substance's lower explosive limit (FM Global, 2012).

Summary

Throughout this chapter, a case history of dust explosions was discussed, the elements necessary for a dust explosion were explored, the theory of dust explosions was described, the accumulation required for an explosion was explained, and best practices for housekeeping and equipment installation and inspection were taken into consideration. For any organization that utilizes a material similar to bituminous coal, one could conclude that the associated dust from such a product would first need to be tested to determine the K_{st}, the MIE, and MEC to estimate its potential explosibility. The size of the dust particles and the airborne concentrations which are normally present would also need to be documented and compared against the OSHA permissible exposure limits. The organization's coal handling system would need to be assessed from the point at which the material arrives on site to when it is ultimately fed into the boiler. The organization's building framework would need to be evaluated to determine the percentage of flat overhead horizontal surfaces that exist, as such may develop moderate dust accumulations. It is recommended that the organization assess the total accumulation on a number of flat horizontal surfaces over a period of time and document the results. Sites selected for the accumulation study are to remain undisturbed throughout the study in order to document the total dust accumulated over the respective period of time.

From a dust accumulation control standpoint, the organization will also need to focus on the current release of coal dust as well as the existing housekeeping practices and then compare such against the recommendations previously identified. Each transport section of the system would need to be assessed to determine the amount of dust which is released at every transition. It must be determined if systems are in place to control the dust release at these areas, and then ascertain if these systems have the recommended sensors and interlocks to notify personnel or stop the transfer of the product if a malfunction occurs. Within an organization that has effective point source control, the potential for dust accumulation still exists and therefore housekeeping practices must be established, effective, and documented. Housekeeping practices must be evaluated for effectiveness and compared against the recommendations which have been established by FM Global, the NFPA, and OSHA. Housekeeping equipment can also present a risk if such is used or installed improperly. A comprehensive study would assist to determine whether or not the housekeeping system is properly bonded and grounded to prevent the occurrence of static electricity and the effectiveness the personnel-based training.

A study of the electrical equipment along the dust producing process must take place in order to determine the classification of the equipment and ensure that an electrical arc will not be present and thus serve as the ignition source of an explosion. It is also imperative to identify all moving mechanical parts and investigate the maintenance history of the equipment and the state of any interlocking devices that exist. The maintenance and inspection history of this mechanical equipment should also be used to determine whether or not such is regularly inspected and lubricated. Examples of mechanical equipment to be assessed include conveyors, the bucket elevator, the dust collection devices and any other mechanisms associated with the transportation or collection of the dust producing material.

An organization's study should conclude with an assessment of the explosion minimization equipment and techniques implemented within the company. Blast doors, flame front diverters, or isolation equipment which are utilized must be compared to the FM recommendations in order to determine adequacy of the equipment. While an organization may not be able to completely eliminate the hazard of combustible dust, an understanding of how and why dust explosions take place which are coupled with sound recommendations for dust accumulation control as well as equipment utilized for limiting loss will ultimately reduce the severity and the probability that a dust-based explosion will occur.

Chapter III: Methodology

The purpose of this study was to determine and document the magnitude of the coal dust accumulation, determine the risk associated with coal dust accumulation, determine and identify control measures to minimize dust release, and develop methods to mitigate the severity or prevent a significant coal dust explosion at Company XYZ's paper mill.

This study detailed several goals which are presented below. These goals allowed the study to focus on specific forms of data that will be collected to ascertain the significance of the exposure and the limits of the current means to prevent and control a dust-based explosion.

- Assess coal dust accumulations throughout the primary coal storage and distribution system.
- Analyze existing dust test reports that have determined the explosivity, auto-ignition temperature, and minimum concentration required for an explosion.
- Analyze coal handling equipment design to identify sources of dust release and potential ignition sources.
- Compare company equipment and handling and clean-up practices against industry best practices and government-based regulations.
- Analyze the current methods and equipment used to mitigate a coal dust explosion.

Instrumentation

In order to effectively assess the equipment and practices used at Company XYZ's paper mill, various forms were developed. These forms were created to compare the existing processes and equipment against a summary of the best practices and recommendations previously gathered from OSHA, NFPA 654 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solid, and FM Global

Data Sheet 7-76 Prevention and Mitigation of Combustible Dust Explosion and Fire. In order to organize information, the tables have been separated by either equipment type or the performed practice. Instrumentation utilized to determine the severity of the coal dust accumulation and comparison to plant equipment to identified best practices can be found as Appendices A-F.

Data Collection Procedures

In order to determine the extent of the coal dust accumulation throughout the coal handling system, several control areas were selected for dust accumulation sampling. Sampling was performed by visual inspection of the area to determine the amount of accumulation present. These sample areas included the tail pulley of the conveyor gallery near the magnetic separator, near the coal crusher and diverter, and next to the head pulley of the coal bucket elevator. These sample points were selected due to the potential to create or release coal dust in these areas because of the material transfer points. Over the course of a week these areas were observed a total of three times each at different times and notable findings and accumulations were documented. The accumulation totals were then referenced against Table 3 below in order to determine the NFPA electrical classification and housekeeping guidance recommendations.

Table 3

Guidance for Area Electrical Qualification and Housekeeping Recommendations (NFPA, 2013)

Depth of Dust Accumulation (in.)	Frequency	Housekeeping Requirements	Area Electrical Classification
Negligible	N/A	N/A	Unclassified (General Purpose)
Negligble to <1/32	Infrequent	Clean up during same shift	Unclassified (General Purpose)
Negligble to <1/32	Continuous/frequent	Clean as necessary to maintain an average accumulation below 1/64 in	Unclassified; however, electrical enclosures should be dust tight
1/32 to 1/8	Infrequent	Clean up during same shift	Unclassified; however, electrical enclosures should be dust tight
1/32 to 1/8	Continuous/frequent	Clean as necessary to maintain an average accumulation below 1/16 in	Class II, Division 2
>1/8	Infrequent	Immediately shut down and clean	Class II, Division 2
>1/8	Continuous/frequent	Clean at frequency appropriate to minimize accumulation	Class II, Division 1

Two samples of the coal dust existing at the facility were collected from a horizontal surface in the crushed coal bunker and subsequently analyzed by two separate laboratories in August of 2011 and July of 2012. A first coal dust sample was collected by FM Global, who then provided Company XYZ with an analysis report which included the explosibility (Kst), the median particle size, bulk density, moisture content, combustion time and the dust explosion classification. The second sample of coal dust was analyzed by Fauske and Associates to determine characteristics that FM did not. Fauske and Associates analyzed the coal dust using ASTM testing methods to determine the minimal explosive concentration (ASTM E 1515), the dust deflagration index (ASTM E 1226), and the minimum ignition energy (ASTM E 2019). It should be noted that both of these samples were collected from a horizontal surface in the boiler #8 coal bunker, which is a point after the finely crushed coal has passed through the crusher.

The equipment associated within the coal processing areas of the facility was assessed to determine compliance with NFPA, FM Global, and OSHA regulations and recommendations. This assessment began by determining the level of isolation of the buildings where coal dust is released from the rest of the facility by the use of fire rated walls and doors as well as fire resistance in penetrations of the floors and walls of the coal handling area. The assessment then proceeded into the dust collection systems that serve the entire coal handling process from unloading to the bunkers. The fire protection and notification system that provides fire suppression and detection for this area was evaluated for effectiveness and compliance with the governing standards. Another key portion of the evaluation is the determination if the potential ignition sources within the coal handling system meet the NFPA recommendations. Identifying and documenting equipment associated with dust source control was performed and the effectiveness of the equipment was investigated and compared against best practices used in the coal handling industry. An assessment was also performed to determine that if the systems designed to minimize the damage created in the event of a dust-based explosion are installed and met the recommendations established by the NFPA and FM Global.

The final portion of this study was intended to determine the effectiveness of the housekeeping practices and equipment used for controlling the release of the dust and create recommendations for improvement if necessary. This investigation will include a review of the procedures and operating instructions for the shower system used in the coal unloading area. The inspection, schedule and expectations related to the housekeeping program currently utilized to minimize the accumulated dust within the area were evaluated.

Data Analysis

Once the information collected on the various form of data identified in the Instrumentation section of this chapter is complete, it will be further analyzed. The tables listed in the appendix were used for quick reference, the information gathered will be compared in detail to the applicable OSHA Standard, FM Global Datasheet 7-76, or the NFPA Code 654. Other information that was used in the analysis includes information from manufacturers, work order history, and other maintenance records. Once each piece of equipment was identified and applicable information is gathered, a list of these regulations and recommendations will be created and tables were used in order to describe whether or not Company XYZ compliant with these standards. The tables used to describe this potential performance gap will be presented in the following chapter. If a performance gap does exist, the tables were also used to portray where the gap exists and its significance. The significance of an identified performance gap depends on the severity and frequency of each issue and was used in order to prioritize recommendations. The severity of each identified performance gap was classified into a three tier system with the most significant performance gaps receiving a priority rating of 1 and the least significant performance gaps received a priority rating of 3. It is recommended that any performance gap that receives a priority rating of 1 is immediately addressed. An identified performance gap with a priority rating of 2 is heavily recommended to complete, and any identified performance gap with a priority rating of 3 would not be viewed as an immediate priority to rectify.

Chapter IV: Results

The purpose of this study was to determine and document the magnitude of the coal dust accumulation, ascertain the risk associated with coal dust build-up, identify control measures to minimize dust release, and develop methods to mitigate the severity or prevent a significant coal dust explosion at the mill. In order to accomplish these objectives existing test results for explosibility testing were initially referenced in order to determine if various regulatory and best practice-based recommendations were applicable. Forms were also created that include brief descriptions of either the applicable best practice or recommendations from OSHA, NFPA, or FM Global. These forms were used as the building, equipment, and housekeeping was assessed.

Presentation of Collected Data

The first objective of this study was to assess the coal dust accumulations throughout the primary coal storage and distribution system. This assessment was performed over the course of one entire work week. The coal handling personnel operate the coal transfer system for approximately eight hours per day, from 4 am- to 11 am. Enough coal is unloaded during this eight hour shift to fill all three fuel storage bunkers for the day's operation. The areas where housekeeping and dust accumulations were assessed include the tail pulley of the conveyor gallery near the magnetic separator, near the coal crusher and diverter, and next to the head pulley of the coal bucket elevator. Table 5 below was used and eventually completed to create an objective description for the associated dust observations.

Table 4

List of Descriptions Used and Classification Requirements for Dust Accumulation

Description Used	**Objective Definition**
No Dust	Surfaces are entirely exposed
Negligable	Equipment color can be seen under thin layer of dust
Noticeable	Equipment color is not visible through the dust, but the accumulation cannot be measured.
Dust Covered	Less than 1/16 of an inch
Unacceptable	Greater than 1/16 of an inch

The assessment of the coal dust accumulations took place three times over the course of an entire work week. The most notable accumulation was the area near the magnetic separator in the basement of the coal thaw building. It was discovered later that this area does not have a clearly defined housekeeping responsibilities as well as the lack of a connection for a central vacuum system used for housekeeping. After an unacceptable condition was noted upon the initial inspection the personnel in the area addressed the accumulation. The areas near the bucket elevator and around the crusher that were assessed were well maintained and minimal coal dust accumulations were immediately addressed before such presented an explosion hazard.

Table 5

Results from Accumulation Assessments

Area Assessed	Dust Accumulation Thickness Description	Time	Date	Comments
Seperator	Unacceptable	4:40pm	4/8/13	No manual or automatic dust collection system
Elevator	Negligible	4:30pm	4/8/13	None

Area Assessed	Dust Accumulation Thickness Description	Time	Date	Comments
Crusher	Noticeable	4:35pm	4/8/13	None
Seperator	Dust Covered	10:15am	4/10/13	Was cleaned after last inspection
Elevator	Noticeable	10:00am	4/10/13	None
Crusher	Noticeable	10:05am	4/10/13	None
Separator	Negligible	1:00pm	4/12/13	Cleaned recently
Elevator	Noticeable	12:50pm	4/12/13	None
Crusher	Dust Covered	12:55pm	4/12/13	None

Note: Accumulations of greater than 1/16th of an inch (i.e., regarded as unacceptable) require immediate attention.

The accumulations of coal dust documented through this portion of the study were expected. As indicated in Table 6, one concerning discovery is the amount of dust which was allowed to accumulate near the magnetic separator in the thaw shed basement. The housekeeping in this area is both the responsibility of the Coal Dumper position which is expected to be performed every day near the end of the shift, and the Cleaner position which is expected to vacuum this area each day on second shift. The Power Department management has created a housekeeping responsibility policy which holds the Cleaners responsible for one-quarter of the power area for the duration of the calendar year. At the end of each year, the areas of responsibility rotate and the employees are then responsible for cleaning a different area within the department. A positive finding within the housekeeping responsibility policy is that if there is ever a significant release of coal or dust, the Cleaner currently on shift is responsible for cleaning it as soon as possible regardless if the release occurred in his/her scheduled area.

The second objective of this study was to analyze existing dust test reports which previously determined the explosivity, auto-ignition temperature, minimum concentration required for an explosion, particle size, as well as other characteristics of both the dust and explosion created by the dust. Two analyses were recently performed by OSHA and Fauske and Associates and the results of such are presented below in Tables 7 and 8. The sample collected and used for these analyses were collected in the coal bunker area and present the finest coal dust in the facility.

Table 6

Dust Analysis Results from FM Global, September 2011

Characteristic	Dust Deflagration Index K_{st}	Max. Explosion Pressure P_{max}	Optimum Explosive Concentration	Duration Of Event	Moisture Content	Bulk Density
Results	196 mbar/s	8.2 bar	95 g/m^3	25 ms	3.9%	31.2 lb/ft^3

Table 7

Dust Analysis Results from Fauske and Associates, July 2012

Characteristic	Minimum Explosive Concentration MEC	Minimum Ignition Energy MIE	Minimum Autoignition Temperature MIT	Mean Particle Size	Moisture Content
Results	59 g/m^3	170 mJ	590^o C	23 um	2.5%

The tables above are a summary of the results of two analyses performed by FM Global and Fauske and Associates in order to determine the explosibility characteristics of the dust collected in the coal bunker area. It is important to note that the moisture content of the coal dust varied between the two samples and this likely affected the results of the analysis. According to the FM Global report, the K_{st} for the dust from Company XYZ's coal bunker was found to be

196 mbar/s, while most coal dust that FM tests has a dust deflagration index between 80-120 mbar/s (FM Global, 2011). This result indicates that the dust tested is considered St1 or a dust that will cause a weak explosion, because the K_{st} is less than 200 mbar/s. Dust with a K_{st} value greater than 200 mbar/s is classified by OSHA as a dust in the St2 class, which is more likely to produce a strong explosion. Additional key characteristic to consider include the minimum explosive concentration (MEC) and the optimum explosive concentration. The MEC is important to understand due to the fact that one could physically measure the accumulated dust in a specific area and determine if an explosion hazard is present. The MEC is likely to contribute to the primary explosion as discussed earlier, while the optimum explosive concentration may contribute to the occurrence of a secondary explosion.

The third objective of this study was to analyze the coal handling equipment's design to identify sources of dust release and potential ignition sources. This included an assessment of the coal moving entity, the dust collecting system, and the electrical equipment. Tables that were described in the methodology section were used and the results from these assessments are found below.

Table 8

Results of Comparing Bucket Elevator Recommendations to Existing Equipment

Recommendations	Existing	Comments
Bucket elevator construction must be in accordance with one of the following (FM 7-76 2.7.1.1)	The explosion doors found on the coal handling bucket elevator do have explosion doors, however these doors do not vent outside.	Explosion doors have been recently installed/replaced. The information and warnings is legible.
Locate the explosion vents no more than 20 ft apart along the height of the bucket elevator. (FM 7-76	The explosion vents found are located more than 20 vertical feet apart. The elevator is approximately	

Recommendations	Existing	Comments
2.7.2.1)	100 feet tall and 3 explosion vents were identified.	
Each explosion vent is to be sized at least as large as two thirds of the cross sectional area of the elevator enclosure. (FM 7-76 2.7.2.1)	Explosion vents are undersized	Cross sectional area is approximately 9 ft^2
Vent the head section of the bucket elevator leg based on a ratio of 1 ft^2 of venting for every 20 ft^3 of head section volume. (FM 7-76 2.7.2.1)	The existing vent at this location is 9"x15".	
Provide explosion venting for the up and downside leg casings (FM 7-76 2.7.2.1)	Explosion venting is found only on the ascending or full side of the elevator.	
Set the explosion vent relief pressure to less than 1 psi and construct vents of lightweight material (FM 7-76 2.7.2.1)	Existing vents meet this recommendation.	
Provide belt driven elevators with a mechanical or electromechanical device to cut power to the drive motor and sound an alarm if the belt slows down more than 20%. (FM 7-76 2.7.3.1 a and NFPA 654 7.10.4.1)	This interlock does not currently exist	
Do not locate or expose bearing within the elevator casing (FM 7-76 2.7.3.1 b and NFPA 654 7.10.6)	Bearings are outside of the elevator casing	
Provide belt-alignment interlocks to shut down the elevator if the belt misaligns (FM 7-76 2.7.3.1 c)	This interlock does not currently exist	
Use antifriction bearings on all elevator legs (FM 7-76 2.7.3.2 a)	Not applicable because the bearings are located outside of the elevator casing.	
Limit the use of combustible linings to impact points, wear surfaces and connected hoppers (FM 7-76	Elevator structure is steel with ceramic tile lined chute.	

Recommendations	Existing	Comments
2.7.3.2 b and NFPA 654 7.10.2)		
Install drive belts that are electrically conductive at 1 megaohm or less, as well as being fire and oil resistant (FM 7-76 2.7.3.2 c and NFPA 654 7.10.5.3)	Conductive belts have recently been installed.	
The drive shall be capable of starting the unchoked elevator under full load (NFPA 654 7.10.8.2)	No documentation indicates that the drive possess this capability.	
Elevators shall have monitors at head and tail pulleys that indicate high bearing temperature and alignment of the head pulley and belt (FM 7-76 2.7.3.2 and NFPA 654 7.10.9.1) Elevators traveling slower than 500 ft/min are excluded.	There are no monitors for bearing temperature and belt alignment.	
Explosion vents are located outside, tethered or not facing an area where they could strike an employee or essential equipment.	While venting is not directly outside, the vents are in areas where there is very little employee exposure.	

As indicated in Table 9 above, the bucket elevator found within the coal handling system at Company XYZ has several identified deficiencies. It is recommended that explosion vents have approximate square footage of 2/3 of the cross functional area and are located every twenty vertical feet. The bucket elevator observed did not meet these recommendations. This bucket elevator is 100 vertical feet in length with a cross sectional area of approximately 9 ft^2. Only three over pressurization vents that are approximately 3 ft^2 currently exist along this structure. The current interlocking deficiencies which exist include the lack of notification when the elevator has slowed down to 80% of its normal operating speed if either a belt misalignment occurs or if excess bearing temperature takes place.

The coal at this facility travels approximately 500 feet via a long conveyor that is enclosed by a structure. Conveying equipment poses risks associated with overheating of the bearings and pins as well as if a significant release of dust occurs in a contained area. Table 10 below was used in order to identify the potential risks and determine the significance of an issue identified.

Table 9

Results of Comparing Conveying Equipment Recommendations to Existing Equipment

Recommendations	Existing	Comments
Housing for enclosed conveyors shall be of metal construction and shall be designed as to prevent escape of combustible dusts. (NFPA 7.11.1.2)	Conveyors are not enclosed. Recommendation is not applicable.	The only enclosure that exists is large enough to include a walkway.
Coverings on cleanout, inspection, and other openings shall be fastened to prevent the escape of combustible dusts (NFPA 7.11.1.3)	Conveyors are not enclosed. Recommendation is not applicable.	Open conveyor system.
All conveyors shall be equipped with a device that shuts off the power to the drive motor and sounds an alarm in the event the conveyor plugs (NFPA 654 7.11.2.1)	High amperage of conveyor drives activate an alarm in the coal handling control room.	Documentation was not available for review.
The alarm shall sound at the operator control station, and feed to the conveyor shall be stopped or diverted. (NFPA 654 7.11.2.2)	High amperage alarm exists, interlocking and shutdown of equipment is not.	

The transfer conveyor within Company XYZ's coal handling facility is not considered an enclosed elevator as the structure housing the equipment is large enough to include a passageway, electrical raceway, fire protection system and lighting equipment. As indicated in Table 10 above, the transfer conveyor only presented one deficiency where the high amperage alarm does not automatically shut down the equipment and thus interrupt the transfer of material. If the high amperage alarm is received by the operators in the control room, the standard operating procedure is to remotely remove the power to the equipment and investigate the cause of the alarm.

According to FM Global, the majority of coal dust explosions and fires are either initiated in or completely destroy the coal dust collecting equipment. Table 11 below was used in order to compare the recommendations set forth by FM and the NFPA to prevent these types of losses versus the equipment which is found at this facility.

Table 10

Results of Comparing Dust Collecting Equipment Recommendations to Existing Equipment

Recommendations	Existing	Comments
Bag-type collectors do not need any type of special conductive bag material to dissipate static electricity charges, however if they are used an inspection program must be maintained (FM 7-76 2.4.3.1)	Bag type collectors are used, the bags are regularly replaced and inspected.	
Provide a reliable grounding connection for the bag cages (FM 7-76 3.1.23)	The cage grounding cable is in place and is inspected on a regular basis.	
For mediatype dust collectors, locate explosion vents entirely on the dirty side of the collector volume. (FM 7-76 2.4.2.2)	A bag style dust collectors is used, this recommendation is not applicable.	
Explosion vents are located outside, tethered or not facing an area where they could strike an employee or essential equipment.	Explosion vents are directed away from used walkways, however because the dust collectors are on the roof it is recommended that the explosion vent be tethered.	
Isolation devices shall be provided for air–material separators in	Rotary airlocks have only been provided on the baghouses where	

Recommendations	Existing	Comments
accordance with 7.1.6. (NFPA 654 7.13.1.4)	the dust exits the baghouse. Another level of isolation should be provided at the dust entry points into the baghouses.	

As indicated in Table 11 above, a noted deficiency found during the assessment of the dust collecting equipment was the lack of an isolation system, method or equipment on the intake side of the air material separators. In the event of an explosion within the dust collecting equipment, an isolation method would prevent the explosion from spreading through the existing ductwork.

Electrical equipment is necessary in all industrial environments, including areas where an explosive condition may exist. Electrical equipment used in areas with the potential for an explosive environment must be properly designed, manufactured, and installed in order to meet the recommendations provided by the NFPA.

Table 11

List of the electrical equipment with identified hazard classification and compliance with the NFPA recommendation.

Equipment Description	Equipment Classification	Does this meet requirements?	Comments
Lighting equipment in conveyor area	No Classification	No, this is a key isolation by location point and all ignition sources should be eliminated	Currently in the process of installing Class II, Division 2 Lights
Motors on crushing equipment	No Classification	No, equipment should be dust tight to prevent buildup inside equipment	Recommend dust tight enclosures
Lighting equipment in the coal bunker	Class 11 Division 1	Yes	
Lighting in the coal handling penthouse	No Classification	No, equipment should be dust tight to prevent buildup inside of lighting equipment	Recommend dust tight enclosures
Conveyor motors	No Classification	No, the conveyor motors are below the coal thaw shed which is routinely exposed to excess accumulations and airborne dust	Recommend Class II, Division 2 equipment

Equipment that can be considered an ignition source does not necessarily mandate a Class II classification and therefore, an understanding of the coal dust accumulation’s which are present within specific areas will determine whether or not the equipment must be rated such. Dust tight enclosures for operating equipment is recommended bear the crushing equipment and the coal handling penthouse, and should be rated as such by the National Electrical Manufacturers Association (NEMA). Enclosures that do not create heat or house moving parts such as electrical junction boxes may be sealed appropriately with a silicone caulk to prevent dust buildup from occurring within these devices.

Fire protection equipment consists of both fire suppression and fire detection devices. Table 13, found below provides the results of the facility fire protection equipment assessment as compared against applicable regulations or recommendations from FM Global and the NFPA.

Table 12

Results of an Assessment of Fire Suppression and Detection as Compared Against Applicable Regulation

Equipment Description	**Equipment Classification**	**Does this meet requirements?**
Fire system protecting coal thaw area, transfer conveyor, coal handling penthouse	Dry Pipe, 155 PSI of Water	Yes
No fire system in basement of coal thaw area	None	No
No fire system in the basement and lower level of crusher area	None	No
Sprinkler head located in the bucket elevator above head pulley.	165^{o}F Rated Sprinkler head	Yes
Manual fire suppression systems located in the thaw shed, the coal transfer conveyor area, third floor of the crusher house, and the coal	1 1/2” fire hose equipped with fog nozzles	Yes

Equipment Description	Equipment Classification	Does this meet requirements?
handling penthouse.		
Portable fire extinguishers located throughout building and coal handling areas.	10-A:60-B:C	Yes, minimum requirement is 4-A.
Fire Detection Systems		
Carbon monoxide (CO) detectors located in the coal handling control room, third level of the crusher house, above each of the coal silos.	Early fire detection system	Yes
Other Fire System Equipment / Operation Issues		
Fire detection and the automatic or manual fire suppression is interlocked with the coal feed system and will deactivate the entire feed system upon actuation.	Fire damage limiting operation	Yes

The fire system that protects the coal handling operations at Company XYZ is a dry piped fire system. When a dry system actuates the air under pressure within the system needs to evacuate through the sprinkler or hose opening until the pressure reaches a point in which the water pressure overtakes the air which is bleeding pressure. This system is commonly used in areas where the fire protection lines are subject to freezing temperatures. This fire system protects the majority of the coal handling process with only the coal thaw basement and the lowest two levels of the crusher house being left unprotected. The two areas unprotected by automatic sprinkler systems do not meet FM Global recommendations to include such protection in all areas of fuel unload, transport and storage. A fire protection system within these buildings is recommended in order to both prevent the uncontrolled fire as well as notify personnel of the hazardous situation.

Several 1 ½" hoses which are used for manual fire protection were located around the facility, and the associated four hose stations are equipped with a fog nozzle and up to an additional fifty feet of hose. In order to prevent fire spread via the coal handling system, this equipment will cease to operate if an alarm on the fire protection system is activated, which would happen when the flow of the water actuates a switch. The coal handling equipment will cease to run because when the fire system is detected as active, an interlocking device shuts down power to the conveyor, crusher, and elevator.

Fire detection systems are also present in some areas of the coal handling system, these areas include the coal handling operators control room, the third floor of the crusher building, and each of the storage silos. In order to detect an incipient stage fire within the entire area, CO detection should be available in these areas. Furthermore, this detection should be interlocked into the operating control and shutdown the transfer equipment to limit the extent of the damage and potentially prevent a dust-based explosion.

Discussion

After the completion of the coal dust analyses, the housekeeping-based observations, and the document review as well as a gap analysis of the physical equipment which is used to transport coal throughout the facility, it is evident that Packaging Company XYZ has many opportunities to reach compliance with the identified regulations and recommendations identified in Chapter II. A review of the two dust analyses presented indicates that the coal dust present at Company XYZ is explosive and creates a risk that can be reduced if all of the applicable recommendations and regulations are met. The housekeeping though out the majority of the operation was satisfactory, and only one major concern was identified in which an excessive accumulation of coal dust was noted near the magnetic separator was addressed almost immediately. The company has established housekeeping policies that clearly identify the duties of responsible parties. A majority of the deficiencies identified in this review are associated with the physical equipment and the explosion prevention equipment within the department. The bucket elevator and the dust collection bag house present the greatest risk and will require significant resources in order to meet the applicable regulations. The bucket elevator requires greater emphasis on operator notification of abnormal conditions and explosion venting and the dust collector requires an isolation device in order to limit damage in the event of a dust-based explosion. Ignition sources present within the coal transfer system also do not meet the recommendations, however it seems that the company is moving towards compliance in this area by currently installing appropriate electrical equipment. Identifying the requirements for electrical equipment in this area is dependent upon the type and duration of the explosion hazard present at the location.

The fire protection systems identified are in favorable operating condition, however, the protection does not meet the recommendations set forth by FM Global. The installation of additional detection, suppression and interlocking devices will not increase the short-term profitability for the facility, however in the long term it will reduce the likelihood that a fire-based event will prevent the plant from operating.

The assessment that was performed compared the identified best-practices identified within Chapter II against the current equipment, operating practices, and policies used within Company XYZ's coal handling system. Within Chapter V, the identified gaps will be summarized in order to assist the company towards the goal of reaching compliance with the governing standards and following identified best practices. The gaps that have been identified by this assessment shall be prioritized in order to assist Company XYZ while attempting to reach compliance.

Chapter V: Conclusions and Recommendations

The purpose of this study was to determine and document the magnitude of facility-based coal dust accumulations, ascertain the risk associated with coal dust build-up, identify control measures to minimize dust release, and develop methods to prevent or at least mitigate the severity of a coal dust explosion at Company XYZ's paper mill. In order to accomplish these objectives, existing results of explosibility testing were initially referenced in order to determine if various regulatory and best practice-based recommendations were applicable. Forms were also created that include brief descriptions of either the applicable best practices or else requirements from OSHA, NFPA, or FM Global. These forms were used to evaluate the building, equipment, and the coal handling facility housekeeping. The information and assessment of the collected data was presented by utilizing the tables described in the methodology.

Conclusions

- The coal dust at Company XYZ's power generation department is explosive based on the results of the explosibility tests that were evaluated.
- The bucket elevator handling this product does not meet recommendations described by the NFPA 654 and FM Global, due to the lack of appropriate deflagration venting and malfunction alarms.
- The dust collection system does not meet recommendations described by the NFPA 654 and FM Global, due to the lack of isolation from the rest of the steam generation plant.

- The electrical equipment utilized within this process does not completely meet the recommendations as described by NFPA 654, as the areas assessed were determined to either require dust proof enclosures or C1D2 ratings.
- Isolation points between at-risk equipment which promote a potential dust explosion to be contained within such devices or buildings do not exist.
- Company XYZ is at risk of experiencing a significant dust-based explosion which could place personnel, property, and the process at risk.

Recommendations

Priority 1

- Install at least four 9ft^3 explosion doors on both the ascending and descending sides of bucket elevator
- Install a rotary valve or a similar isolation device between dust bag house and the remainder of steam generation plant
- Install devices to monitor the head and tail pulley bearing temperature of the bucket elevator to alert operators to potential dust ignition-based issues
- Install a device that alerts personnel and shuts down the bucket elevator in the event of belt misalignment
- Interlock the overload alarm on the conveyor system to notify operators and shut down the conveyor and its associated feed system

Priority 2

- Identify gaps which may exist in housekeeping responsibilities near the magnetic separator, correct such with updates to the established policy and assess regularly to maintain strong housekeeping standards
- Extend the vacuum system to reach the magnetic separator to maximize the employees' ability to clean the basement of the thaw shed
- Install an interlocking device that will initiate a shutdown of the bucket elevator when the belt slows to 80% of its normal operating speed
- Develop hazard communication training program for combustible dust and provide annual training to all of the associated employees on this topic

Priority 3

- Perform drive tests on the bucket elevator drive motor to ensure that it can operate from stop to full speed during full load situations
- Tether the explosion doors on the dust collector to minimize the potential for such to release during an explosion and contact personnel or property at lower elevations.
- Replace all electrical equipment in the crusher area, penthouse, and conveyor gallery with dust tight enclosures in order to minimize the potential for internal dust buildup within such potential ignition sources
- Install automatic fire detection and suppression equipment in the basement of the coal crusher area and the coal thaw basement

Recommended Areas of Further Research

- An investigation should take place in other dust-generating departments in order to determine other similar explosion-based exposures.
- A follow up investigation in one years' time is recommended in order to determine the extent that identified recommendations are completed.
- An investigation at Company XYZ other power generation plants is recommended to determine if similar risks exist in such locations

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Appendix A: Form Used to Document Dust Accumulation

Form for accumulation assessment and documentation				
Area Assessed	Dust Accumulation Thickness	Time	Date	Comments
Note: Accumulations of greater than 1/16th of an inch, require immediate attention.				

Appendix B: Form Used to Compare Identified Housekeeping best practices/existing standard to current practices and/or equipment

Recommended Best Practice / Equipment	Current Practice / Equipment	Comments
Continous suction to minimize the escape of dust shall be provided for processes where combustible dust is liberated in normal operation (NFPA 654, 8.1.1)		
The housekeeping frequency shall be established to ensure that the accumulated dust levels do not exceed the threshold (NFPA 654 8.2.1.1)		
The housekeeping procedure shall include specific requirements establishing time to clean local spills or short-term accumulation (NFPA 654 8.2.1.3)		
Vacuuming shall be the preferred method of cleaning (NFPA 654 8.2.2.2)		
Combustible dusts are properly identified on MSDS (OSHA 1910.1200)		
Applicable Vacuum Cleaner Requirements (NFPA 654 8.2.3.1)		
Hoses shall be conductive or static dissipative		
All conductive components shall be bonded and grounded		
Materials of construction shall comply with 7.13.2 and 9.3.2		

Appendix C: Form Used to Compare Bucket Elevator Recommendation to Existing Equipment

Recommendations	Existing	Comments
Bucket elevator construction must be in accordance with one of the following (FM 7-76 2.7.1.1)		
Locate the explosion vents no more than 20 ft apart along the height of the bucket elevator. (FM 7-76 2.7.2.1)		
Each explosion vent is to be sized at least as large as two thirds of the cross sectional area of the elevator enclosure. (FM 7-76 2.7.2.1)		
Vent the head section of the bucket elevator leg based on a ratio of 1 ft^2 of venting for every 20ft^3 of head section volume. (FM 7-76 2.7.2.1)		
Provide explosion venting for the up and downside leg casings (FM 7-76 2.7.2.1)		
Set the explosion vent relief pressure to less than 1 psi and construct vents of lightweight material (FM 7-76 2.7.2.1)		
Bucket Elevator Ignition Source Control (FM 7-76 2.7.3.1)		
Provide belt driven elevators with a mechanical or electromechanical device to cut power to the drive motor and sound an alarm if the belt slows down more than 20%. (FM 7-76 2.7.3.1 a and NFPA 654 7.10.4.1)		
Do not locate or expose bearing within the elevator casing (FM 7-76 2.7.3.1 b and NFPA 654 7.10.6)		
Provide belt-alignment interlocks to shut down the elevator if the belt misaligns (FM 7-76 2.7.3.1 c)		
The following measures should exist when practical (FM 7-76 2.7.3.2)		
Use antifriction bearings on all elevator legs (FM 7-76 2.7.3.2 a)		
Limit the use of combustible linings to impact points, wear surfaces and		

Recommendations	Existing	Comments
connected hoppers (FM 7-76 2.7.3.2 b and NFPA 654 7.10.2)		
Install drive belts that are electrically conductive at 1 megaohm or less, as well as being fire and oil resistant (FM 7-76 2.7.3.2 c and NFPA 654 7.10.5.3)		
Drive and Monitoring Requirements		
The drive shall be capable of starting the unchoked elevator under full load (NFPA 654 7.10.8.2)		
Elevators shall have monitors at head and tail pulleys that indicate high bearing temperature and alignment of the head pulley and belt (FM 7-76 2.7.3.2 and NFPA 654 7.10.9.1) Elevators traveling slower than 500 ft/min are excluded.		
Explosion vents are located outside, tethered or not facing an area where they could strike an employee or essential equipment.		

Appendix D: Form Used to Compare Conveying Equipment Recommendations to Existing Equipment

Summary of Recommendations for Conveying Equipment		
Recommendations	Existing	Comments
Housing for enclosed conveyors shall be of metal construction and shall be designed as to prevent escape of combustible dusts. (NFPA 7.11.1.2)		
Coverings on cleanout, inspection, and other openings shall be fastened to prevent the escape of combustible dusts (NFPA 7.11.1.3)		
All conveyors shall be equipped with a device that shuts off the power to the drive motor and sounds an alarm in the event the conveyor plugs (NFPA 654 7.11.2.1)		
The alarm shall sound at the operator control station, and feed to the conveyor shall be stopped or diverted. (NFPA 654 7.11.2.2)		

Appendix E: Form Used to Compare Dust Collecting Equipment Requirements to Existing Equipment

Recommendations	Existing	Comments
Bag-type collectors do not need any type of special conductive bag material to dissipate static electricity charges, however if they are used an inspection program must be maintained (FM 7-76 2.4.3.1)		
Provide a reliable grounding connection for the bag cages (FM 7-76 3.1.23)		
For mediatype dust collectors, locate explosion vents entirely on the dirty side of the collector volume. (FM 7-76 2.4.2.2)		
Explosion vents are located outside, tethered or not facing an area where they could strike an employee or essential equipment.		
Isolation devices shall be provided for air–material separators in accordance with 7.1.6. (NFPA 654 7.13.1.4)		

Appendix F: Form Used to List the Electrical Equipment and Identified Hazard Classification

List of Electrical Equipment		
Equipment Description	Equipment Classification	Does this meet requirements?

Appendix G: Form Used to List the Fire Protection Equipment and Compare against Applicable Regulations

List of Fire Protection Equipment		
Equipment Description	Equipment Classification	Does this meet requirements?