Area Zoning, its role in a Risk-Based Process Safety Program for Combustible Dusts

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An overview of hazardous area electrical classification will be presented using detailed case studies. The case studies this paper presents a discussion on the role of electrical zoning in process safety, particularly as it relates to combustible dust explosion hazards. In each case study, electrical equipment was identified as a potential ignition source for a combustible dust explosion. Lessons learned involve improper equipment selection, inadequate process safety information, and similar deficiencies will also be presented.

Introduction

Hazardous area classification, as it relates to electrical equipment, is a systematic method of sub-dividing, three dimensionally, a facility into zones of different categories according to the probability of occurrence of an explosive atmosphere. There are numerous national and international standards and directives governing area classification developed by multiple different agencies including BSI, HSE, NFPA, IEC, CEN, and CENELEC (ATEX118a directive). While regulatory compliance during the design and commissioning phase is important for any facility, other aspects of a facility's process safety program are often necessary to ensure the effectiveness of the electrical classification process as a means of ignition source control. For example, a strong safety culture that reinforces the meaning and intent of electrical zoning may be necessary to ensure that, during operation of a facility, the hazards within an area remain consistent with its anticipated electrical zone.

Using two case studies this paper presents a discussion on the role of electrical zoning in process safety, particularly as it relates to combustible dust explosion hazards. In each case study, electrical equipment was identified as a potential ignition source for a combustible dust explosion. Lessons learned involve improper equipment selection, inadequate process safety information, and similar deficiencies.

The Role of Area Classification in a Risk-Based Process Safety Program

As a process facility matures from the design phase, through commissioning, into operation, changes inevitably occur, and even the most diligent preventative maintenance program has a difficult time staving off the aging process. Similarly, an engineered system may function differently than originally anticipated, due to intentional or inadvertent operational changes. A robust process safety management program will make note of many of these changes through periodic revalidation and management of change. However, many facilities handling combustible dust have few, if any, formal policies and procedures in place to ensure that combustible dust hazards are understood and properly controlled for the *life* of the facility.

For example, a combustible dust collection system, despite being properly sized and installed during the design phase of a facility, may no longer meet the design intent due to changes in facility operation or equipment; these changes can occur as a result of aging or as a result of a deliberate process change. This failure to meet the original design intent of the dust collection system could result in fugitive combustible dust being transported from Zone 20 to Zone 22 areas of a facility or to an unzoned or under zoned area. A facility may become aware of this issue in time to mitigate the hazard through a commitment to process safety principles such as operator training and operational discipline. However, all too often, the facility is alerted to a change in the fire/explosion hazards associated with a process when it is too late, following an incident.

Below, two combustible dust hazard case studies have been selected to illustrate how process lifecycle deviations and as-operated conditions can have an effect on the electrical zone of an area or facility. Additional, the role of the electrical classification in the incident case studies will be examined from the roll of electrical classification in a complete process safety program.

Introduction to combustible dust hazards

Combustible dust is defined 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."[1] Despite these hazards, combustible dusts are irreplaceable within modern technology and within the stream of commerce.[2] It has been estimated that three-quarters of all raw materials used in chemical and process industries, and half its products on a weight basis, are particulate solids which can present both explosion and fire hazards. Any oxidizable material that has been divided into fine enough particles can combust under the right conditions. This includes a vast array of organic and metallic particulates present in the process industries. If a sufficiently high concentration of this material is suspended into air, in the presence of a competent ignition source, a fire or explosion may occur. The earliest recorded dust explosion in a grain-handling facility occurred in a flour mill in Turin, Italy, in 1785.[3] Over the last 300 years, coal mines, grain processing facilities, and numerous other manufacturing facilities have experienced catastrophic accident resulting in both a loss of life and a loss of property.

For over 100 years, scientists and industrial safety experts have endeavoured to understand and control the hazards associated with combustible dusts, yet recent history is littered with examples in which these hazards were realized, such as the landmark incidents that occurred at Imperial Sugar in 2008 and the DeBruce Grain elevator in 1998 (Figure 1 and Figure 2).[4] Obviously, maintaining dust concentrations below the lower explosive limit (LEL) would generally prevent these explosions from occurring. Similarly, inerting the atmosphere to remove oxygen or other oxidants would also prevent these explosions. However, in many circumstances, this is simply unachievable. Thus, in areas where the concentration may enter the flammable envelope, special considerations are required to control ignition sources, including electrical fixtures and equipment. These areas are typically referred to as zoned areas of a facility, and may be subject to specific regulatory requirements, depending on the application and jurisdiction. A detailed discussion of area zoning is discussed in subsequent sections.

Figure 1. Imperial Sugar facility in Port Wentworth, Georgia following the February 7, 2008 explosion.

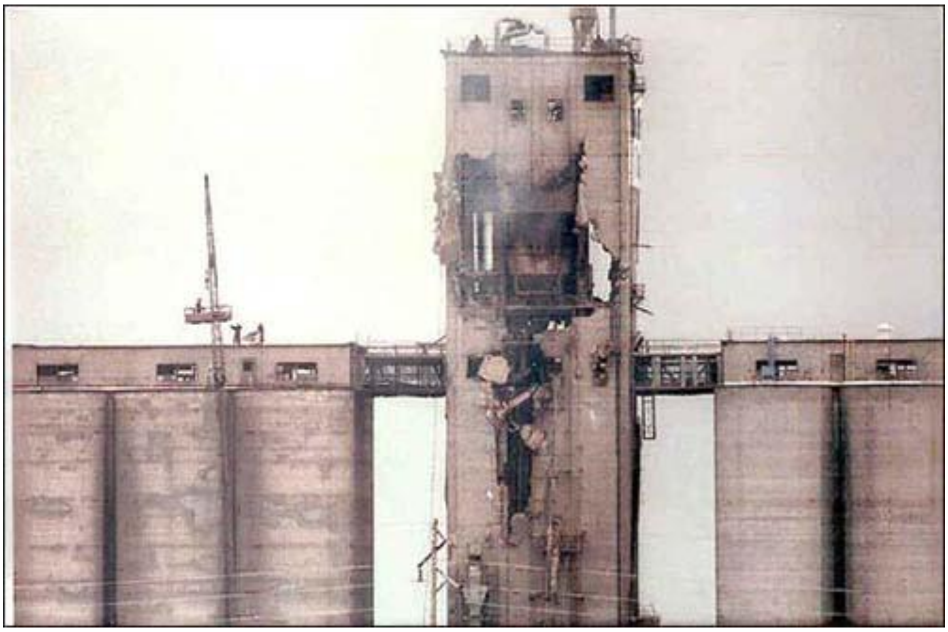

Figure 2. DeBruce Grain Elevator explosion, June 8, 1998.

Electrical Classification and Area Zoning

Industrial or commercial processes that include the handling of flammable gases or vapors, combustible dusts, or fibers or flyings must consider the electrical equipment in the area of these processes as potential ignitions sources until such time as an electrical classification process has been completed. In short, these materials provide a flammable or combustible fuel that, if allowed to interact with electrical equipment via normal or abnormal process operation, an explosion or fire could occur due to the fact that the electrical equipment could be or become an ignition source through its normal or abnormal operation.

This hazard has been identified throughout the world by multiple different agencies including BSI, HSE, NFPA, IEC, CEN, and CENELEC (ATEX118a directive). We will focus on the ATEX Directive and combustible dust in this paper; however, the general principle of eliminating electrical ignition sources by determining locations where flammable or combustible fuels may be present and then installing appropriate electrical equipment for the potentially explosive environment or removing inappropriate electrical equipment from the potentially explosive environment is consistent with recommendations from different agencies.

ATEX is the harmonization of European regulations to promote free trade between EU Member States. Under ATEX there is the Work Place Directive 137: 1999/92/EC and the Equipment Directive 2014/34/EU. The Work Place Directive provides the minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres. While the Equipment Directive approximates the laws of Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres.

Depending on the region of the world one is discussing, there are different levels of responsibility for an employer associated with protecting their employees. For example, in the United Kingdom the Dangerous Substance and Explosive Atmospheres Regulation 2002 (DSEAR) communicates that the employer is responsible to eliminate or control the risks from explosive atmospheres in the workplace. The Work Place Directive 137 specifies specific obligations of the employer. For example, an employer must prevent and protect against explosions, carry out an assessment of the explosion risks, classify the areas where an explosive atmosphere may occur into Zones including where appropriate the marking of entry points into such areas, and prepare an explosion protection document

Once the classification assessment is completed, and the zones are defined, the employer needs to ensure that the minimum requirements discussed in Annex II of Direct 137 are applied. These requirements include, but are not limited to:

- training workers who may work in areas where explosive atmospheres may occur with regards to explosion protection;
- plant equipment, protective systems, and any associated connecting devices must only be brought into service if the explosion protection document indicates that they can be safely used in an explosive atmosphere;
- before a workplace containing areas where explosive atmospheres may occur is used for the first time, the areas overall explosion safety must be verified by a person competent in the field of explosion protection.

Hazardous area classification is used to divide areas into zones based on the frequency and duration of the occurrence of an explosive atmosphere. In this paper, the explosive atmosphere considered would be created due to combustible dust Zone 20, Zone 21, and Zone 22 are used to identify areas associated with combustible dust. Specifically, Zone 20 is defined by the Work Place Directive 137 as "a place in which an explosive atmosphere in the form of a cloud of combustible dust in air is present continuously, or for long periods or frequency." Zone 21 is "a place in which an explosive atmosphere in the form of a cloud of combustible dust in air is likely to occur in normal operation occasionally" and Zone 22 is "a place in which an explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation but, if it does occur, will persist for a short period only." Directive 137 also notes that "layers, deposits and heaps of combustible dust must be considered as any other source which can form an explosive atmosphere" and that "normal operation means the situation when installations are used within their design parameters."

With this understanding of the intent, purpose, and role of electrical zoning as ignition source control for combustible dust atmospheres, the two case studies presented below will highlight recent industrial experience where proper facility zoning was not followed and an explosion occurred.

Case Study 1: Combustible Dust Explosion at a coal fired power plant

Combustible dust explosions can cause widespread damage throughout a facility. In a typical dust explosion, the initial event is usually small and produces localized damage. However, the initial blast can liberate additional accumulated dust in the area. Once dispersed, the additional fuel can be ignited, leading to propagation and growth of the initial explosion resulting in additional damage. Based on Exponent's investigation, a coal fired power station experienced a combustible dust explosion, where an initial explosion near the coal Surge Bin propagated multiple explosions downstream into and beyond the coal galleries.

Although the cause of the initial combustible dust explosion could not be determined, the propagation of the explosion was the result of residual coal dust that had accumulated within the facility. As part of Exponent's investigation, several causal factors were identified; here, a causal factor is defined as an action or condition that if changed in the event timeline would have prevented the incident or significantly reduced its consequences. Exponent identified one of the causal factors for the explosion to be the result of potential electrical ignition sources for the initial explosion stemming from electrical equipment deficiencies for a zoned combustible dust hazard area.

In this case, the facility completed a hazard analyses and ATEX zoning analysis on some portions of the coal dust handling process. These analyses revealed a large number of deficiencies of electrical equipment in zoned areas. For example, approximately two years prior to the explosion, a combustible dust risk assessment was performed on the coal fired power station which reported over 1100 equipment deficiencies within the zone 20 and zone 21 hazard areas of coal handling system. The combustible dust assessment identified numerous types of deficiencies including approximately 100 instances of electrical grounding issues and approximately 300 instances of motors or electrical equipment that were not rated for the zoned area where it was installed. Nevertheless, at the time of the explosion two years later, few of these deficiencies had been corrected.

As discussed earlier, as process facility matures, changes inevitably occur, and in this case, the changes to the electrical equipment were likely the result of an inappropriate maintenance program. A robust process safety program will make note of many of the changes to the zoned electrical equipment through periodic revalidation and management of change. However, this facility lacked the formal policies and procedures in place to ensure that combustible dust hazards are understood and properly controlled for the life of the facility. Maintenance activities performed, or lack thereof in some cases, on the electrical equipment in zoned areas of the facility introduced possible electrical ignition sources that may have contributed to the coal dust explosion in this case. In addition to the identified deficiencies of electrical equipment in zoned areas, notable coal dust accumulations were observed throughout the facility.

During Exponent's investigation, accumulated coal dust was observed throughout the coal galleries. The plant owner granted access to one of the non-incident power units which provided an example of the typical levels of coal dust accumulation expected during normal plant operation. Despite that the examined non-incident power unit had been cleaned 36 hours prior to the inspection, dust accumulation was observed on the floor and elevated surfaces within the coal handling system as illustrated in Figure 3. Additionally, an earlier report produced during the course of the investigation included a discussion of the importance of dust collection and suppression systems, and noted that the amount of dust in the air indicated the dust collection system was either not working or inadequate. The report also recommended the wash down of the coal handling areas needed to be more consistent and thorough. The amount of dust observed during the inspection indicated that poor housekeeping contributed to the accumulation of combustible dust within the units and that numerous deficiencies reported to the plant prior to the explosion had not been addressed.

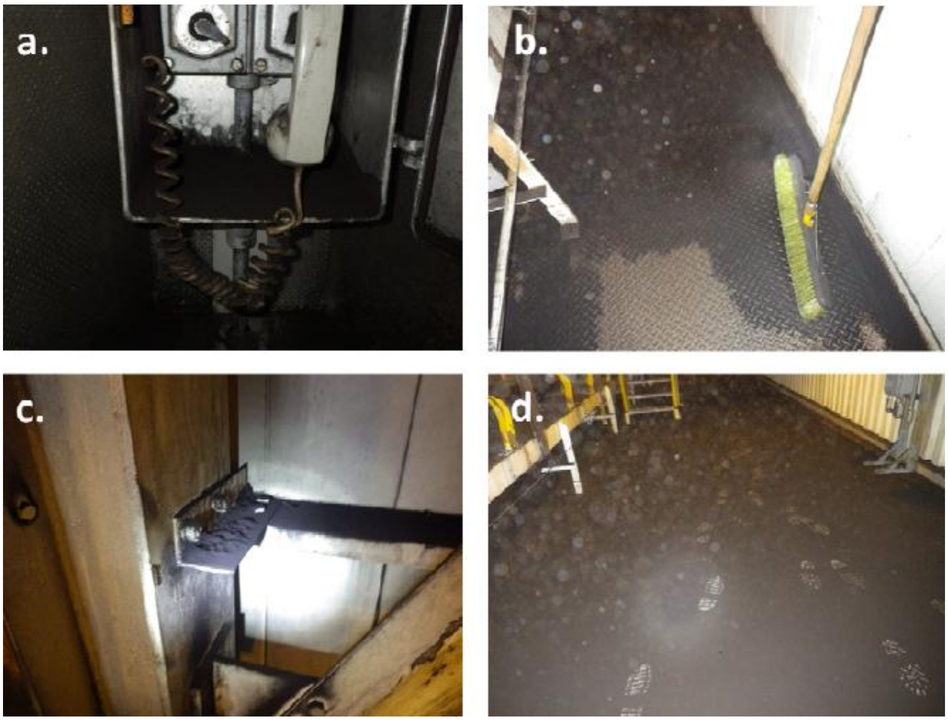

Figure 3. Examples of dust accumulation of surfaces with the coal handling system.

As illustrated in Figure 3, fugitive coal dust accumulation were present throughout the facility and were being transported from zoned areas of a facility to an unzoned or under zoned area of the facility. The level of accumulations observed throughout the facility were likely a result of a combination of factors that included poor housekeeping. equipment maintenance, and the age of the operational equipment within the facility. Based on the observable dust accumulation in Figure 3, it may have been necessary to re-evaluate the zoning of areas within the facility and to complete a facility level evaluation and audit of the currently installed electrical equipment.

Case Study 2: New Material Safety Review Failed to Identify Combustible Dust Hazard[5]

In 2003, an explosion occurred at a pharmaceutical company that manufactured rubber drug delivery components, killing six workers and injuring an additional 38. An investigation into the incident was performed by the United States Chemical Safety and Hazard Investigation Board (US CSB), and its findings were detailed in a report.[6] The explosion occurred in the afternoon of an otherwise typical workday, and no workers indicated any sights, sounds, or odours that would have indicated the subsequent explosion. The US CSB determined that the only credible fuel for the explosion was fugitive accumulations of an anti-tack agent, polyethylene powder. The polyethylene powder was not present in the original design, but was added after several years of operation as a replacement for another material. The facility performed a New Material Safety Review in advance of this change, but failed to identify an associated combustible dust hazard with the introduction of polyethylene powder to the production process.

The US CSB concluded that the facility's engineering assessment of the use of polyethylene powder was inadequate. The facility performed a New Material Safety Review, but relied upon findings from prior material evaluation activities (performed four years earlier), rather than consulting the most recent hazard communication information available. As a result, the facility was not aware of warnings that had been added to the most recent Material Safety Data Sheet (MSDS), including advice to consult National Fire Protection Association (NFPA) 654 *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Dust Particulate Solids*. The prior versions of the MSDS did contain warnings suggesting combustible dust hazards related to static electricity, but facility managers reportedly deemed these warnings irrelevant to the application. No reference to NFPA 654 was made in the prior MSDS.

While the US CSB did not conclusively determine the ignition source for the explosion, four hypotheses were considered and detailed in its report. Of the four, two hypotheses involved nearby electrical equipment not rated for use near combustible dust, and a third involved an electric motor. Standard fluorescent light fixtures provided lighting for the area identified as the origin of the explosion, and new lights had been installed the year before the incident. The US CSB hypothesized that an accumulation of dust on these fixtures could have caused a ballast to overheat and ignite nearby dust, leading to secondary explosions that were responsible for the observed damage and injuries.

Additionally, the US CSB stated that general-purpose wiring, junction boxes, and fixtures were used. Thus, it considered (and failed to eliminate) the hypothesis that an electrical spark from a malfunctioning light fixture or wiring component or unsealed connection might have ignited the dust layer above the ceiling. The US CSB indicated that, at minimum, electrical equipment would be required to be dust-tight because the accumulation of combustible dust in most areas above the ceiling at most times would have resulted in zones 21 or 22 for the area under the US National Electric Code (NEC, NFPA 70).

The third hypothesis was attributed to the facility's internal investigation, which concluded that a small dust explosion in an air duct supplying fresh cooling air to nearby electric motors initiated the larger explosion. Dust and splatter consistent with residue from an explosion were both found inside this duct, which also showed signs of overpressure damage. The dust may have entered through a worn canvas coupling. The exact ignition mechanism associated with this hypothesis was not described in the US CSB report; however, identification of the worn canvas coupling, in conjunction with the evidence of dust being present inside the supply ducting is indicative of the migration of combustible dust throughout the facility, specifically to areas of the facility that were not designed or rated for combustible dust environments.

http://www.csb.gov/assets/1/16/NewsDimensionMain/West_Pharm.jpg

Figure 4. Aerial photograph of the facility post-explosion.

According to the US CSB contributing factors to the incident included a failure to recognize combustible dust hazard despite a process change that triggered a New Material Safety Review. This failure to recognize the combustible dust hazard resulted in the use of electrical equipment that was not appropriately rated for the specific area. Additionally, the facility did not have a protocol for identifying dust accumulation above the suspended ceiling, as recommended in this application. CSB observed that these accumulations were not readily apparent and were missed by several safety inspectors, including NCOSHA two months before the explosion. Thus, depending on the actual ignition scenario, recognition of combustible dust hazard in conjunction with good engineering practices surrounding electrical classification may have prevented this incident

Concluding Remarks

As demonstrated in the two presented case studies, there existed numerous opportunities for combustible dust hazards to be identified and, in part, be mitigated by the successful application of ignition source control through a proper and updated electrical classification assessment of various areas of the facilities. In one instance a well-documented process change introduced a new combustible dust to the process but no apparent combustible dust hazard assessment was performed. While in the other study, the facility lacked the formal policies and procedures in place to ensure that combustible dust hazards were understood and properly controlled for the life of the facility. For example, the maintenance and housekeeping procedures considered during the electrical classification assessments were likely not being followed.

It should be expected that as a process facility matures from the design phase, through commissioning, into operation, changes inevitably occur, and even the most diligent preventative maintenance program has a difficult time staving off the aging process. Therefore, a robust process safety program is necessary to note these changes through periodic revalidation and management of change. A stronger commitment to process safety on behalf of these facilities may have resulted in an updated and accurate combustible dust hazard assessment, which would have likely identified the hazard. This then would have prompted the additional electrical classification assessment that was needed.

[1] NFPA 654 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids, 2013 Ed.
[2] Ogle, R.A. Dust Explosion Dynamics. Butterworth-Heinemann (2017).
[3] Count Morozzo, Repertory of Arts and Manufacturers 2 (1795):416-432 (referred to in R. N. Palmer, Dust Explosions and Fires, pp. 7-8. 1973).
[4] Eckhoff, RK. Current status and expected future trends in dust explosion research. Journal of Loss Prevention in the Process Industries 18 (2005) 225–237.
[5] Note, the following discussion relies on the investigation and findings of the United States Chemical Safety and Hazard Investigation Board, and does not represent the findings or opinions of the authors.
[6] Investigation Report – Dust Explosion, U.S. Chemical Safety and Hazard Investigation Board, Report No. 2003-07-I-NC, September 2004.