PREVENTING DUST EXPLOSIONS AND FIRES IN THE DIE CASTING INDUSTRY

INTRODUCTION

This paper outlines the causes and occurrence of dust explosions and fires. This has been found to be a significant industrial safety problem. The paper discusses how these events occur and how dust explosions and fires may have catastrophic consequences. Materials used in particular die casting operations that may be involved in dust explosions and/or fires are examined. Combustible metals are used in die casting plants. Combustible metal dust can be and is produced. Methods to reduce dust explosion severity how they may be prevented are explained.

This presentation is based on "Combustible Dust in Industry. . ." - OSHA Safety and Health Information Bulletin (SHIB 07-31-2005) (download at http://www.osha.gov/dts/shib/index.html) and NFPA 484 "Standard for Combustible Metals", 2009 Ed.

> (Note: NFPA documents are available online in readable format, without charge, at:
> http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp
> At the above web address, the following steps will allow in accessing a NFPA standard only in readable format: 1) select the standard, 2) click "Preview this Document", 3) agree to the disclaimer, and 4) open the standard.)

This document has been prepared as part of the North American Die Casting Association course on combustible dust in the die casting Industry.

COMBUSTIBLE DUST EXPLOSIONS IN INDUSTRY

A US Chemical Safety Board (CSB) study indicated that there were about 280 explosions and fires of significance between about 1980 and 2005. The Chairman of the CSB testified before a congressional committee that CSB had identified an additional 82 between January 2006 and August 2008, an increase in frequency.

Dust explosions are often catastrophic events. The CSB and OSHA have identified several horrific explosions in recent years. They include three organic dust explosions and fires in Massachusetts, North Carolina and Kentucky that claimed a total of 16 killed and 84 injured, a metal dust explosion and fire in Indiana that killed one and injured one and a recent sugar dust explosion near Savanna, Georgia that killed fourteen and injured 40. Common causal factors include unacceptable housekeeping to control dust accumulations; design flaws in the ventilation system; lack of hazard assessment; and, lack of explosion prevention and mitigation.

A disastrous series of explosions and fires occurred at the Imperial Sugar Company in Port Wentworth Georgia on February 7, 2008. A series of photographs obtained by the CSB show the process of the explosion through the lens of a security camera two miles away. A large brilliant fire ball is shown bursting from the plant. Within seconds a large, radiant, mushroom cloud has formed and has risen high above the plant. These photographs are witness to a catastrophe.

Safety Board found a pattern of catastrophic dust explosions. They recommended that OSHA take actions to prevent them, including new standards and an inspection program. They also found that MSDS sheets often fail to provide dust explosion information. In response OSHA established the Combustible Dust National Emphasis Program. The OSHA inspectors are to go out and inspect facilities across the US.

DUST EXPLOSIONS AND HOW THEY OCCUR

A fire is usually considered to involve fuel, the air, and heat as an ignition source. What is different about a dust explosion is dispersion of finely divided particles and confinement.

A dust explosion or deflagration may occur when:
When:

- Dust is combustible;
- Dispersed in air or another oxidant;
- Present in a concentration at or above the minimum explosible concentration (MEC);
- There is an ignition source; and
- Confinement produces the disaster.

The flame front of an expanding fire ball formed around the ignition point approaches the barrier confining the event. It is pushing concentrated fuel out in front of it, speeding up the reaction as it approaches the barrier. High pressure bursts the barrier. A catastrophic dust explosion involves those five things: fuel; ignition source; oxygen; dispersion; and, confinement. It is rare that all these things will come together and produce an explosion but it is a catastrophe when it happens.

A dust explosion occurs in a work area because there is deposited dust around. The dust settles on bar joists, beams, ledges, equipment and other surfaces. Some event disturbs the settled dust into a cloud. The dust cloud is ignited and explodes, a catastrophic event.

A dust explosion occurs more frequently in equipment. When a dust collector is substantially built to contain a pressurizing event, it can be safely vented out an engineer weak point or safety vent. It is engineered and calculated for the type of event that could occur. The event exits a weak point as a jet of flame. It is very possible and desirable to position the safety vent and dust collector so that all employees are safely positioned outside the zone of danger.

In an experiment, about 4.4 lbs.(2 kilograms) of combustible dust was placed on a shelf in front of a similar vent door. The dust inside and the dust “accumulated” on the shelf outside the vent produced a much larger event. The same bursting of that flame jet outside the container occurs, but a more generalized combustion event happens outside the containment. This illustrates why housekeeping is important and why not having dust deposited around the facility is important. A person in the event environment or nearby is exposed to injury or death.

An initial (primary) explosion in processing equipment or in an area where fugitive dust has accumulated may shake loose more accumulated dust, or damage a containment system (such as a duct, vessel, or collector). The additional dust dispersed into the air may cause one or more secondary explosions. These can be far more destructive than a primary explosion. Often the primary event, called a deflagration, occurs inside process equipment. The time involved in these events varies but is a matter of milliseconds or thousandths of a second. The shock wave caused by the primary deflagration spreads throughout the facility. This may involve only a few milliseconds. Shock waves reflected by surfaces within the building cause accumulated dust to go into suspension. Dust clouds are thrown into the air. The deflagration breaks out of the equipment enclosure, creating a source of ignition. This ignites a secondary, more generalized, event within the facility. This Secondary Deflagration is propagated through the dust clouds and around the work area. It burst from the building roof and walls – an explosion. In what may only be one third of a second or less, what remains is a collapsed building and residual fires.

A combustible dust explosion hazard may exist in a variety of industries. Some examples are:

- Food (e.g., Candy, Starch, Flour, Feed);
- Plastics;
- Wood;
- Rubber;
- Furniture;
- Textiles;
- Pesticides;
- Pharmaceuticals;
- Dyes;
- Coal;
- Metals (e.g., aluminum, chromium, iron, magnesium, and zinc); and,
- Fossil fuel power generation.

DUST PARTICLES

The dust explosion hazard has been described as ". . .any industrial process that reduces a combustible material, and some normally noncombustible materials, to a finely divided state presents a potential for a serious fire or explosion." This description is in the NFPA Fire Protection Handbook and is well recognized by industry safety experts.

The hazard of combustible dust increases as particle size decreases. Intuitively, we understand that more particles of a small size in a given volume provide a larger surface area for combustion. It is thought that fine particles may have a larger role in dust cloud ignition and explosion propagation. The smaller the particle, the easier it is to heat to the kindling temperature of the substance.

There are a series of ASTM tests that are recognized by OSHA and industry professionals as appropriate. These tests are used to determine if there is a combustible dust hazard at the plant. Screening the dust is one of them. A .42 mm or 420 micron particle is thought to be large enough to remain airborne or dispersed for a considerable period. This size particle may pass through #40 US standard screens. It is considered a laboratory standard. Particles 420 microns or smaller are considered "dust". We will discuss this a little more later. Generally, particles smaller than white granulated sugar are dust size.

Dusts may occur in the process stream and cause a hazard, regardless of starting particle size of the material. This is because larger particles may break into small or very small particles. They may strike the sides of a vessel, duct or other object, or perhaps hit other particles many times.

FACILITY ANALYSIS

There are several items to consider when analyzing and examining a facility to determine if there is a combustible dust hazard. Some points to check include:

- Materials that can be combustible when finely divided;
- Processes which use, consume, or produce combustible dusts;
- Open areas where combustible dusts may build up;
- Hidden areas where combustible dusts may accumulate;
- Means by which dust may be dispersed in the air; and
- Potential ignition sources.

Combustibility

To determine if an explosion can occur at a facility, an assessment of the dust must be made. The primary factor in an assessment is whether the dust is in fact combustible. It is determined if a dust cloud will detonate, deflagrate, present a fire hazard or will not burn or ignite at all. This is usually done through a series of laboratory tests. There are a series of ASTM tests that are recognized by OSHA and other industry professionals as appropriate.

.
A detonation is a combustion event that burns faster than the speed of sound as it burns and consumes the fuel. A detonation has a shattering force and creates its own confinement. These materials are not common in industry and are not generally the problem in an industrial dust explosion. A deflagration is a combustion even that travels slower than the speed of sound. A deflagration has a pushing force that is the mechanism of destruction in most combustible dust explosions.

Until the 2006 edition of an NFPA dust standard, NFPA 654, a combustible dust was defined as follows: "Any finely divided solid material that is 420 microns or smaller in diameter (material passing a U.S. No. 40 Standard Sieve) and presents a fire or explosion hazard when dispersed and ignited in air" is a combustible dust. In the 2006 edition the definition was changed to "a combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape." The intent was to be more inclusive and address the issue of some larger particles that would deflagrate but could not pass through a #40 US screen at the laboratory. These particles have a larger surface to volume ratio than a hypothetical 420 micron particle that will pass through the screen. The larger particles of this type will remain airborne long enough to ignite and propagate a deflagration through a cloud.

The point of this is to determine if there is a combustible dust hazard. An important part of this is "concentration in air". The question, "how much dust can cause an explosion?" must be answered. A much greater concentration than enough dust to cause a health hazard is one answer. Approximately 1000 times more dust in air than the range of concentrations that is thought enough (and is listed as hazardous in the OSHA health regulations).

This level of dust concentration is normally found only inside ducts or collectors or within other dust processing or control equipment. Such a concentration may occur when accumulated dust is thrown into the air in a dust explosion. This makes plant housekeeping critical in preventing a catastrophic dust explosion.

A cloud of dust that obscures light (making nearby objects impossible to see) may be at the explosive level. This is enough dust to deflagrate and is an explosion hazard. A 25 watt light bulb probably can not be seen through six feet of a mixture of combustible dust in air, suspended at a concentration greater than the minimum explosible concentration. An example is a 40 g/m3 concentration of coal dust. A 25 watt bulb can not be seen through a cloud of this type.

A thin fog of combustible dust is far less than a combustible mixture. It is still a dust problem however. The dust particles in the air have not been trapped or confined and are going to settle out on the floors, walls, bar joists and other surfaces. This settling out and building up of a dust layer creates a potentially catastrophic hazard.

Die casting shops routinely use magnesium and aluminum alloys that are able to form explosive dust clouds. This may occur within equipment or within the plant work area (if dust has been allowed to settle out and form a layer thick enough to be a hazard). A hazardous layer is thick enough to obscure (make it impossible to see) the color beneath the dust. The combustibility of zinc alloys should be tested to determine if the materials are a dust hazard. If this is not done, it must be assumed that zinc alloys are a combustible dust as well.

It is best to rely on “As used” test data to determine the combustibility of dust produced by grinding and polishing operations in the die casting industry. There are other sources of information, e.g.: supplier test data; MSDS sheets; and published tables. There are variables that affect the reliability of the information including particle size, shape, changes in the material produced by process equipment and many others. Dust used in die casting plants is almost always combustible when dispersed in air at the correct concentration.

Electrical Classification

Another Hazard Analysis consideration involves and electrical equipment and facilities at the die casting plant. OSHA and the National Electrical Code require special electrical equipment and facilities for metal dust areas. They are called Class II Group E hazardous locations.

Codes and standards that address the type of electrical equipment necessary at die casting plants include the following:

- OSHA Electrical standard (29 CFR Part 1910 Subpart S);
- NFPA 70, the National Electrical Code®;
- NFPA 499 . . . Classification of Combustible Dusts and of Hazardous (classified) Locations for Electrical Installations in Chemical Process Area.

How much dust is present in an area is critical. If the dust is present, or frequently present, in air in a concentration that could explode, e.g.: within a dust collector, it is considered a Class II (indicating dusty), Division 1 location. This designation has the most stringent requirements. (Class I locations are those with flammable gases or vapors like Hydrogen.) A location with combustible metal dust, like dust produced by grinding and polishing in die casting, is identified as a Group E location by OSHA and the NEC.

Outside of enclosures, if clean-up is reasonably constant and dust layer is not apparent, surface color is discernible; and, there is no dust around, then the area is not considered a hazardous location. A storage area with bags, drums, or closed hoppers might meet these criteria. Ordinary electrical equipment is considered suitable in these areas. If ledge dust obscures the color of the surface beneath it (the color can not be determined) that area of the shop is a hazardous location, a group E metal dust hazard, and an NEC Class II location. This is illustrated in NFPA 499 figure 5.8(e). (See attachment A and B.) An indoor, unrestricted area with open or semi-enclosed equipment and a significant dust layer is illustrated. The Division 1 area is (for example) includes an area surrounding a dusty piece of equipment for a distance of 20 feet all around. This is indicated as an area where a moderate or dense dust cloud or layer greater that one eighth inch thick is formed. An additional safety zone is established around the Division 1 area where the surface color beneath the layer is not discernible. It is identified as an "additional Division 1 area". Chapter 502 of the NEC outlines the type of electrical equipment to found within Class II Group E hazardous locations. Some examples of the requirements are:

- Switches and Motor Controllers in all Class II, Division 1 areas must be provided with identified dust-ignition proof enclosures. Magnesium or aluminum dust enclosures are to be identified for such locations.
- Motors and Generators must be identified for Class II, Division 1, or totally enclosed pipe-ventilated type equipment.
- Lighting Fixtures must be identified for hazardous locations, marked to indicate the maximum lamp wattage; and for magnesium or aluminum dust, identified for the specific location.
- Receptacles and Attachment Plugs must be three wire plug-in type and identified for Class II locations.

It is important to check the label on the equipment for these descriptions. The label must be from a nationally recognized testing laboratory (UL, FM, ETL or similar laboratory). A label that identifies the equipment as suitable for Class II Group E is acceptable for Division 1 locations.

NFPA 499 is blunt about Group E metal dusts. It indicates they ". . . could cause a short in the electrical equipment . . . (Electricity may find) the path of least resistance through a dust layer, heating up the dust particles in its path and thus providing a source of ignition. The resulting electric arc could ignite a dust layer or dust cloud." See NFPA 499 (2008) Sec 4.4.

NFPA 70 the National Electrical Code (2005), Article 500, contains this warning: "Dusts containing magnesium or aluminum are particularly hazardous, and the use of extreme precaution is necessary to avoid ignition and explosion. Group E. Atmospheres (contain) combustible metal dusts, including aluminum, magnesium, and their commercial alloys, or other combustible dusts whose particle size, abrasiveness, and conductivity present similar hazards. . ."

OTHER HAZARD ANALYSIS CONSIDERATIONS

A thorough analysis will consider all possible scenarios in which dust can be disbursed, both the normal process and potential failure modes. Where dust is concentrated in equipment such as dust collectors, a combustible mixture could be present whenever the equipment is operating. Other locations to consider are those where dust can settle, both in occupied areas and in hidden concealed spaces. After hazards have been assessed, one or more of the following prevention, protection and/or mitigation methods should be applied to the situation to control the combustible dust hazard: dust control , ignition control, damage control and training.

Dust Control

NFPA 484 contains comprehensive guidance on dust control. Some recommendations are:

- Minimize the escape of dust from process equipment or ventilation systems.
- Use dust collection systems.
- Inspect for dust residues in open and hidden areas, at regular intervals.
- Clean dust residues at regular intervals.
- Use cleaning methods that do not generate dust clouds.
- Only use vacuum cleaners approved for dust collection.
- Locate relief valves away from dust hazard areas.
- Develop and implement a hazardous dust inspection, testing, housekeeping, and control program.
- This program should be prepared in writing and establish the frequency and method to be used.

The OSHA inspection program discusses housekeeping in detail. The inspection program provides insight on how they interpret housekeeping. The program is listed on the web at

http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=DIRECTIVES&p_id=3830

The OSHA program indicates that an employer is in violation when cleaning is not begun immediately whenever a dust layer of 1/32-inch thickness accumulates. This is approximately the thickness of a paper clip wire. The program describes an area larger than 5% of the room floor area (not to exceed 1000 square feet) as a hazard when a layer thicker than 1/32 inch exists. Important areas for housekeeping are overhead beams, joists, ducts; the tops of equipment, and other surfaces, even vertical surfaces if they are dusty. Rough calculations may show that the surface area of bar joists is approximately 5% of the floor area. The equivalent surface area for steel beams can be as high as 10% of the room area.

OSHA compliance officers are instructed to look for dust layers greater than 1/32 inch thick in the following areas:

- Structural members;
- Conduit and pipe racks;
- Cable trays;
- Floors;
- Above ceilings; and,
- Around equipment.

They will look for leakage of dust around dust collectors and ductwork.

Ignition Control

Appropriate electrical equipment and wiring methods must be used. Static electric arcing and sparking must be controlled. Required bonding of equipment to ground must be implemented and maintained. Smoking, open flames, and sparks must be eliminated around combustible dust.

Heating systems must be separated from dusts. Hot water or low pressure steam systems are usually preferred. Cartridge activated tools are a special concern as they involve an ignition source, a concussion and the potential to have a "lost" cartridge cause an ignition later. Maintaining equipment and controls for proper function prevents many potential sources of ignition from occurring in the workplace.

OSHA regulates powered industrial trucks at 29 CFR 1910.178 (c). The regulation does not permit powered industrial trucks where combustible metal dust is present in hazardous concentrations, e.g.: Heavy dust concentrations, or where there is a layer of combustible metal dust. NFPA 505, "Fire Safety Standard for Powered Industrial Trucks . . ." discusses this in detail and is referenced by the OSHA standard.

Damage Control

Some methods controlling and reducing hazard involve Separation of the hazard (isolate with distance) and Segregation of the hazard (isolate with a barrier). These can fit into carefully planned engineering solutions where operations are extensive.

There are a variety of Segregation methods for isolating the hazard with a barrier. Two common devices, an automatic, fast-acting isolation valve and a flame front diverter, must be engineered and installed to address the hazards of the particular combustible metal dust found at the facility. Adequate strength and spacing of the devices are important issues.

The purpose of an automatic fast acting valve or similar device is to seal off an area of the material handling system from the spread of a fire or deflagration. It is intended to stop the flame front and isolate the section of the equipment where the deflagration is occurring. The purpose of an airflow control diverter valve is to redirect the explosion flame front harmlessly to a safe area. It is intended to seal mechanically and close the duct system, preventing air or material leakage.

The typical method of controlling metal dust deflagrations within equipment at die casting plants is with a deflagration vent panel. This method may also be used for a room or building through the use of a “blow out” wall. Deflagration venting is required for rooms or buildings containing a dust explosion hazard. The vent closures must be directed toward a restricted area; the closure must not be a missile hazard; and the blast pressure and fireball must not impinge on unrestricted personnel pathways.

It may also be possible to suppress an explosion relatively “as it starts” and before it does catastrophic damage. This is because a typical fire ball expands at about 30 feet per second. The pressure wave that precedes it during the course of the event expands at 1100 feet per second, more or less. Using this interval, it is often possible to apply an extinguishing agent to the fire ball and extinguish the fire. A detector senses the rise in pressure, alarms and signals the suppression device to quickly release extinguishing agent. The entire process may take no more than 50 mille-seconds to suppress the explosion.

It may not be possible to protect metal dust by this method. Metal powders and similar dusts burn with a flame speed that far exceeds that of a typical dust. In addition the temperature and amount of heat may exceed the extinguishing system’s ability to remove heat from the flame front. Testing can determine if this technology is applicable. Dust produced by grinding or polishing (or other similar operations) at the die casting plant probably does not fall in the “undoable” category. These dusts often burn in a more typical fashion.

Engineering may indicate that more than one type of control measure is applicable to a particular system.

In general dry dust collectors greater than 8 cubic feet in volume must be located outside. The location must prevent employee exposure to burn or other injury in the event of a deflagration. A dry dust collector of appropriate design strength and safety relief to an outside safe location may be acceptable. Also acceptable is an inside dust collector protected by a properly installed and maintained explosion protection system. Wet dust collectors are greatly preferred for metal dusts and may be located inside.

OSHA has fined facilities where dry dust collectors are located inside the building (some exceptions exist) and/or dust collectors return air back inside the building. Another area of OSHA and safety concern is ductwork. Ducts that are not grounded, have continuity to ground throughout or are not constructed of metal are a static electricity ignition hazard and have also been fined.

The Ontario Fire Code, a commonly available reference, section 5.10.1.10, requires velocity to exceed 1068 meters/minute or 18 meters per second. The purpose of this is to ensure the transport of both coarse and fine particles. It will prevent dust from settling out within the ducts and create a hazard a hazard within the duct system.

Training

Employees need to be trained to recognize and prevent hazards associated with combustible dust. They also need to know how to take preventative action, and/or how to alert management to a hazard that needs attention. They need to know the safe work practices applicable to their job tasks and the overall plant programs for dust and ignition source control. Training must be completed before they start work; periodically to refresh their knowledge; when reassigned; and when hazards or processes change.

Management must take responsibility complying with the hazard communication standard relating to combustible dust. A qualified team must conduct a facility analysis (or have one done by qualified outside persons) prior to the introduction of a hazard. A prevention and protection scheme tailored to the operation must be developed.

Supervisors and managers should be aware of and support the plant dust and ignition control programs. Their training should include identifying how they can encourage the reporting of unsafe practices and facilitate abatement actions.

GUIDELINES AND STANDARDS

Lists of standards and guidelines important to the control of combustible dust hazards are attached to this document as Attachment C. It is obvious that NFPA standards are significant in providing guidance on this topic. As stated in the introduction, the NFPA documents are available online without charge in readable format.

SUMMARY

This paper discussed the causes and occurrence of dust explosions and fires, a significant industrial safety problem. How these events have occurred and the catastrophic consequences of these events were explained. Materials used in particular die casting operations involved in dust explosions and/or fires were examined. Methods to reduce dust explosion severity and explosion prevention techniques were discussed.