The potential for lubricant dust explosions in the wiredrawing industry

This article reviews the factors that could cause dry powder lubricants to ignite and suggests ways to minimize that potential.

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On Feb. 7, 2008, a huge fire and explosion, causing millions in damage, major injuries and loss of life, occurred at a food packaging plant near Savannah, Georgia. This explosion occurred not at a chemical plant or a metal manufacturing plant but at a food processing plant, routinely handling an innocuous product that we all take for granted: sugar. However, if sugar is looked at closely, it is a compound composed of just carbon, hydrogen and oxygen. Compounds containing these atoms tend to burn very easily. Gasoline and alcohol are also common examples of compounds that contain just carbon, hydrogen and oxygen, but with widely different ratios and molecular structures. We are very aware of the combustibility of these materials and take appropriate precautions when handling them.

Another group of compounds containing carbon, hydrogen and oxygen, but also other chemical elements, is wiredrawing lubricant powders. Like sugar, wiredrawing lubricants are used on a routine basis and are considered very safe to handle. However, it was learned from this disaster that all chemicals have the potential to be hazardous if handled incorrectly.

There is a fundamental difference between materials like gasoline and alcohol, and solids like sugar and wiredrawing lubricants. The first two are low-boiling point liquids that easily vaporize in air to form an ignitable gas mixture. However, wiredrawing lubricants and sugar are high-melting point solids that remain solid, during and after use, with no vaporization into a gas. Thus it is necessary to look at the conditions that can potentially turn an innocuous solid into a dangerous, explosive hazard.

Shortly after the sugar plant disaster, which occurred after other equally destructive events at other chemical and

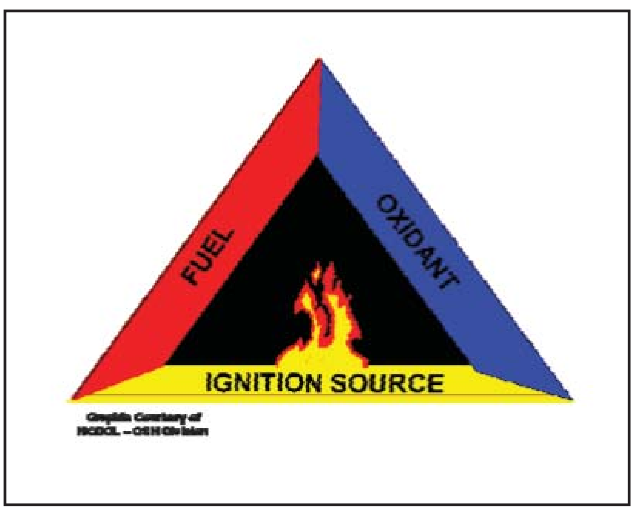

Fig. 1. The Fire Triangle.

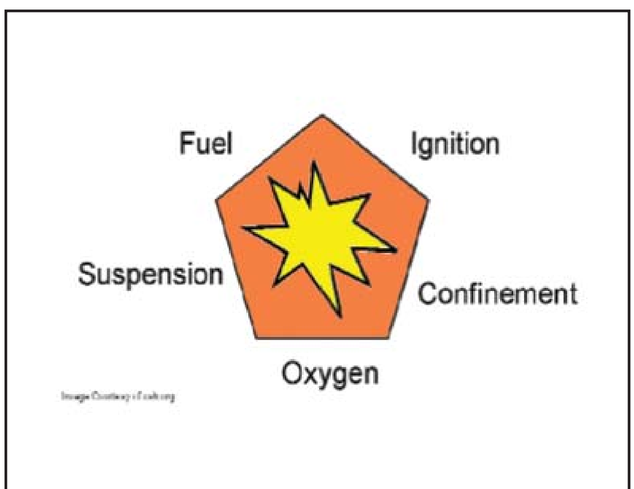

Fig. 2. Explosivity Pentagon.

Fig. 3. Paper clips made from 0.033 in. (or 838 micron) wire.

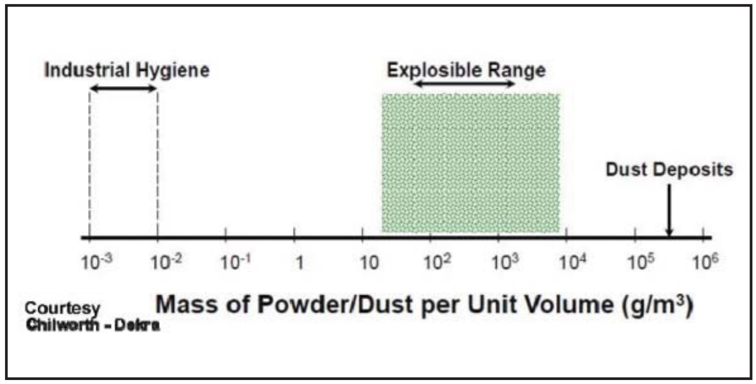

Fig. 4. Explosible range of a dust cloud.

metal manufacturing plants, The US Department of Labor's Occupational, Safety and Health Administration (OSHA) issued a National Emphasis Program (NEP) to deal with combustible dust issues in the workplace[1]. OSHA carried out an intensive review that resulted in work place safety enforcement using existing standards and regulations developed by the National Fire Protection Association (NFPA), insurance companies, and state and federal governments.

Conditions for fire and explosion

In order to understand the combustible dust hazard, an understanding of combustion or fire is required. A fire requires three components: fuel, oxidant and ignition source; these components constitute the Fire Triangle shown in Fig. 1. The fuel is anything that is capable of burning or rapidly oxidizing in the presence of an ignition source. Generally, as described above, these powders contain carbon, hydrogen and oxygen. However, metals such as aluminum, magnesium, zirconium, etc., can also oxidize rapidly or burn.

The oxidant is air and the ignition source can be an electric or frictional spark, an overheated bearing, or any other energy source capable of raising the fuel's temperature to its autoignition point. If any one of the three components is removed, it is impossible to start a fire.

To generate an explosion, two additional components need to be added to the Fire Triangle in Fig. 1; the addition of suspension and confinement form the Explosivity Pentagon shown in Fig. 2. The fuel particles must be highly aerated or suspended in the oxidizing media. Particles are more easily suspended if their size is less than 420 µm or 40 U.S. mesh. This size is equivalent to approximately ½ the thickness of a standard paper clip made from 0.033 in. (838 µm) wire. See Fig. 3. However, if the material can readily burn (e.g., nylon or cotton flock), the particle size can be much larger. In addition, this process must take place in a confined space. All five components working together create the conditions for a Combustible Dust Explosion.

If a fire starts, there are three possible outcomes that could occur: the fuel burns slowly and the flame front does not travel; the fuel burns rapidly and the flame front does not travel; and the fuel burns rapidly and the flame front propagates quickly.

Characterization of a powder's explosivity

There are three main factors for characterizing a powder's explosivity as cited below:

Minimum Explosive Concentration (MEC). MEC in grams per cubic meter (g/m^3) is the minimum concentration of suspended dust in a cloud required for an explosion to occur. R.K. Echhoff[2] reported that many carbon-based materials as well as many metal dusts have a limited ignitable range. Fig. 4 shows that the typical explosible range for combustible powders varies from about 10 to 10^4 g/m^3. Indeed, the MEC values for unused wiredrawing soap powders, independent of % combustibles in the product, tested from 40 to 200 g/m^3. Similarly, MEC values for iron fines are reported from 30 to 500 g/m^3 depending on the form of the iron[3].

While it is important to know the product's MEC value, its significance in assessing the explosivity hazard risk is minimal. The reason for this, as shown in Fig. 4, is that the explosible range lies about two orders of magnitude midway between two more significant concentration ranges that are

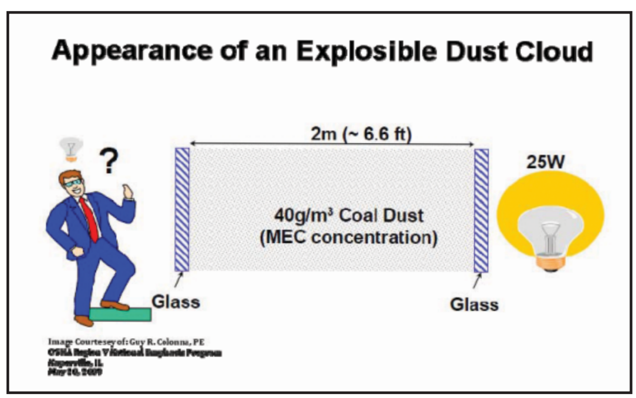

Fig. 5. A cloud of 40 g/m^3 of coal dust in air is so dense that a glowing 25 W light bulb can hardly be seen through a dust cloud of 2 m (6.6 ft) thickness.

Dust	Minimum Ignition Energy (mJ)
PVC	1,500
Zinc	200
Sugar	30
Aluminum	10
Iron	>1000
Rich Sodium Wire Drawing Lubricant A	>500
Rich Calcium Wire Drawing Lubricant B	>500
Lean Calcium Wire Drawing Lubricant C	>500

Table 1. Minimum Ignition Energy (MIE) for some familiar products[3].

Minimum Ignition Energy of the Powder (mJ)	Characterization
500	Low sensitivity to ignition; ground plant when ignition energy is at or below this level.
50	Consider grounding personnel when ignition energy is at or below this level.
25	The majority of ignition incidents occur when energy is below this level. The hazard from electrostatic discharges from dust clouds should be considered.
10	High sensitivity to ignition; take precautions and consider restrictions on the use of high resistivity materials (plastics). Electrostatic hazard from bulk powders of high resistivity should be considered.
3	Extremely sensitive to ignition. Precautions should be as for flammable liquids and gases when ignition energy is at or below this level.
Note: The above guidelines may not ensure safety in the case of powders in large nonconducting containers or handling and storage of granules or flakes.	

Table 2. Guide to electrostatic precautions for powders[4].

routinely encountered in manufacturing plants. At the lower end is the breathable dust limit at 10^{-3} to 10^{-2} g/m^3 and at the upper end are dust accumulations at 10^6 g/m^3. Below the explosible range, there is not enough fuel to sustain ignition and propagation. Above the explosible range, there is not enough oxidant to sustain ignition.

In addition, if an explosible dust cloud were encountered, as Fig. 5 suggests, visibility would be limited and it would be difficult to breathe without a respirator. That is, it would be immediately obvious that there was a major issue.

The danger, however, is that if a dust pile is disturbed, the dust concentration in the immediate area can quickly fall into the material's explosible range. Frequently an initial small dust explosion will cause dust deposits on roof beams to fall, creating a large dust cloud that results in secondary and tertiary explosions. This is the primary reason for minimizing dust build up.

Dust	Deflagration Index, Kst (bar.m/sec)
PVC	≈168
Zinc	85 - 125[7]
Sugar	≈80
Aluminum	≈555
Iron	<200
Rich Sodium Wire Drawing Lubricant A	≈120
Rich Calcium Wire Drawing Lubricant B	≈150
Lean Calcium Wire Drawing Lubricant C	≈60

Table 3. Deflagration index of common materials.

Minimum Ignition Energy (MIE)

The Minimum Ignition Energy (MIE) in millijoules (mJ) is the minimum amount of energy required to ignite a dust cloud. The lower the value, the easier it is for a substance to ignite. This is a concern because it is very easy for a worker to acquire a static electric charge of 40 mJ. Furthermore, nonconductive powders tumbling against each other in mixers or conveyors can induce charges up to 25 mJ. Table 1 lists the MIE values for some familiar products.

With reference to Table 1, unused wiredrawing lubricants have fairly high MIE values (>500 mJ); they are characterized as low sensitivity to electrostatic ignition (Table 2). However, plant environments also have other electrical discharge sources such as motors, arcing switches and electrical shorts that have considerably more energy than a static discharge and are capable of igniting materials with higher MIE values.

Dust Explosion Class	Deflagration Index, Kst (bar.m/s)	Characterization
St 0	0	Non-explosible
St 1	0 < Kst < 200	Weak to moderately explosible
St 2	200 < Kst < 300	Strongly Explosible
St 3	Kst > 300	Very strongly explosible

Table 4. Deflagration index hazard classification.

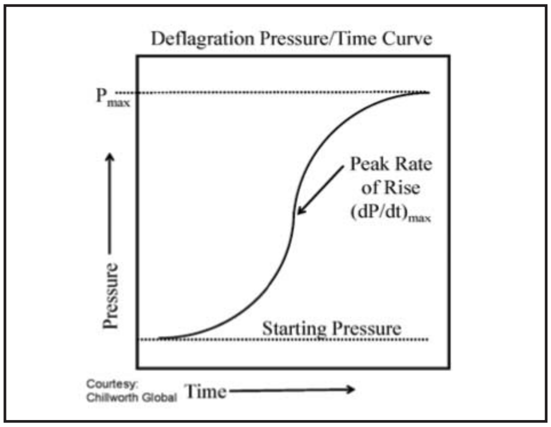

Fig. 6. Deflagration Pressure Time Curve indicating the calculation of Kst.

Fig. 7. Imperial Sugar Plant, Port Wentworth GA, Feb. 7, 2008. Courtesy OSHA Presentation "Combustible Dust National Emphasis Program," March 25, 2010.

For clarification, the rich wiredrawing lubricants that were tested and are referenced in Tables 1 and 2, contain over 60% reacted fatty acid while the lean wiredrawing lubricant had less than 50% reacted fatty acid. In addition, all of the products were unused, specially prepared with an atypical particle size of 100% less than 75 µm (200 US Mesh). These values are for guideline purposes only. Used wiredrawing lubricants will contain metal fines and other contaminants that can affect the test results. The combustibility of these materials can be verified with testing.

Deflagration Index (Kst)

The third parameter, Deflagration Index, Kst indicates the force or severity of the explosion. The graph in Fig. 6 shows how the pressure changes as a function of time when a substance ignites. The maximum pressure change with time $(dP/dT)_{max}$ times the cube root of the enclosure volume equals Kst. It has units of bar-meter per sec (bar.m/sec).[5]

Table 3 lists several common materials with their respective Deflagration Index, Kst,[3] while Table 4 shows the relationship between Kst and explosivity strength[6].

Table 3 indicates that typical wiredrawing lubricants will provide a good size "kick" as they explode in a combustible dust cloud. Fig. 7 shows the damage resulting from the Feb. 2008 sugar explosion at the Imperial Sugar Factory. Sugar has a Kst value comparable to many dry powdered wiredrawing lubricants, but it has a much lower MIE (e.g., 30 vs. >500) and is thus easier to ignite.

Results and discussion

In wiredrawing plants, a considerable amount of the fine dust results from the degradation of the wiredrawing lubricant particles. This change can be caused by handling or from mechanical means, i.e., the draw bench and its many moving parts. However, it must be understood that the breaking down to smaller particles is necessary to allow the wire drawing lubricant to function properly.

Fig. 8 shows that in order for the lubricant to reach the die-wire interface in Zone 3, where it forms a hydrodynamic lubricant film, the particles must break down into finer particles in Zone 2. Only then can the particles be affected by the heat from the metal deformation process in Zone 3 and transform into a plastic-like film that provides hydrodynamic separation in Zone 4.

In addition to the handling of the product from its storage container to the draw bench lubricant box, other actions also contribute to excess dust generation. Dust can be caused by both operation actions and from selecting the incorrect lubricant for the process.

An example of an operation action is the overfilling of the lubricant box as shown in Fig. 9. The forward action of the wire moving through the lubricant box forces lubricant accumulation to the front of the box. If there is not enough room left in the box to allow this action, overflow occurs onto the bench and floor. Likewise, over-aggressive stirring can force excess lubricant from the box onto the bench and floor.

The choice of lubricant can be considered incorrect when its friability or softening point creates excessive dust generation. Fig. 10 shows an example of extreme feathering that occurs when the lubricant's softening point is too high.

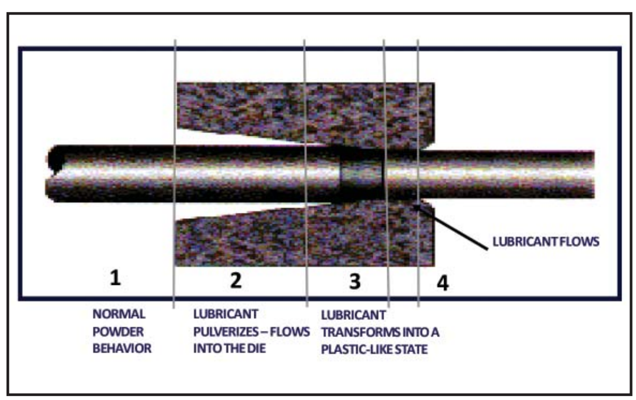

Fig. 8. Large particles need to break into finer particles in Zone 2 to lubricate the die/wire interface in Zone 3.

Fig. 9. An example of lubricant becoming a dust issue from over filling the lubricant box.

Fig. 10. An example of incorrect lubricant choice resulting in significant feathering.

The high softening point causes formation of a fine, wispy material that is ejected from the die exit. The fine powder can then be picked up by various air currents and deposited elsewhere in the plant.

In addition, the incorrect choice of lubricant can result in excess lubricant being deposited onto the wire; this excess flakes off when it comes in contact with anti-chatter devices or from the wire flexing around the block and sheaves.

If the softening point of the lubricant is too low, it tends to melt in the die and flow back into the lubricant box. The melt-back that forms in the box cannot flow back into the die. As it accumulates in the lubricant box, operators discard it during routine box maintenance. Removal of the hard spaghetti-like filaments often carries along with it usable lubricant powder, which collects on the draw bench and can then fall to the floor to be stepped on and crushed into a fine powder.

Dust hazard minimization programs

Minimizing the combustible dust hazard involves three approaches: minimizing dust accumulations, reducing ignition sources and minimizing dust formation rates with better lubricant selection.

Minimizing dust accumulations. Dust in the work place is inevitable during ferrous and some nonferrous wiredrawing. Common sense engineering and preventative maintenance will minimize dust accumulations. Many different agencies have made useful recommendations[8-12]. Some of these include:

- Good housekeeping practices. Do not allow dust to accumulate. Periodically remove the dust from around and on the equipment (1/32-1/16 in. (0.8-1.6 mm). See Fig. 3.
- Install dust collection systems at the draw bench and in other areas of the plant where dust is generated.
- Cover the soap box and/or the draw bench to trap fugitive dust emissions.
- Cover horizontal surfaces (girders, beams and ledges) with a smooth sloped surface so that no dust build up can occur. Frequently, an initial small dust explosion will cause dust deposits on these surfaces to fall, thereby creating a large dust cloud that results in secondary and tertiary explosions.

Reducing ignition services

- Ensure the equipment is properly grounded to prevent static electric build-up.
- Ensure that electrical equipment is rated for use in dusty environments.
- Ensure all wires and connections are in good condition.
- Eliminate presence of very hot metal through good preventative maintenance practices.

Dust minimization. Minimize dust formation rates with correct lubricant selection. The physical and chemical properties of lubricants affect the rate of dust generation during wiredrawing.

- Lubricants generating the least amount of dust tend to be beaded, pelletized or in other forms that do not readily dust during handling.
- Lubricants leaving appropriate residual amounts on the wire reduce dust formation rates should be selected.
- Lubricants formulated with low dust forming tendencies reduce the dust generation rate during drawing.

Summary and conclusion

It is recognized that a dust cloud combustibility hazard can be expressed as:

$$\text{Risk of Explosion} = (\text{Probability of event}) \times (\text{Severity of the event})$$

The severity of the event, in this case the explosion, is dependent upon the Deflagration Index, Kst, and the size of the dust cloud. The probability depends upon several factors including: Minimum Explosive Concentration (MEC); Minimum Ignition Energy (MIE); dust generation rate; dust accumulation amount, especially dust on elevated surfaces; the number and nature of the ignition sources; and the correct lubricant choice

Like many other products, wiredrawing lubricants are capable of creating explosive dust clouds. Recent combustibility studies classified them as weak explosion hazards by current standards. The products tested had Kst<150 bar-m/sec giving them a Dust Explosion Classification of 1 on a scale of 0 to 3. While $Kst_{(lean)} < Kst_{(rich)}$, the explosivity risk is not significantly reduced. At the same time, the studies also suggested very low probability of electrostatic ignition with MIE>500 mJ, unlike sugar that had a considerably lower value of 30. The study showed no correlation between combustible content of the drawing lubricant and the MIE value.

It is important to acknowledge that the studies were on unused materials, specially prepared with an atypical particle size of 100% less than 75 µm (200 US Mesh). Dust found in wiredrawing plants often contain other materials, such as metal fines, that can affect the explosivity results. Verification of the exact risks can be determined with testing. While the risk of an explosion from wiredrawing lubricants appears low, additional reduction in risk can be achieved by improved maintenance, correct drawing practices, better lubricant selection and elimination of ignition sources.

Often lubricants designed to lower dust generation also provide other benefits, such as higher drawing speeds along with improved die life and lower lubricant consumption rates. Minimizing both the generation of dust and its accumulation provides a safer and more productive work environment for a win-win situation for the wire drawer and lubricant supplier.

References

1. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=directives&p_id=3830, 3/11/3008.

2. R.K. Eckhoff, "Understanding dust explosions. The role of powder science and technology, *Journal of Loss Prevention in the Process Industries,"* Jan. 2009, pp.105-116.

3. Values, Chilworth-Dekra, Dust Collection Technical Handbook, National Filter Media, Salt Lake City, p. 73, and DGUV (Germany Social Accident Insurance), Berlin-Mitte, Germany, and actual testing.

4. NFPA 77 (2008 Edition) Section 5.3.5 Static Discharge from the Human Body.

5. Deflagration Index, Kst, defined by ASTM E 1226.

6. OSHA Directive Number CPL-03-00-008.

7 "Average particle size varying between 85-125 µm." Dust Collection Technical Handbook, p. 79. www.nfmfilter.com.

8. "Dust explosion prevention & protection techniques: fire explosion and thermal hazards training courses," Chilworth - Dekra, May 2010, Plainsboro, NJ.

9. "Combustible Dust in Industry: Preventing and Mitigating the Effects of Fire and Explosions, Safety and Health Information Bulletin," SHIB 07-31-2005, OSHA.

10. Health Canada, Environmental & Workplace Health, Hazard – Specific Issues – Dust Explosibility website, http://www.hc-sc.gc.ca/ewh-semt/occup-travail/whmis-simdut/dust-poussiere-eng.php

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

12. Factory Mutual Insurance Company, 2009, FM Global Loss Prevention Data Sheets 7-7. ■


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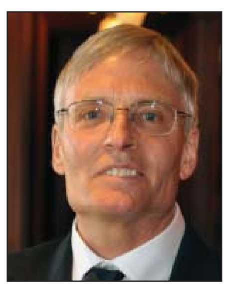
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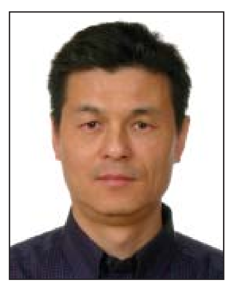
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