



# Metal Dust Explosion Protection: What Chemical Plant Managers Need to Know

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## **Abstract**

Dust explosions are a known hazard in chemical processing, and metal dusts pose a unique danger. Learn why this concern is growing in urgency and the steps industry regulators and technology leaders are taking to improve risk mitigation.

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## Introduction

Industrial explosions may be relatively rare, but the associated human, environmental, and business costs are unacceptable. Chemical plants handling combustible dusts are prone to explosive situations, so proactive steps must be taken to avoid and mitigate the risks. Metal dusts are of concern due to their peculiar combustion properties.

Many chemical plants implement metals due to their exceptional mechanical, optical and catalytic properties. Metals enter into the composition of plastics, rubber, fibers, paints, coatings, inks, pesticides, detergents, and even drugs; they are used for the catalysis of major chemical reactions (Grignard, Claus, Haber and Fisher-Tropsch), and are being explored as a possible clean alternative to fossil fuels.

These plants are susceptible to explosion hazards due to the handling, processing, and storage of metal dusts that can create combustible dust clouds and dust accumulations. Potential ignition sources include electrostatic discharges, electrical equipment, hot surfaces and open flames. The most hazardous processes involve the smaller particles, which are the most ignition-sensitive and reactive ones.

This paper will explore why and how chemical plants handling metal dusts should take adequate precautions to mitigate a deflagration. It will address:

- Special hazards of metal dusts
- The growing number of explosions involving metal dusts
- Regulatory guidance and compliance
- How effective solutions are being developed
- Finding a solution partner
- Future developments in explosion risk assessment

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## What makes metal dusts unique?

Metals differ from organic fuels due to their chemical and physical nature. Metal dusts typically require a lower amount of energy to ignite (ultrafine particles can actually be prone to spontaneous burning when coming in contact with the air), and they have a higher energetic content (i.e., more heat is released in the case of a fire or a deflagration). These two characteristics complicate the prevention and mitigation of metal dust deflagrations.

Metal dust deflagrations are generally accompanied by more severe consequences in terms of human loss and financial impact. Aluminum dust deflagrations, especially, produce high temperatures and elevated explosion pressures which can cause severe burns and heavy damage. Metal dusts can also react with water to produce hydrogen and create a very reactive hybrid gas-dust mixture.

## Frequency and severity of incidents is cause for concern

Metal dusts have been involved in more explosions in recent years due to their increased use and the lack of awareness of their specific hazards.

“As technology advances and as processing equipment and process designs become increasingly efficient, manufacturers are able to produce a much more intricate and finished product in much less time. This ultimately results in more dust being produced in more areas, and additional dust collection is needed,” explains Rick Seidel, Explosion Systems Sales and Division Manager at Suppression Systems. “The increased number of dust collection areas coupled with more sources of fine dust being generated subsequently increases the amount of areas and vessels that could be prone to an upset condition.”

It is noteworthy that the last three out of four Chemical Safety Board (CSB) combustible dust investigations involved metal dusts (iron, titanium/zirconium, and aluminum). Metal dust deflagrations have also been regularly reported in

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Europe, Japan, and China. The last aluminum dust deflagration that occurred in Kunshan, Jiangsu Province, claimed the lives of 146 people. Statistically, most explosions occur in dust collectors because they concentrate the smallest particles.

## Valuable safety guidance is becoming available

Dust explosion hazards must be assessed and controlled in order to protect personnel, equipment and facilities. Because of the greater risks and the growing number of incidents, standards are becoming more stringent for plants handling metal dusts.

In the U.S., dust explosion prevention and protection are treated in NFPA 68 “Standard on Explosion Protection by Deflagration Venting” and NFPA 69 “Standard on Explosion Prevention Systems.” NFPA 484 “Standard for Combustible Metals,” on the other hand, specifically covers processes handling metal dusts to help minimize the occurrence of, and resulting damage from, fire or explosion.

NFPA 484 standard requires dust collectors to be protected against a deflagration, and pipes to be equipped with explosion isolation devices to prevent deflagration propagation between connected processes. It further recommends basing the explosion protection system design on the tested dust properties, process conditions and equipment size, and justifying that the system is suitable for metal dust hazards with experimental evidence.

“Unfortunately, industry has long thought there was nothing that could be done to protect against such a scenario, so instead many plants focused their compliance resources elsewhere,” says Seidel. “They typically only revisit combustible dust issues when they are forced to do so, either because of a near miss, an audit that renews focus, or an event that causes property damage, destruction, physical injury or death.”

## Effective solutions are derived from large-scale testing

Advances have been made in explosion protection research and technology, and some manufacturers now provide effective protection systems for metal dust hazards, says Seidel. “The key for a user is identifying the hazard itself, having the specific dust tested to know exactly what it is capable of and how it will behave in a deflagration, and then, most importantly, conveying that information to an expert resource to ensure the available technology is correctly applied to the specific metal dust hazard.”

The high energetic content of metal dusts poses important challenges to conventional explosion protection systems in terms of robustness and response time. Large-scale testing is essential to gain understanding of the hazards posed by metal dusts, and to adapt explosion protection solutions to each specific case. Following are the most common methods to mitigate metal dust deflagrations.

### 1. *Venting*

Explosion venting is the simplest and preferred approach for the protection against a dust deflagration. It enables pressure developed during a deflagration to be safely released into the environment, preventing the process enclosure from being damaged or destroyed.

Key features of a suitable explosion vent panel for metal dust applications include:

- Low and reliable static burst pressure, to ensure the vent will open in the early stages of the deflagration
- Fast opening, to quickly discharge the overpressure created by the deflagration
- Strong design, to avoid fragmentation of the panel during the venting process

These characteristics can only be fully validated by large-scale testing under realistic deflagration conditions.

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As a part of an ongoing research program, Fike Corporation recently carried out vented deflagration tests in a 2-m<sup>3</sup> vessel using organic and metal dusts (iron, silicon, aluminum). Comparisons with NFPA 68 venting equation predictions were made, and indicate that metal dusts exhibit a peculiar behavior compared to organic dusts.

While venting allows the control of the explosion pressure, it can generate large fireballs and give rise to secondary explosion hazards. Tests carried out by the Health and Safety Laboratory (HSL, UK) with aluminum dust showed that very intense thermal radiation levels can be reached outside the protected enclosure. Additional safety distance is required to protect personnel against the secondary effects of metal dust deflagrations.

## ***2. Suppression***

Explosion suppression is the process of controlling deflagrations, mainly by absorbing the energy produced by the combustion reaction. An explosion suppression system typically consists of a pressure sensor, a control panel, and a high rate discharge (HRD) suppressor. After detection of the pressure waves emitted by the deflagration, suppressant discharge is initiated to extinguish the fireball by reducing the temperature of the combustible dust.

Suppression has generally been considered very difficult for metal dusts. To establish proper guidelines, Fike Corporation carried out specific tests in its 1-m<sup>3</sup> vessel, and also mandated a third-party laboratory (FSA) in Germany to study the scalability of suppression in larger vessels. A low activation pressure, in combination with an increased concentration of suppressant agent, has proven to successfully quench the fireball at its incipient stage.

## ***3. Isolation***

Explosion isolation is used to prevent pressure and/or flame propagating from one piece of equipment to other parts of the process. However, isolation is difficult to achieve when both flame speed and explosion pressure are high, as is characteristic of metal dusts.

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Isolation can be accomplished with mechanical systems that physically interrupt or block the passage of flame, and with suppression methods that extinguish the arriving flame and prevent ignition of the unburned fuel. Placement of the isolation system is a key aspect, as it must not be placed too far from, or too close to, the initial deflagration to be able to stop it.

Two isolation tests reported in the scientific literature reveal the challenges presented by metal dusts. One study found that flame is twice faster when testing aluminum as compared to cornstarch, while pressure is increased by more than a factor of 10. Another study concluded that dusts (3 organic and 1 metallic) with similar deflagration index values or  $K_{st}$  do not show similar behavior when propagating through ducts with a much higher pressure measured for the metal dust.

To address these more severe conditions, Fike Corporation carried out large-scale testing and developed specific guidelines with mechanical and chemical isolation devices used in combination. Mechanical blocks can also be used alone under less severe conditions, for example smaller diameter pipes. Fike Corporation also has the unique ability to validate the application of explosion protection solutions to specific customer conditions at a large scale, combining venting or suppression and explosion isolation designs.

## Experience does matter

Accurate knowledge of dust explosibility parameters is essential to properly characterize the hazard and to propose an adequate explosion protection solution. The type of metal, particle size and shape, and degree of oxidation are known to have a significant influence on these properties.

Through the years, Fike Corporation has worked on many industrial processes handling metal dusts, and carried out several experimental campaigns dedicated to the scalability of metal dust explosibility, venting, suppression, and isolation. The results have been shared with standardization committees and the scientific community to communicate the specific hazards posed by metal

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dusts and the efficient ways to mitigate these risks. Fike Corporation continues to invest in this area to develop expertise and help customers to protect their processes against catastrophic losses.

## Future developments in metal dust explosion risk assessment and protection

The extreme severity of metal dust deflagrations and their growing prevalence in the chemical processing industry will drive refinements in explosion risk assessment, prevention, and protection. “New methodologies are needed to better take into account process conditions that may impact the severity of a dust deflagration, and thus affect the design of explosion prevention and protection systems,” says Jef Snoeys, Director of Research and Academy at Fike Corporation.

Technological developments are likely, such as systems with faster response times and greater ability to deal with high temperatures and pressures. Combinations of different explosion protection techniques are considered, too. Work is also being done to better understand the relationship between dust concentration, turbulence intensity, and explosion severity.

Thanks to the continuous improvement of computer processing power, commercial software has become more reliable in simulating real process conditions and predicting the effects of dust deflagrations in complex geometries. This is opening new doors for the design of customized explosion prevention and protection systems.

Greater attention to the risks must also be paid by chemical plant managers. “Though it is true that dust explosions are very rare and require a precise mixture of ingredients to occur, a history of silence does not guarantee a future free of noise - and, unfortunately, this is the ‘strategy’ that many facilities employ, in many cases unknowingly,” says Seidel. Now is the time for course correction.



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Element	Oxidation products	Heat of combustion (kJ/mol O <sub>2</sub> )	Maximum adiabatic flame temperature (°C)	Deflagration Index
Al	Al <sub>2</sub> O <sub>3</sub>	1,100	3,790	St3
Mg	MgO	1,240	3,340	St3
Si	SiO <sub>2</sub>	830	2,970	St2
Zn	ZnO	700	1,800	St1
Fe	Fe <sub>2</sub> O <sub>3</sub>	530	2,220	St1
C	CO <sub>2</sub>	400	1,500	St1

Figure 1: Properties of selected metal dusts compared to carbon (Eckhoff, 2003; NFPA 484, 2015)



Figure 2: Combustion of cornstarch, iron, and aluminum dusts in a Hartmann tube (Fike Corporation)

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Figure 3: Damage after an aluminum dust deflagration: dust collector (left picture), drop box (center picture) and interior of the facility (right picture) (Chemical Safety Board, 2005)



Figure 4: 1-m<sup>3</sup> spherical vessel (Fike Corporation)

For additional photos of metal dust testing and references used to compile this paper,  
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