DUST

IS EXPLOSIVELY DANGEROUS

THE MILL MUTUALS

USE YOUR HEAD... BE A SPIC’N’SPAN HOUSEKEEPER
Fundamentals of Static Electricity

- Basic Concepts
- Calculation Methods
- Guidelines
- Case Histories
Fundamentals of Static Electricity

- How Do Charges Accumulate?
- How Do Accumulated Charges Discharge?
- How Do You Estimate Discharge Energy in Relationship to the Minimum Ignition Energy?
Flammable Dusts

Generally accepted rules of thumb for the minimum energies required to ignite gas and dusts are:

- Flammable gases need 0.1 mJ or more.
- Flammable dust suspensions need 10 mJ or more. Some chemical dusts with very small particles are known to have MIEs lower than 5 mJ.
Flammable Dusts

- Acetamide
- Adipic Acid
- Aluminum
- Barley
- Carbon

- Cellulose
- Coffee
- Corn
- Epoxy resin
- Iron
Flammable Dusts (Cont.)

• Milk
• Nylon
• Paper
• Polystyrene
• Starch

• Steel
• Sucrose
• Wheat
• Wood
• Zinc
### Some MIE Values

<table>
<thead>
<tr>
<th>Grains &amp; Foods</th>
<th>MIE (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>110</td>
</tr>
<tr>
<td>Wheat starch</td>
<td>25</td>
</tr>
<tr>
<td>Rice</td>
<td>50</td>
</tr>
<tr>
<td>Sugar (cane)</td>
<td>30</td>
</tr>
<tr>
<td>Tapioca</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical Dusts</th>
<th>MIE (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Epoxy resin</td>
<td>1</td>
</tr>
<tr>
<td>Herbicide</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Polyethylene (particle dia. &lt;25 micron)</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>
# Minimum Ignition Energies

<table>
<thead>
<tr>
<th>Vapors</th>
<th>mJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>1.0</td>
</tr>
<tr>
<td>Acrolein</td>
<td>0.1</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.2</td>
</tr>
<tr>
<td>Carbon Disulfide</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Heptane</td>
<td>0.2</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.2</td>
</tr>
</tbody>
</table>
MIEs

Additionally, a chemical dust may contain residual solvents which usually have MIEs below 1 mJ. In the chemical industry, therefore, more attention needs to be devoted to the prevention of potential dust explosions. The added sensitivity of chemicals may require the elimination of even low energy static electricity discharges (depending upon the MIE of the chemical).

Under some circumstances inerting may also be required; inerting is the concept of decreasing the concentration of oxygen to below the level required to support combustion (called the limiting oxygen concentration, LOC).
Dusts have minimum ignition energies (MIEs) as previously shown. It is also known that the MIE decreases as the particle size decreases and it also decreases as the temperature is increased. Some finely ground dusts are known to ignite with MIEs below 5 mJ.
Flammable Dusts

Likewise, among the parameters that can affect MIE is moisture content of the dust. More moisture in the dust elevates MIE, which is helpful.

This though, leads to another misconception or myth, pointed out in the “Deadly Dust III” video: that a humid environment can prevent dust explosions. In reality, they have occurred even during thunderstorms.
Flammable Dusts

Note then, that the ignition energy is a property of the dust, and not a function of the size of the plant or operation.

As pointed out in the “Deadly Dust III” video, it is a misconception or myth that smaller plants can be immune to dust explosions.
Additionally, a chemical dust may contain residual solvents which usually have MIEs below 1 mJ. Hybrid systems are those containing flammable vapors in addition to dusts.

Under some circumstances inerting may also be required; inerting is the concept of decreasing the concentration of oxygen to below the level required to support combustion (called the limiting oxygen concentration, LOC).
**MIE vs. Particle Size**

*Ref: Dust Explosions, W. Barkenach*

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**Minimum Ignition Energy, mJ**

- **Optical Brightener**
- **Polyethylene**
- **Aluminum**

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**Mean Particle Size, microns**

Source: Robert Gravell, DuPont Engineering
Further information on the flammability of dusts and gases can be found in NFPA 61A, B, C, and D; 77, and 650.
Charge Accumulation

It is important to understand the concept of charge accumulation, because one method to prevent static electricity ignitions is to prevent the accumulation of charges. There are four methods for accumulating charges:

- Contact and Frictional,
- Double Layer,
- Induction, and
- Transport.
Contact and Frictional Charging

Contact and Frictional Charging occurs during:

- Dust transport; e.g., pneumatic transport.
- Pouring powders; e.g., down chutes.
- Gears and belts; e.g., transporting charges from one surface to another.
Double Layer Charging

Double layer charging is essentially friction at interfaces on a microscopic scale.

- liquid—liquid
- solid-liquid
- solid-solid
- gas-liquid
- gas-solid
Induction charging is best described with an example: If you walk up to a large metal vessel that is positively charged due to a previous charging operation, your body's electrons will migrate towards the positively charged vessel. If you touch the vessel, some of your body's electrons will be transported (spark) to the vessel. Your hand was positively charged by induction. The results could be a static electricity ignition. This example assumes that your shoes are nonconductive and/or the floor is nonconductive.
Induction Charging

Example of Induction Charging
(ref. ISSA Prevention Series No. 2017)

Non-conductive bag
Filled with charged solids

Source: Robert Gravell, DuPont Engineering
Charging by Transport

Charging by transport is the result of charged dust, liquid, or solid particles settling onto a surface and transporting their charges to this new surface. In each of these charge accumulation processes, the rate of charge accumulation is a function of the rate of transportation. Lightening is an example of this type of charging phenomenon.
Electrostatic Ignitions

Electrostatic ignitions are the result of transferring the accumulated charges to another surface. If the energy of this discharge exceeds the MIE of a flammable gas or dust, then the result is a fire or explosion.
Electrostatic Ignitions

There are four types of static electricity discharges which are relevant to dust cloud ignitions. While their propensity to ignite dust clouds varies, they would all have discharge energies >1mJ, so they would all be expected to ignite flammable vapors and gases.
ELECTROSTATIC IGNITIONS

- SPARKS
- PROPAGATING BRUSH
- BRUSH
- CONICAL PILE
SPARK DISCHARGE

- BETWEEN TWO CONDUCTORS
- ENERGETIC (E < 10 JOULE)
- CAN IGNITE FLAMMABLE
  - DUSTS
  - VAPORS
Propagating Brush Discharge

Propagating brush discharges are very important; they are believed to be the major contributor of static electricity ignitions. They occur between a conductor and a nonconductive lining on another conductive surface.
PROPAGATING BRUSH DISCHARGE

- BETWEEN A CONDUCTOR AND NON-CONDUCTIVE LINING
- VERY ENERGETIC (E > 100 JOULE)
PROPAGATING BRUSH DISCHARGE (CONT.)

- LINING BREAKDOWN VOLTAGE > 4 kV
- CAN IGNITE FLAMMABLE
  - ✓ VAPORS
  - ✓ DUSTS
Brush Discharge

- Between Non-Conductor and a Conductor
- Energetic (E < 5 mJ)
- Breakdown Voltage > 4 kV
Brush Discharge (Con.)

- Lining Thickness Greater Than 2 mm
- Can Ignite Flammable Vapors and Rarely Dusts
Conical Pile Discharge (Maurer Discharge)

- Between Sliding Solids and Charged Air
- Volume Greater than $1 \text{ m}^3$
- Energetic ($E < 1\text{ Joule}$)
- Powder with $R > 10^{10} \text{ Ohm-m}$
CONICAL PILE DISCHARGE (MAURER DISCHARGE) (CONT.)

- LARGER PARTICLES (DIA. > 1 mm)
- FAST FILLING RATE > 0.5 kg/s
- CAN IGNITE FLAMMABLE DUSTS AND VAPORS
Energy and Capacitance

The calculation methods for handling liquids are well known. Methods for handling solids are not published as broadly. This slide shows the most important equations which are used when handling solids.
Energy and Capacitance

The objectives are usually:

(a) determine the accumulated charge, $Q$, expressed in coulombs,

(b) determine the capacitance, $C$, of the object or container contents, expressed in farads or coulombs per volt, and

(c) then compute the accumulated energy, $E$, expressed in joules (J) or milijoules (mJ).
Energy and Capacitance

This accumulated energy is then compared to the minimum ignition energy (MIE) of the dust; this MIE is an experimentally determined property of the dust being handled. This slide shows the calculations for the capacitance of a sphere, capacitance of a plate, and various equations for the energy.
Energy and Capacitance

- Energy: \[ E = \frac{Q^2}{2C} = \frac{C \cdot V^2}{2} = \frac{QV}{2} \]

- Capacitance: \[ C = \frac{Q}{V} \]

- Capacitance of Sphere: \[ C = 4\pi \cdot \varepsilon_r \cdot \varepsilon_0 \cdot r \]

- Capacitance of Plates: \[ C = \varepsilon_r \cdot \varepsilon_0 \cdot \frac{A}{L} \]
Energy and Capacitance

For a sphere, the capacitance is:

\[ C = 4\pi e_r e_0 r \]

where,

- \( C \) = the capacitance, farads or coulomb/volt
- \( e_r \) = the relative dialectric constant which is the property of a liquid or gas, unitless
**Energy and Capacitance**

\( e_o = \text{the permittivity constant; i.e.: } = 2.2 \times 10^{-12} \text{ coul/volt} \cdot \text{ft} \)

or

\( = 8.8 \times 10^{-12} \text{ coul/volt m} \)

or

\( = 8.85 \times 10^{-14} \text{ s/ohm cm} \)

\( r = \text{the radius, m} \)

\( s = \text{the time, seconds.} \)
Energy and Capacitance

For a flat plate, the capacitance includes an \( A/L \) term where:
\[ A = \text{the plate surface area, } m^2 \]
\[ L = \text{the thickness of the plate, } m. \]
Energy and Capacitance

The energy is computed using one of these three equations, where:

\( E = \text{energy, joules} \)

\( Q = \text{charge, coulombs} \)

\( V = \text{voltage, volts} \)

\( C = \text{capacitance, coulombs/volt} \).
Energy and Capacitance

The accumulated charge is determined by (a) multiplying the charge capacity for a specific operation, coulomb per kg, (b) times the feed rate, kg per second, and then multiplying this charge rate, coulomb per second, times the duration of the operation, s.

The next slide illustrates the charging capacity for various commonly used process operations.
<table>
<thead>
<tr>
<th>PROCESS</th>
<th>CHARGE CAPACITY (COULOMBS/KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIEVING</td>
<td>$10^{-9}$ TO $10^{-11}$</td>
</tr>
<tr>
<td>POURING</td>
<td>$10^{-7}$ TO $10^{-9}$</td>
</tr>
<tr>
<td>GRINDING</td>
<td>$10^{-6}$ TO $10^{-7}$</td>
</tr>
<tr>
<td>SLIDING DOWN INCLINE</td>
<td>$10^{-5}$ TO $10^{-7}$</td>
</tr>
<tr>
<td>PNEUMATIC TRANSPORT</td>
<td>$10^{-5}$ TO $10^{-7}$</td>
</tr>
</tbody>
</table>
Energy and Capacitance

The total accumulated charge is computed in coulombs by multiplying the charge capacity, times the charging rate, times the time of the operation:

\[ Q = (\text{Charge capacity}) \times (\text{Charge rate}) \times (\text{time}) \]

\[ Q = (\text{coulombs/kg}) \times (\text{kg/s}) \times (\text{s}) \]

\[ Q = \text{coulombs} \]
Accumulated Charge

Q = Charge Capacity \times \text{Charge}

\[ Q = \left( \frac{\text{Coulombs}}{\text{kg}} \right) \left( \frac{\text{kg}}{\text{s}} \right) (\text{s}) \]

\[ Q = \text{Coulombs} \]
Accumulated Charge

Example: Determine the potential hazard of pneumatically transporting a dry powder (dry powder with a particle size greater than 1 mm) at a rate of 30,000 kg/hr into a metal vessel which has a volume of 70 m$^3$. 
Accumulated Charge

Given: The powder has a bulk density of 600 kg/m$^3$; the vessel has a spherical geometry; and 70 m$^3$ of the powder is charged into this vessel. The powder is flammable with an MIE of 20 mJ.

As illustrated, the radius of this vessel is 2.5 m, and the capacitance is $2.83 \times 10^{40}$ coulomb per volt. Notice that the dielectric constant ($e_r$) is for air, $e_r = 1$, because a static electric discharge jumps across an air gap.
RADIUS = \left( \frac{3 \text{ VOL}}{4\pi} \right)^{1/3} = \left( \frac{3 \times 70}{4\pi} \right)^{1/3} = 2.5 \text{ m}

C = 4 \pi \varepsilon_r \varepsilon_o r

C = 4 \pi \left(1\right) \left(8.8 \times 10^{-12} \frac{\text{COUL}}{\text{V m}}\right) \left(2.5 \text{ m}\right)

C = 2.8 \times 10^{-10} \frac{\text{COUL}}{\text{V}}
FEED = 70 \, m^3 \times 600 \, \frac{kg}{m^3} = 42,000 \, kg

CHARGE = \left( 10^{-5} \, \frac{Coul}{kg} \right) \left( 42,000 \, kg \right) = 0.42 \, Coul

E = \frac{Q^2}{2 \, C} = \frac{(0.42 \, Coul)^2}{2 \left( 2.83 \times 10^{-10} \, \frac{Coul}{V} \right)}

E = 3.1 \times 10^8 \, Joule
Accumulated Charge

The calculations on this slide use a charging capacity of $10^{-5}$ coul/kg that corresponds to the pneumatic transportation process. The final accumulated energy is $3.1 \times 10^8$ joule which needs to be compared to the MIE of the powder (20 mJ). If there is sufficient air (above the LOC) in the vessel, this operation would be very hazardous. Notice that this energy is very large.
Prevent Ignitions

• This type of problem is minimized or eliminated by:
  • Inerting
  • Static Neutralizers
    1. Passive Corona Device
    2. Active Corona Device
    3. Ionizing Blowers
Prevent Ignitions

Inerting is the process of decreasing the oxygen concentration to below the LOC by adding an inert gas; for example, nitrogen or carbon dioxide.

Proper inerting to an oxygen level below the LOC eliminates the possibility of the dust exploding.
The Limiting Oxygen Concentration (LOC) is the minimum oxygen required for combustion of a dust cloud at any concentration.
Prevent Ignitions

It is related to the particular dust and determined experimentally. Values usually run in the range 8-15%.
Prevent Ignitions

Related to the LOC concept, is the concept of operating under vacuum, where appropriate. Vacuum operation is an alternate way of reducing oxygen availability for combustion. The vast majority of dusts will not burn if atmospheric pressure is below about 40 mm Hg.
Prevent Ignitions

Passive corona devices are grounded rods or wires which are structurally mounted in the silo. Barbed wire has also been used successfully. Narrow diameter rods or wires (1mm in dia. or less) induce corona discharges which are a diffuse type discharge with energies lower than the MIE of dusts. Rods with larger diameters will induce brush discharges which may have energies exceeding some dust MIEs. In all cases metal grounded and bonded construction is necessary.
Prevent Ignitions

In one case history, a piece of tramp metal was accidentally dropped into the feed of a powder bin. The metal tumbled down the solids pile and eventually approached the grounded metal wall. A spark ignited a flammable dust suspension which produced a significant explosion. This type of explosion has generated important design standards for powder handling systems; i.e.: (a) use screens in powder charging systems to trap tramp metal and/or (b) use magnetic tramp metal traps (good, of course, only for magnetic metals).
Prevent Ignitions

The following calculations illustrate the potential for this tramp metal to accumulate enough energy to ignite a powder, say a powder with a MIE of 10 mJ. It is assumed that this tramp metal is a wrench with an equivalent diameter of 8 cm (3.1 inch).
Prevent Ignitions

Similar to a previous calculation, the capacitance is determined to be $4.4 \times 10^{-12}$ coulomb per volt. The relative dielectric constant, $e_r$, is again equal to one (for air) because the spark jumps through air.
Prevent Ignitions

The maximum field intensity is an empirical value; it is 3 MV per m in air. As illustrated, this is converted to coulombs per m\(^2\) by multiplying it by a unit conversion factor (8.8 \(\times 10^{-12}\) coul/(V\(\cdot\)m)).
\[ \text{RADIUS} = \left( \frac{8 \text{ cm}}{2} \right) \left( \frac{\text{m}}{100 \text{ cm}} \right) = 0.04 \text{ m} \]

\[ C = 4 \pi \varepsilon_r \varepsilon_0 r \]

\[ C = 4 \pi (1) \left( 8.8 \times 10^{-12} \frac{\text{Coul}}{\text{V m}} \right) (0.04 \text{ m}) \]

\[ C = 4.4 \times 10^{-12} \frac{\text{Coul}}{\text{V}} \]
\[ Q_{\text{MAX}} = \left( \frac{3 \text{ MV}}{\text{m}} \right) \left( 8.8 \times 10^{-12} \frac{\text{COUL}}{\text{V m}} \right) \left( 2 \times 10^{-2} \text{ m}^2 \right) \]

\[ Q_{\text{MAX}} = 5.4 \times 10^{-7} \text{ COUL} \]

\[ E = \frac{Q^2}{2C} = 0.033 \text{ JOULE} = 33 \text{ m J} \]
Prevent Ignitions

The additional calculation computes the accumulated energy in joules, which corresponds to this maximum accumulated charge. As shown, this computed energy, 33 mJ, exceeds the MIE of this dust.
Guidelines

How to Prevent Discharges:

1. Sparks: Ground and Bond
2. Propagating Brush: Keep $U_d < 4$ kV
3. Brush: $U_d < 4$ kV and Coating Thickness $< 2$ mm
Guidelines

The preventive measures listed previously address sparks from causes other than mechanical failure.

The “Deadly Dust III” video doesn’t cover the effects of specific mechanical failure.

Explosion prevention for these types of events can be effectively achieved by a strong Mechanical Integrity element of a facility’s process safety management program.
Guidelines

Spark discharges between two conductors can be prevented by eliminating the air gap between them, that is, bonding the two conductors.

Source: "Understanding Explosions" D. Cowl, CCPS Concept Books
Guidelines (Cont.)

When to Use Inerting:

• Hybrid Systems

• Systems with Conical Discharges
Recommendations

• Understand Fundamentals and Apply Guidelines

• Know Physical Characteristics of Dusts
Recommendations (Cont.)

• Use Team Approach to Solve Problems
• When in Doubt – Use Specialists