Combustible Dust Test Planning
Start with the End Game in Mind

Sigma-HSE, Inc.

Awareness Session: Risk Based Test Planning

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A Passion for Safety

Michelle Murphy, MSc., President, Sigma-HSE, Inc.

- Chemical engineer with 25 years consulting on process safety
- Over 10 years in combustible dust safety
- Works with food and agricultural, metal, wood, automotive, specialty chemical, and pharmaceutical manufacturers
- Designed, built, and managed a combustible dust and chemical reactivity testing laboratory
- Experienced dust hazard analysis (DHA) and process hazard analysis (PHA) leader
- Capabilities in combustible dust characterization, deflagration vent system design, chemical reactivity characterization, kinetic modeling, pressure relief system design
- Published in multiple peer reviewed journals and industry magazines

This education session will provide a framework for test plan development

- Recognize potentially combustible dusts
- Articulate the importance of dust characterization
- Identify the fire, flashfire, and explosion hazards of combustible dusts
- Recall the current status of codes and standards
- Recall recognized and generally accepted good engineering practices, RAGAGEP
- Identify what tests are available
- Develop a test plan
  - Samples to test
  - How to prepare samples
  - Tests to conduct
- Document the sampling plan

Most materials are combustible in fine form

Combustible dust – finely divided combustible particulate solid that presents a flash-fire hazard or explosion hazard
Source: NFPA 652 2019 Edition

- Metal
- Wood
- Coal and carbon
- Plastic
- Biosolid
- Organic
- Textile
- Agricultural (corn, wheat, sugar)
- Candy, spice
- Rubber
- Fertilizer

Source: CSB, Malden Mills Fire, December 2005

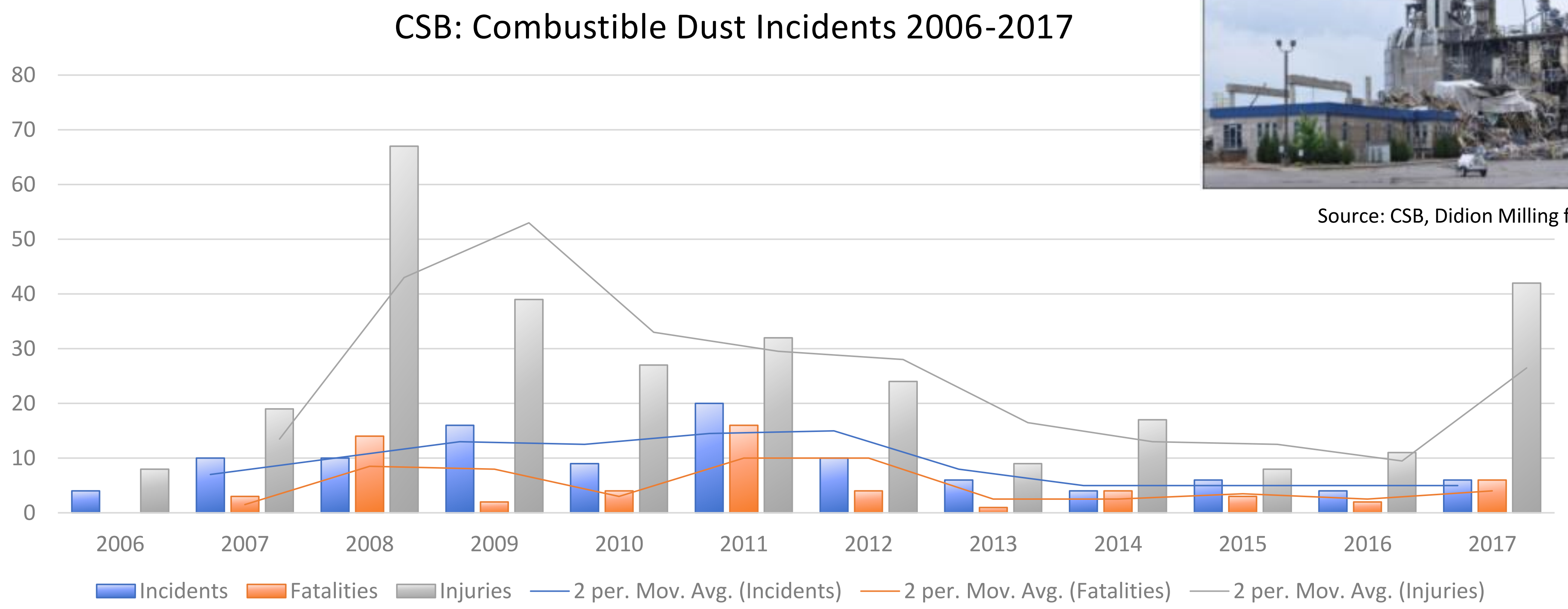
… and so most industries are affected

- Agricultural and food
- Equipment manufacturing
- Rubber and plastic products
- Metal industries
- Chemical manufacturing
- Lumber and wood products
- Electric services

Smoke-logged building after explosion in Tuas, Singapore Source: Facebook/SCDF

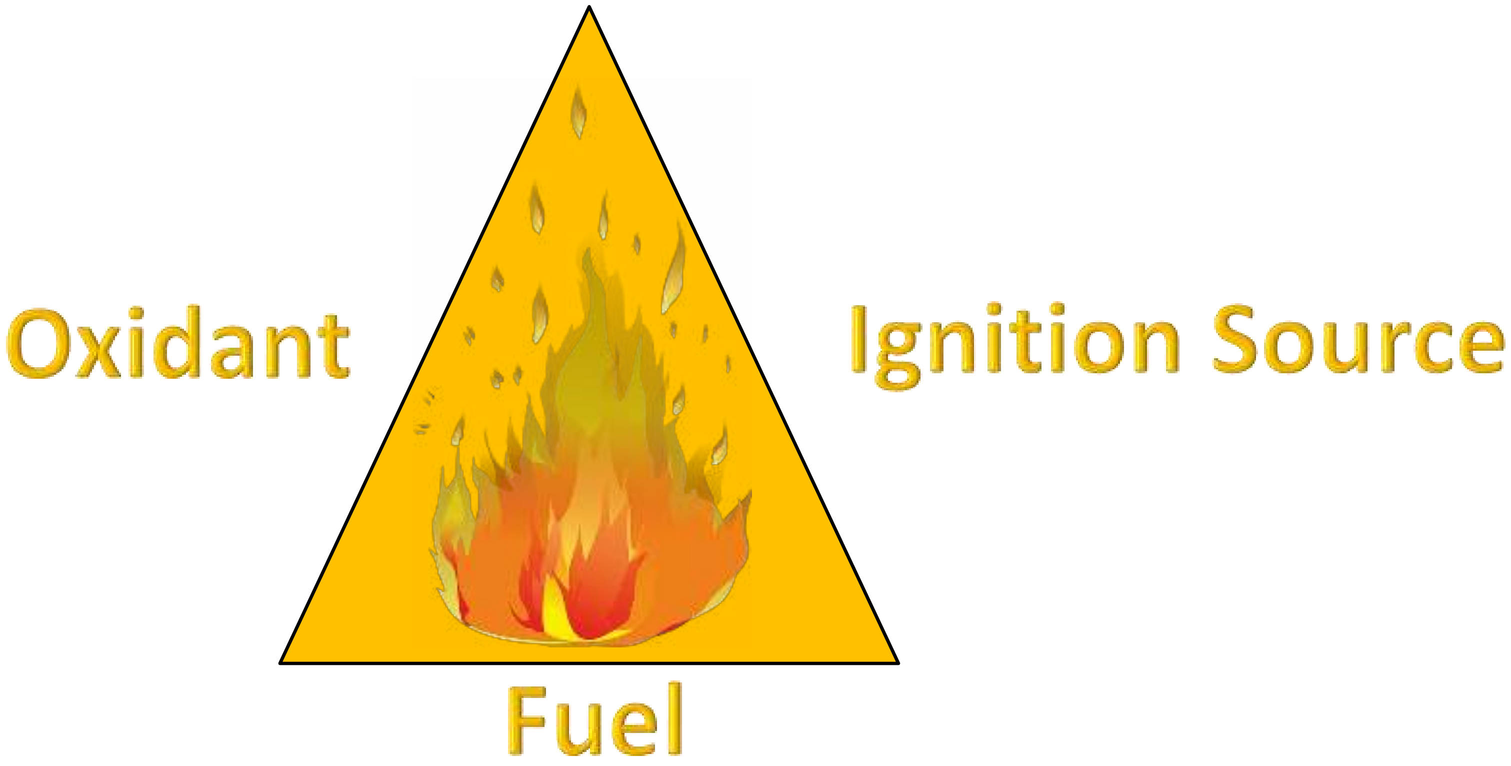
In 2021, 3 people were killed and 7 people were injured at a fire protection and electrical systems manufacturer in Tuas, Singapore

The overall trend of incidents, fatalities, and injuries is not going down



Source: CSB, Didion Milling facility, May 2017

Combustible dust fires follow the well-known fire triangle

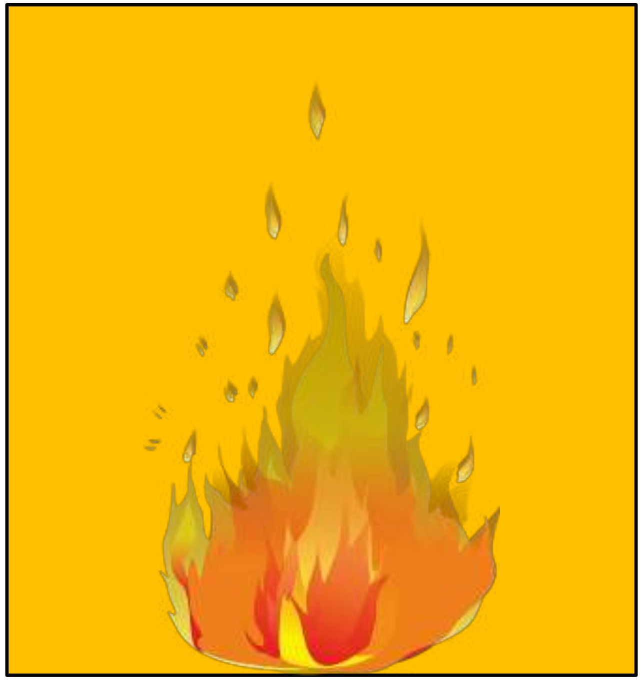


Fire Image by versal1992 from Pixabay

Flash fires occur when the dust is dispersed into a cloud

Dispersion

Oxidant



Ignition Source

Fuel

Fire Image by versal1992 from Pixabay

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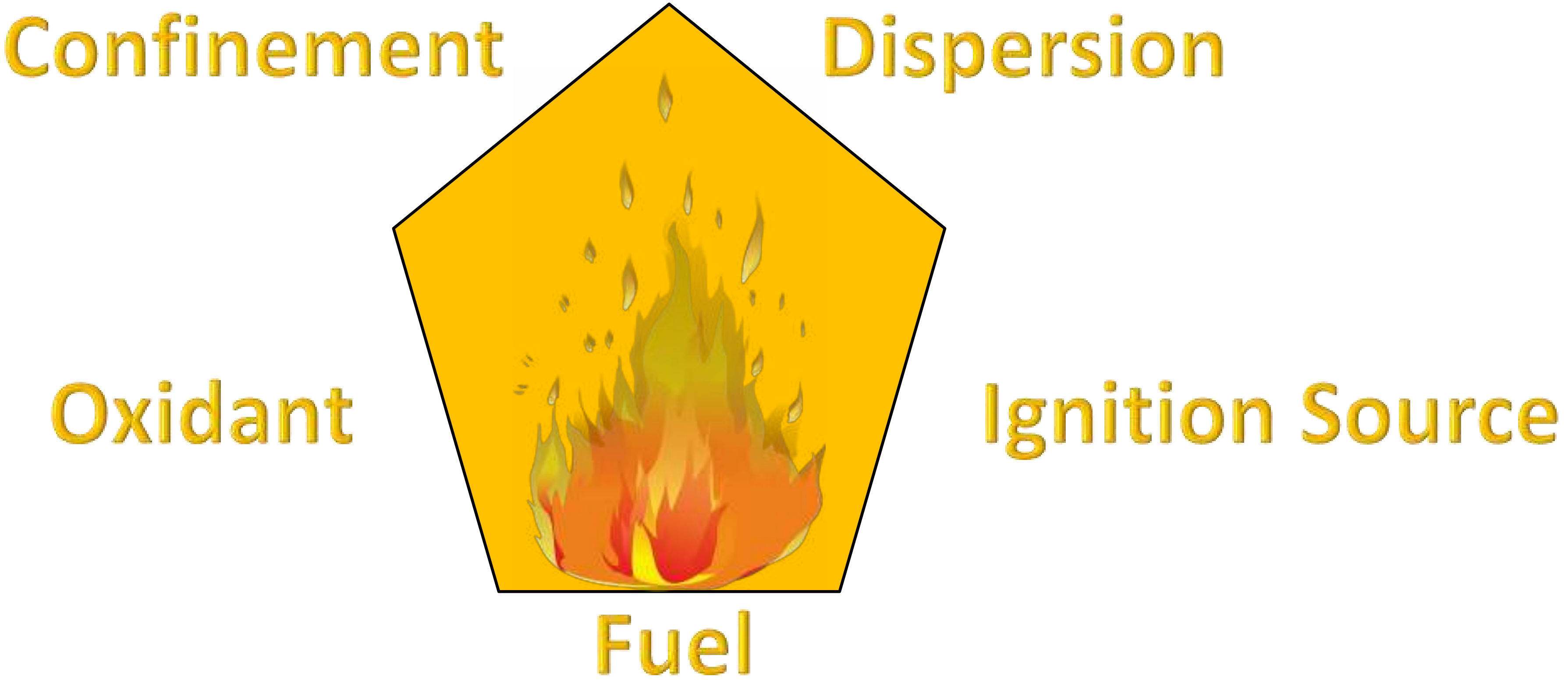
Explosions occur with ignition of a dispersed cloud in a confined space



Fire Image by versal1992 from Pixabay

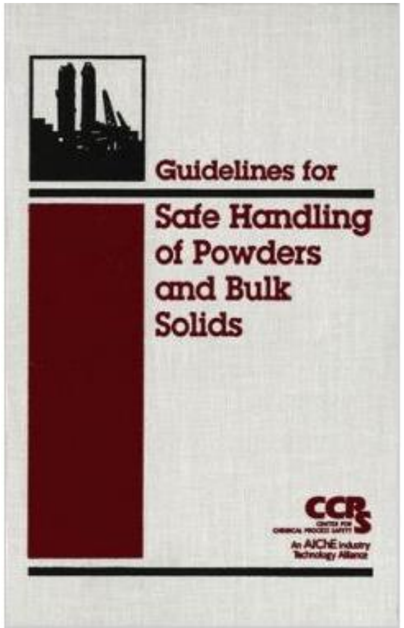
In the US and Canada, there is no comprehensive combustible dust regulatory standard

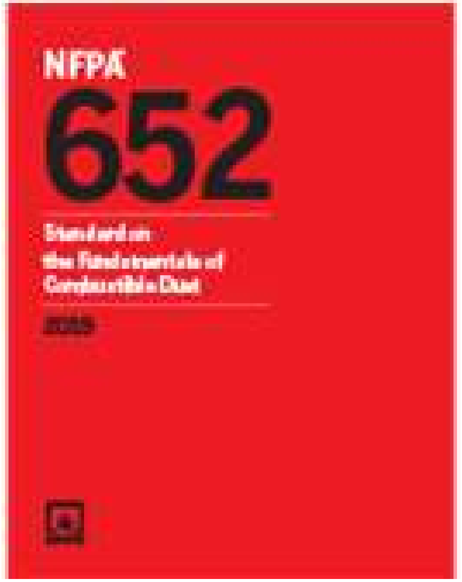
- United States OSHA
  - General Duty Clause
  - Various standards with provisions: Housekeeping, Emergency Action Plan, Specific Industries, Hazard Communication
  - National Emphasis Program
- Canada CCOHS
  - OSH Answers Fact Sheets
  - 1 Federal, 10 Provincial, 3 Territorial on various aspects of CD hazards

Recognized and generally acceptable good engineering practices fill the gap

- NFPA
- CCPS of American Institute of Chemical Engineers
- FM Global Data Sheets
- ASTM
- IEC

OSHA will often reference NFPA in their Citations





The most widely applied consensus standards on combustible dust in North America come from NFPA

Fundamentals of Combustible Dust

Industry	Installation/Operation
General (Chemical)	Explosion Protection
Agricultural and Food	Deflagration Venting
Metals	National Electric Code
Wood Processing	Electrical Classification
Sulfur	Static Electricity
	Ovens & Furnaces
	Air Conveying

NFPA is consolidating their industry-specific standards into one, NFPA 660

NFPA 652 lists four responsibilities of owner/operators

- Determine the combustibility and explosibility hazards of materials
- Identify and assess fire, flash fire, and explosion hazards
- Manage the identified hazards
- Communicate the hazards to affected personnel

OSHA NEP, NFPA, and other sources list a high number of combustible dust tests

OSHA NEP

Percent through 40 mesh
Percent moisture content
Percent combustible material
Percent combustible dust
Metal dusts will include resistivity
Minimum explosive concentration (MEC)
Minimum ignition energy (MIE)
Class II test
Sample weight
Maximum normalized rate of pressure rise (dP/dt) – Kst Test
Minimum ignition temperature

NFPA 652 Annex A

Minimum ignition energy of dust cloud in air
Minimum ignition temperature (T_c) of dust clouds
Minimum explosion pressure (P_{max}), rate and maximum rate of pressure rise (dP/dt) and explosion severity (K_{St})
Minimum explosible concentration (MEC)
Minimum ignition temperature (T_L) of dust layers
Limiting oxygen concentration (LOC)

Where do you start?

Start with the End Game in Mind

The owner/operator is responsible to determine the hazards of materials

Determine if combustible or explosible

- Characterize their properties
- Support the DHA

Acquire the data necessary to support

- Performance-based design method
- DHA
- Risk assessments
- Specification of hazard mitigation and prevention

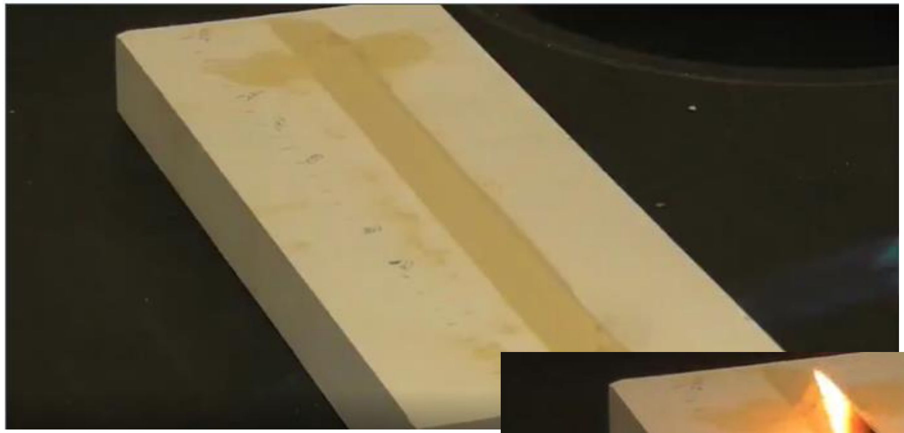
Decisions to be made

- Which materials to test
- What tests to conduct
- How to prepare the samples

Combustible dust testing starts with *screening* followed by *characterization.*

Determination of combustibility or explosibility is a screening process

- Historical facility
- Published data
- Screening tests
- Assumed



For combustible and/or explosible materials, additional characterization testing will be needed

Source: ioKinetic.com

In risk-based test planning, we consider the scenario

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Severity of Incident

- Explosion severity (P_{max}, dP/dt_{max}, K_{St})
- Minimum explosible concentration (MEC)

Sensitivity to ignition

- Minimum ignition energy (MIE)
- Minimum auto-ignition temperature, cloud ($MAIT_{cloud}$)
- Minimum auto-ignition temperature, layer (MIT_{layer})
- Limiting oxygen concentration (LOC)

NFPA 652 requires development and documentation of a sampling plan

- Representative samples of dusts identified and collected for testing
- Identification of locations where dust is present
- Identification of representative samples
- Collection of representative samples
- Preservation of sample integrity
- Communication with the test lab on sample handling
- Documentation of samples taken
- Safe sample collection practices

Mixtures have special requirements

Approximate proportions of each general category of particulate solid should be determined and documented

More than 10% by mass of metal, treat as metal dust (see NFPA 484)

More than 50% by mass of wood (and < 10% metal), treat as wood (see NFPA 664)

More than 50% by mass of agricultural dust (and < 10% metal), treat as agricultural (see NFPA 61)

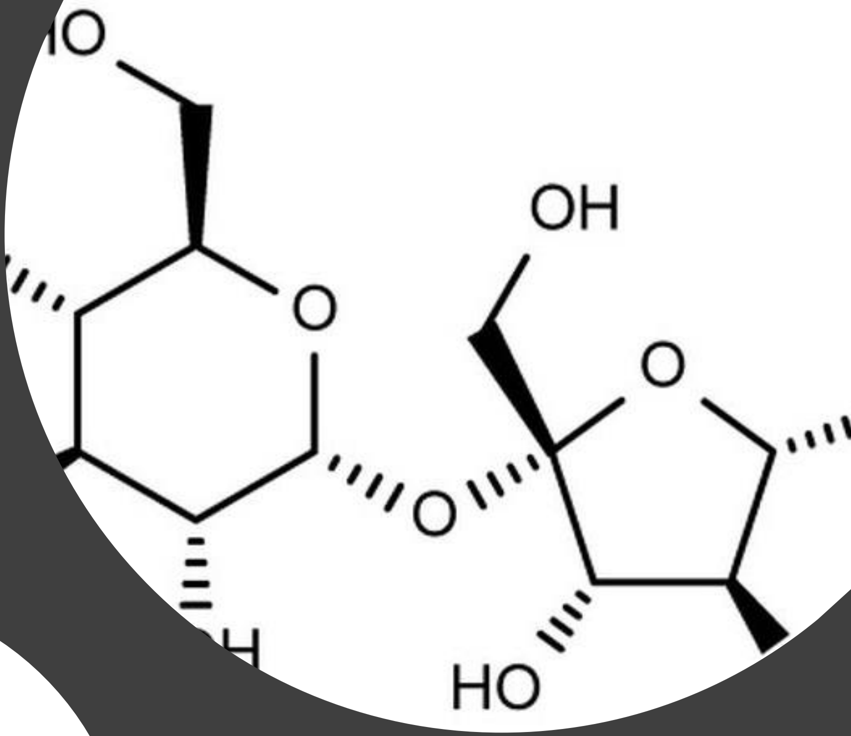
Other mixtures treated as chemical dust (see NFPA 654)

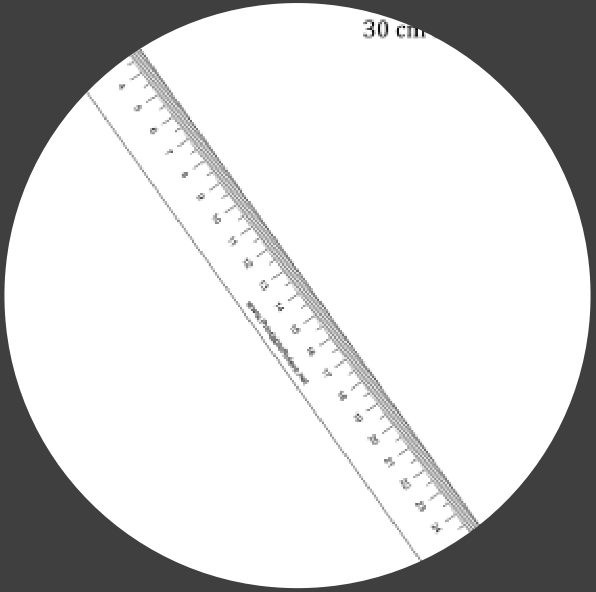
Combustible dusts are defined by their physical state

Chemical composition

Moisture content

Particle size





Use a hierarchical approach

- Is the dust combustible
  - Expected to be
  - Not expected to be
- What unit operations are being evaluated
  - Temperature hazards
  - Mechanical hazards
  - Electrical hazards
  - Electrostatic hazards
- Are building spaces to be evaluated
- Is explosion protection to be specified

Identification of the materials handled
Consideration of the operations involved
Overall hazards to be evaluated

Severity of Incident

Sensitivity to ignition

There are two options for sample preparation

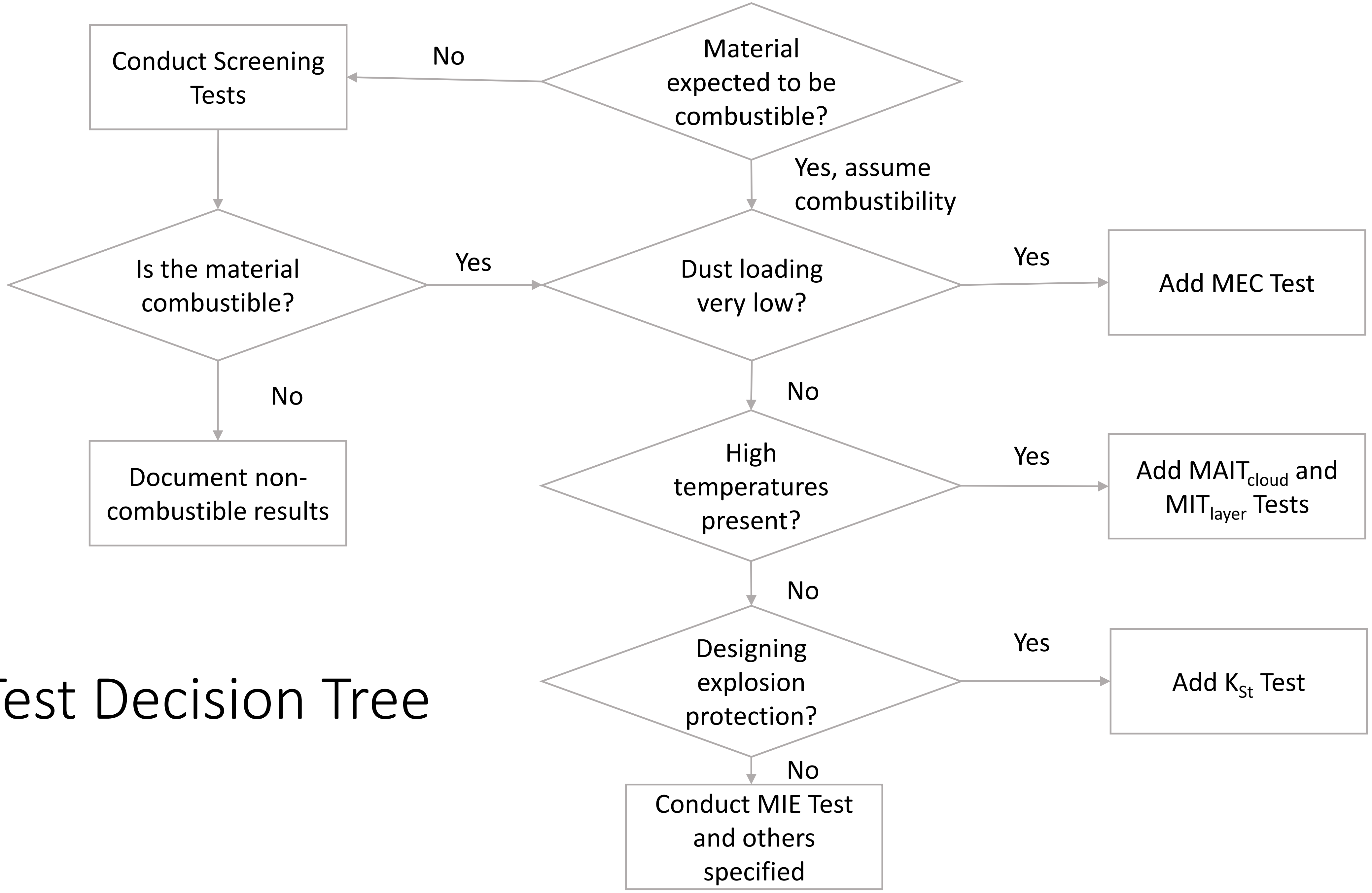
ASTM Recommended particle size and moisture content

- $< 5\%$ moisture content
- $95\% < 75\ \mu m$
- Useful for more broad application of the test results

As received

- More representative of a specific application
- May not apply to multiple pieces of equipment
- Should be applied with care

Test Decision Tree



Generally minimum tests per Unit Operation

Unit Operation	Thermal Stability	MIE	$MAIT_{cloud}$	MIT_{layer}	MEC
Bulk Unloading		✓			
Silos	✓	✓			
Bucket elevators		✓			
Pneumatic conveyors		✓			
Mechanical conveyors		✓			
Sifters and screens		✓			
Filter receivers		✓			
Use or surge bins		✓			
Size reduction	✓	✓	✓	✓	
Ovens and dryers	✓	✓	✓	✓	
Dust collectors		✓			
FIBC		✓			
Hand add stations		✓			
Packaging units		✓			
Building spaces	✓	✓	✓	✓	

Typically conducted in low load operations

Applicable tests for evaluations

- Performance-based design
  - Review the unit operations in the proposed design vs table to see which apply
  - Consider what basis is involved in the performance design to see if other testing is needed
- DHA
  - Review the unit operations in the proposed design vs table to see which apply
- Risk assessments
  - Review the unit operations in the proposed design vs table to see which apply
  - Consider what scenarios are included in the assessment to see if other testing is needed
- Specification of hazard mitigation and prevention
  - Explosion severity

Should you apply worst-case data?

- If the application does not cost additional time or money
- If the specific case can not be defined
- If you are evaluating hazards of fugitive dust

Case Study 1: Buffing operation of chromium parts

Challenge

- Operation involves buffing of chromium machined components
- SDS of buffing wheel media states it is a potential combustible dust

Test plan

- Sample from dust collector sent for testing, as received
- PSA 59% < 425 µm

P_{max}	6.6 bar
K_{St}	121 bar-m/sec
MIE	510 mJ
MEC	800 g/m^3

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Case Study 1: Buffing operation of chromium parts

Lessons learned

- Buffing by-product has large particle size
- High MIE and MEC

Summary

- It is possible that the dust collection system never reaches the MEC and in fact operates at < 25% of the MEC
- Additional work is ongoing to measure the concentration of dust in the dust collector

Case Study 2: Polymer handling facility

Challenge

- Testing for upcoming DHA of facility making polymer trays
- Client wanted to save money by applying worst-case test results
- Equipment included mills, bins, pneumatic conveying, cyclones, mechanical conveyors, blenders, bulk storage, dust collectors, reclaim system

Test plan

- Four samples were taken from different pieces of equipment
- Particle size analysis was conducted on all four and the smallest particle size distribution sample was chosen for characterization testing, a dust collector
- PSA 63% < 75 µm

P_{max}	7.9 bar
K_{St}	184 bar-m/sec
MIE	3-10 mJ
MEC	20-25 g/m^3
$MAIT_{cloud}$	430-440°C

Case Study 2: Polymer handling facility

Lessons learned

- During the DHA much frustration ensued over applying this "worst-case" sample to the entire operation
- It was difficult to know what the particle size might be at various points in the operation, but it was known to be larger than the "worst-case"
- After the first DHA meetings, the client took grab samples in multiple locations and tested these to be representative of in-process dust, two were found to be non-explosible
- Multiple nodes in the DHA were re-evaluated with the results of these representative samples
- Additional findings recommended testing more representative samples from other pieces of equipment to evaluate the true hazard inside those pieces of equipment

Summary

- The short-sighted decision to save money on testing cost the facility much more
  - Additional money in DHA time
  - Bad feelings between facility folks and corporate folks
  - DHA findings that need extensive follow-up. Additional testing is required followed by re-evaluation of the hazards. This would have been avoided if appropriate testing was completed before the DHA.

Keeping good records of the samples and testing is necessary for assuring **representative material application**

- Sampling plan
- Sample collection point
- Sample preparation
  - Drying approach
  - Particle size reduction approach
- Preservation of sample integrity method
- Sample identification
- Testing results
  - Particle size as received and as tested
  - Moisture content as received and as tested
  - Measured dust characterization parameter

With the knowledge gained, get started on your test plan

- Review SDS and other information (think CoA) to find potentially combustible dusts
- Consider how the test results will be used
- Determine tests needed to meet the objectives of the test program
- Determine sample preparation needed
- Document your test plan
- Explain to management the importance of the test plan

Choosing samples to collect and test depends on application of the data

Will the test results be applied to equipment?

- All equipment
- Specific equipment

Start with the End Game in Mind

Will the test results be applied to fugitive dust analysis in building spaces?

- Fugitive dust is by nature finer than what is found in the process
- The higher up in the building, the finer the dust accumulations are
- Analysis of fugitive dusts typically requires ASTM sample preparation (or collection of dusts from the highest building space)

Which ignition sources may be present?

This approach will often require additional testing

- Specific applications may warrant additional testing
- Results of these initial tests may suggest follow-up testing
  - MIE < 25 mJ requires volume resistivity testing
- DHAs may need additional testing for specific hazard evaluation

This is to be expected and is a necessary factor when risk-based test planning is conducted

$$Cost\ of\ Risk-based\ Testing \ll Cost\ of\ Prescriptive\ Testing$$

References

- OSHA NEP
- NFPA 652
- Dr. Ashok Dastidar Introduction to Combustible Dust Test Methods
- Editors Paul Amyotte and Faisal Khan. Methods in Chemical Process Safety (Vol 3): Dust Explosions Chapter 4. Dust Explosion: (written by Dr. Dastidar)
- Podcast at Dust Safety Science: http://www.dustsafetyscience.com/54
- Presentation in Fundamentals Section of the 2021 Digital Dust Safety Conference

About Sigma-HSE, Inc.

We provide actionable process safety solutions so you can focus on what really matters, protecting your business, people, workplace and the environment.

Our European and Asian laboratories specialize in testing combustible dusts/powders/vapors/liquids/gases.

Our US, European, and Asian based offices combine global consultancy with local expertise. From harmonizing global plant safety for multinationals to DHA’s for single site operations, Sigma-HSE, Inc. can draw on experts nationally and internationally to guide you on your safety journey.