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Methods to Assure A Successful Dust Collection System

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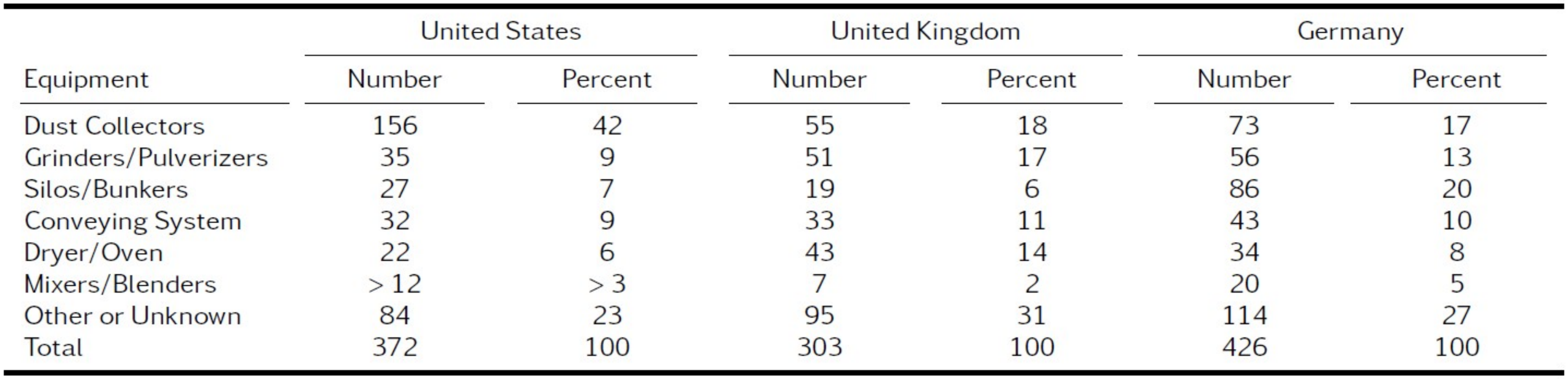
Today's Presenters

MARTIN CLOUTHIER, MSC, PENG
Director
JENSEN HUGHES,

Outline

- Importance of testing
- Overview of dust explosibility parameters (with emphasis on explosion severity)
- Factors that influence explosibility parameters
- Challenges with testing at different scales (and why the 1-m^3 chamber is better)
- Case examples of how test data can be used
- Conclusions

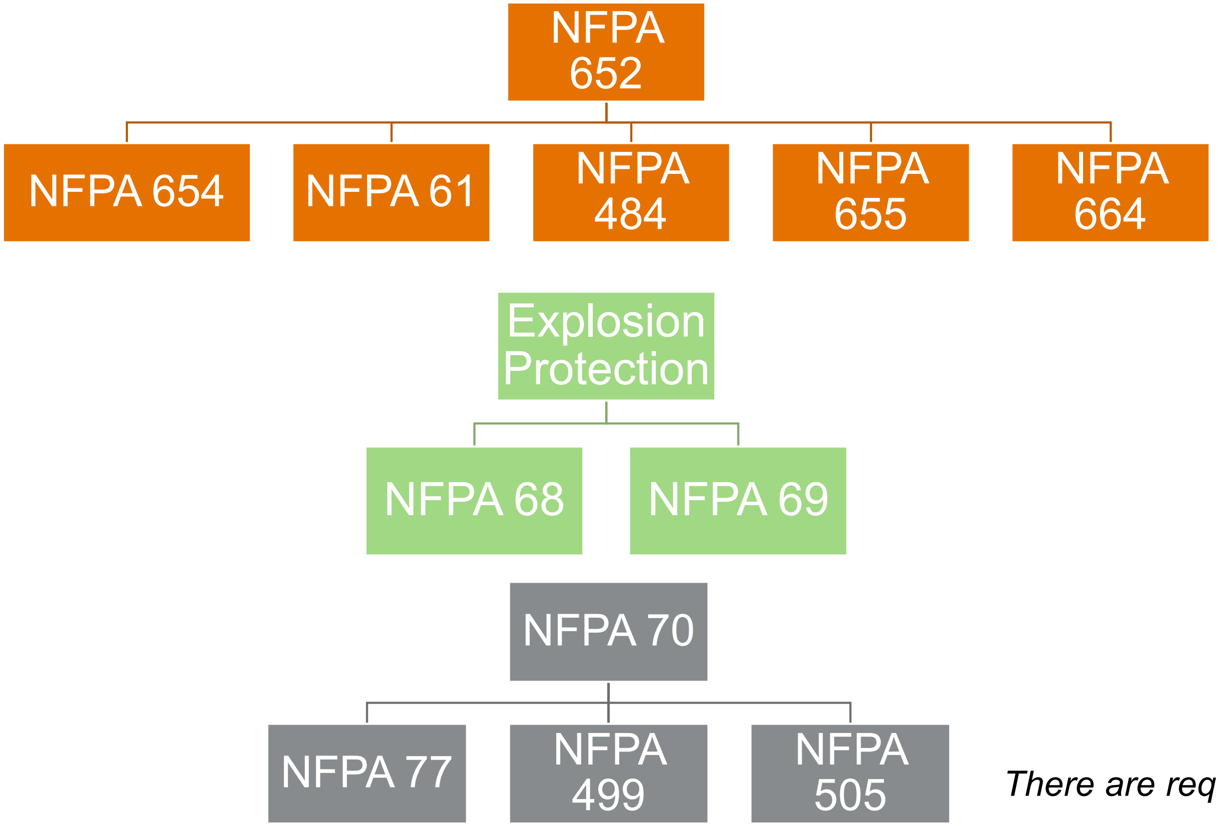
DUST EXPLOSION INCIDENTS (~10 year period)



	United States		United Kingdom		Germany	
Equipment	Number	Percent	Number	Percent	Number	Percent
Dust Collectors	156	42	55	18	73	17
Grinders/Pulverizers	35	9	51	17	56	13
Silos/Bunkers	27	7	19	6	86	20
Conveying System	32	9	33	11	43	10
Dryer/Oven	22	6	43	14	34	8
Mixers/Blenders	> 12	> 3	7	2	20	5
Other or Unknown	84	23	95	31	114	27
Total	372	100	303	100	426	100

What relevant standards exist for dust explosion hazards?

NFPA STANDARDS APPLICABLE TO DUST HAZARDS



NFPA 652

NFPA 654

NFPA 61

NFPA 484

NFPA 655

NFPA 664

Explosion Protection

NFPA 68

NFPA 69

NFPA 70

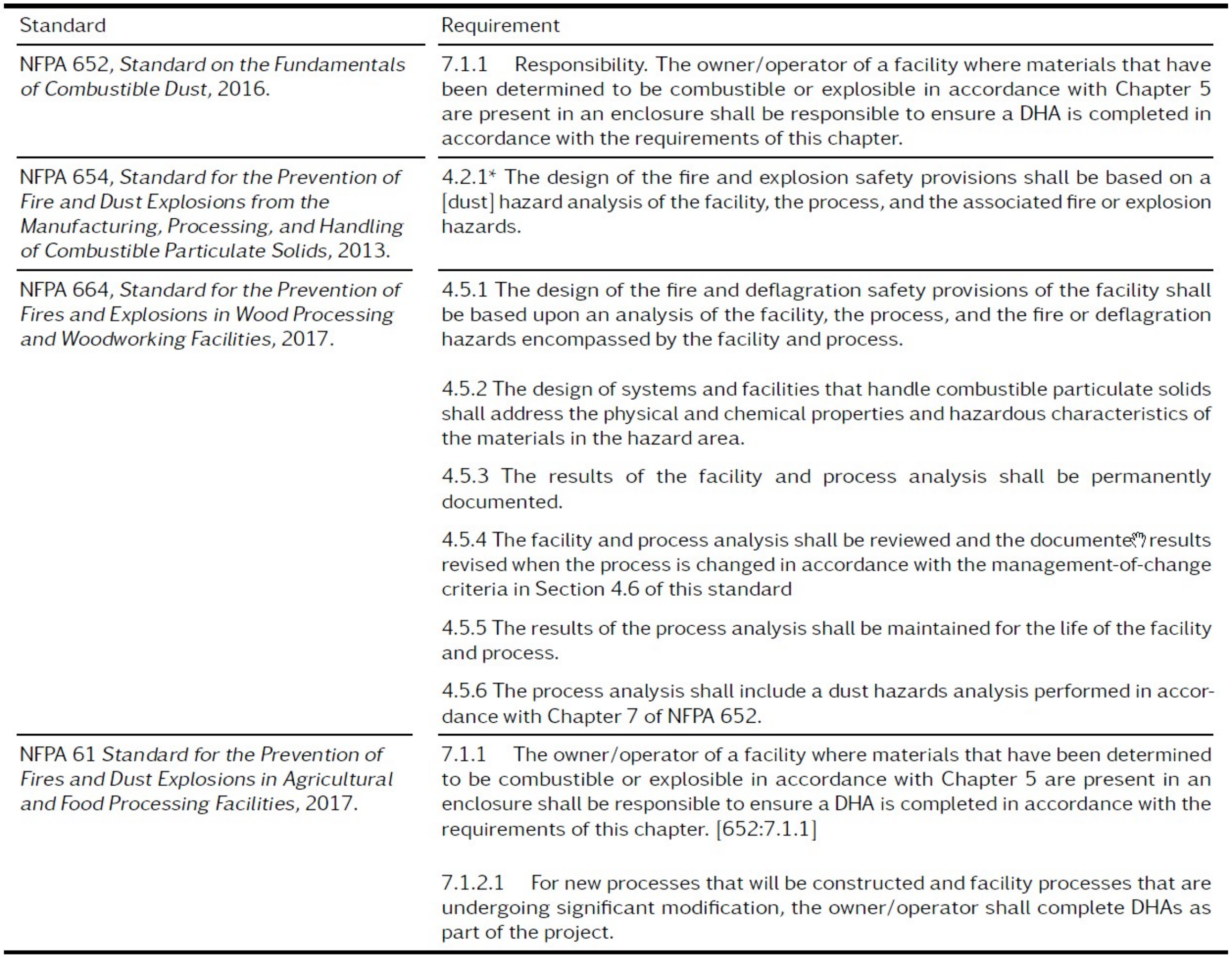
NFPA 77

NFPA 499

NFPA 505

There are requirements for testing and DHA

NFPA prescriptive requirements for dust hazard analyses.



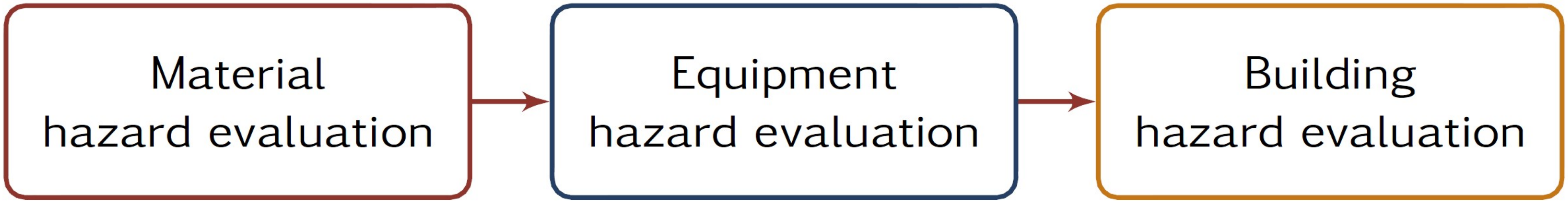
Standard	Requirement
NFPA 652, *Standard on the Fundamentals of Combustible Dust*, 2016.	7.1.1 Responsibility. The owner/operator of a facility where materials that have been determined to be combustible or explosible in accordance with Chapter 5 are present in an enclosure shall be responsible to ensure a DHA is completed in accordance with the requirements of this chapter.
NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, 2013.	4.2.1* The design of the fire and explosion safety provisions shall be based on a [dust] hazard analysis of the facility, the process, and the associated fire or explosion hazards.
NFPA 664, *Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities*, 2017.	4.5.1 The design of the fire and deflagration safety provisions of the facility shall be based upon an analysis of the facility, the process, and the fire or deflagration hazards encompassed by the facility and process. 4.5.2 The design of systems and facilities that handle combustible particulate solids shall address the physical and chemical properties and hazardous characteristics of the materials in the hazard area. 4.5.3 The results of the facility and process analysis shall be permanently documented. 4.5.4 The facility and process analysis shall be reviewed and the documented results revised when the process is changed in accordance with the management-of-change criteria in Section 4.6 of this standard 4.5.5 The results of the process analysis shall be maintained for the life of the facility and process. 4.5.6 The process analysis shall include a dust hazards analysis performed in accordance with Chapter 7 of NFPA 652.
NFPA 61 *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, 2017.	7.1.1 The owner/operator of a facility where materials that have been determined to be combustible or explosible in accordance with Chapter 5 are present in an enclosure shall be responsible to ensure a DHA is completed in accordance with the requirements of this chapter. [652:7.1.1] 7.1.2.1 For new processes that will be constructed and facility processes that are undergoing significant modification, the owner/operator shall complete DHAs as part of the project.

NFPA 652, 2018 edition:

“For existing facilities, a DHA is permitted to be phased in and completed not later than September 7, 2020.”

Testing is a key requirement of a DHA?

DHAs – Material hazard evaluation is a key step

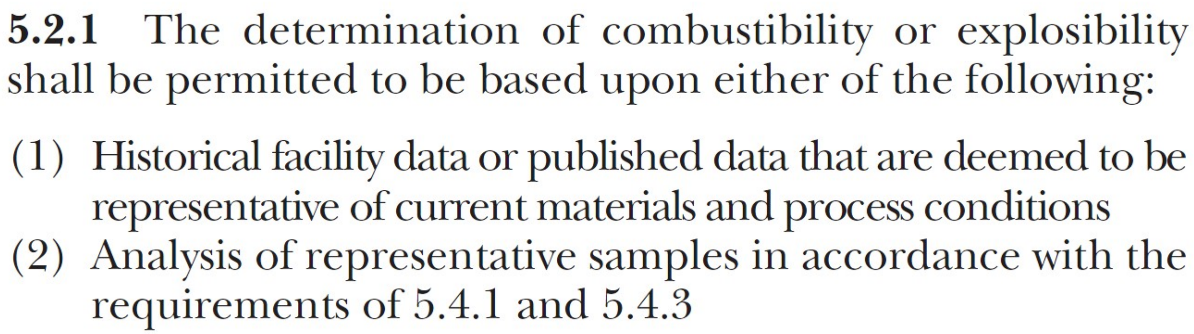


Material hazard evaluation

Equipment hazard evaluation

Building hazard evaluation

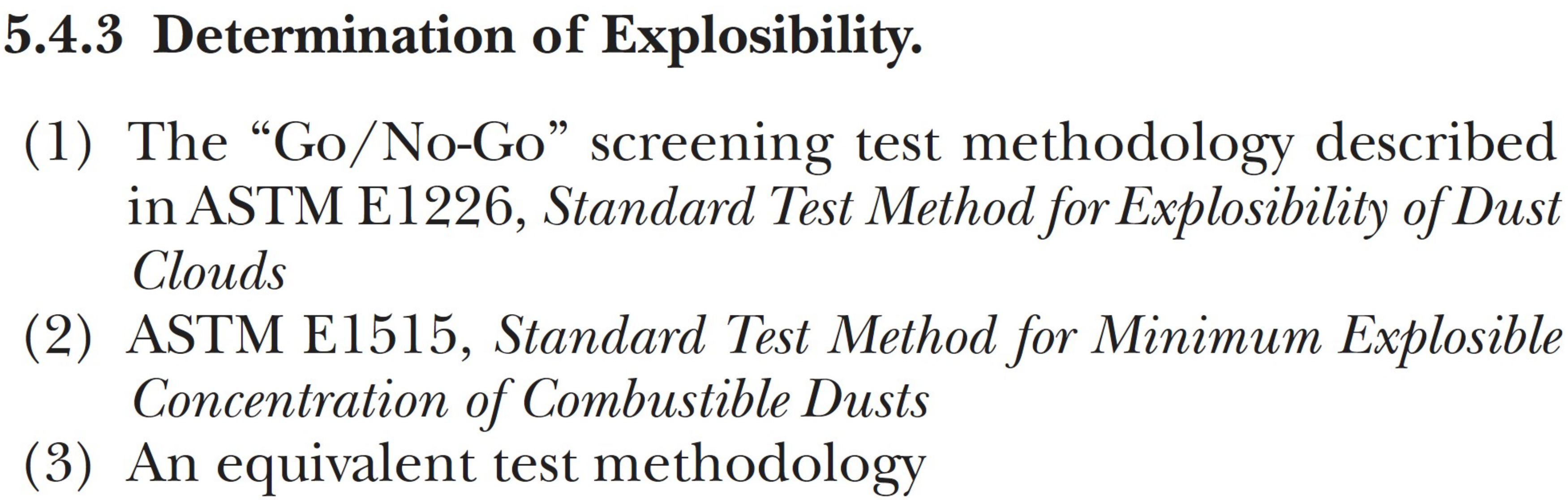
Step 1 – Is the dust explosible?



5.2.1 The determination of combustibility or explosibility shall be permitted to be based upon either of the following:

(1) Historical facility data or published data that are deemed to be representative of current materials and process conditions
(2) Analysis of representative samples in accordance with the requirements of 5.4.1 and 5.4.3

NFPA 652 – Hazard Identification



5.4.3 Determination of Explosibility.

(1) The "Go/No-Go" screening test methodology described in ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*

(2) ASTM E1515, *Standard Test Method for Minimum Explosible Concentration of Combustible Dusts*

(3) An equivalent test methodology

NFPA 652 – Hazard Identification

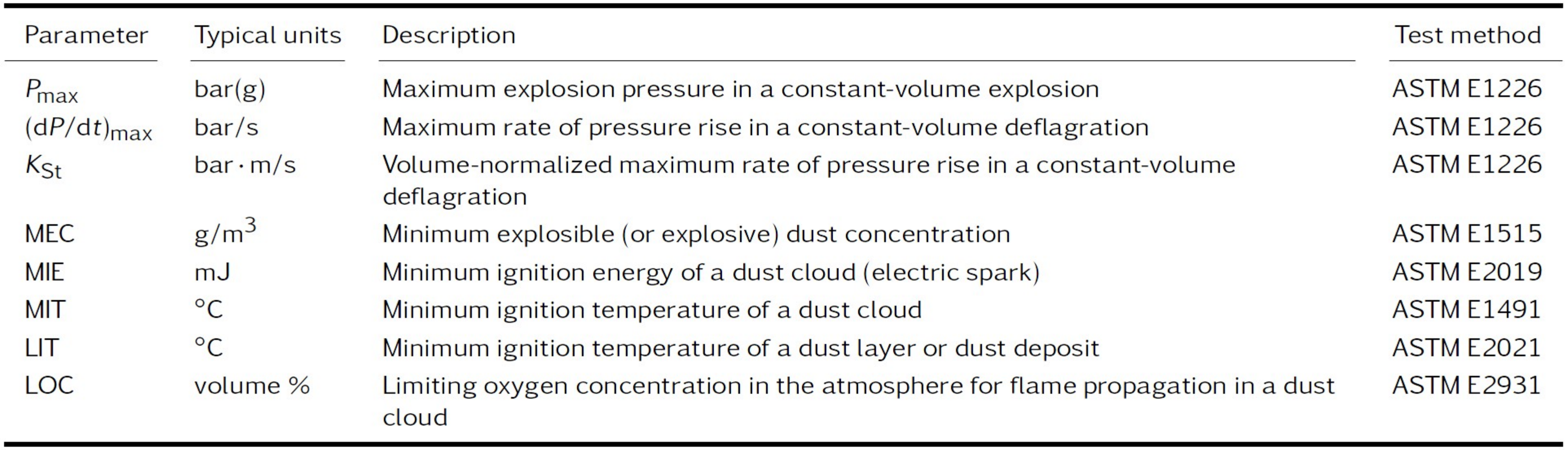
5.4.4.1* Where dusts are determined to be combustible or explosible, additional testing shall be performed, as required,

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

There are a suite of tests that are commonly performed...

Important dust explosibility parameters

Important dust explosibility parameters (adapted from Amyotte & Eckhoff [2010]).



Parameter	Typical units	Description	Test method
P_{max}	bar(g)	Maximum explosion pressure in a constant-volume explosion	ASTM E1226
$(dP/dt)_{\mathrm{max}}$	bar/s	Maximum rate of pressure rise in a constant-volume deflagration	ASTM E1226
K_{St}	bar · m/s	Volume-normalized maximum rate of pressure rise in a constant-volume deflagration	ASTM E1226
MEC	g/m^3	Minimum explosible (or explosive) dust concentration	ASTM E1515
MIE	mJ	Minimum ignition energy of a dust cloud (electric spark)	ASTM E2019
MIT	°C	Minimum ignition temperature of a dust cloud	ASTM E1491
LIT	°C	Minimum ignition temperature of a dust layer or dust deposit	ASTM E2021
LOC	volume %	Limiting oxygen concentration in the atmosphere for flame propagation in a dust cloud	ASTM E2931

Examples of explosion severity data…

Example values for explosion severity

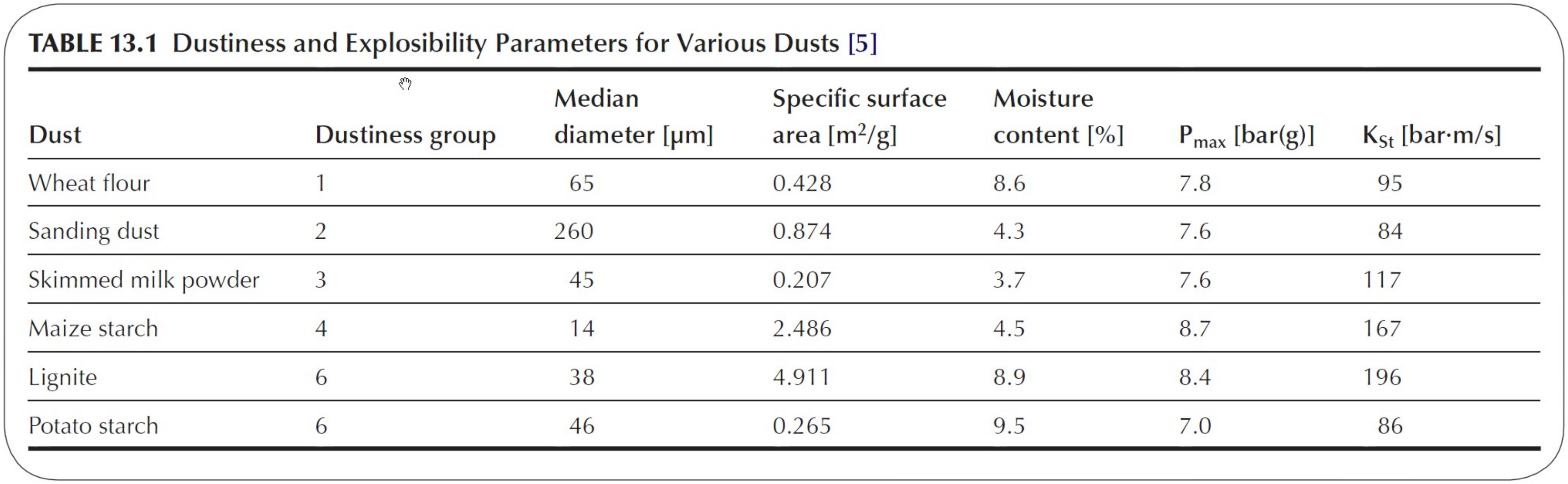


TABLE 13.1 Dustiness and Explosibility Parameters for Various Dusts [5]

Dust	Dustiness group	Median diameter [μm]	Specific surface area [m²/g]	Moisture content [%]	P_{max} [bar(g)]	K_{St} [bar·m/s]
Wheat flour	1	65	0.428	8.6	7.8	95
Sanding dust	2	260	0.874	4.3	7.6	84
Skimmed milk powder	3	45	0.207	3.7	7.6	117
Maize starch	4	14	2.486	4.5	8.7	167
Lignite	6	38	4.911	8.9	8.4	196
Potato starch	6	46	0.265	9.5	7.0	86

Source: Amyotte (2013)

Explosibility parameters are not fundamental properties…

Variability in literature values

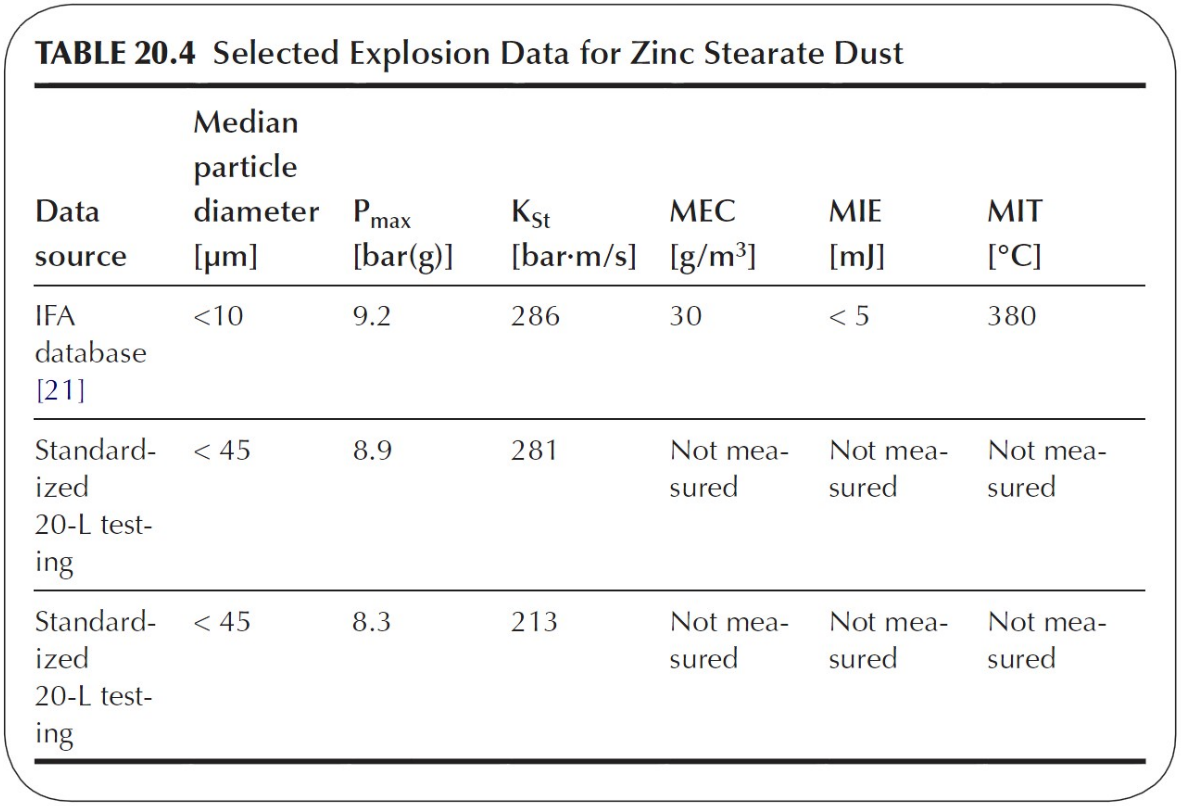


TABLE 20.4 Selected Explosion Data for Zinc Stearate Dust

Data source	Median particle diameter [μm]	P_{max} [bar(g)]	K_{St} [bar·m/s]	MEC [g/m^3]	MIE [mJ]	MIT [°C]
IFA database [21]	<10	9.2	286	30	< 5	380
Standardized 20-L testing	< 45	8.9	281	Not measured	Not measured	Not measured
Standardized 20-L testing	< 45	8.3	213	Not measured	Not measured	Not measured

Source: Amyotte (2013)

Dust explosibility parameters are not fundamental properties.

Dust explosibility parameters are process-dependent.

Atomized aluminum particle explosibility data

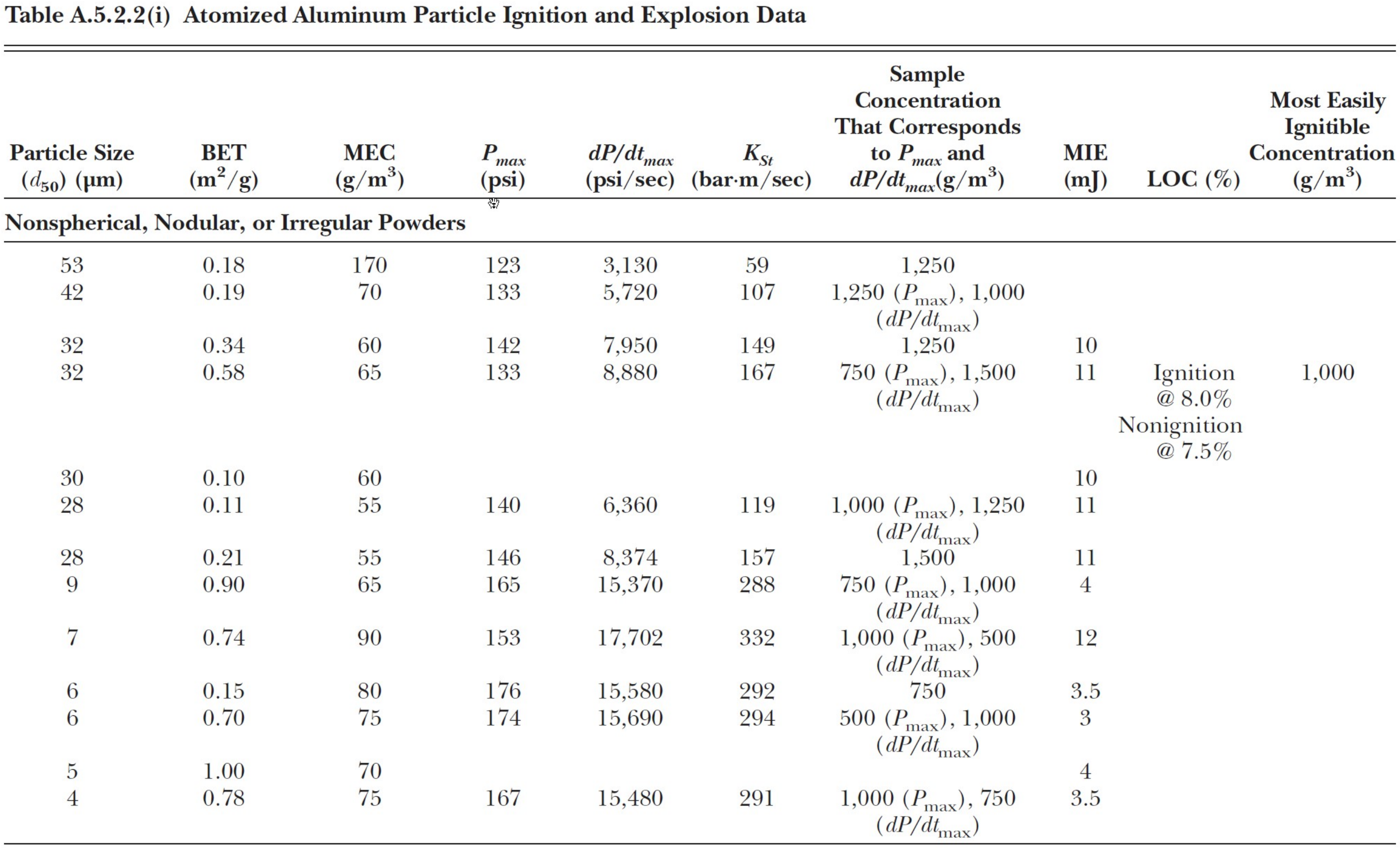
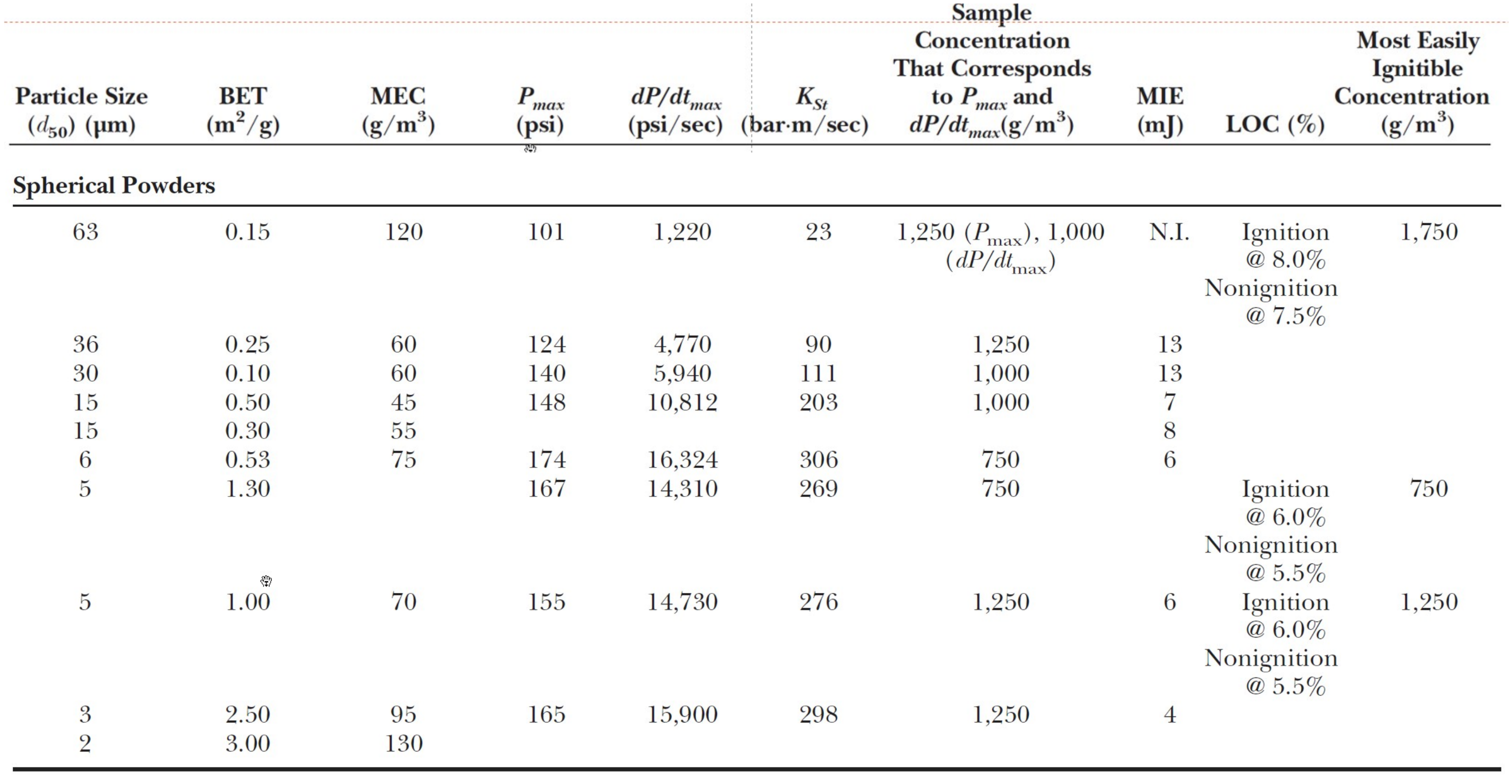


Table A.5.2.2(i) Atomized Aluminum Particle Ignition and Explosion Data

Particle Size (d_{50}) (μm)	BET (m^2/g)	MEC (g/m^3)	P_{max} (psi)	dP/dt_{max} (psi/sec)	K_{St} (bar·m/sec)	Sample Concentration That Corresponds to P_{max} and dP/dt_{max} (g/m^3)	MIE (mJ)	LOC (%)	Most Easily Ignitible Concentration (g/m^3)
Nonspherical, Nodular, or Irregular Powders									
53	0.18	170	123	3,130	59	1,250			
42	0.19	70	133	5,720	107	1,250 (P_{max}), 1,000 (dP/dt_{max})			
32	0.34	60	142	7,950	149	1,250	10		
32	0.58	65	133	8,880	167	750 (P_{max}), 1,500 (dP/dt_{max})	11	Ignition @ 8.0% Nonignition @ 7.5%	1,000
30	0.10	60					10		
28	0.11	55	140	6,360	119	1,000 (P_{max}), 1,250 (dP/dt_{max})	11		
28	0.21	55	146	8,374	157	1,500	11		
9	0.90	65	165	15,370	288	750 (P_{max}), 1,000 (dP/dt_{max})	4		
7	0.74	90	153	17,702	332	1,000 (P_{max}), 500 (dP/dt_{max})	12		
6	0.15	80	176	15,580	292	750	3.5		
6	0.70	75	174	15,690	294	500 (P_{max}), 1,000 (dP/dt_{max})	3		
5	1.00	70					4		
4	0.78	75	167	15,480	291	1,000 (P_{max}), 750 (dP/dt_{max})	3.5		

Source: NFPA 652 (2016)

Atomized aluminum particle explosibility data



Particle Size (d_{50}) (µm)	BET (m^2/g)	MEC (g/m^3)	P_{max} (psi)	dP/dt_{max} (psi/sec)	K_{St} (bar·m/sec)	Sample Concentration That Corresponds to P_{max} and dP/dt_{max} (g/m^3)	MIE (mJ)	LOC (%)	Most Easily Ignitible Concentration (g/m^3)
Spherical Powders									
63	0.15	120	101	1,220	23	1,250 (P_{max}), 1,000 (dP/dt_{max})	N.I.	Ignition @ 8.0% Nonignition @ 7.5%	1,750
36	0.25	60	124	4,770	90	1,250	13		
30	0.10	60	140	5,940	111	1,000	13		
15	0.50	45	148	10,812	203	1,000	7		
15	0.30	55					8		
6	0.53	75	174	16,324	306	750	6		
5	1.30		167	14,310	269	750		Ignition @ 6.0% Nonignition @ 5.5%	750
5	1.00	70	155	14,730	276	1,250	6	Ignition @ 6.0% Nonignition @ 5.5%	1,250
3	2.50	95	165	15,900	298	1,250	4		
2	3.00	130							

Source: NFPA 652 (2016)

Some terminology…

TERMINOLOGY

- Combustion – rapid, self-sustaining oxidation of fuel
- Flaming combustion – hot column of gaseous combustion products
- Combustion wave – narrow region in which combustion occurs
- Flame – combustion wave at a velocity less than speed of sound with
- Deflagration – flames that move through the unburnt mixture
- Dust explosion – deflagration with associated rise in pressure
- Flash fire – deflagration in the open, no rise in pressure

What are some key differences between gas and dust explosions?

KEY DIFFERENCES BETWEEN GAS AND DUST

- Necessary conditions for an explosion – explosion pentagon
- Chemical purity of the fuel
- Particle size and shape
- Uniformity of fuel concentration and initial turbulence
- Range of fuel concentrations
- Heterogeneous and homogeneous chemical reactions
- Incomplete combustion

Source: Ogle

What are the most common ways to protect equipment from dust explosions?

DEFEATING THE EXPLOSION PENTAGON

FUEL	OXIDIZER	IGNITION SOURCE	SUSPENSION	CONFINEMENT
Substitute noncombustible material	Reduce oxygen concentration in equipment with inert gas	Eliminate open flames	Avoid excessive air current velocities	Design equipment to contain explosion pressures
Add inert material	Install oxygen sensors and interlocks to shutdown equipment if oxygen level is exceeded	Install explosion-proof electrical service	Control fugitive dust accumulations	Install explosion vent panels
Agglomerate to larger particle size		Control static electricity	Apply inert liquid to dust deposits to prevent entrainment by convection	Install explosion isolation
		Administer hot work safety program		
		Explosion suppression		

Source:Ogle

What are the most common ways to protect equipment from dust explosions?

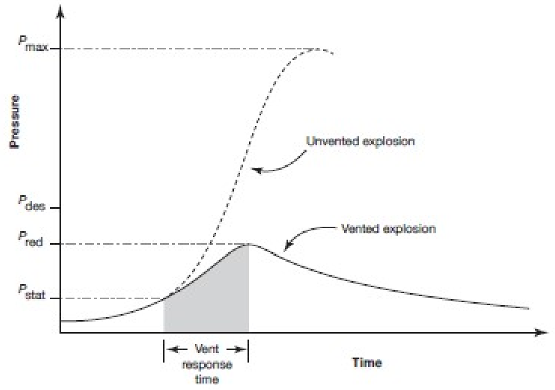
MOST COMMON FORMS OF EXPLOSION PROTECTION

Explosion venting

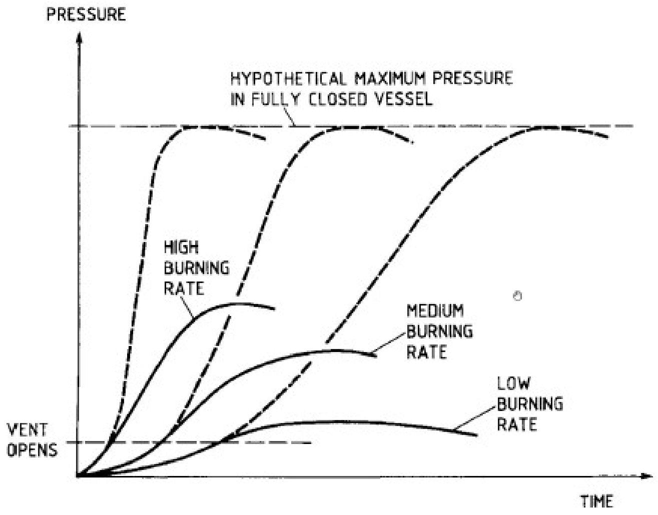
Explosion suppression

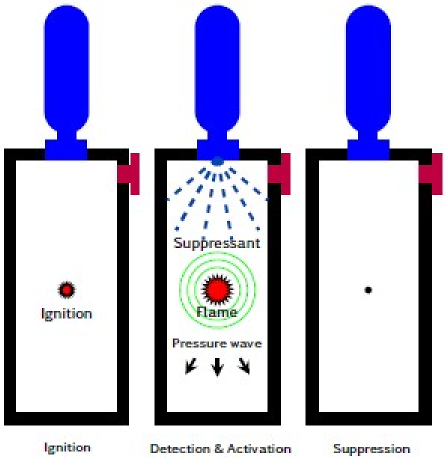
What are the driving factors that influence the design of explosion protection?

EXPLOSION VENTING OR SUPPRESSION



Explosion venting

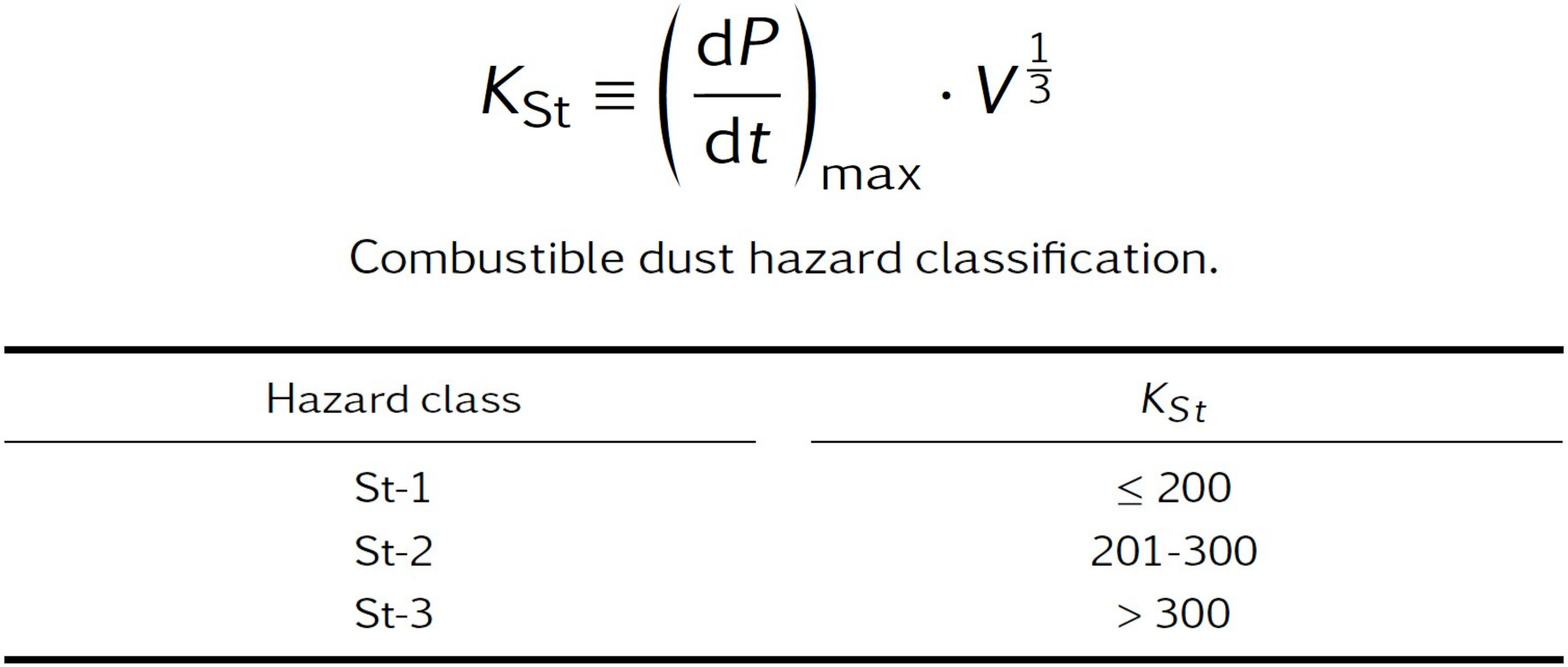




Explosion suppression

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left(1 + 1.54 \cdot P_{stat}^{4/3}\right) \cdot K_{St} \cdot V^{3/4} \cdot \sqrt{\frac{P_{max}}{P_{red}} - 1}$$

Combustible dust hazard classification



$$K_{St} \equiv \left(\frac{dP}{dt}\right)_{max} \cdot V^{\frac{1}{3}}$$

Combustible dust hazard classification.

Hazard class	K_{St}
St-1	≤ 200
St-2	201-300
St-3	> 300

Source: Bartknecht

Explosion severity pressure-time trace

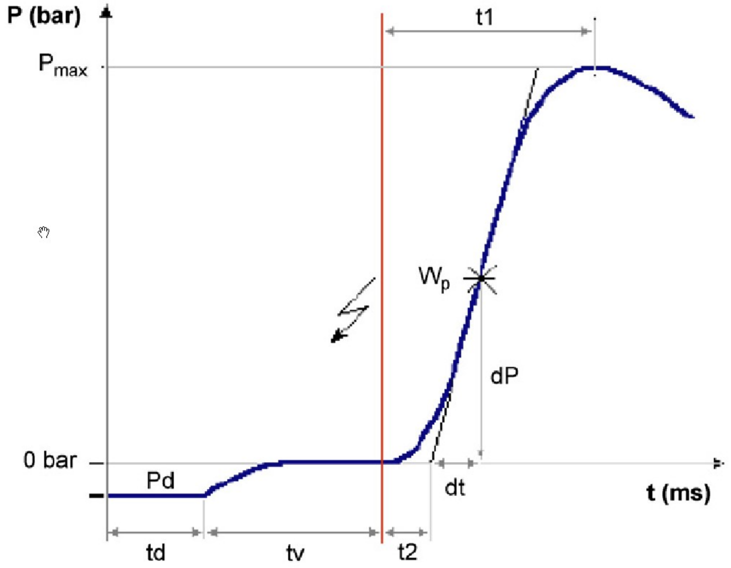
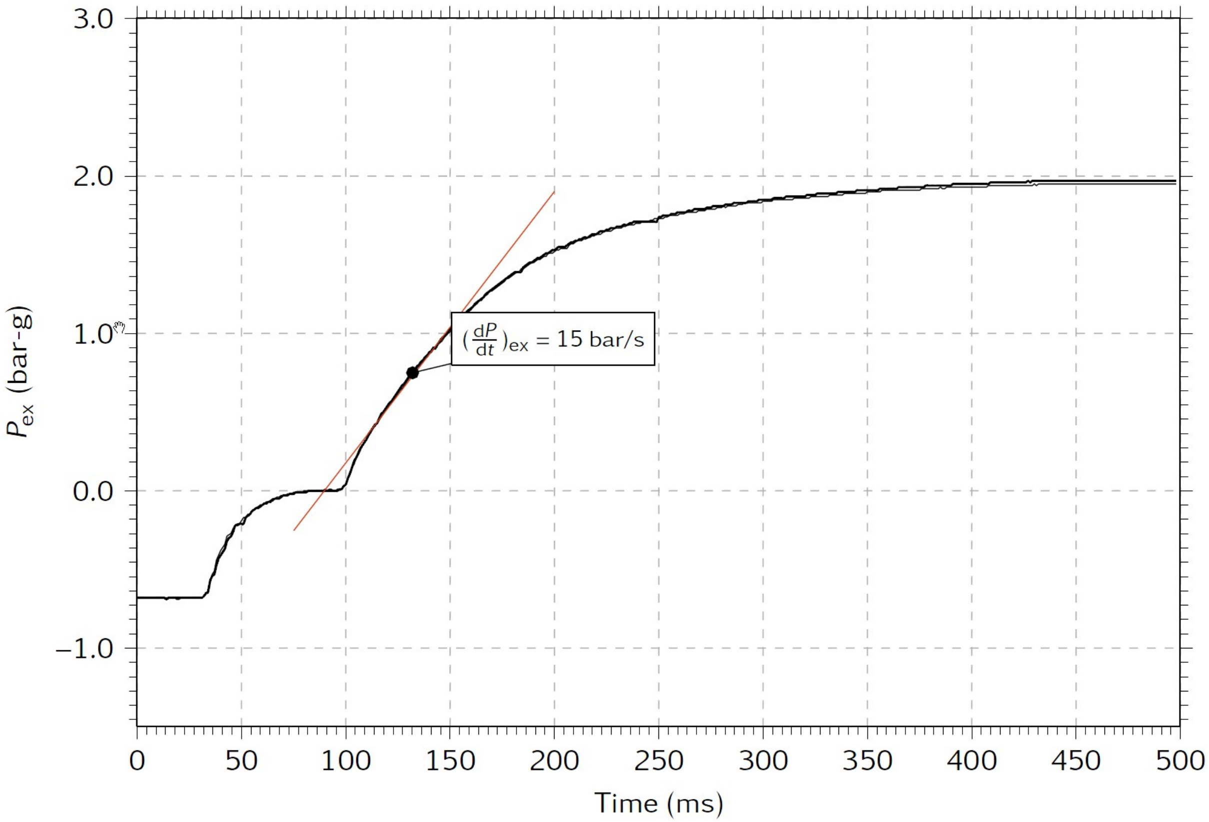


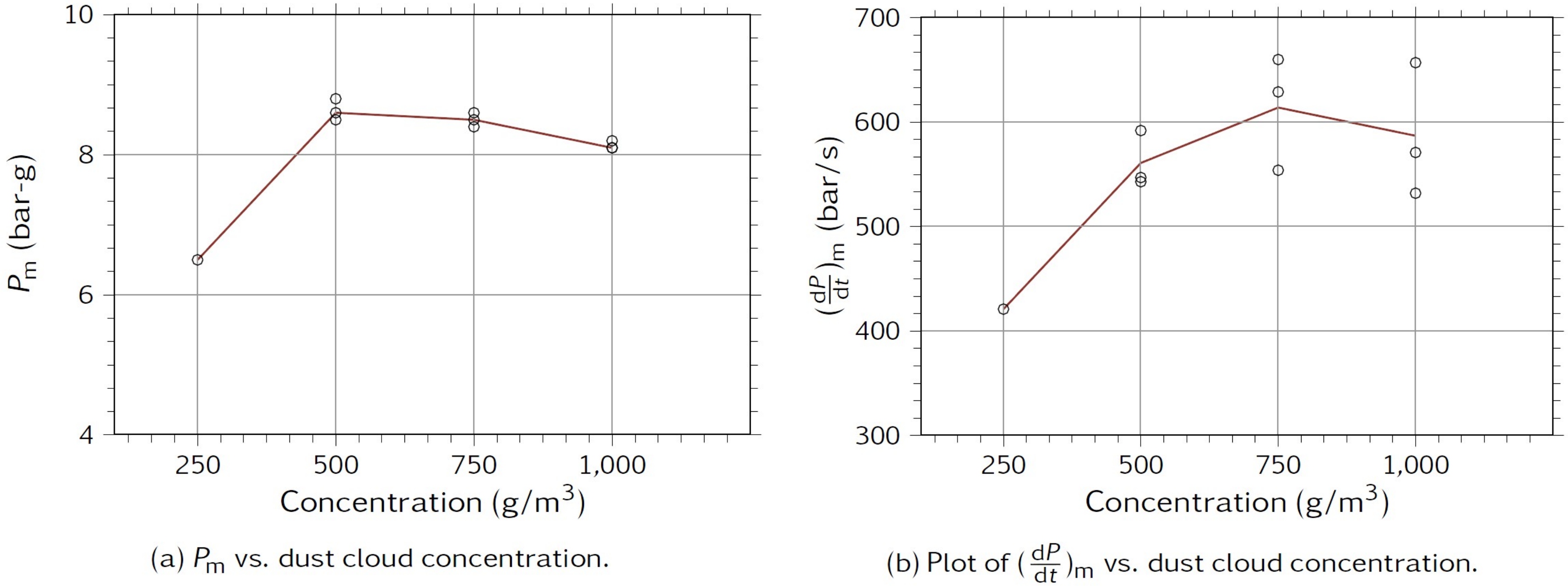
Fig. 1. Typical overpressure versus time during a dust explosion. t_1 (combustion time), time between ignition and P_{ex}; t_2 (induction time), time between ignition and intercept with $P = 0$ line of the tangent to the inflexion point W_p; P_d, expanding pressure (if any) of the dust reservoir given as the difference between initial pressure before and after dust dispersion; t_v, time between beginning of the dust dispersion and ignition; and $(dP/dt)_{max}$ is the slope of the tangent at W_p.

Source: Proust et al. (2007)

Explosibility test data



Explosion severity test results



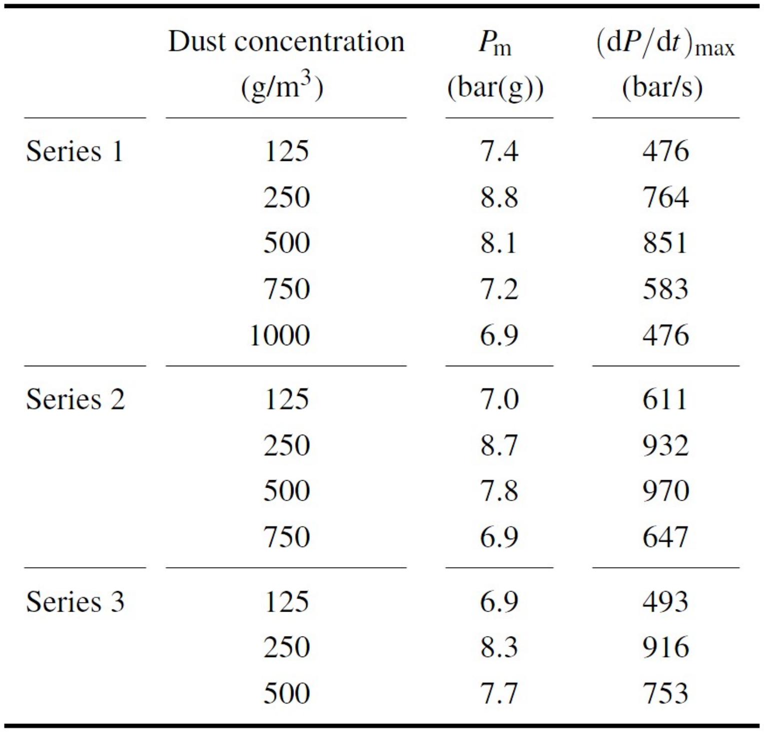
(a) P_m vs. dust cloud concentration.

(b) Plot of $(\frac{dP}{dt})_m$ vs. dust cloud concentration.

Explosion severity test results.

HOW K_{ST} IS DETERMINED

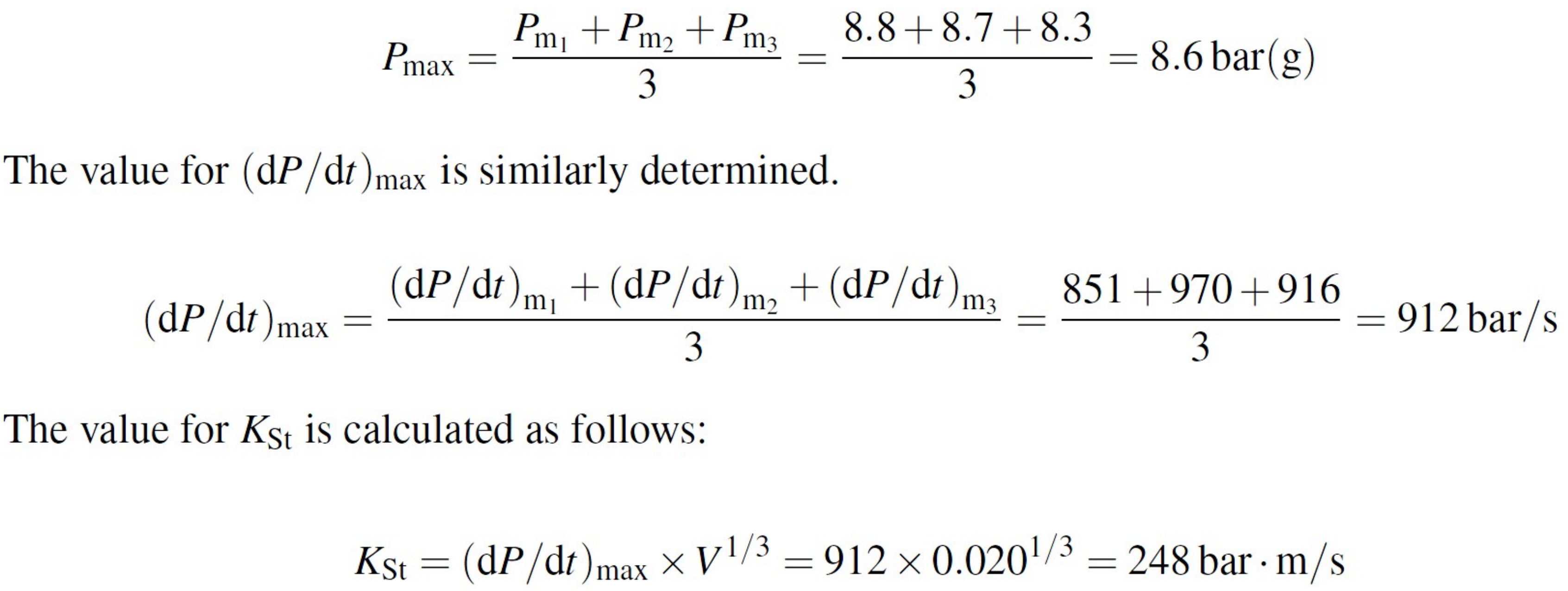
Table 1: P_{max}/K_{St} Data Determined in a Siwek 20-L Chamber According to ASTM E1226.



	Dust concentration (g/m^3)	P_m (bar(g))	$(dP/dt)_{max}$ (bar/s)
Series 1	125	7.4	476
	250	8.8	764
	500	8.1	851
	750	7.2	583
	1000	6.9	476
Series 2	125	7.0	611
	250	8.7	932
	500	7.8	970
	750	6.9	647
Series 3	125	6.9	493
	250	8.3	916
	500	7.7	753

Source: Amyotte (2013)

HOW K_{ST} IS DETERMINED



$$P_{\max} = \frac{P_{m_1} + P_{m_2} + P_{m_3}}{3} = \frac{8.8 + 8.7 + 8.3}{3} = 8.6\,\text{bar(g)}$$

The value for $(dP/dt)_{\max}$ is similarly determined.

$$(dP/dt)_{\max} = \frac{(dP/dt)_{m_1} + (dP/dt)_{m_2} + (dP/dt)_{m_3}}{3} = \frac{851 + 970 + 916}{3} = 912\,\text{bar/s}$$

The value for K_{St} is calculated as follows:

$$K_{St} = (dP/dt)_{\max} \times V^{1/3} = 912 \times 0.020^{1/3} = 248\,\text{bar}\cdot\text{m/s}$$

Source: Amyotte (2013)

SCALABILITY BETWEEN 20-L AND 1-M^3 CHAMBERS

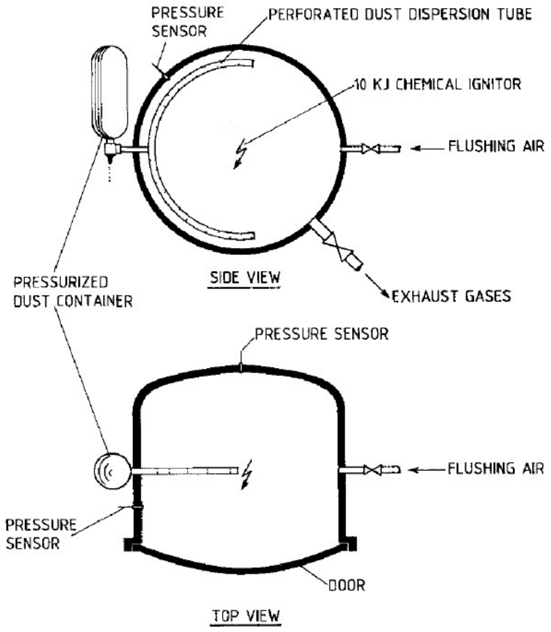
Jensen Hughes 1-m3 chamber

Jensen Hughes 20-L chamber

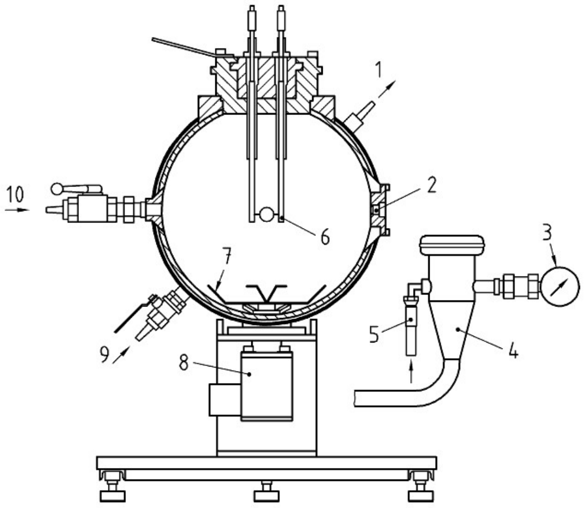
“Cubic relationship” $$\left(\frac{dP}{dt}\right)_{\text{max}} \times \sqrt[3]{V} \equiv K_{St} \approx \text{constant}$$

How are P_{max} and $(dP/dt)_{max}$ determined?

Standardized test apparatuses

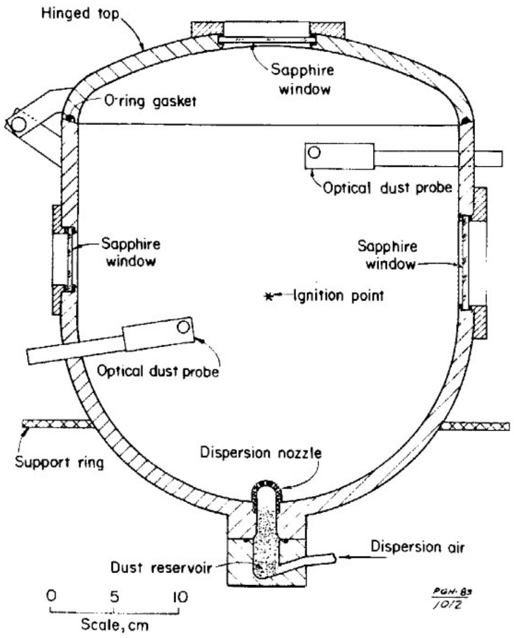


1-m^3 ISO



1	water outlet
2	pressure sensors
3	manometer
4	dust container (0,6 dm^3)
5	air inlet
6	ignition source
7	rebound nozzle
8	fast acting valve
9	water inlet
10	outlet (air, reaction products)

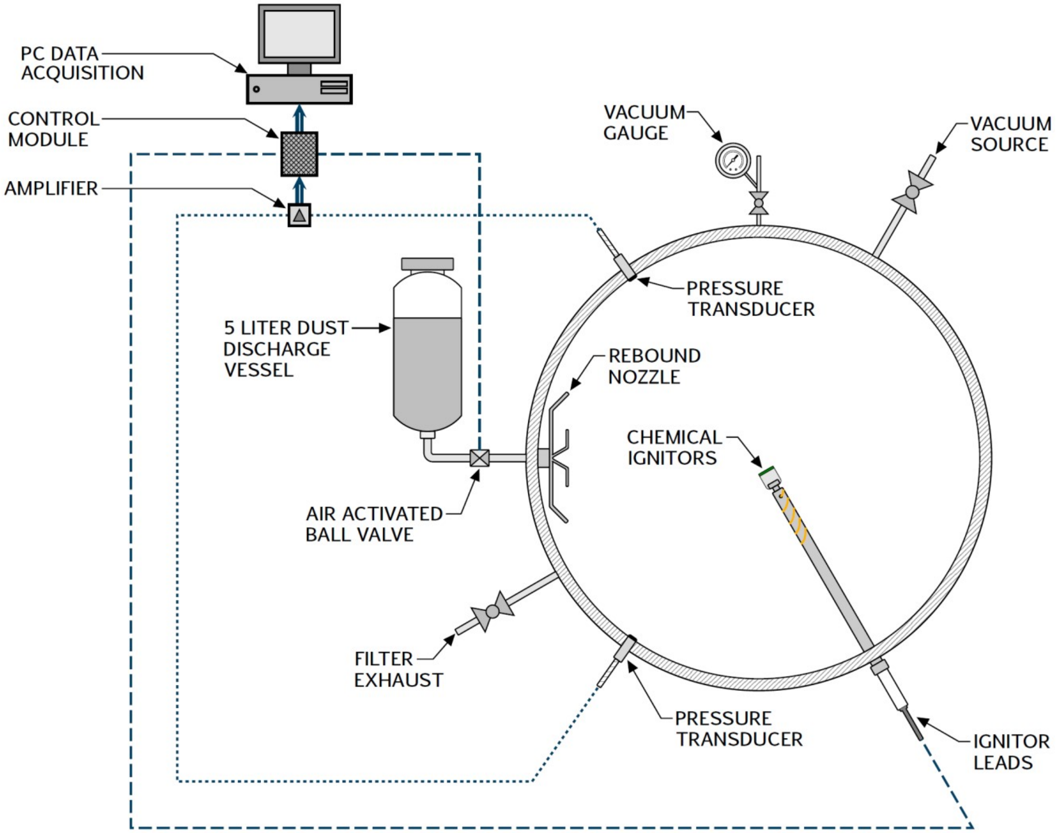
20-L Siwek chamber



USBM 20-L

Source: Eckhoff (2003)

Standardized test apparatuses



Key differences among these apparatus…

Standardized test apparatuses

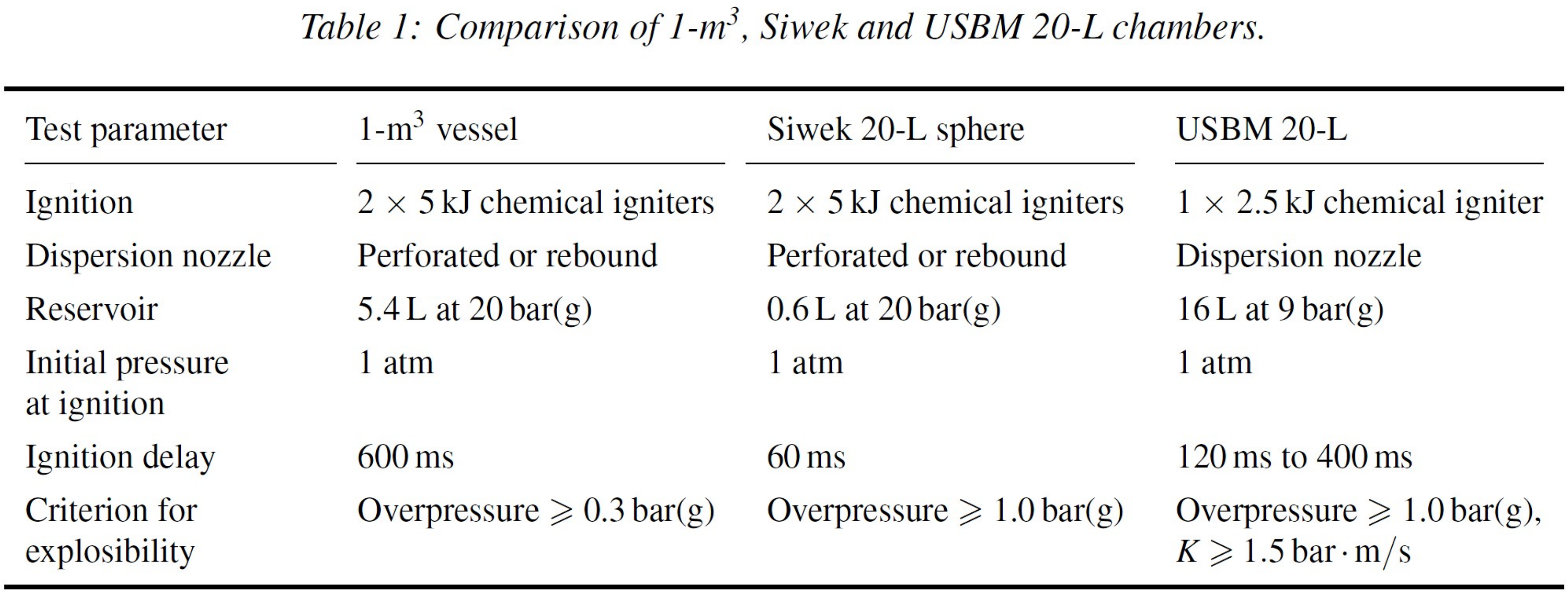
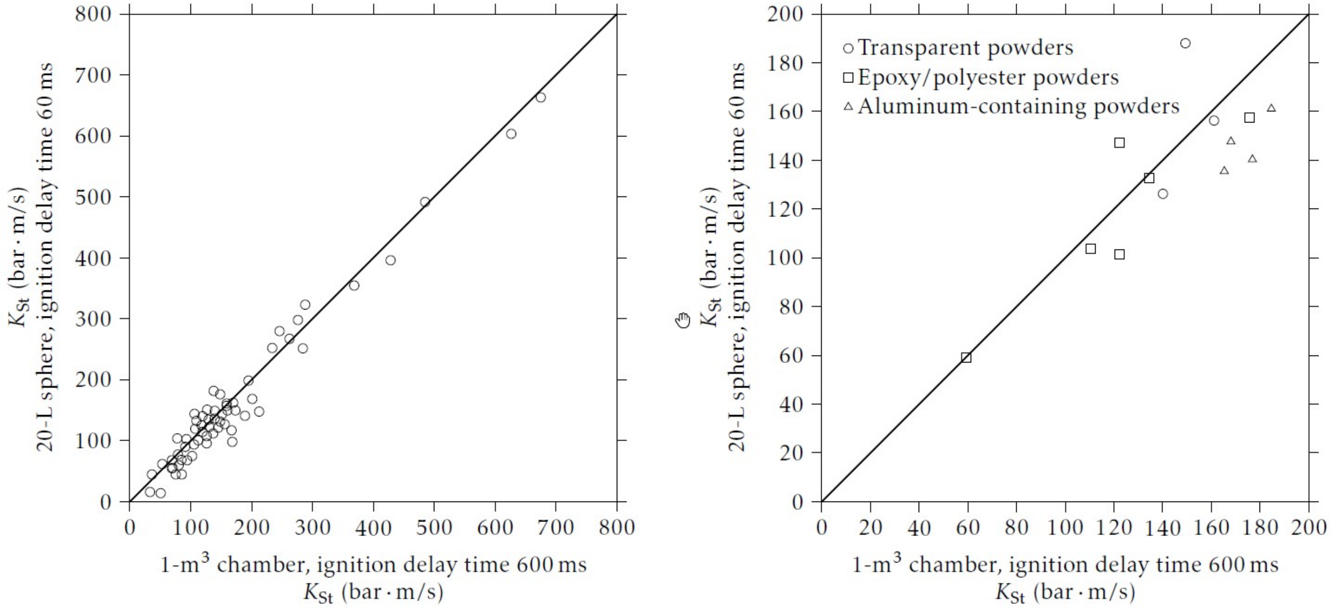


Table 1: Comparison of 1-m^3, Siwek and USBM 20-L chambers.

Test parameter	1-m^3 vessel	Siwek 20-L sphere	USBM 20-L
Ignition	2 × 5 kJ chemical igniters	2 × 5 kJ chemical igniters	1 × 2.5 kJ chemical igniter
Dispersion nozzle	Perforated or rebound	Perforated or rebound	Dispersion nozzle
Reservoir	5.4 L at 20 bar(g)	0.6 L at 20 bar(g)	16 L at 9 bar(g)
Initial pressure at ignition	1 atm	1 atm	1 atm
Ignition delay	600 ms	60 ms	120 ms to 400 ms
Criterion for explosibility	Overpressure $\geqslant 0.3$ bar(g)	Overpressure $\geqslant 1.0$ bar(g)	Overpressure $\geqslant 1.0$ bar(g), $K \geqslant 1.5$ bar · m/s

20-L K_{St} values have been shown to correspond to those of the one cubic-meter …

CONTEXT: SCALABILITY BETWEEN 20-L AND 1-M^3 CHAMBERS



K_{St}-values of various dusts measured in the 1-m^3 vessel and the 20-L Siwek chamber (Bartknecht, 1989). This figure adapted from Dahoe et al. (2001)

There are many materials for which the 20-L and 1-m^3 data do not correspond…

ROUND-ROBIN TESTING WORLD WIDE

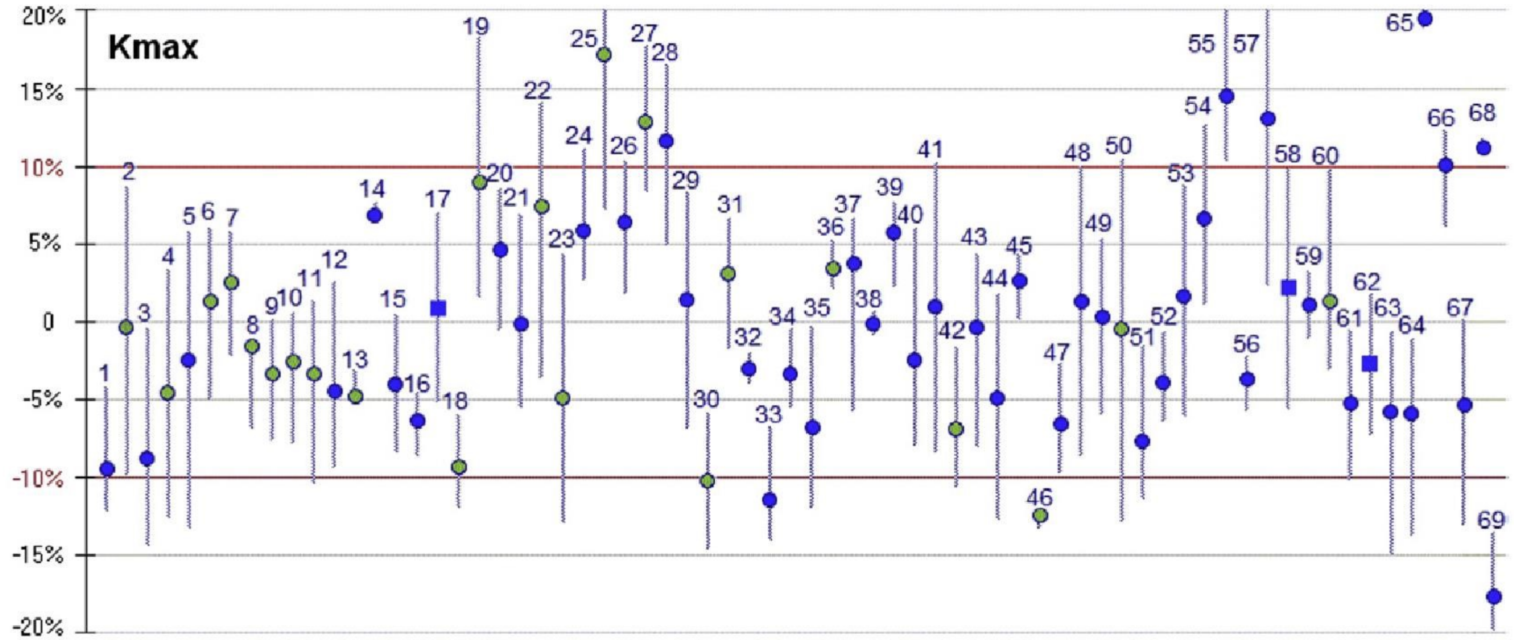
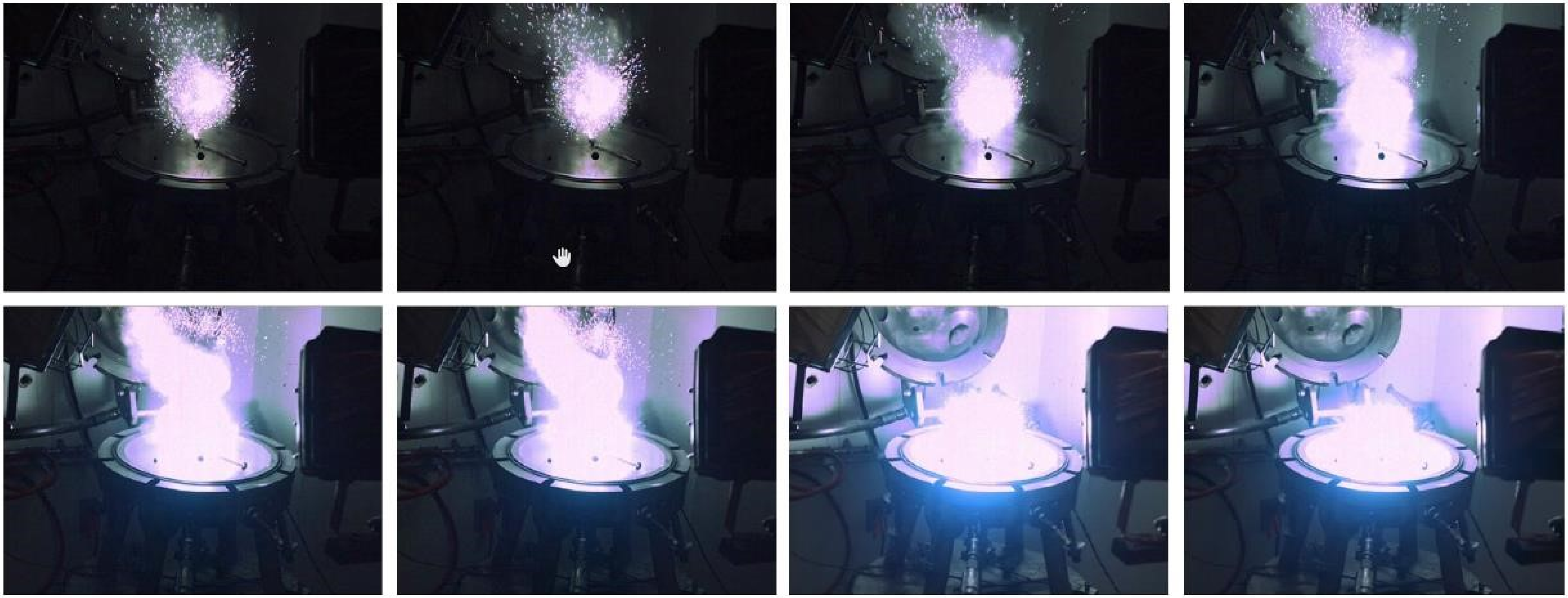


FIGURE 19.2 Results of international calibration-round-robin testing (CaRo 11) for K_{St} (or K_{max}) [8]. The circles represent data from 66 standardized 20-L chambers (using chemical ignitors from either of two manufacturers); the squares represent data from three standardized 1-m^3 chambers.

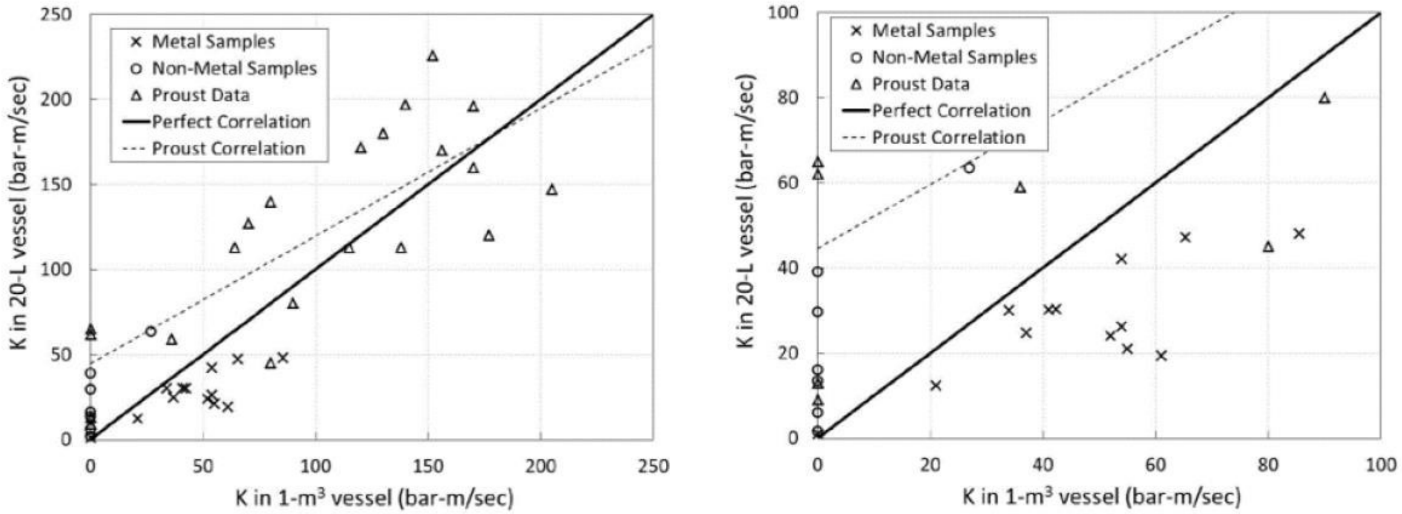
Source: Amyotte (2013)

INFLUENCE OF IGNITERS ON 20-L TESTING



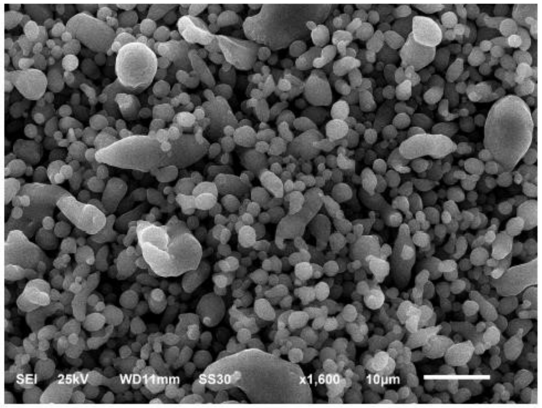
The scalability of the 20-L chamber was shown to not correspond for some materials…

COMPARISON OF KST VALUES

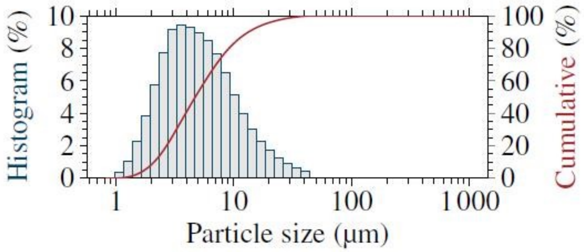


Discrepancies between 20-L and 1-m^3 data (Busher et al. (2012))

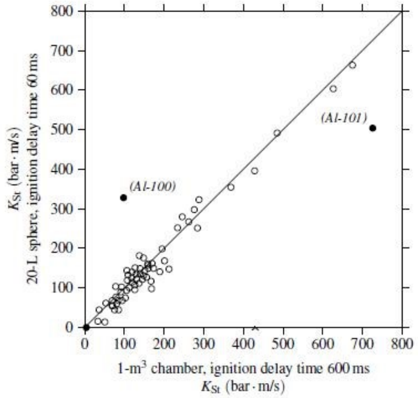
EXAMPLE – Aluminum

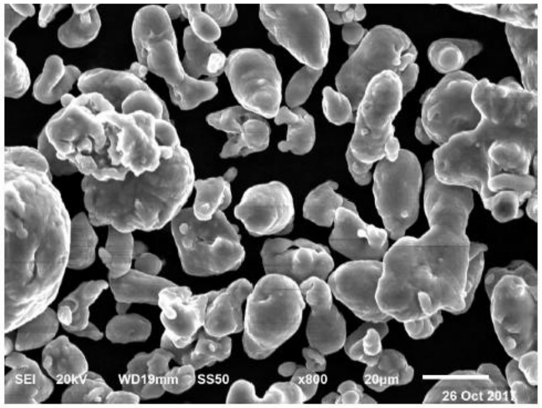


SEM for Al 100 (×1600)

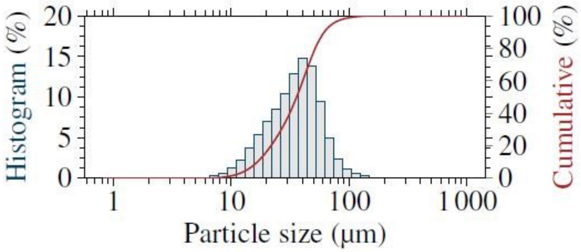


Al 100





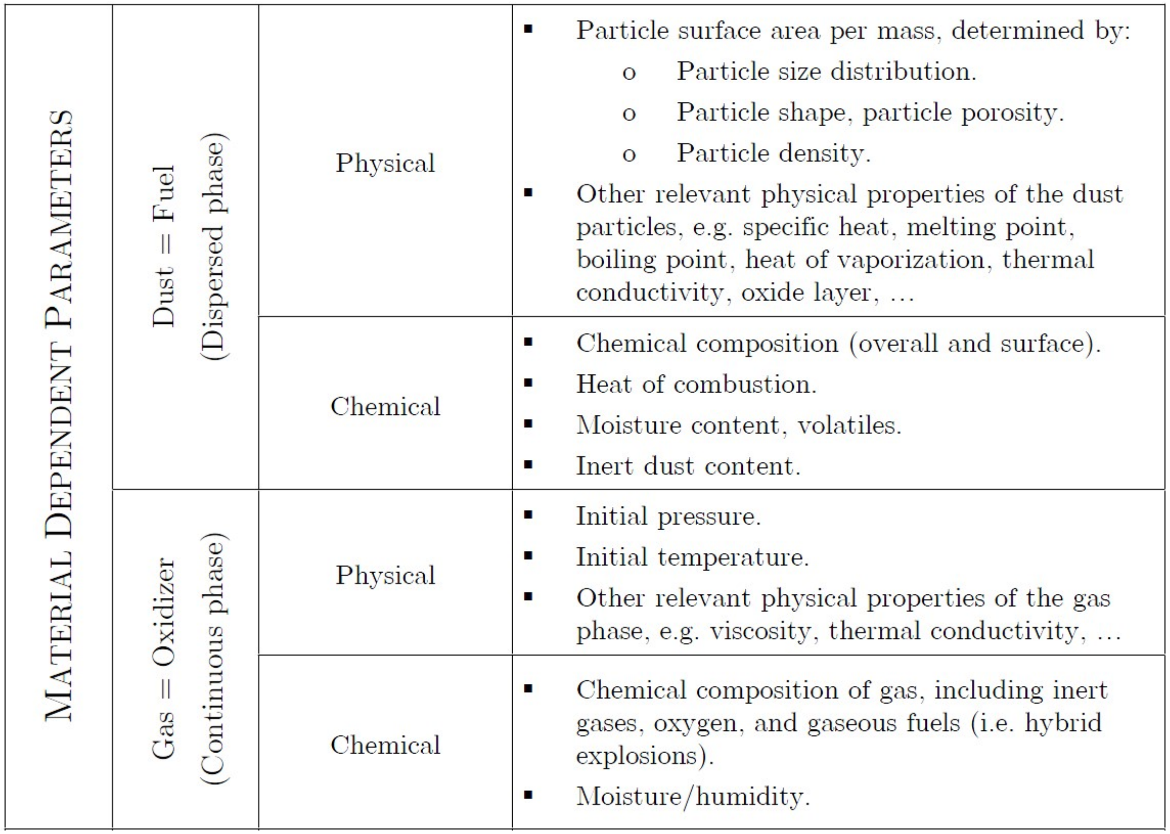
SEM for Al 101 (×800)



Al 101

There are other materials

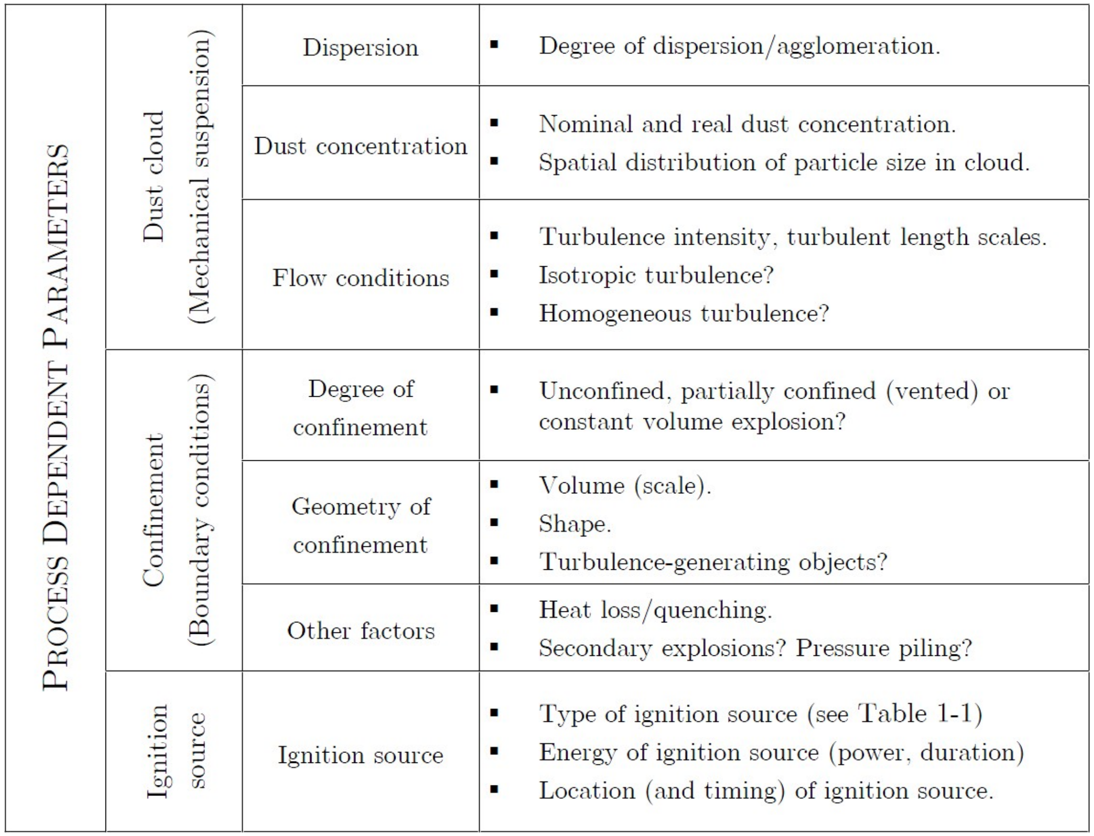
Material-dependent parameters



MATERIAL DEPENDENT PARAMETERS	Dust = Fuel (Dispersed phase)	Physical	▪ Particle surface area per mass, determined by: o Particle size distribution. o Particle shape, particle porosity. o Particle density. ▪ Other relevant physical properties of the dust particles, e.g. specific heat, melting point, boiling point, heat of vaporization, thermal conductivity, oxide layer, …
		Chemical	▪ Chemical composition (overall and surface). ▪ Heat of combustion. ▪ Moisture content, volatiles. ▪ Inert dust content.
	Gas = Oxidizer (Continuous phase)	Physical	▪ Initial pressure. ▪ Initial temperature. ▪ Other relevant physical properties of the gas phase, e.g. viscosity, thermal conductivity, …
		Chemical	▪ Chemical composition of gas, including inert gases, oxygen, and gaseous fuels (i.e. hybrid explosions). ▪ Moisture/humidity.

Source: Skold (2003)

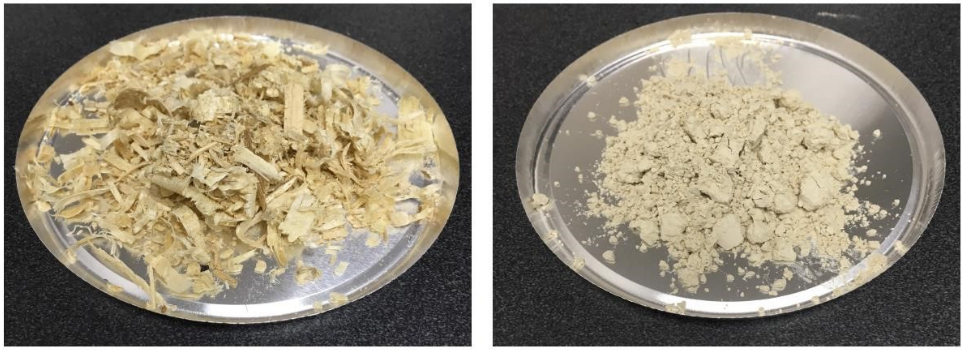
Process-dependent parameters



PROCESS DEPENDENT PARAMETERS	Dust cloud (Mechanical suspension)	Dispersion	▪ Degree of dispersion/agglomeration.
		Dust concentration	▪ Nominal and real dust concentration. ▪ Spatial distribution of particle size in cloud.
		Flow conditions	▪ Turbulence intensity, turbulent length scales. ▪ Isotropic turbulence? ▪ Homogeneous turbulence?
	Confinement (Boundary conditions)	Degree of confinement	▪ Unconfined, partially confined (vented) or constant volume explosion?
		Geometry of confinement	▪ Volume (scale). ▪ Shape. ▪ Turbulence-generating objects?
		Other factors	▪ Heat loss/quenching. ▪ Secondary explosions? Pressure piling?
	Ignition source	Ignition source	▪ Type of ignition source (see Table 1-1) ▪ Energy of ignition source (power, duration) ▪ Location (and timing) of ignition source.

Source: Skold (2003)

Particle size distribution



(a) Sample as received.

(b) Sample as tested.

(c) Sample as received.

(d) Sample as tested.

Figure 1: Samples as received and as tested.

Particle size distribution

(a) Dried dust sample as received.

(b) Ground dust sample as tested.

TURBULENCE

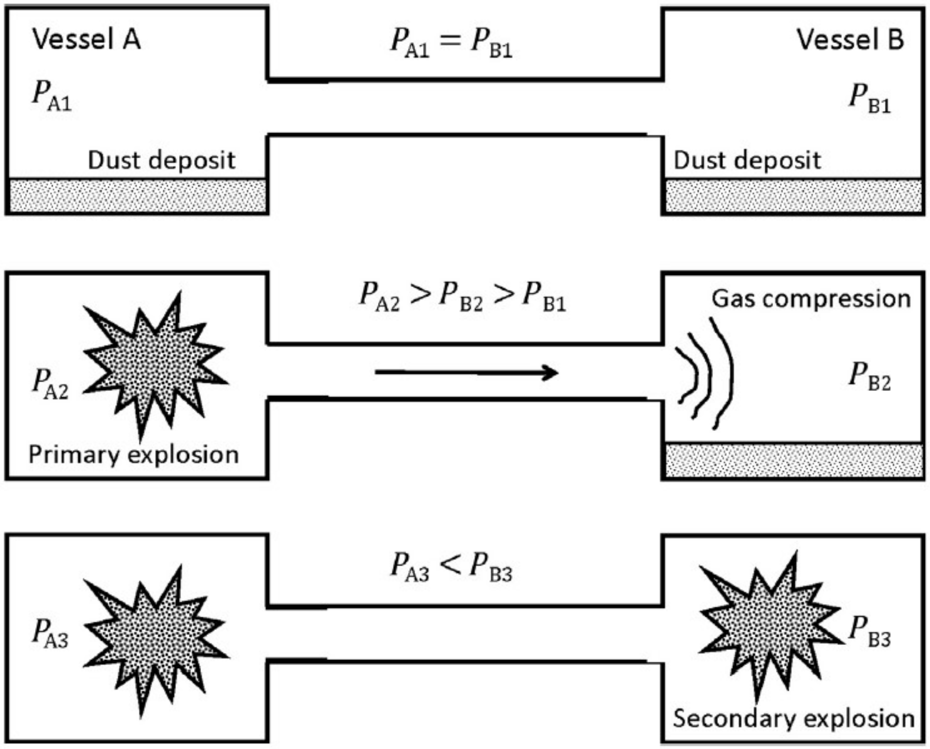
(a) Highly turbulent diffusion flames emanating from a burning oil well.

(b) Coffee creamer.

(c) Candle flame and smoke showing transition from laminar to turbulent flow.

Figure 7: Non-technical visualizations of turbulence eddies.

TURBULENCE --- PRESSURE PILING



Source: Ogle

Effect of turbulence

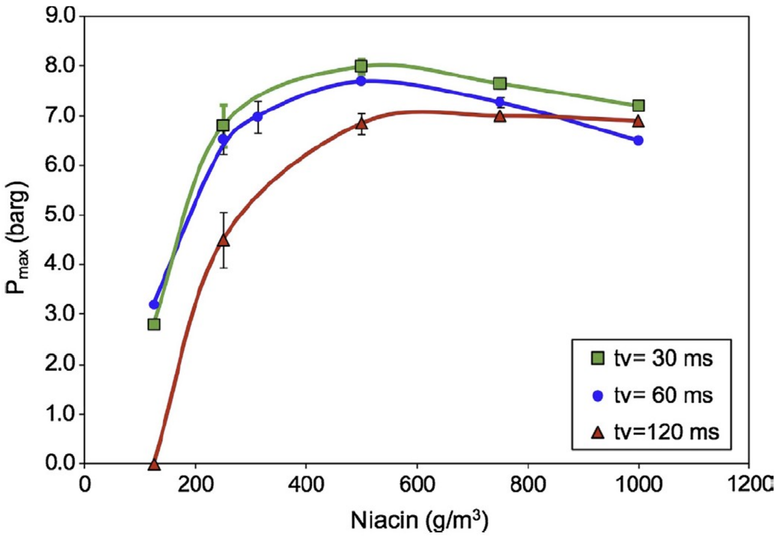


FIGURE 14.3 Influence of ignition delay time on the explosion overpressure of niacin dust in a Siwek 20-L chamber with a 10-kJ ignition energy [12].

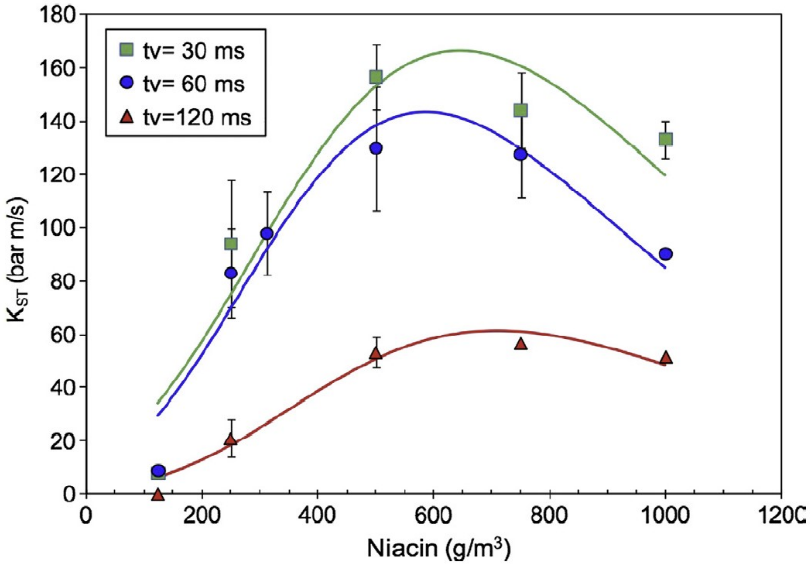


FIGURE 14.4 Influence of ignition delay time on the rate of pressure rise of niacin dust in a Siwek 20-L chamber with a 10-kJ ignition energy [12].

Source: Amyotte (2013)

Effect of turbulence P_{max}

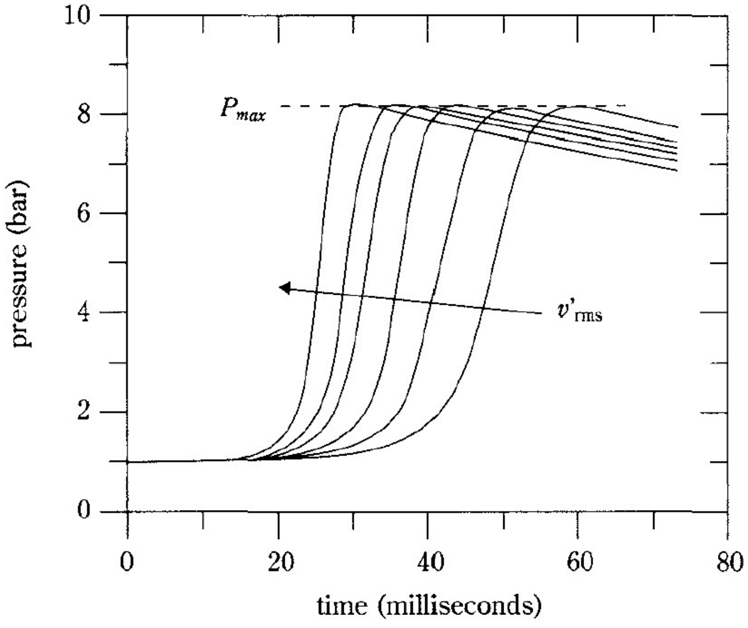


Fig. 2 Explosion curves of stoichiometric methane-air mixtures ignited at various turbulence levels: $v'_{rms}=2.40\ ms^{-1}$, $1.92\ ms^{-1}$, $1.44\ ms^{-1}$, $1.20\ ms^{-1}$, $0.96\ ms^{-1}$, and $0.72\ ms^{-1}$ [1].

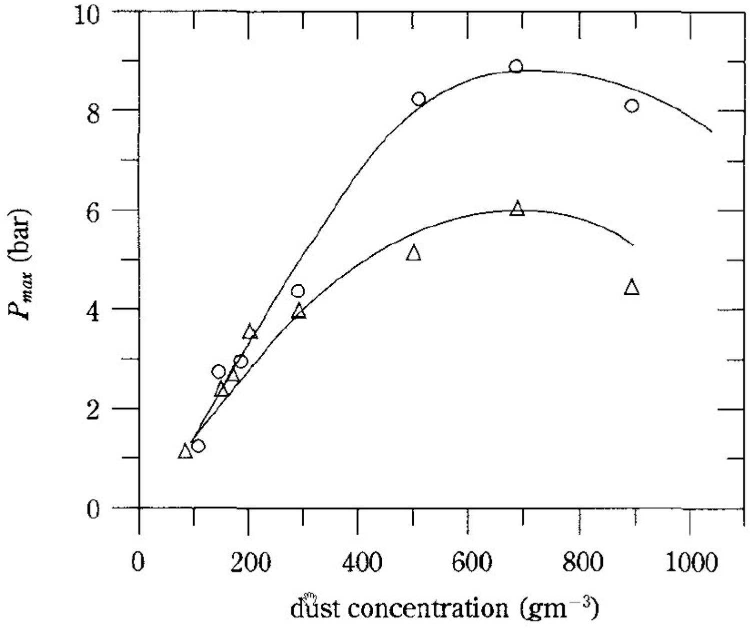


Fig. 3 The maximum explosion pressure of cornstarch-air mixtures ignited at two different turbulence levels: $v'_{rms}=4.2\ ms^{-1}$ (○) and $v'_{rms}=1.5\ ms^{-1}$ (△) [2].

Influence of specific surface area (particle size)

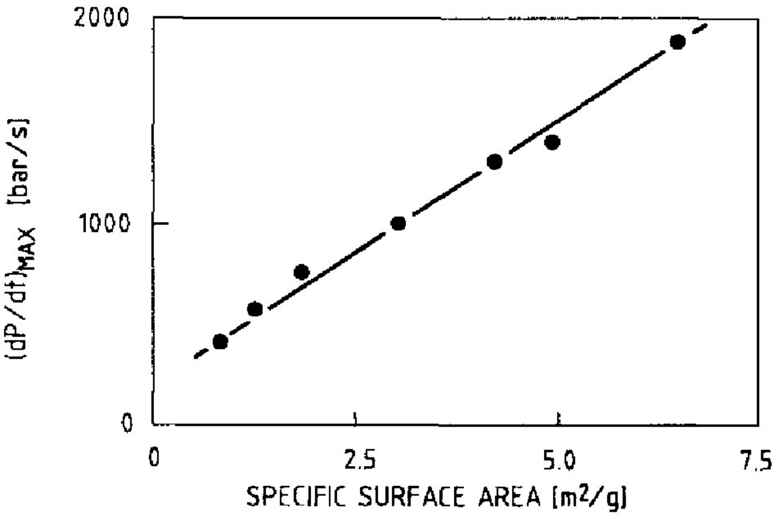


Figure 1.23 *Influence of specific surface area of aluminum dust on the maximum rate of pressure rise in standard 1 m^3 ISO vessel (From Bartknecht, 1978).*

Source: Eckhoff (2003)

Influence of specific surface area (particle size)

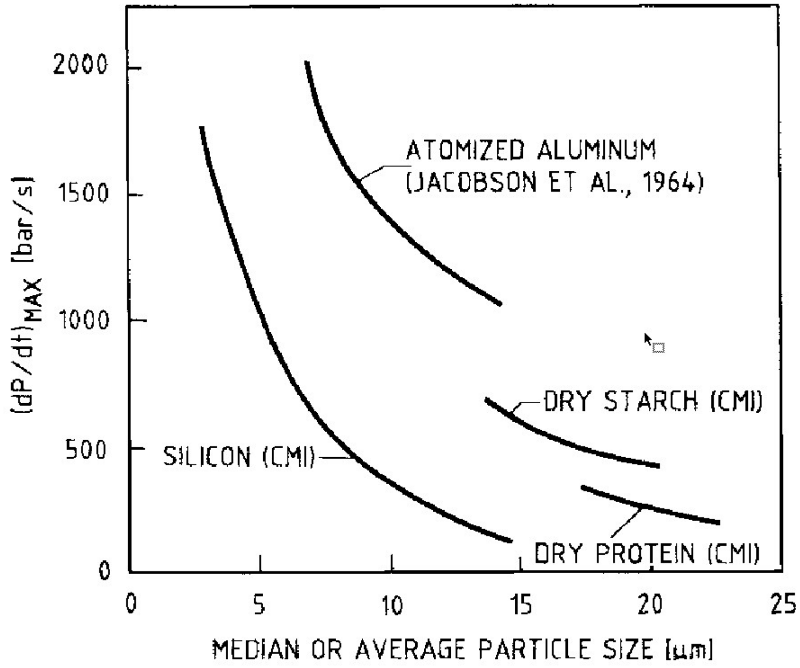


Figure 1.28 *$(dP/dt)_{max}$ in Hartmann bomb of clouds in air silicon dust, aluminum dust, and dust from natural organic materials, as functions of particle size (From Eckhoff et al., 1986).*

Source: Eckhoff (2003)

Influence of specific surface area (particle size)

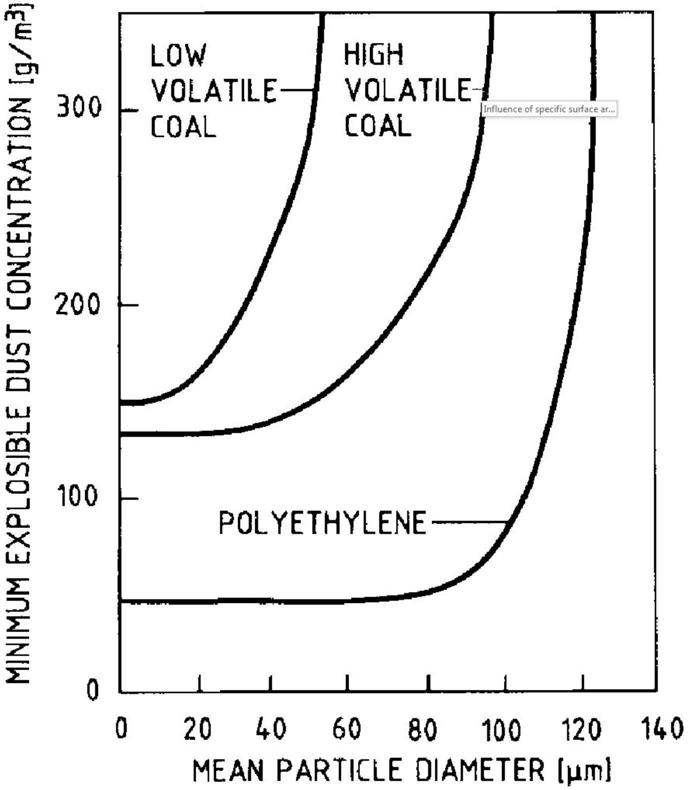


Figure 1.29 *Influence of mean particle diameter on minimum explosible concentration for three different dusts in a 20 liter USBM vessel (From Hertzberg and Cashdollar, 1987).*

Source: Eckhoff (2003)

Effect of particle size

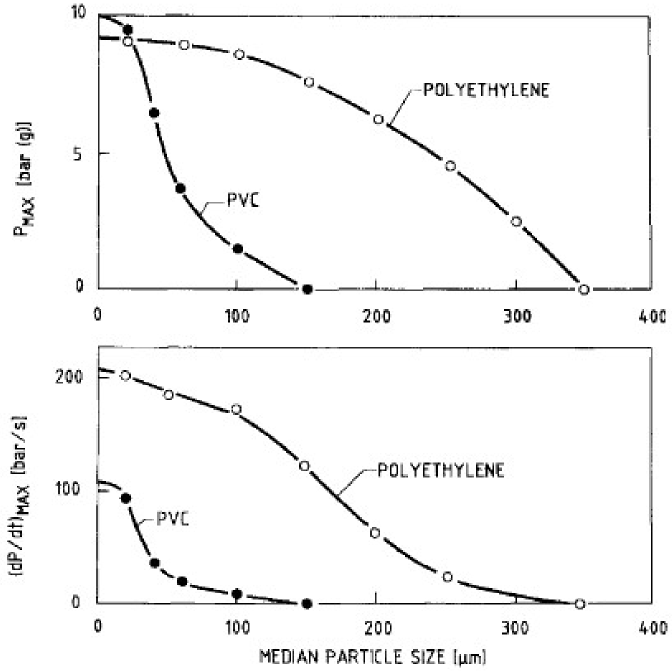


Figure 1.18 *The influence of chlorine in molecule of dust material on maximum explosion pressure and maximum rate of pressure rise in 1 m^3 standard ISO vessels, for various particle sizes (From Bartknecht, 1978).*

Influence of moisture content

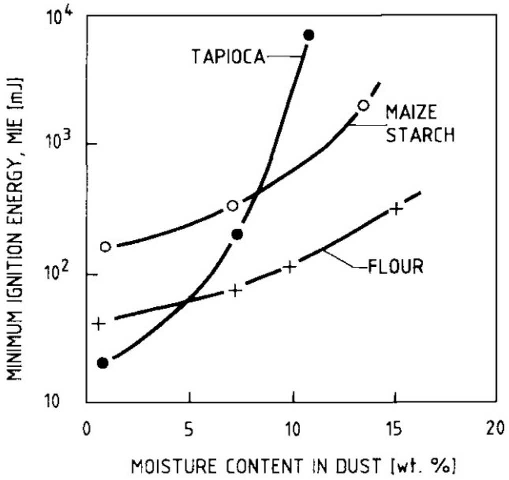


Figure 1.19 *Influence of dust moisture content on minimum electric spark ignition energy for three dusts (From van Laar and Zeeuwen, 1985).*

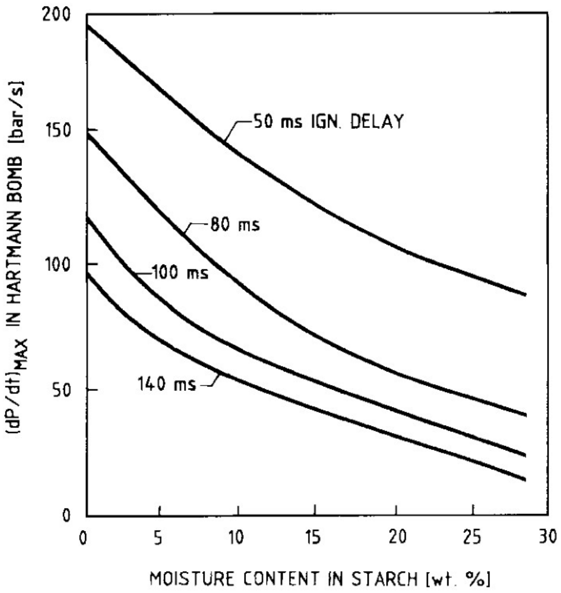


Figure 1.20 *Influence of moisture content in maize starch on maximum rate of pressure rise in Hartmann bomb for various ignition delays (time from dust dispersion to ignition) (From Eckhoff and Mathisen, 1977/1978).*

Source: Eckhoff (2003)

Effect of dust concentration

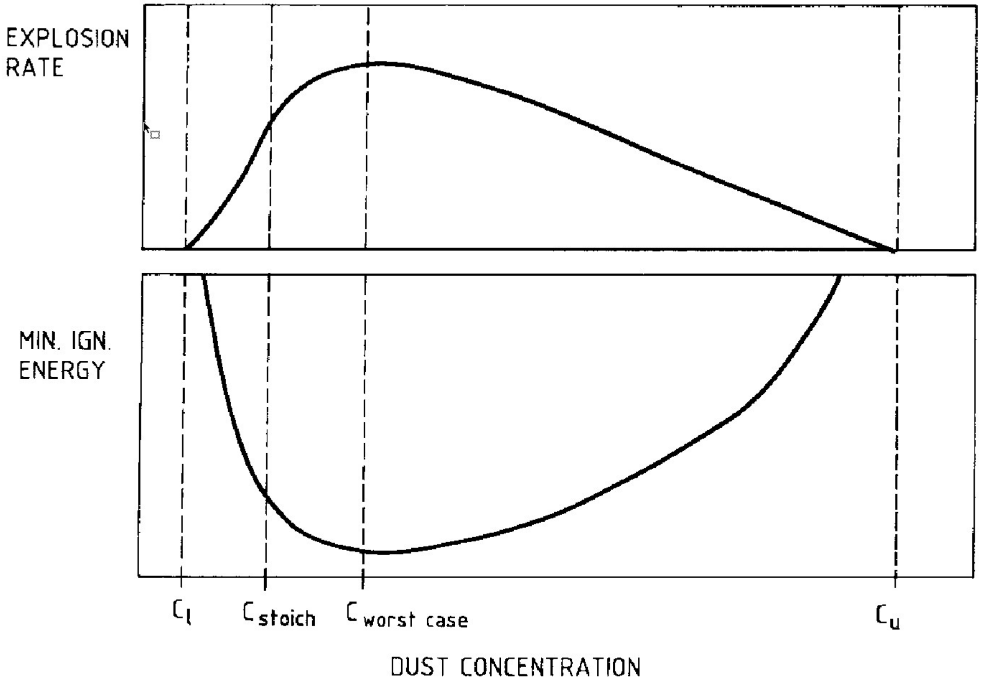


Figure 1.35 *Illustration of typical variation of explosion rate and minimum electric spark ignition energy with dust concentration within the explosible range.*

Source: Eckhoff (2003)

Effect of dust concentration

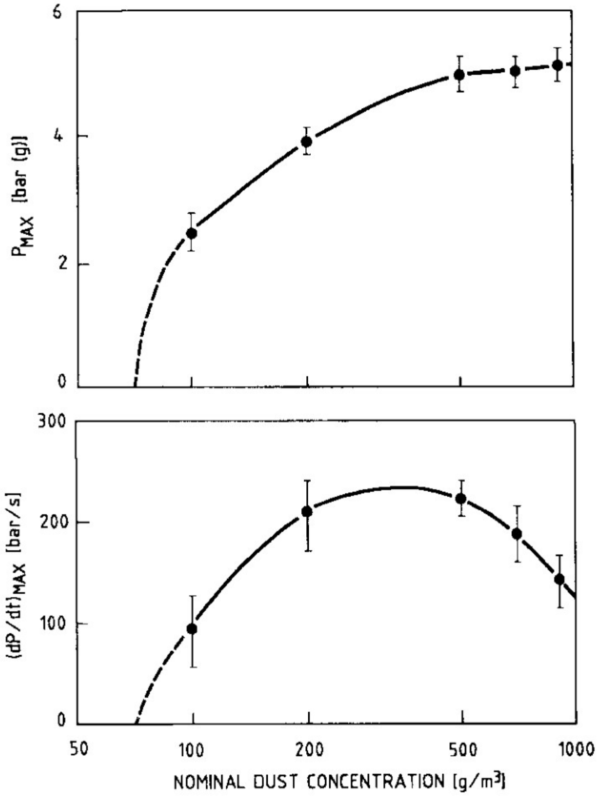


Figure 1.36 *Influence of nominal dust concentration in a Hartmann bomb on maximum explosion pressure and maximum rate of pressure rise. Maize starch containing 11% moisture. The bars through the points show ±1 standard deviation (From Eckhoff, Fuhre, and Pedersen, 1985).*

Source: Eckhoff (2003)

Effect of dust concentration

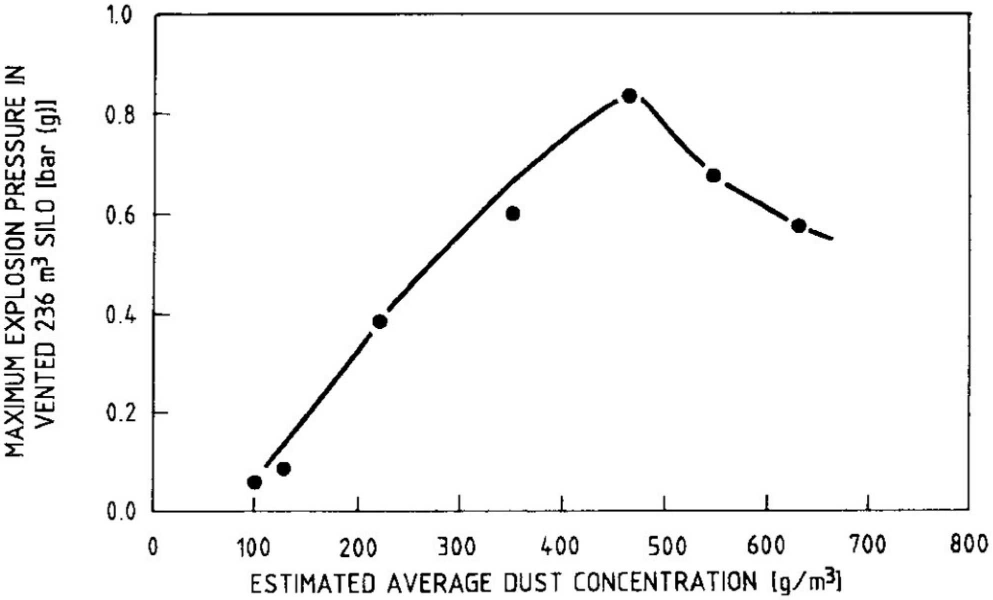


Figure 1.37 *Influence of estimated average dust concentration in exploding cloud in 236 m^3 silo of L/D = 6, on maximum explosion pressure in vented silo. Vent area at the top of the silo is 5.7 m^2. Maize starch contains 11% moisture. Ignition is close to the bottom of the silo (From Eckhoff et al., 1985).*

Source: Eckhoff (2003)

Effect of dust concentration

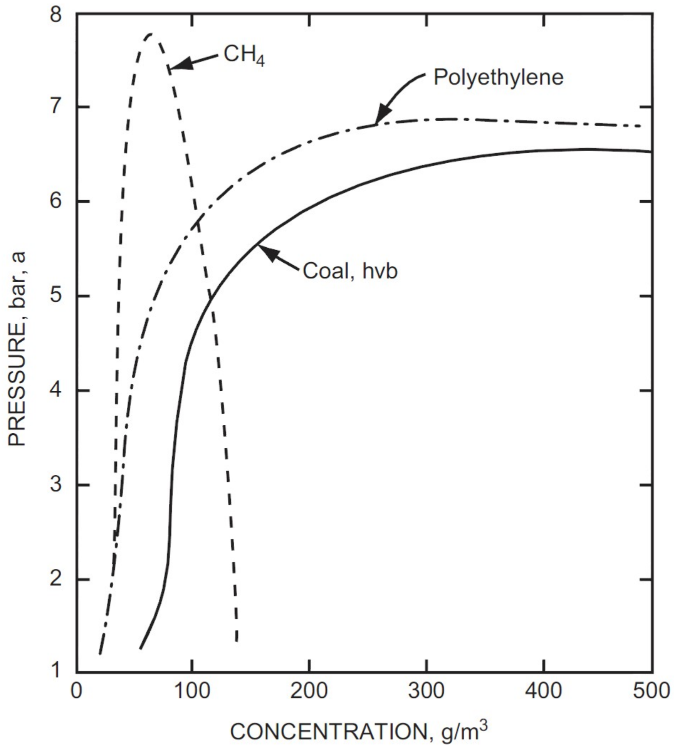
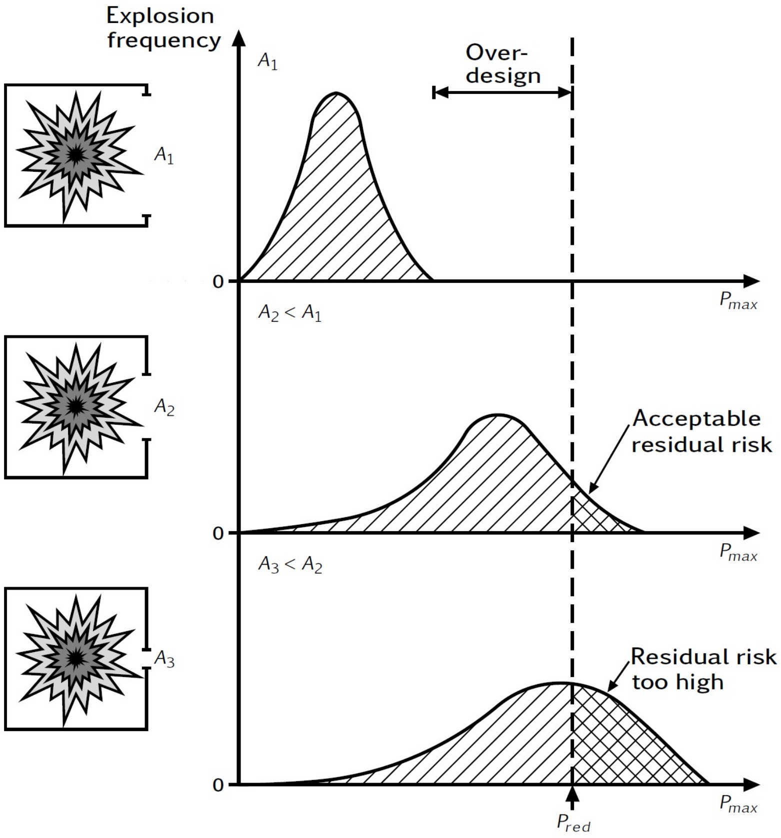


FIGURE 5.4 Explosion pressure data for methane compared with polyethylene and coal (high-volatile bituminous or hvb) dusts [2].

Source: Amyotte (2013)

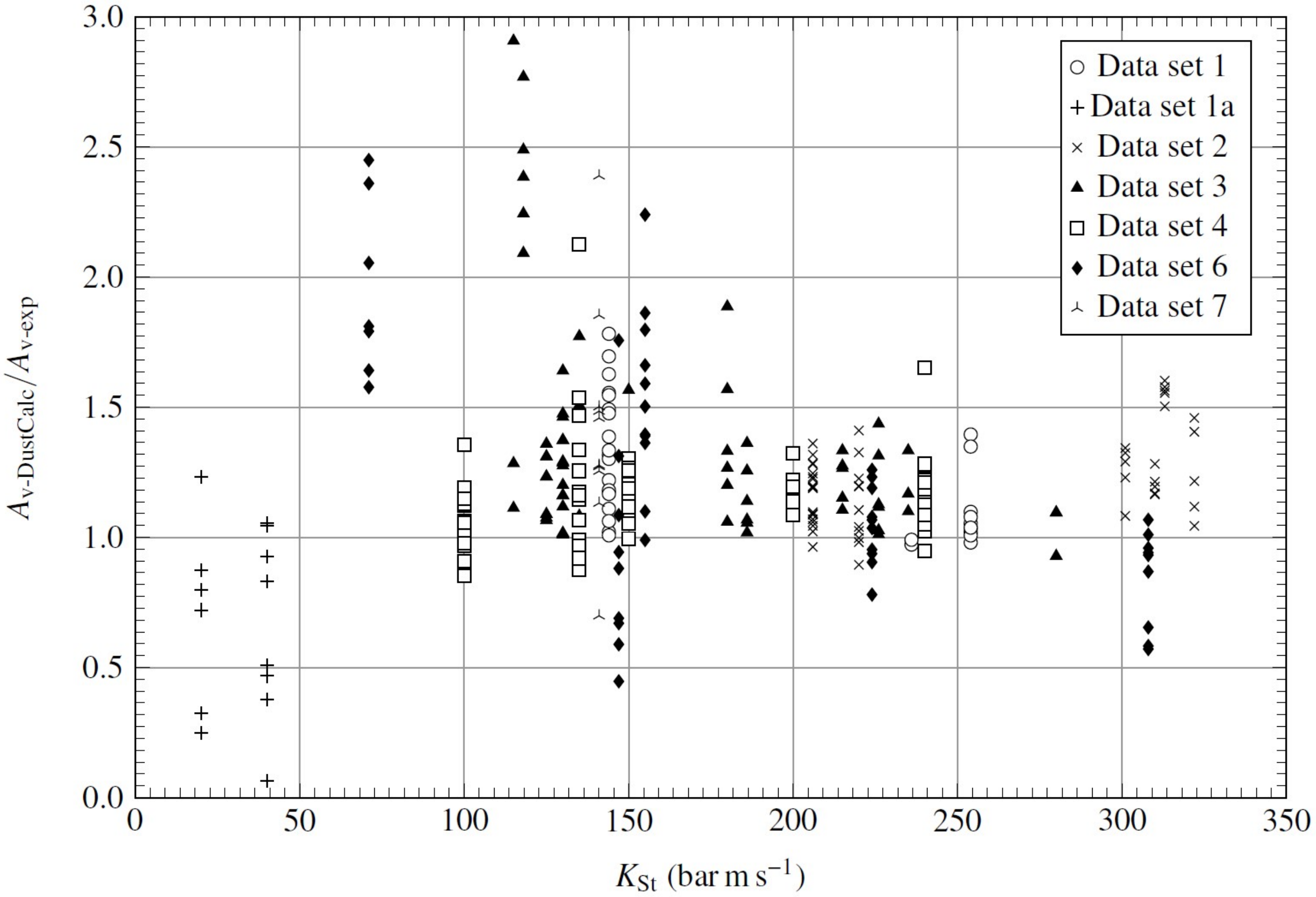
APPLICATIONS

RESIDUAL RISK



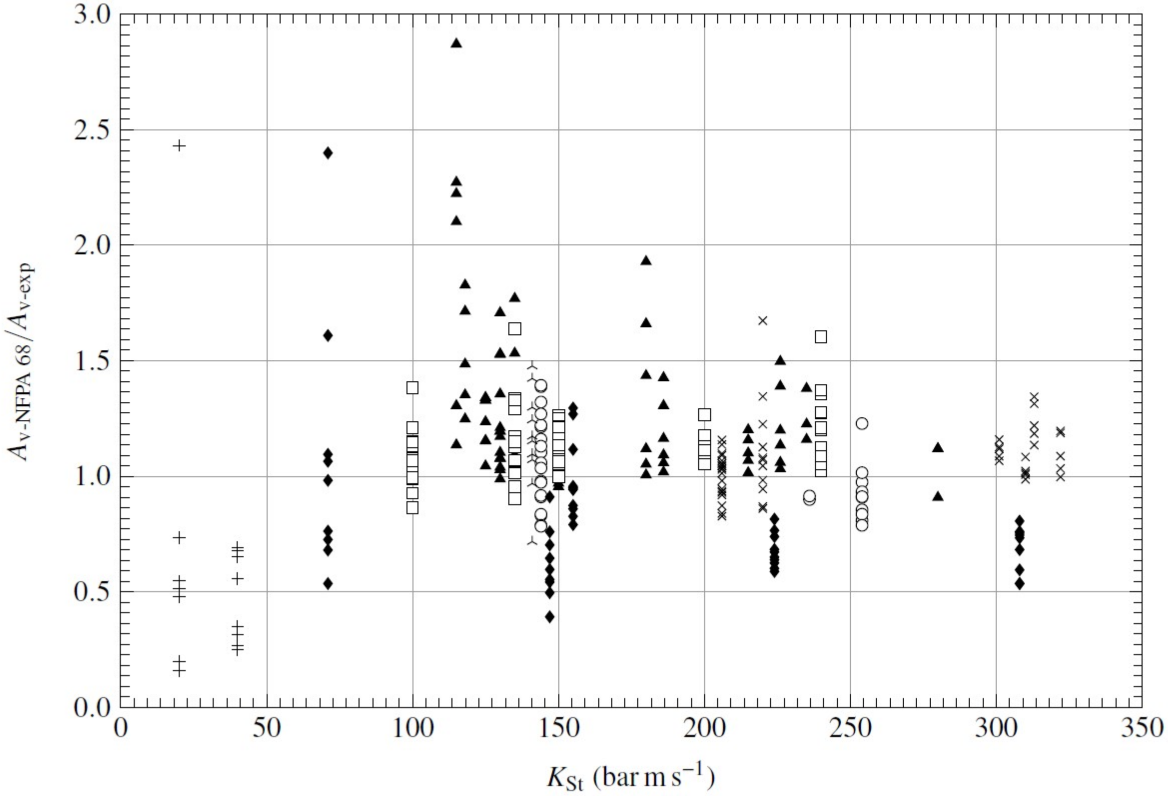
How is this concept reflected in design guidelines and standards?

FM GLOBAL VENT SIZING – VALIDATION

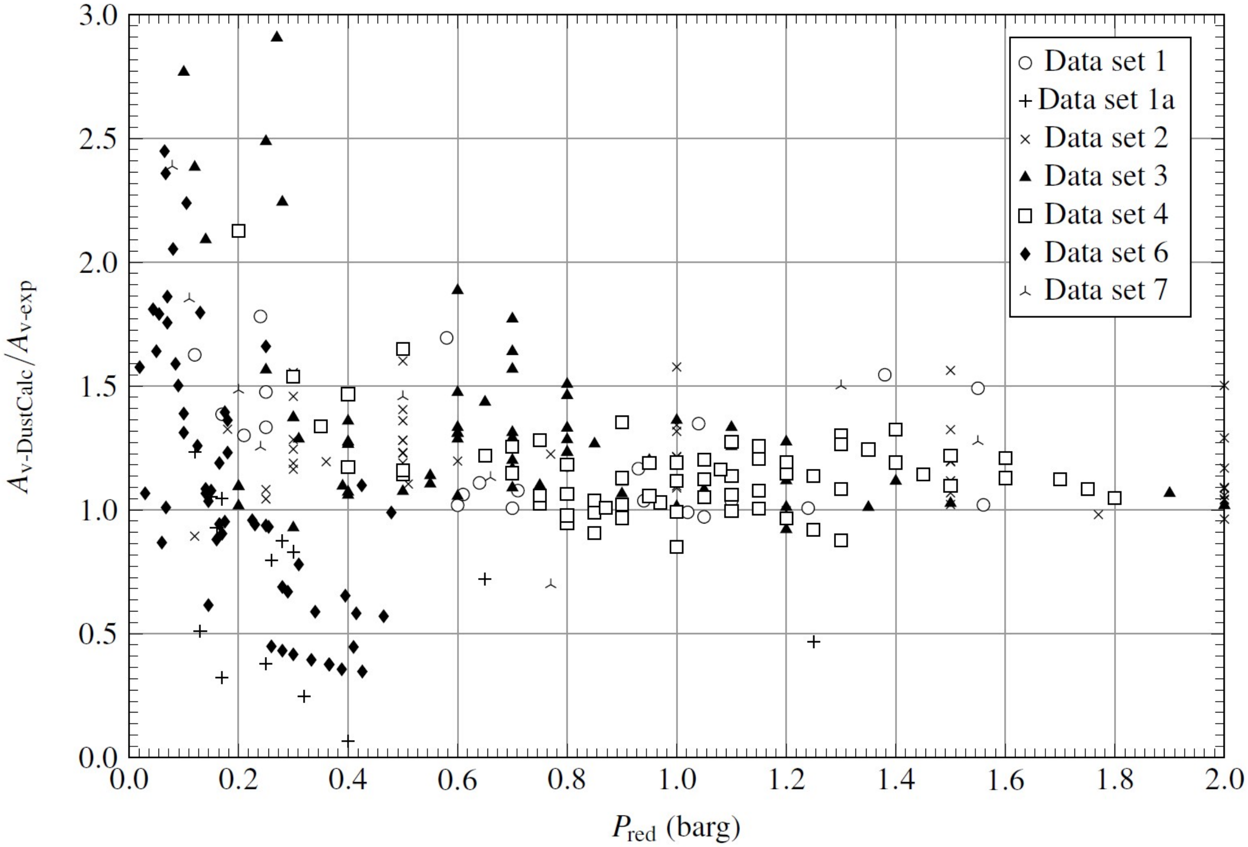


NFPA 68 VENT SIZING – VALIDATION

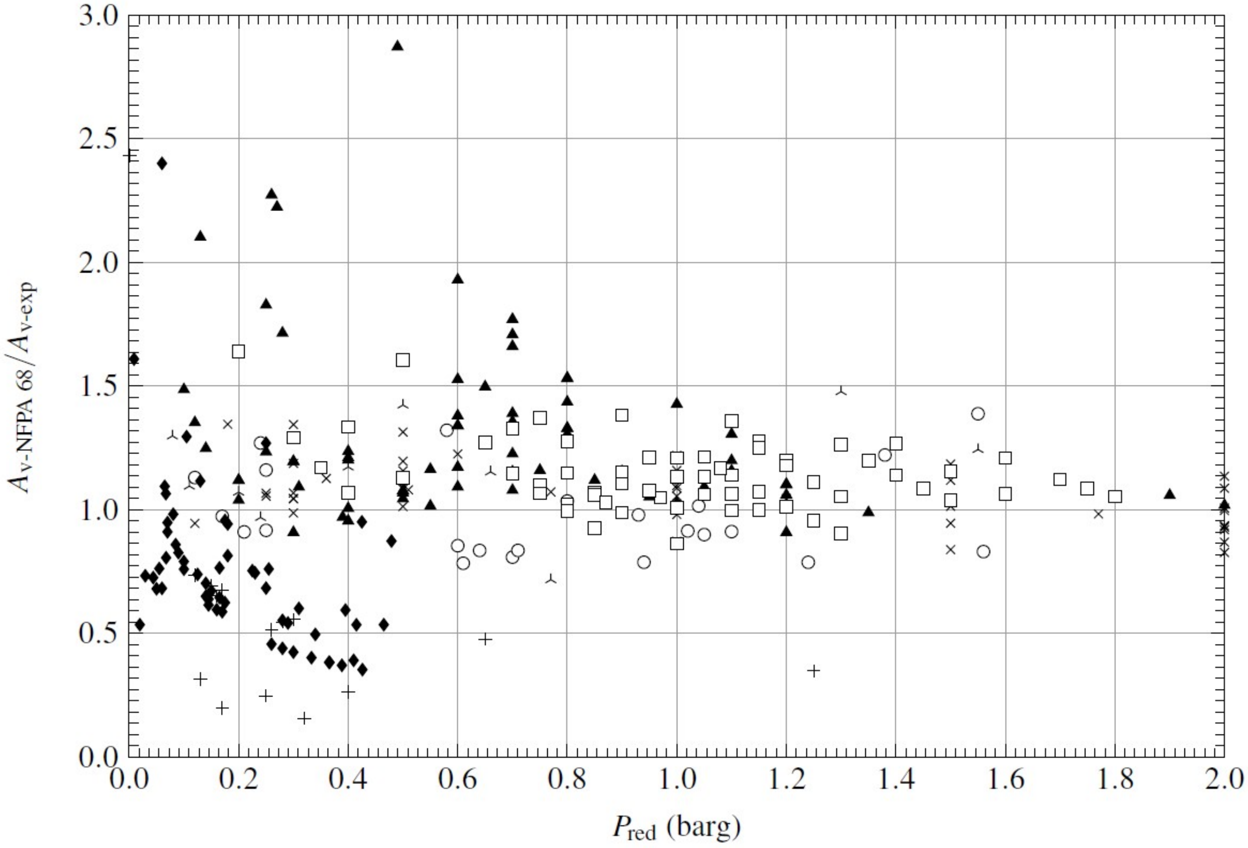
$$A_{v0} = 1 \cdot 10^{-4} \cdot \left(1 + 1.54 \cdot P_{stat}^{4/3}\right) \cdot K_{St} \cdot V^{3/4} \cdot \sqrt{\frac{P_{max}}{P_{red}} - 1}$$



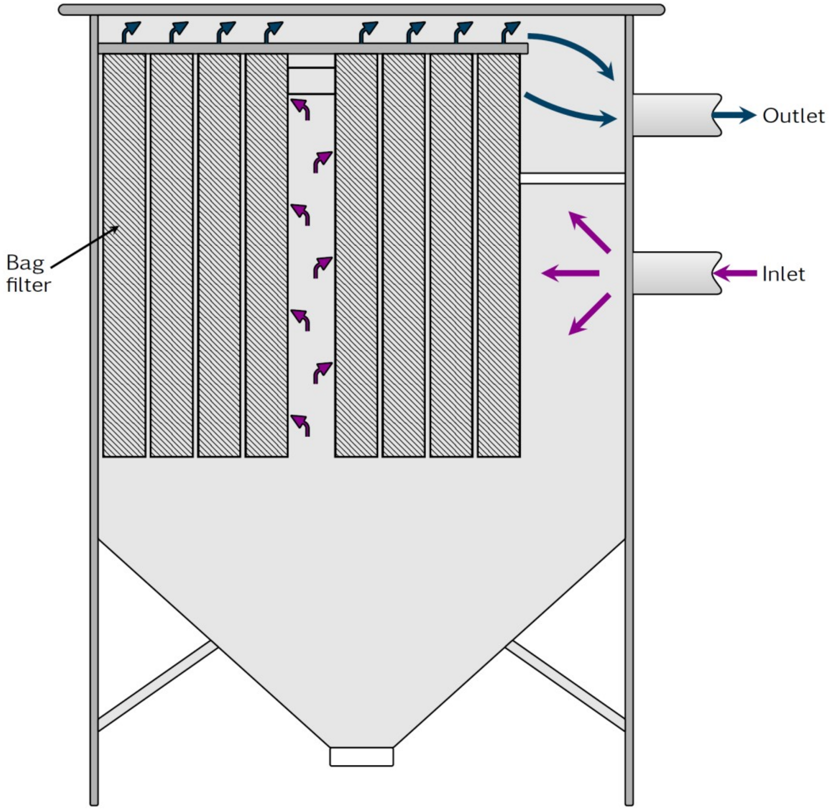
FM GLOBAL – VALIDATION

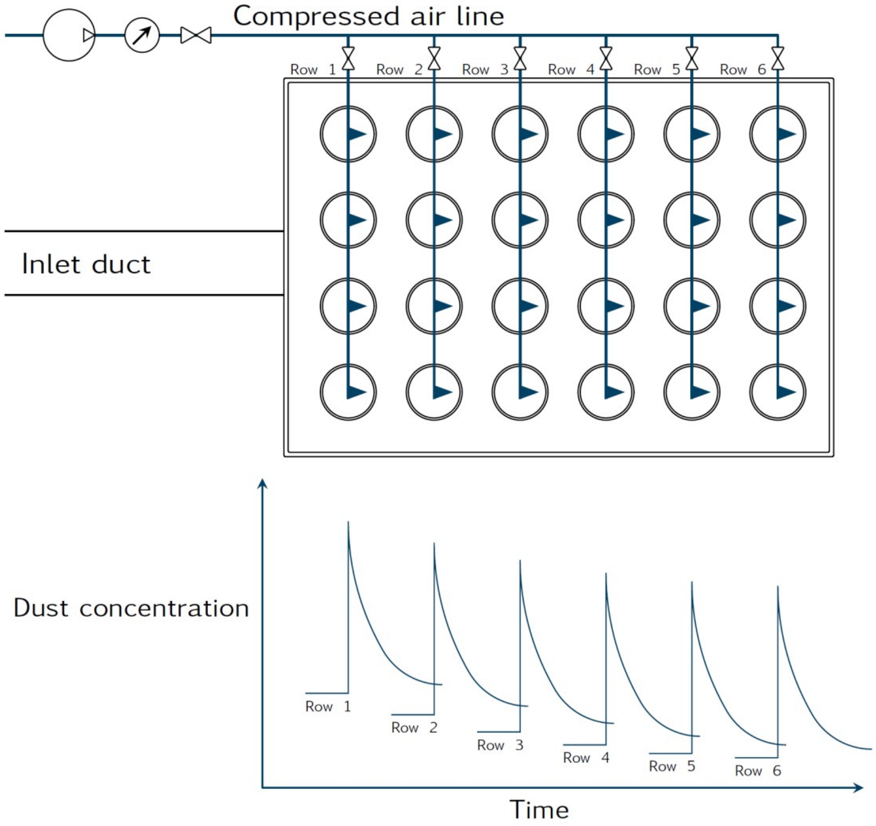


NFPA 68 – VALIDATION

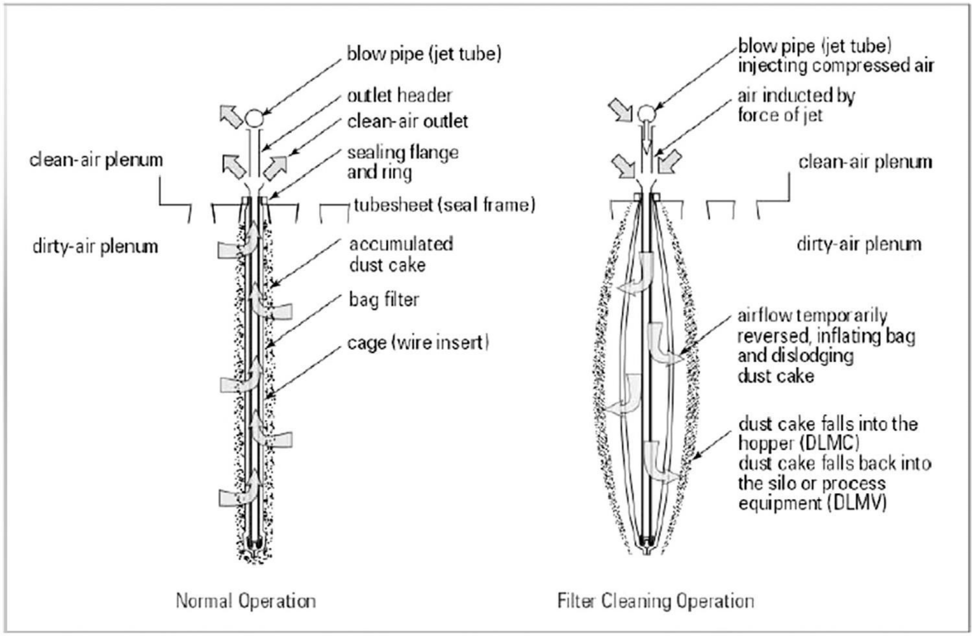


Dust collector quantitative hazard evaluation





Dust collector quantitative hazard evaluation



Timed pulsing:

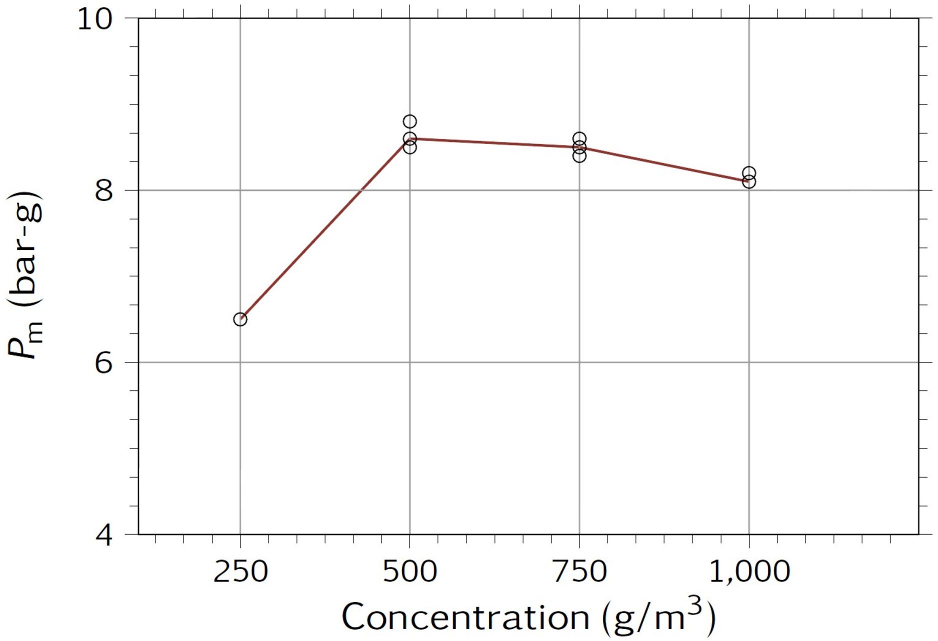
$$c_{pulse} = \frac{c_{in} Q_a t_{cycle} K_{max}}{2 w L H_{bag} N_{row}}$$

Pressure drop:

$$c_{pulse} = \frac{\left(m''_{pulse} - m''_{att}\right) A_{bag} N_{bag}}{V_{dirty}}$$

Source: Zalosh (2015)

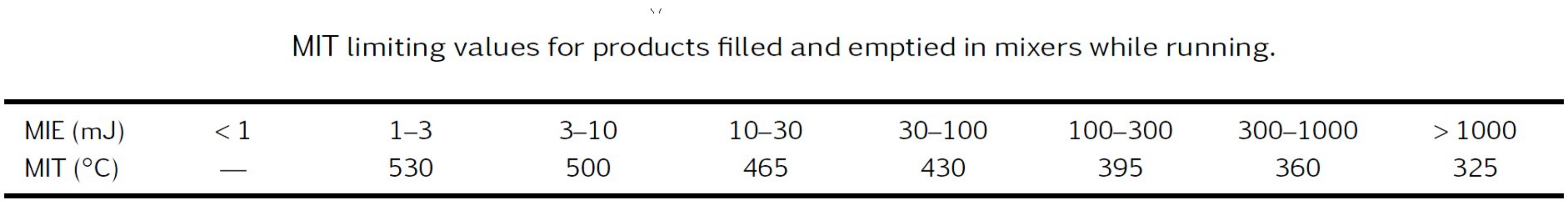
Application of explosion severity test data



$$\alpha_{\text{fill}}(\text{flash fire}) \leqslant \frac{0.03}{(P_{\text{ex}} - 1.013)}$$

Source: Ogle (2016)

Application of MIT and MIE data



MIT limiting values for products filled and emptied in mixers while running.

MIE (mJ)	< 1	1–3	3–10	10–30	30–100	100–300	300–1000	> 1000
MIT (°C)	—	530	500	465	430	395	360	325

Source: CCPS Guidelines for Safe Handling of Powders and Bulk Solids (2005)

Application of MIE data (without inductance)

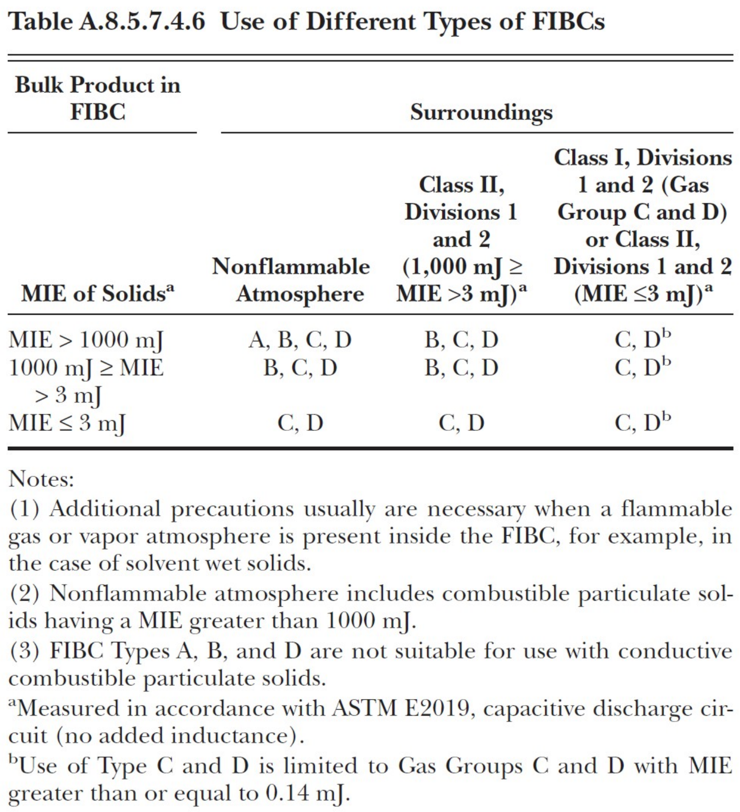


Table A.8.5.7.4.6 Use of Different Types of FIBCs

Bulk Product in FIBC	Surroundings		
MIE of Solids[a]	Nonflammable Atmosphere	Class II, Divisions 1 and 2 (1,000 mJ ≥ MIE >3 mJ)[a]	Class I, Divisions 1 and 2 (Gas Group C and D) or Class II, Divisions 1 and 2 (MIE ≤3 mJ)[a]
MIE > 1000 mJ	A, B, C, D	B, C, D	C, D[b]
1000 mJ ≥ MIE > 3 mJ	B, C, D	B, C, D	C, D[b]
MIE ≤ 3 mJ	C, D	C, D	C, D[b]

Notes:

(1) Additional precautions usually are necessary when a flammable gas or vapor atmosphere is present inside the FIBC, for example, in the case of solvent wet solids.

(2) Nonflammable atmosphere includes combustible particulate solids having a MIE greater than 1000 mJ.

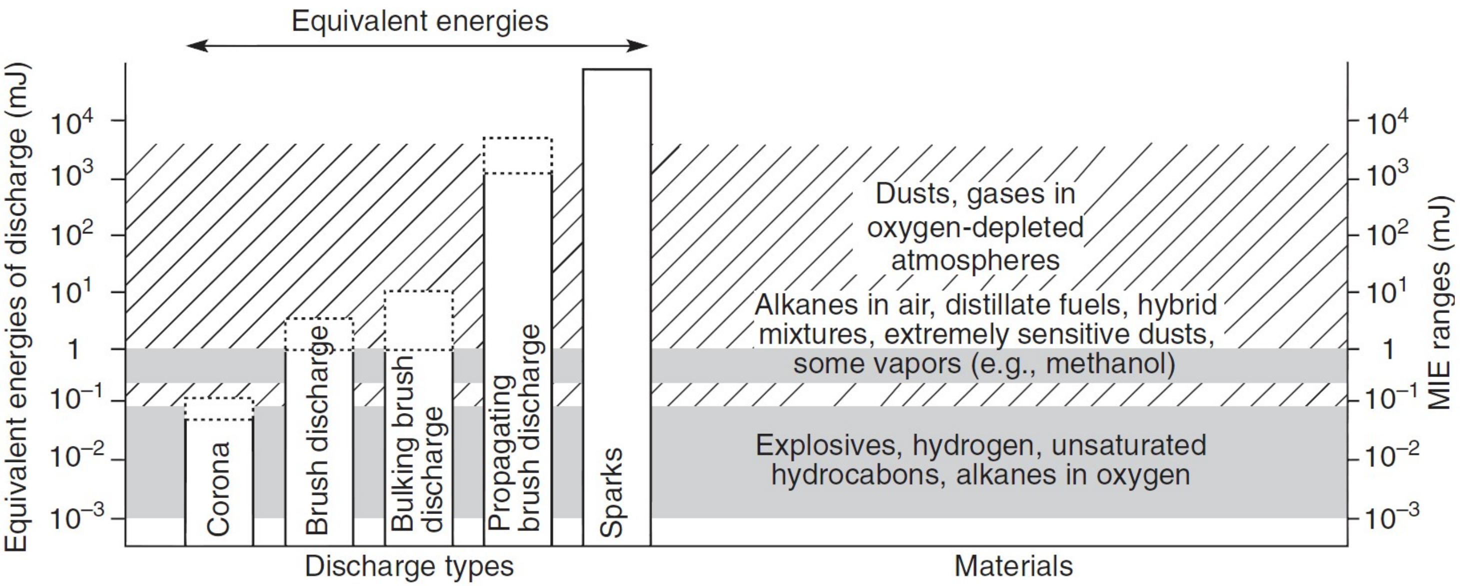
(3) FIBC Types A, B, and D are not suitable for use with conductive combustible particulate solids.

[a] Measured in accordance with ASTM E2019, capacitive discharge circuit (no added inductance).

[b] Use of Type C and D is limited to Gas Groups C and D with MIE greater than or equal to 0.14 mJ.

Source: NFPA 652 (2016)

Application of MIE data (without inductance)



Approximate Energies of Types of Discharges Compared with Minimum Ignition Energies (MIEs) of Typical Combustible Materials. (From NFPA 77, *Recommended Practice on Static Electricity*, 2014.)

Source: NFPA 77 (2014), adapted from Eckhoff (2003)

Application of test data from 20-L sphere – MIC

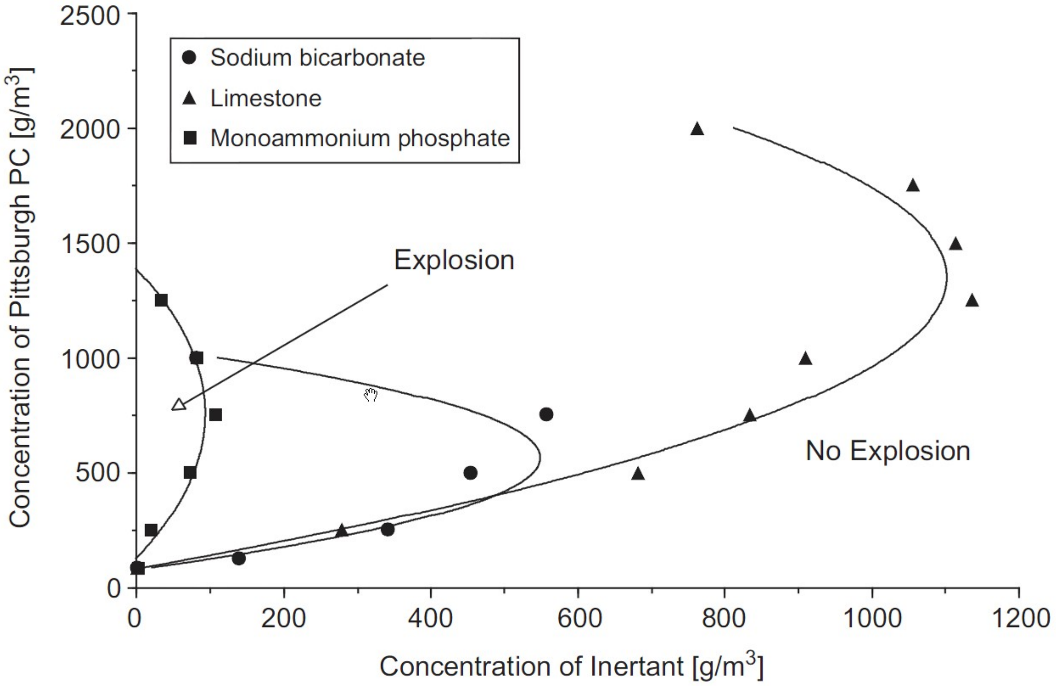


FIGURE 7.4 Inerting envelopes showing minimum inerting concentration (MIC) values for Pittsburgh pulverized coal dust with limestone, sodium bicarbonate, and monoammonium phosphate as inertants; experiments conducted in a spherical 1-m^3 chamber [7,8].

Source: Amyotte (2013)

Application of test data from 20-L sphere – MIC

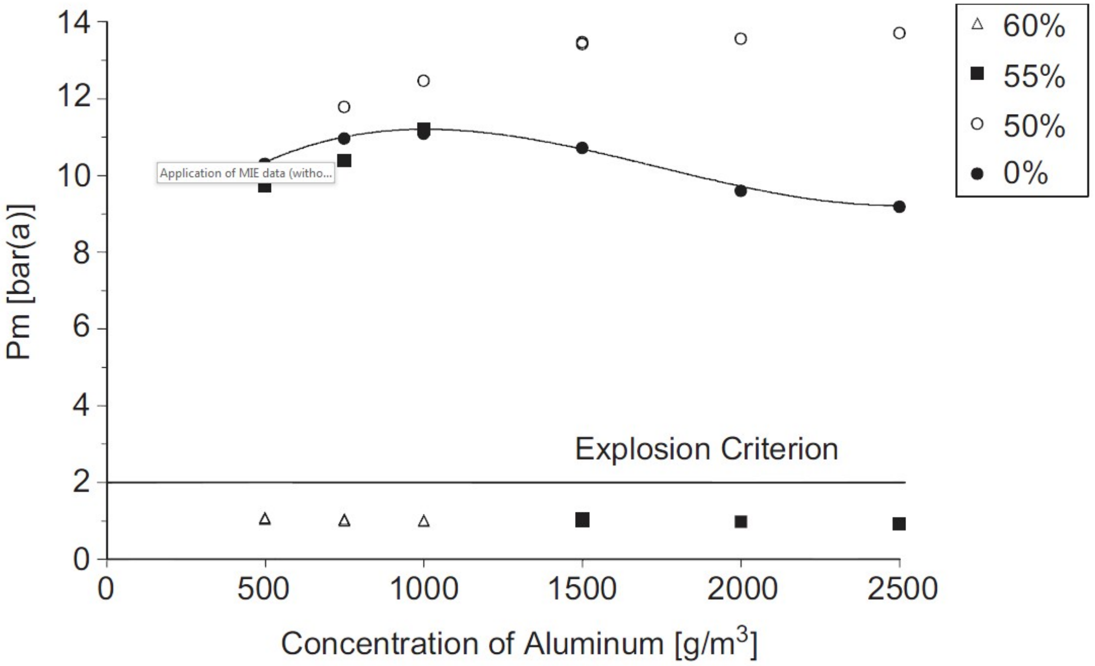


FIGURE 7.5 Explosion overpressure as a function of aluminum concentration for different amounts of admixed SBC, showing the occurrence of SEEP (Suppressant Enhanced Explosion Parameter) in a spherical 1-m^3 chamber [8].

Source: Amyotte (2013)

Conclusions

- Explosibility parameters are
    - Not fundamental properties
    - Useful in evaluating hazards, designing explosion protection systems
    - Required as part of a dust hazard analysis
    - If there is sufficient dust, better to perform one cubic-meter testing
- Sampling and test strategies should be developed
    - Samples should be representative, credible, conservative
    - Particle size distribution
    - MIE with or without inductance
- Many factors influence explosibility
    - Particle size is dominant
    - Effect of moisture content for many materials can be discounted below 5%
- Challenges with testing a different scales
    - Metallic (aluminum)
    - Low-K_{St}, low-P_{max} dusts
    - Hybrid mixtures

Please submit your questions via the text box.

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Thank you for attending

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- Visit Aerodyne Environmental: https://www.dustcollectorhq.com/
- Visit C&W Environmental: www.cwmfg.com
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