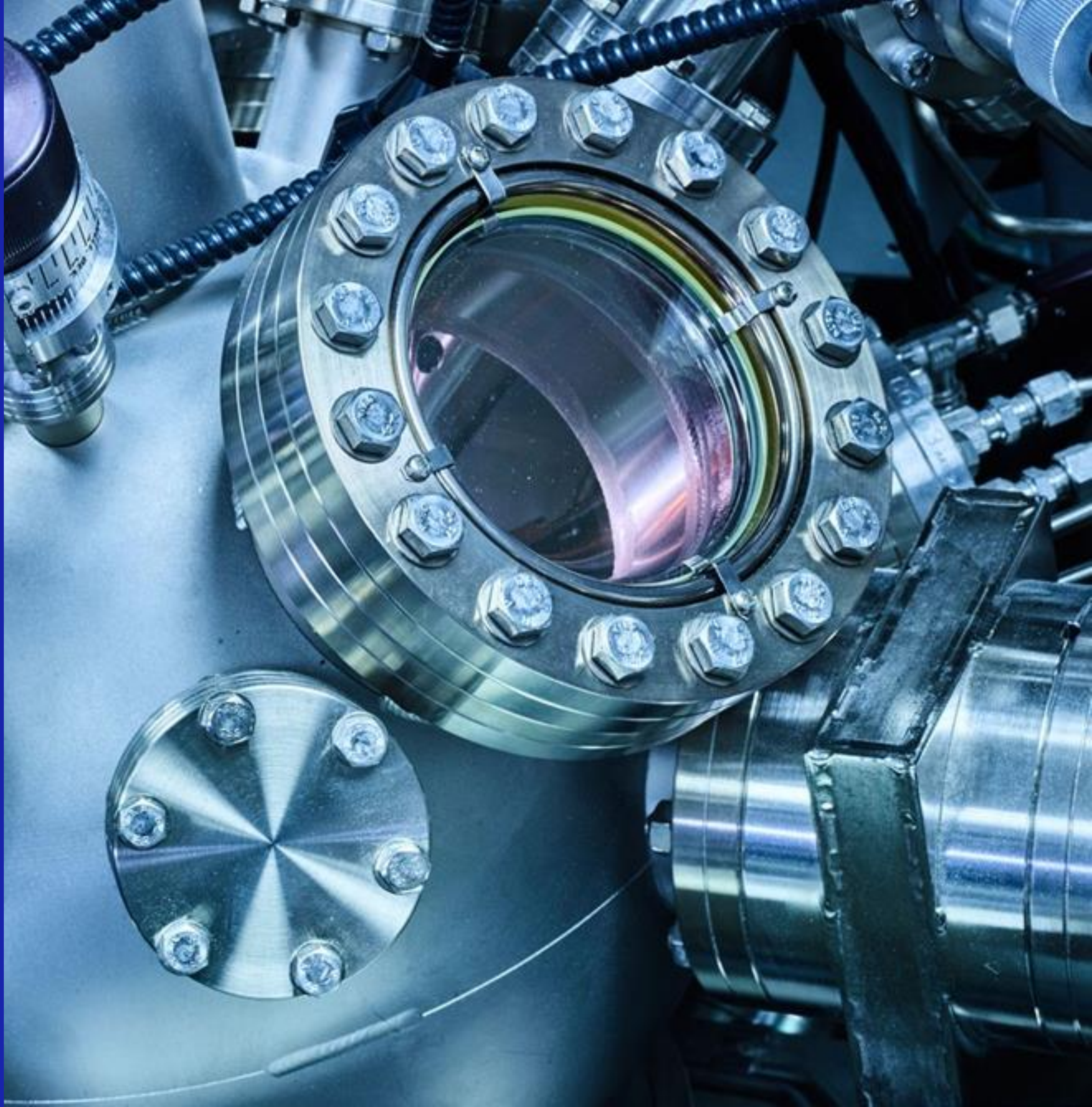
Combustible powder: safety data

P2SAC spring conference - Robert Woodman

8th May 2024

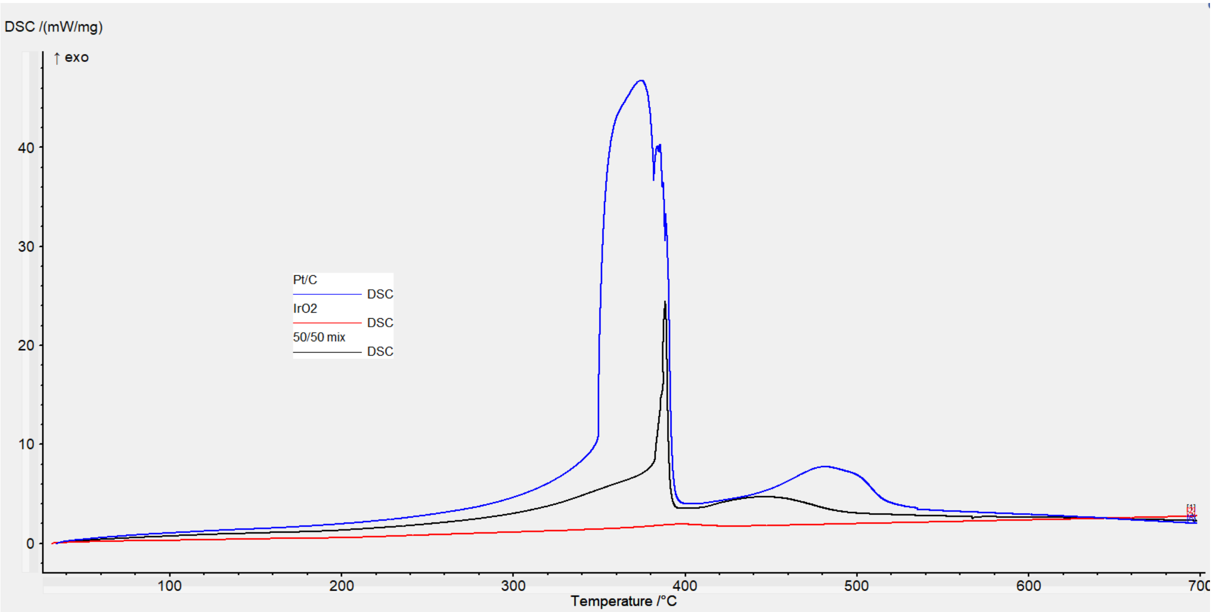


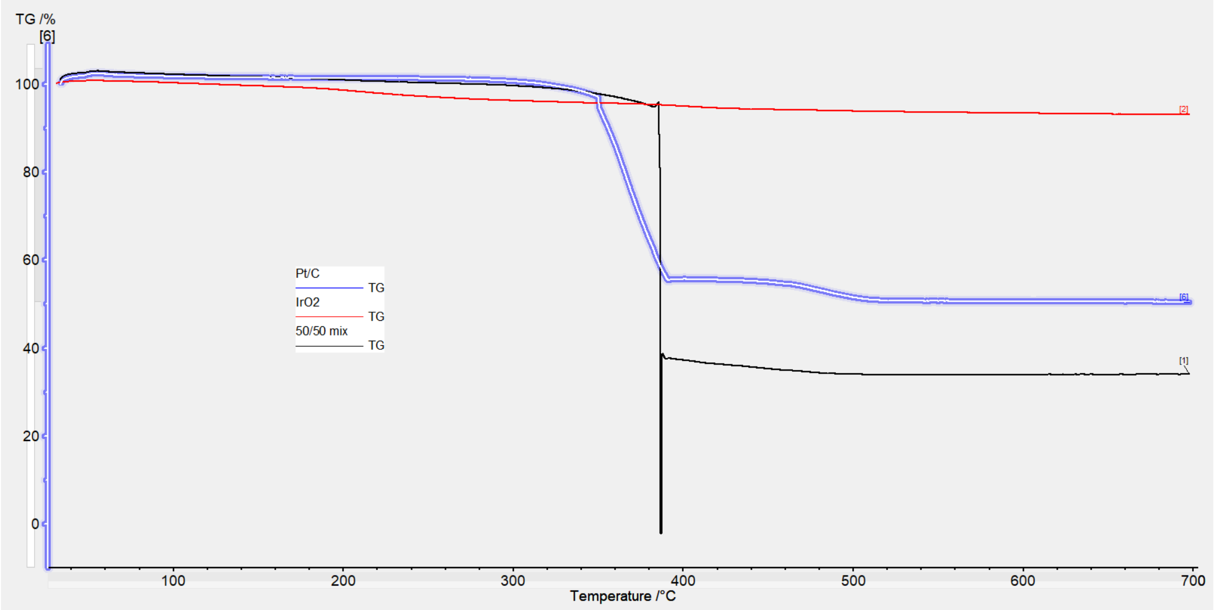
Basis of safety(BoS)

Decreasing reliability of BoS

- Is there a hazard
- Avoid forming a flammable atmosphere(limiting oxygen or dust concentration)
- Controlling ignition sources to prevent ignition(zoning: earthing, limiting temperatures)
- Ensuring no one is harmed from explosion(Blast panels, containment)

Do I have a hazard?





SDSs, H Phrases

Are any of the reactants/products likely to form flammable dust clouds?

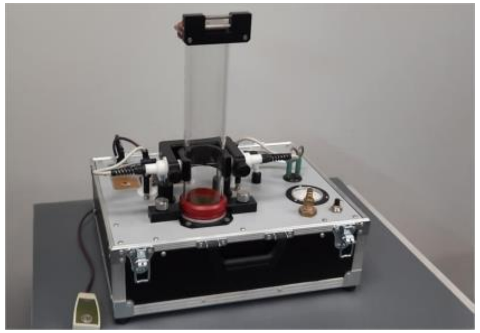
- Are they solids?
- Are they sufficiently small to get air borne?
  - IEC 60079-10-2 & 80079-20-2; NFPA 70 & 499 - <500 microns, US sieve size 35
  - IFC 2018 - <420 microns, US sieve size 40
  - NFPA 77, 652, 654, 68 & 69 – state no size limits
- Are they oxidisable? (DSC/TGA)

TGA and DSC plots courtesy of JMTC Sonning performed by Deena Modeshia

Do I have a hazard?

Go/No Go - testing

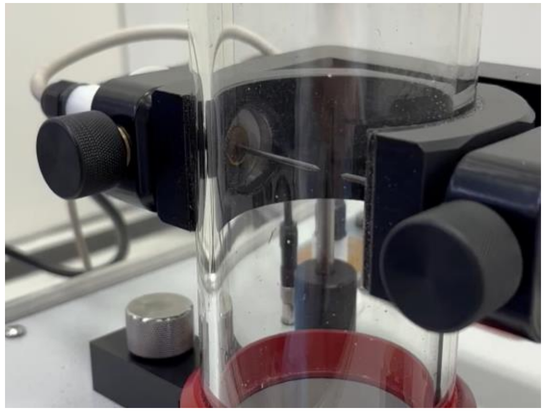
- Standards for Go-No Go testing
  - IEC 80079-20-2
  - ASTM E1226-19
- JM have a portable Hartman tube and are currently installing a G-G oven.
- Problems with arcing of conductive powders
  - ASTM E2019003



Constant Arc and hot coil ~10j

2 X 1000j igniters

Test Hartman tube with spark
Ignition
Test Hartman tube with Hot coil
Ignition
Sufficient material
Test in G-G oven at 1000C
Ignition
Verify
Test in 20L sphere
Ignition
Material is NOT a combustible dust
Material is a combustible dust



Schematic of Go/No Go testing Based on IEC 800179-20-2
Pictures of portable Hartman tube, 20L sphere and G-G oven from **ANKO**

Basis of safety(BoS) and testing requirements

Decreasing reliability of BoS

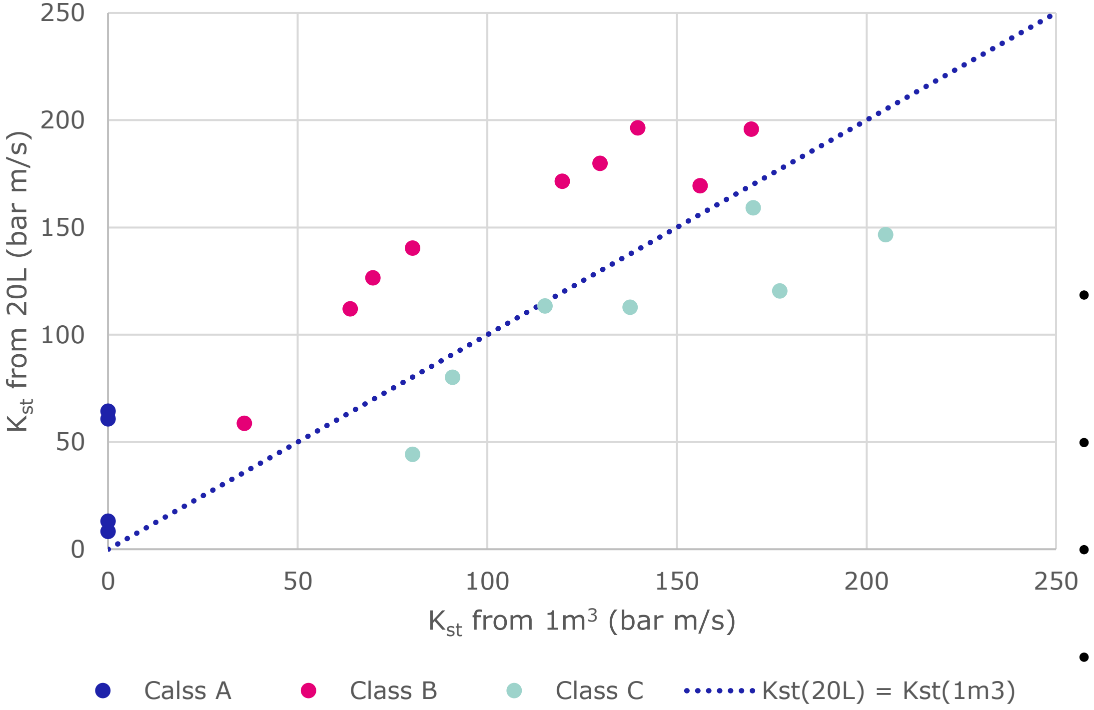
Test equipment

BoS	Test equipment
Is there a hazard • Screening tests (Go/No Go)	Hartman tube & G-G oven or 20L sphere
Avoid forming a flammable atmosphere(limiting oxygen or dust concentration)	
Controlling ignition sources to prevent ignition(zoning: earthing, limiting temperatures)	
Ensuring no one is harmed from explosion(Blast panels, containment)	

Avoiding a flammable atmosphere

20L sphere

$1m^3$ sphere



- **MEC** – Minimum explosive concentration – in practice rarely used
- **LOC** – Limiting oxygen concentration – used where interion is the BoS, introduces asphyxiation hazards
- Testing carried out in 20L sphere as they have larger igniters than Hartman tube to find the limits of flammability; Standards:
  - ASTM E1515-14 & E2931-13
    - ASTM uses 2.5KJ or 5KJ pyrotechnic igniter
    - ASTM uses a pressure ratio of 2 to define an ignition.
  - BS EN 14034-3 & 14034-4
    - BS EN uses 2 X 1KJ pyrotechnic igniters
    - BS EN uses a pressure rise of 0.3.
- High ignition energy can result in over driven results for weak explosives i.e. anything less than 50KST may be a false positive and testing in the 1m3 vessel should be considered.
- The Hartman tube can be used to get a feel for MEC by varying loaded concentration
- Would like to look at varying oxygen content in Hartman tube to a similar feel for LOC values.
- Though neither value will be definitive due to the lower ignition source but potentially useful as an early indicator.

Graph generated with data from: Portarapillo, M, Sanchirico, R, Di Benedetto, A. On the pyrotechnic ignitors role in dust explosion testing: Comparison between 20 L and 1 m^3 explosion vessels. *Process Saf Prog*. 2021; 40: 289– 295. https://doi.org/10.1002/prs.12249

Pictures of 20L sphere and 1m3 vessel from **ANKO**

Basis of safety(BoS) and testing requirements

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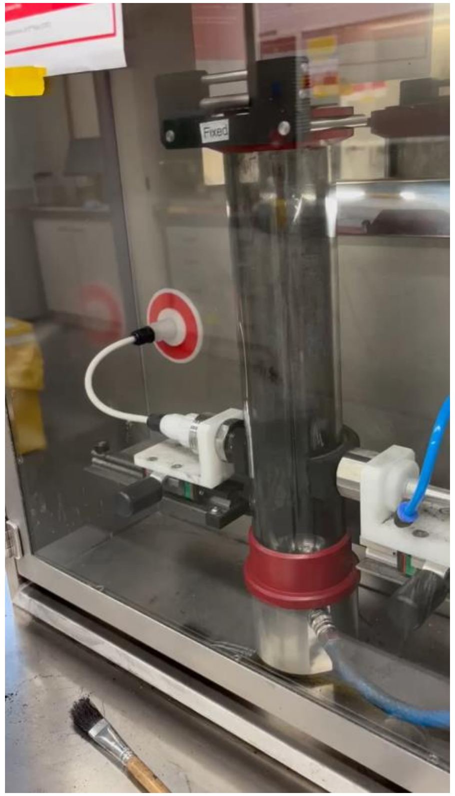
Is there a hazard • Screening tests (Go/No Go)	Hartman tube & G-G oven or 20L sphere
Avoid forming a flammable atmosphere(limiting oxygen or dust concentration) • Minimum explosive concentration (MEC) • Limiting oxygen concentration (LOC)	20L explosion sphere
Controlling ignition sources to prevent ignition(zoning: earthing, limiting temperatures)	
Ensuring no one is harmed from explosion(Blast panels, containment)	

Control of ignition sources – MIE

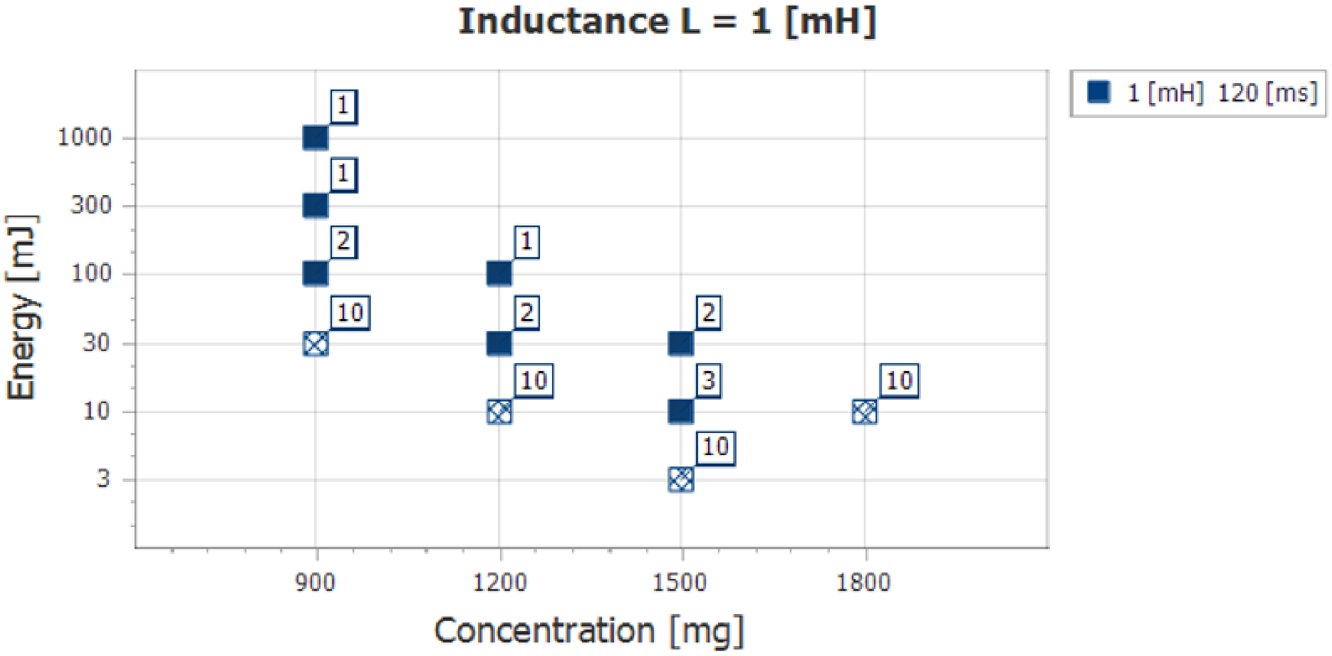
- **MIE** – measured in Hartman tube, ASTM and IEC standards are well aligned.
  - ASTM: E2019-03
  - IEC: 80079-20-2
- Problems with testing JM powders
  - Conductive powders can interfere with charging of electrode
  - Damage to equipment due to smouldering
  - Modifications with ANKO to electrode holders
  - Subtly different ignition definition used i.e. smouldering not flame propagation



Pictures of JM Hartman Tube by Toby Stephenson

Control of ignition sources – MIE

Minimum Ignition Energy of the Powder (mJ)	Comment
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	Most ignition incidents occur when ignition energy is below this level. The hazard from cone discharges should be considered.
10	High sensitivity to ignition. Take the above precautions and consider restrictions on the use of high resistivity materials (plastics) if energy is at or below this level. 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.



- The lower the ignition energy the more effort needs to go into avoiding sparks
- Induction or no induction:
  - Induction needed to test incendiary/mechanical sparks
  - Static best assessed by no induction
  - IEC standard states: "usually testing is carried out with induction"

Table of MIE thresholds based on data from DEKRA reports
MIE charts generated by Toby Stephenson using Minor 3.2

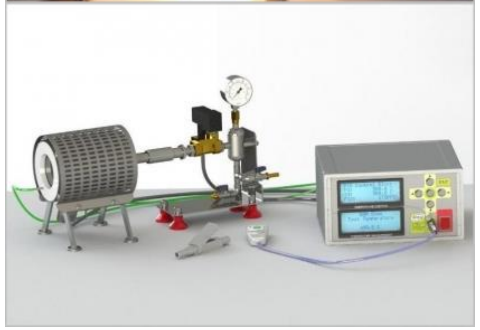
Control of ignition sources – Electrostatics and dust types

Dust Type	NFPA 70 502 & 503	IEC/ATEX NFPA 70 506
Coal dust	Class II F	Dust group IIIB
Nonconductive dusts	Class II G	
Metal & conductive dusts	Class II E	Dust group IIIC
Fibres and flyings	Class III	Dust group IIIA

- Combustible flyings:
  - IEC 80079-20-2: states that a fibre has one dimension longer than 500micron and ratio of length to width is 3 or more
  - NFPA 70 and 499 mention that one dimension is longer than 500microns but do not state a ratio.
- Conductive powders
  - **Volume resistivity**
    - IEC 80079-20-322: < 10^3ohm.m
    - ASTM D257-99 & NFPA 652: < 10^6ohm.m
    - High resistivity more likely to generate static
  - **Charge decay -** measures how quickly a powder loses charge.
    - ASTM: D4470-18
    - BS: 7506
  - **Chargeability -** measure the ability of a powder to acquire a charge when flowing though different material tubes.
    - No standards

Picture of charge Decay analyser by Toby Stephenson and resistivity device by Luke Luisman

Control of ignition sources – Temperature class



- **MIT** – ignition temperature of a dust cloud
  - Godbert Greenwlad oven (G-G)
  - BAM oven
  - BAM gives more conservative results.
  - Comparable ASTM and IEC tests
    - IEC: 80079-20-322
    - ASTM: E1491-06
- **LIT** – ignition temperature of a layer – hot plate test
  - Standards
    - IEC: 80079-20-322
    - ASTM: E2021
  - Big differences between ASTM and IEC testing 1/2” vs 5mm thick layer i.e. IEC test will use less material.
  - This will give lower LIT if tested under ASTM vs IEC.

Pictures of G-G oven, BAM oven and LIT plates courtesy of ANKO

Control of ignition sources – Temperature class

	IEC 60079-32-2	NFPA 499	NFPA 70	NFPA 652 & 484	NFPA 654 & 664
LIT	-75	0	0	-50	0.8
MIT	2/3	0	0	-50	0.8
Temperature class	Min of LIT & MIT	Use LIT unless sample melts then use MIT	Min of ignition temperature or 165	Min of LIT & MIT	Min of LIT & MIT

- Both LIT and MIT needed to assess temperature class under ATEX/IEC.
  - NFPA codes are more variable
  - Big concern is combining IEC testing with NFPA codes could be unsafe, equally combining ASTM testing with ATEX could be overly conservative.

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Controlling ignition sources to prevent ignition(zoning: earthing, limiting temperatures)
• Layer ignition temperature (LIT)
• Minimum Ignition temperature (MIT)
• Minimum ignition energy(MIE)
  • For less than 10mj MIEs then further testing of resistivity of dust is likely to be required
  • some equipment suppliers don’t design for materials with MIE<10mj
	Heated plate
	G-G or BAM Oven
	Modified Hartman tube

Ensuring no one is harmed from explosion(Blast panels, containment)	

Containing an explosion

- Explosion suppressant systems and building equipment to contain an explosion
- **dp/dt** – Peak rate of pressure rise
- **Pmax** – the maximum pressure generated
- Testing carried out in 20L sphere; Standards:
  - ASTM E1226-19
    - ASTM uses 2 X 5KJ pyrotechnic igniter
    - ASTM uses a pressure ratio of 2 to define an ignition.
  - BS EN 14034-3 & 14034-4
    - BS EN uses 2 X 1KJ pyrotechnic igniters
    - BS EN uses a pressure rise of 0.3barg.

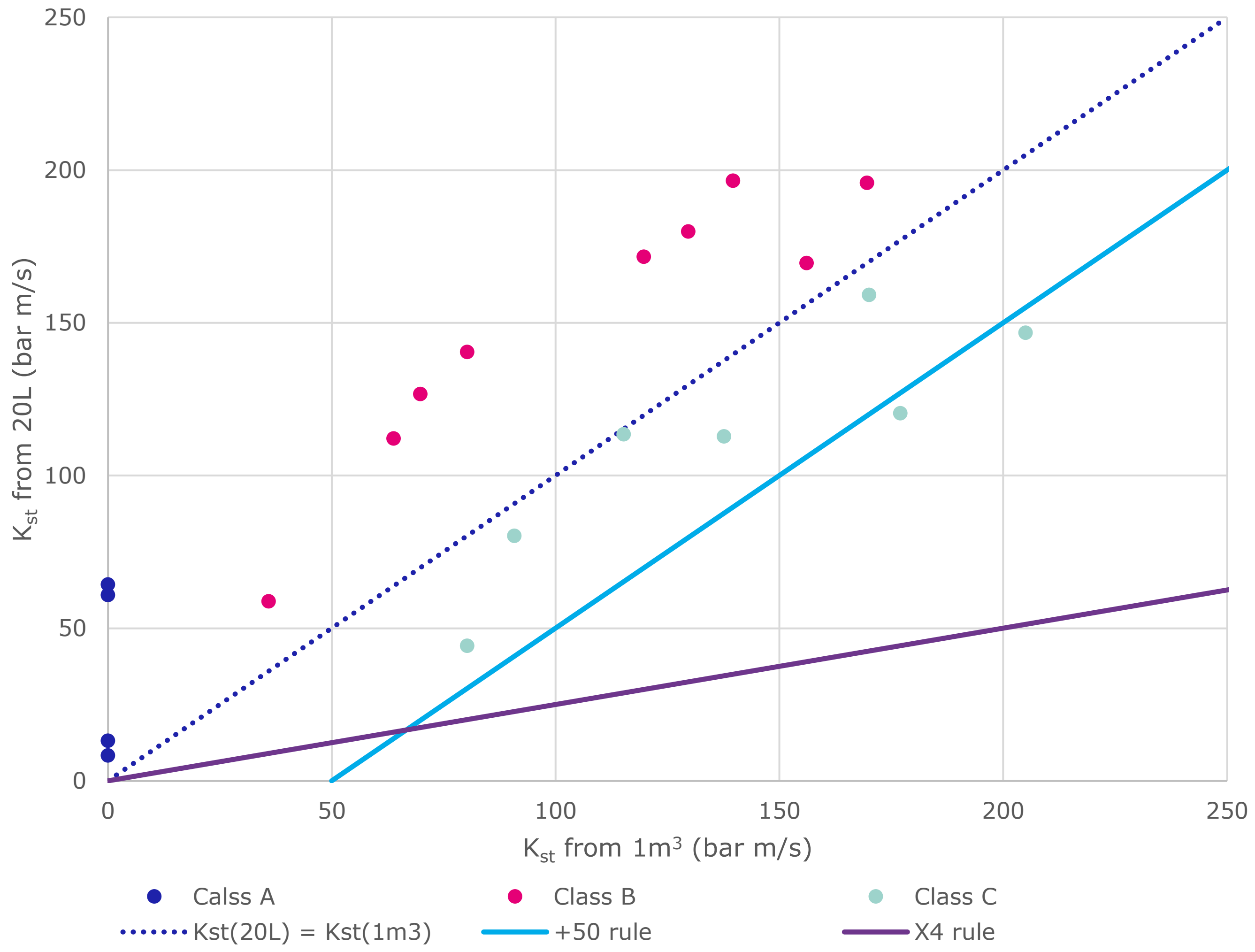
$$K_{St} = (dP/dt)_{max} \cdot V^{1/3}$$

- Historically smaller Hartman bomb has been used though these results have been discredited as not being comparable to scale
- 1m3 tests are regarded as the gold standard
- 20ltr tests generally regarded as comparable to 1m^3 tests for most cases
- Results from 20ltr test measure the rate of pressure change dp/dt. This needs converting to the KST value using the cube root rule

Picture of 20L sphere and 1m3 courtesy of **ANKO**

Containing an explosion

Pitfalls with the 20ltr explosion sphere



- Overdriving
  - The effect of having relatively large igniters in a small vessel
  - Results in false positives for materials with low KSt values
- Under driving
  - Heat is better lost from a smaller vessel and so causes with artificially low values
  - Metal dusts are susceptible to this in part due to having lower heat capacities and higher heats of combustion

Graph generated with data from: Portarapillo, M, Sanchirico, R, Di Benedetto, A. On the pyrotechnic ignitors role in dust explosion testing: Comparison between 20 L and 1 m^3 explosion vessels. *Process Saf Prog*. 2021; 40: 289– 295. https://doi.org/10.1002/prs.12249

Containing an explosion – Hartman tube

- Hartman tube can be fitted with a flap to give an indication of ST class these are often labelled as ST class H1 etc.
- We have this capability in JM and, a useful indicator but must not be used for specifying equipment
  - We are looking are potentially starting a project with a UK university to look at high speed footage of Hartman tube ignitions to estimate flame propagation velocity to see if this can be corelated with KST values

KST	ST class	flap	HST class
No ignition	ST0	No ignition	HST 0
<200	ST1	Part open	HST 1
200-300	ST2	Fully open	HST 2
>300	ST3	N/A	N/A

Hartman tube footage courtesy George Truc and Toby Stephenson

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Hartman tube & G-G oven or 20L sphere

Avoid forming a flammable atmosphere(limiting oxygen or dust concentration)

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- Limiting oxygen concentration (LOC)

20L explosion sphere

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Heated plate
G-G or BAM Oven
Modified Hartman tube

Ensuring no one is harmed from explosion(Blast panels, containment)

- Maximum rate of pressure increase (dp/dt)
- Maximum overpressure generated (Pmax)
- Explosion index (Kst)

20ltr explosion sphere

JM Johnson Matthey

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