A dust explosions overview

Status and developments in basic knowledge and practical application

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Outline

- *Practical challenges*
- *Some relevant research topics*
- *Highlight on some special issues*
  - *CFD modelling*
  - *Validation experiments*
  - *Design of electrical apparatus*
  - *"Inherently safer plants"*
  - *Nano-particle dust explosions*
  - *Education and training*

Table 1. Schematic overview of means of preventing and mitigating dust explosions.

EXPLOSION PREVENTION		EXPLOSION MITIGATION
PREVENTING EXPLOSIVE DUST CLOUDS	PREVENTING IGNITION SOURCES	
Inerting of dust clouds by N_2, CO_2 and rare gases	Smouldering combustion in dust, dust fires	Explosion-pressure resistant construction
Intrinsic inerting of dust cloud by combustion gases	Other types of open flames (e.g. hot work)	Explosion isolation (sectioning)
Inerting of dust cloud by adding inert dust	Hot surfaces (electrically or mechanically heated)	Explosion venting
Keeping dust conc. outside explosive range	Heat from mechanical impact (metal sparks and hot-spots)	Automatic explosion suppression
Inherently safer process design	Electric sparks and arcs and electrostatic discharges	Partial inerting of dust cloud by inert gas
		Good housekeeping (dust removal/cleaning)

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Table 2. Fundamental aspects addressed in dust explosion research

Dust cloud formation processes	**Dust cloud ignition processes**	**Flame propagation processes in dust clouds**	**Blast waves generated by burning dust clouds**
Inter-particle forces in dust deposits (cohesion)	General theories for ignition of single particles and clouds	Single-particle ignition and combustion in hot oxidizer gas	Blast wave properties as a function of properties of burning dust clouds
Entrainment of particles from dust deposits by shock waves passing across the deposit surface	Ignition by smouldering combustion in dust layers/deposits	Laminar and turbulent flames in dust clouds	Effects of blast waves on humans and mechanical structures
	Ignition by hot surfaces		
Entrainment of particles from dust deposits by turbulent gas flows	Ignition by flying burning metal particles	Mechanisms of heat transfer (conduction, convection, radiation)	Ability of blast waves from dust explosions to transform dust layers into explosive dust clouds (coupled to first column of table)
	Ignition by electric sparks and arcs		
Transport of dust particles in turbulent gas flows	Ignition by electrostatic discharges	Limit conditions for flame propagation in dust clouds (particle properties, dust conc., oxygen conc., geometry).	
	Ignition by hot gas jets		
	Ignition by shock waves		
Measurement and characterization of turbulence in dust clouds	Ignition by hot-spots from focused light beams	Acceleration of flames in dust clouds by turbulence mechanisms	
Measurement and characterization of spatial distribution of particles in dust clouds	Influences on dust cloud ignition sensitivity of cloud properties (composition, size, shape of particles, dust concentration, composition, turbulence, temperature and pressure of gas phase)	Detonation phenomena in dust clouds	

CFD-modelling

- *Predicting the course of dust explosions for realistic industrial plant scenarios is very demanding. Differentiation and tailoring will be required to a steadily increasing extent*
- *CFD-based modelling seems to be the only feasible approach for the foreseeable future*
- *Adequate CFD-modelling requires that relevant basic phenomena are understood and adequately accounted for*
- *These challenges will be discussed later this morning by Trygve Skjold*

A special CFD challenge:

Dust explosion development in ***coupled systems***


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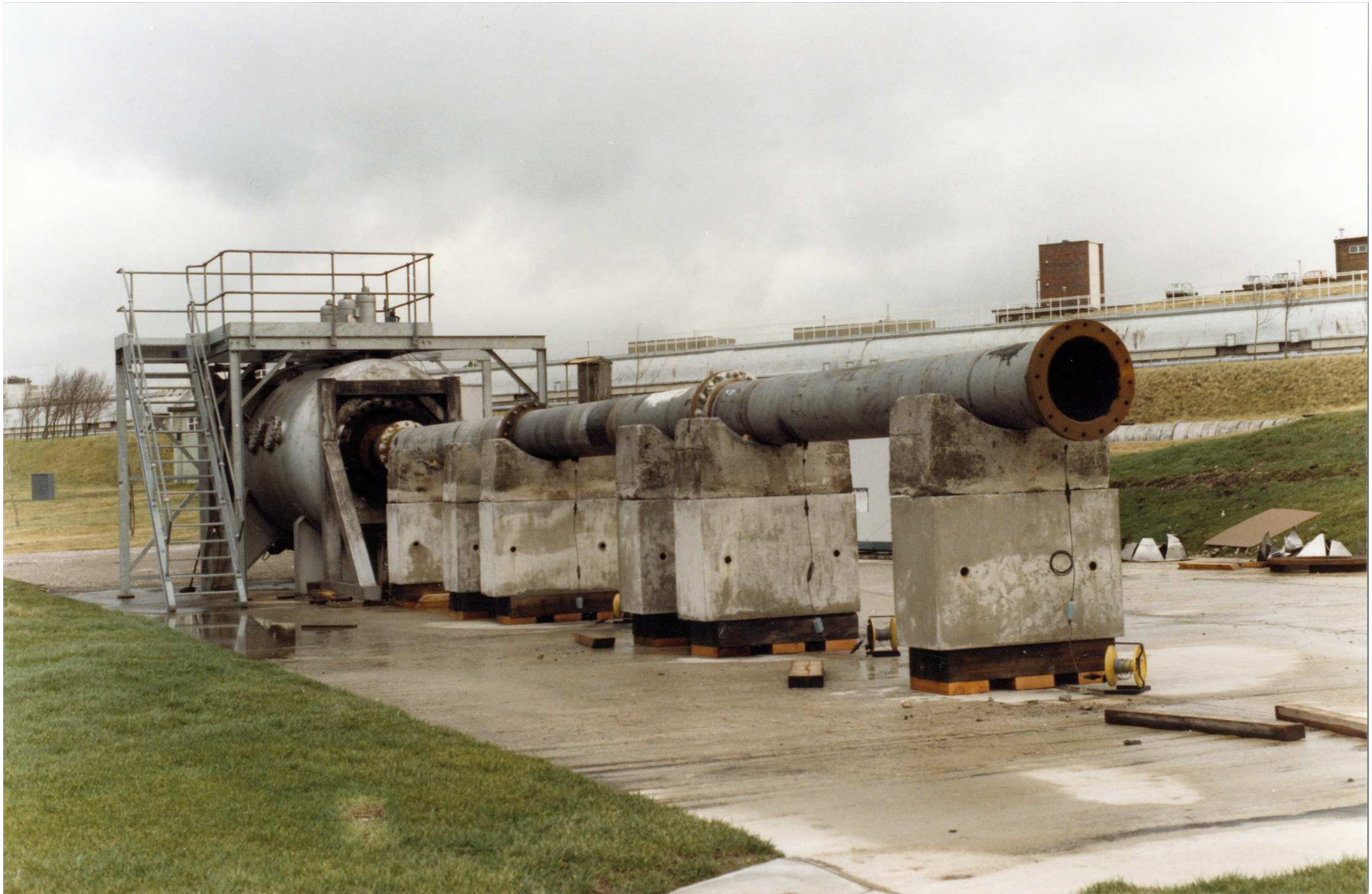
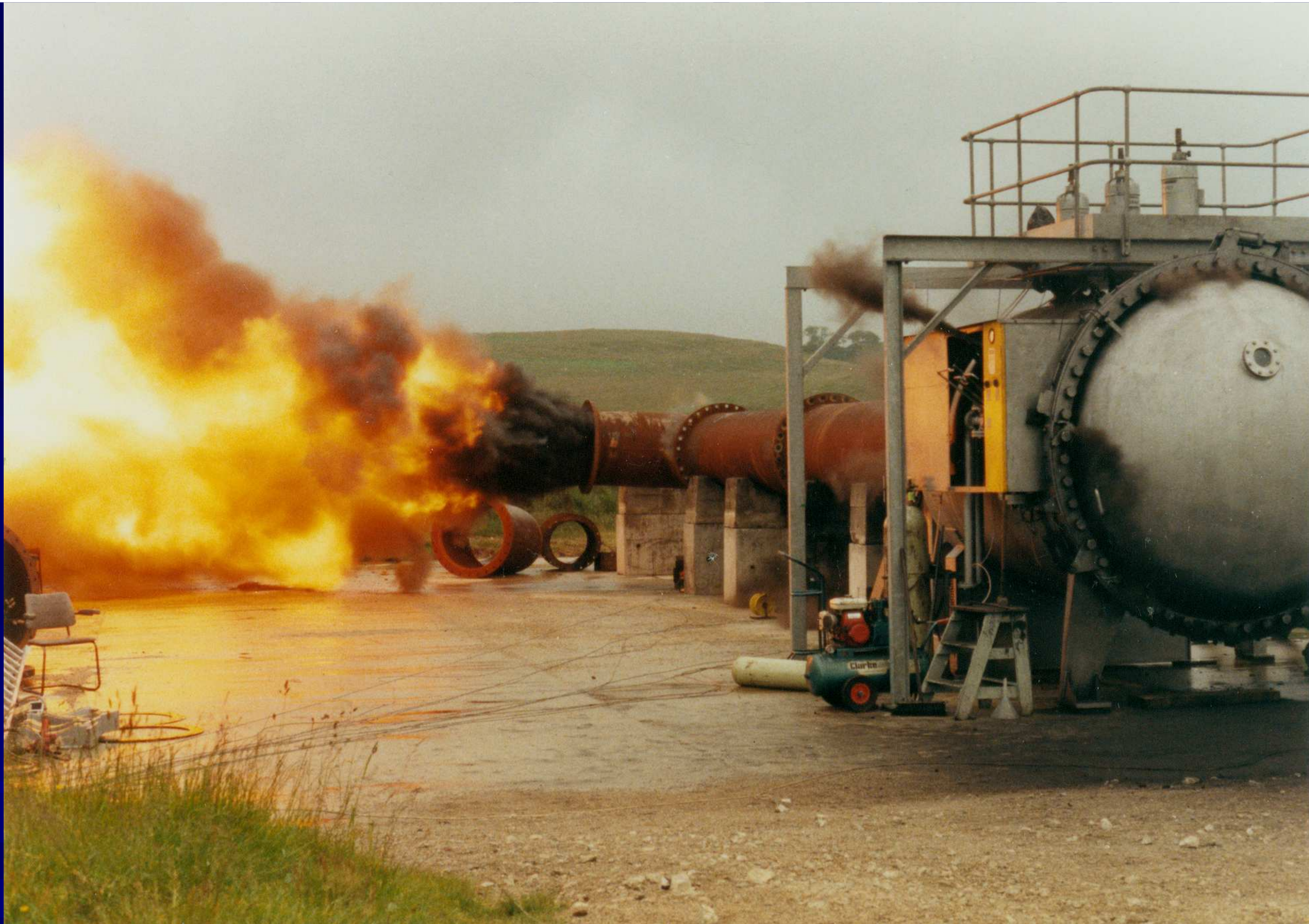
Experimental validation of CFD models is crucial

- *Full-scale experiments essential*
- *This will be discussed later this morning by Kees van Wingerden*





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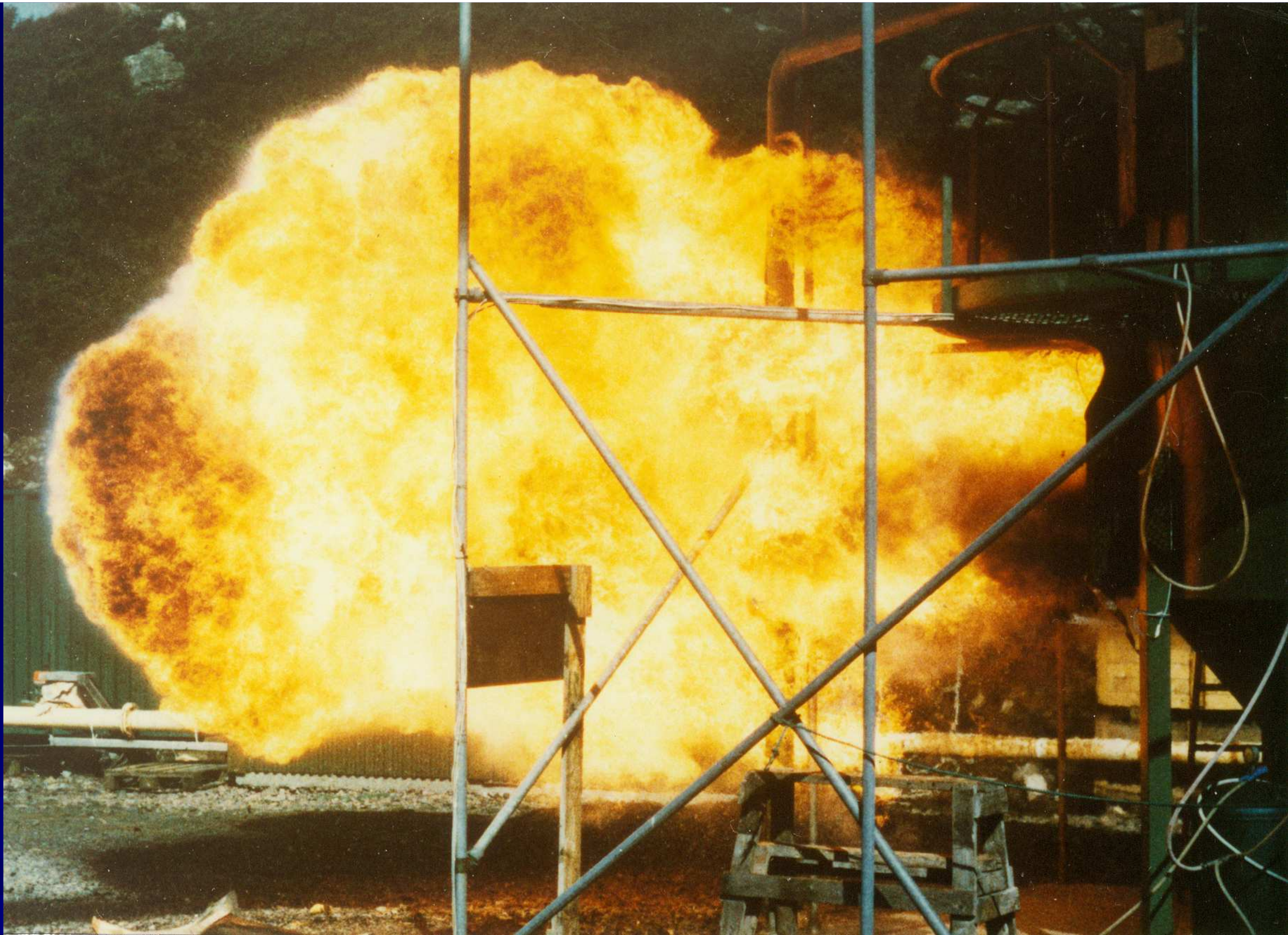

Design of electrical apparatus for use in areas containing combustible dust

- *Dusts differ from gases in some very significant ways*

Gases and ***dust clouds*** have similar ***ignition*** and ***combustion*** properties

- *flammability/explosibility limits*
- *laminar burning velocities and quenching distances*
- *response of burning velocity to cloud turbulence*
- *detonation phenomena*
- *adiabatic constant-volume explosion pressures*
- *well-defined minimum ignition energies*
- *well-defined minimum ignition temperatures*

The crucial ***difference*** between ***dusts*** and ***gases*** is in how the explosive ***clouds*** are ***generated***


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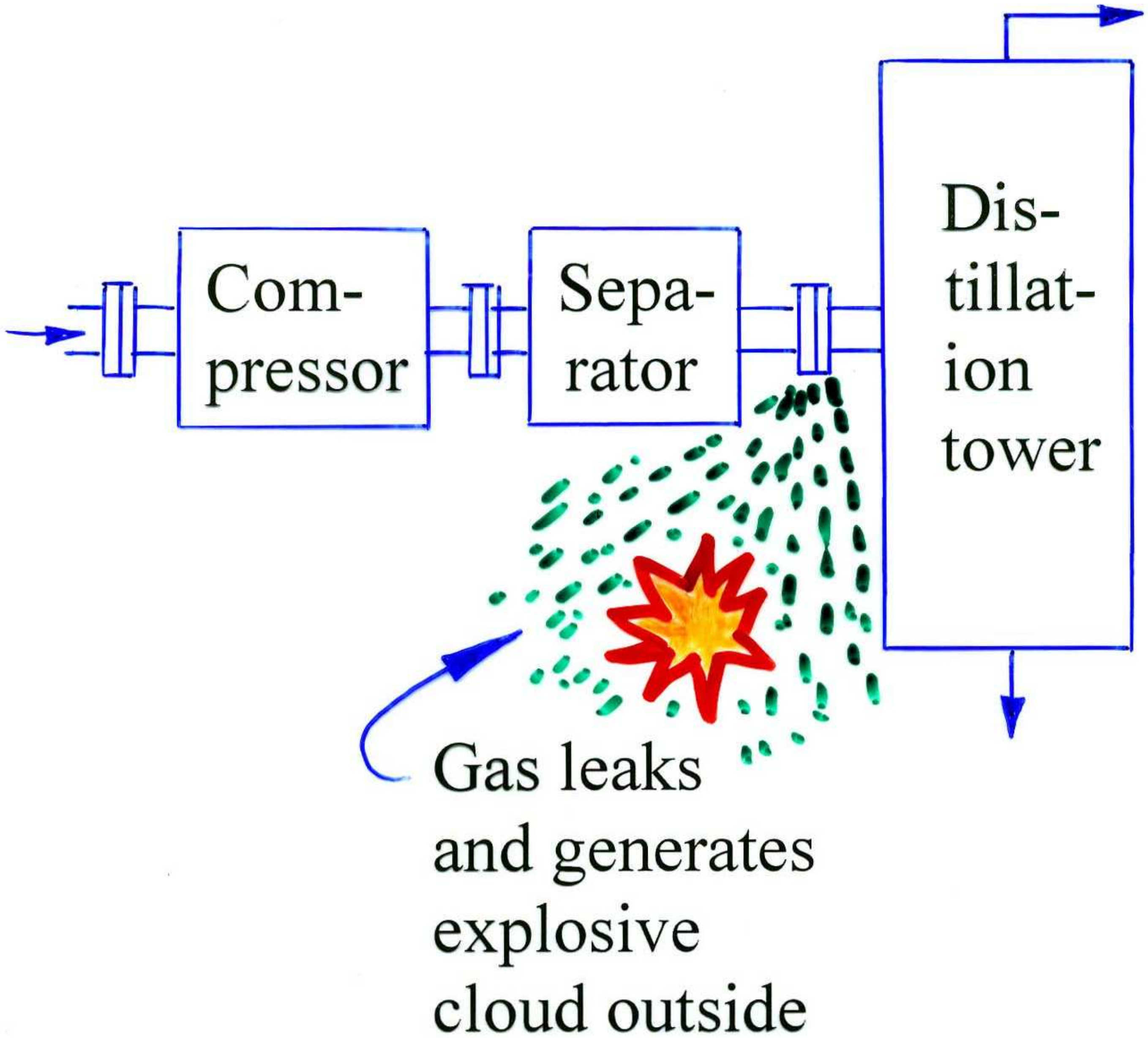
Where do we find

- *explosive **dust** clouds*
- *explosive **gas** clouds*

*in the **process industries***

?


Com-
pressor
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Dis-
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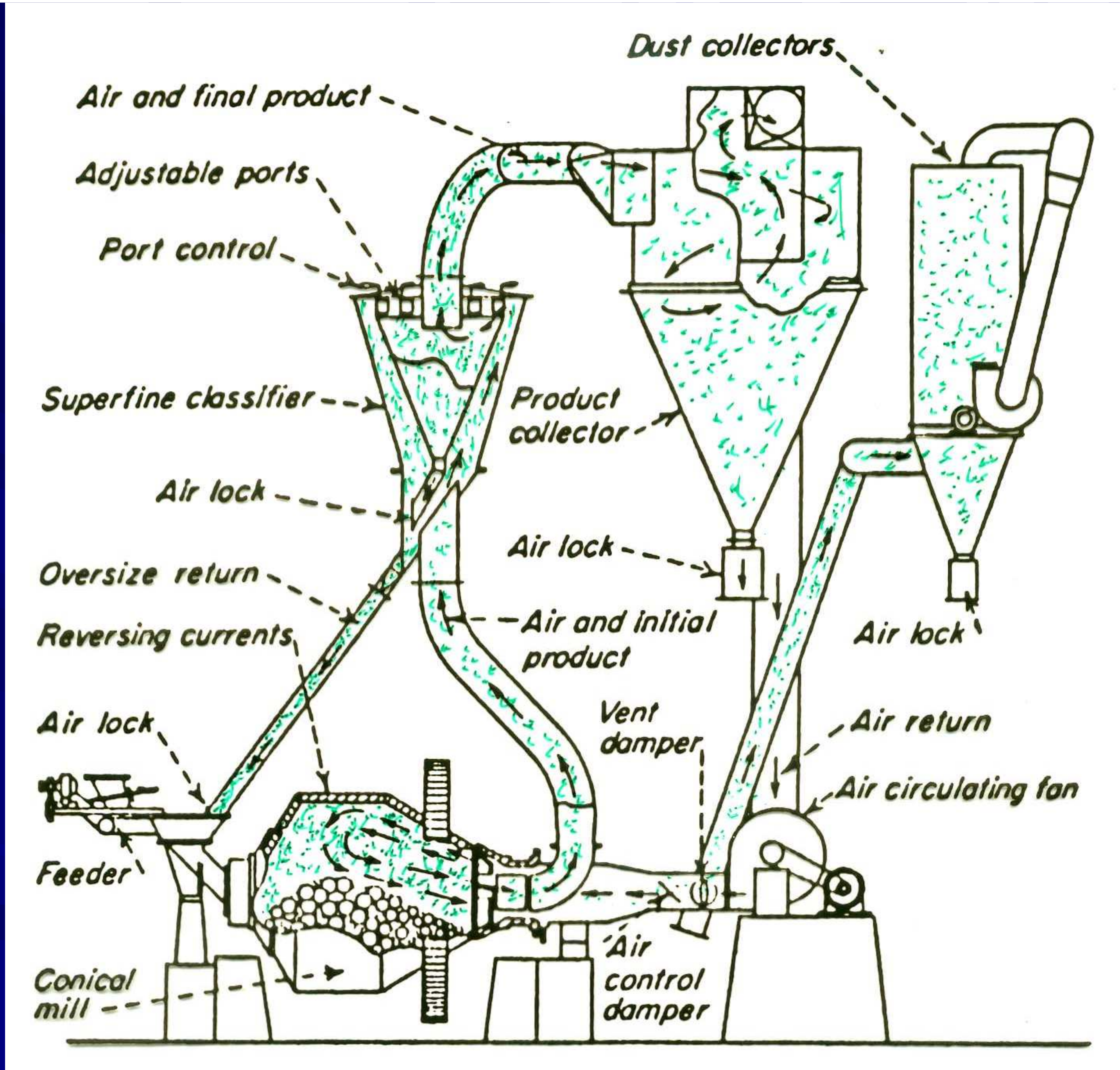
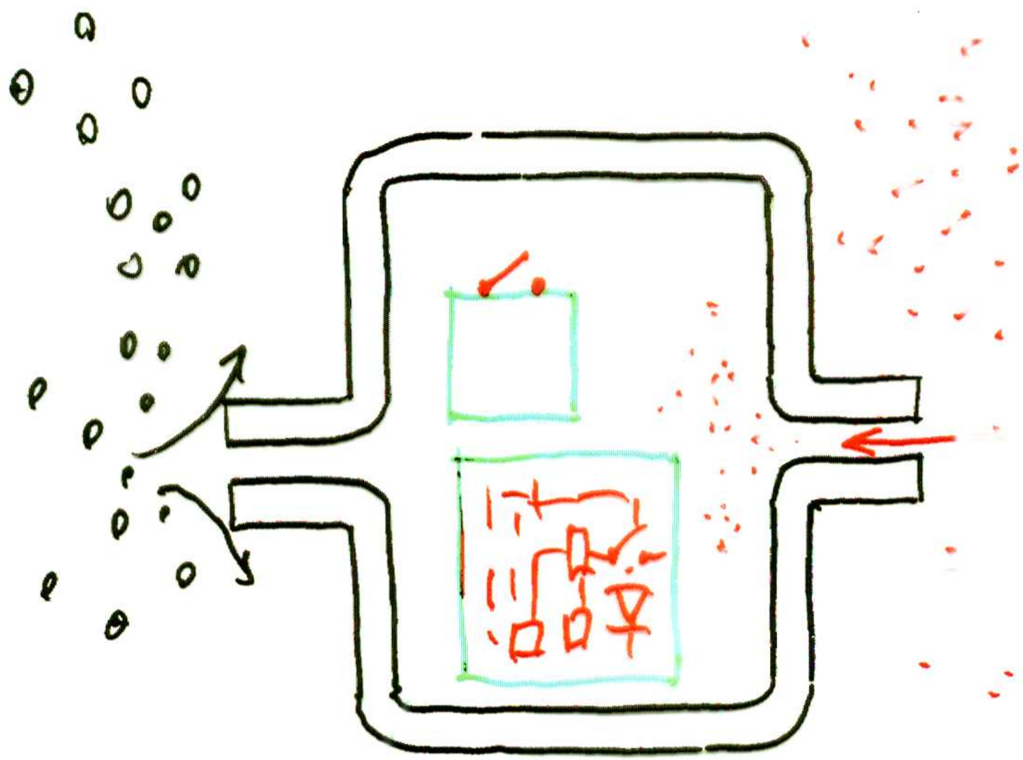
ion
tower
Gas leaks
and generates
explosive
cloud outside


Dust collectors
Air and final product
Adjustable ports
Port control
Superfine classifier
Product collector
Air lock
Oversize return
Reversing currents
Air lock
Feeder
Conical mill
Air lock
Air and initial product
Vent damper
Air control damper
Air lock
Air return
Air circulating fan

Dust *particles* ***cannot*** *migrate through narrow* ***holes*** *and* ***gaps*** *in walls and form explosive clouds on the down-stream side, as* ***gas molecules*** *can*

BASIC DIFFERENCE BETWEEN

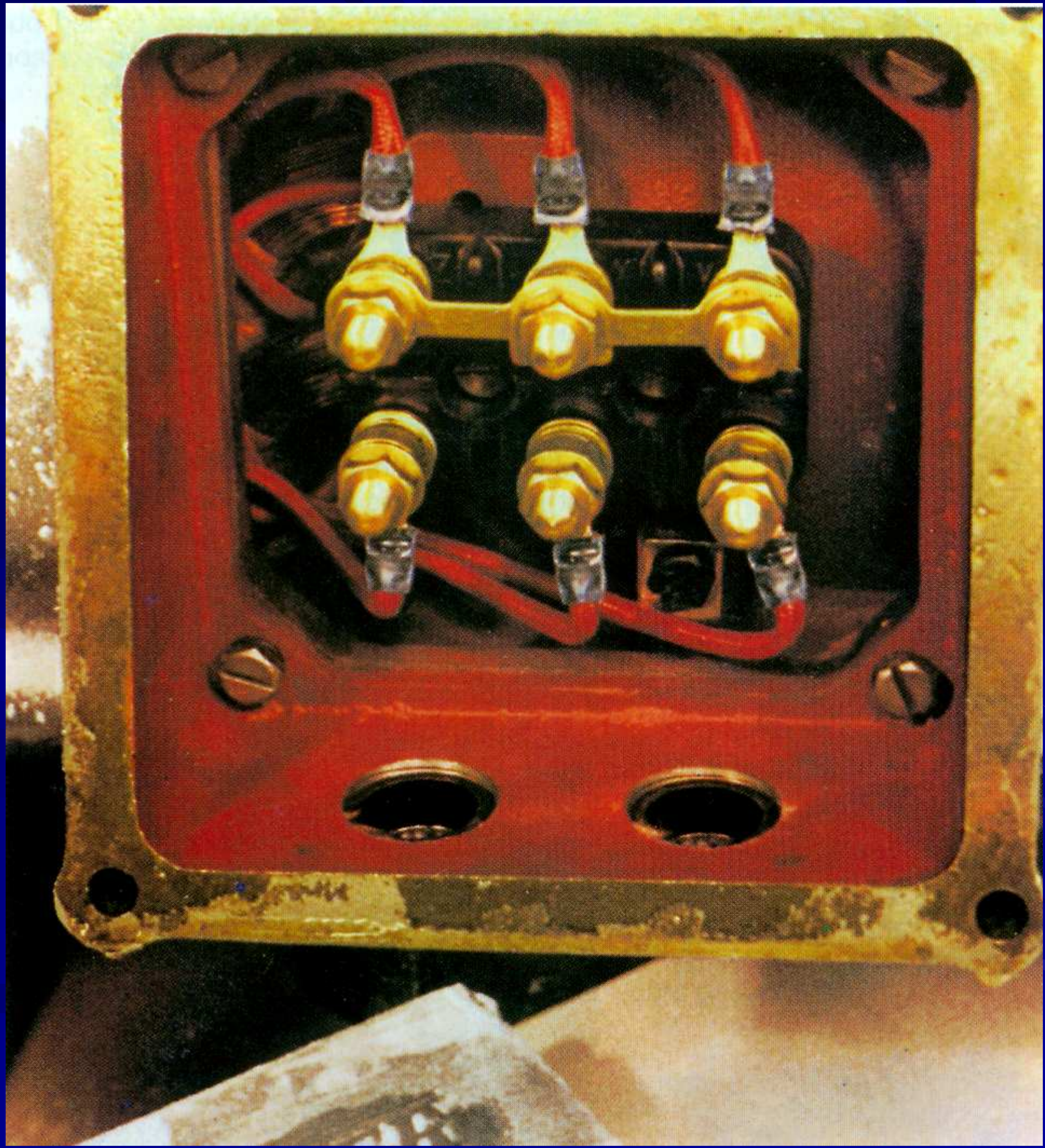
DUST AND GAS



Terminal box of geared motor unit with IP 65 protection, after standard dust ingress test

No sign of dust inside enclosure

(From Greiner, Germany)



*Clarification of **basic gas/dust differences** is entirely **absent in 'ATEX'** (directives 94/9/EC and 1999/92/EC and supporting/derived documents)*

*Definition of **explosive atmosphere***

(dir. 94/9/EC, article 1, item 3)

*A **mixture** with **air**, under atmospheric conditions, of **flammable substances** in the form of **gases, vapours, mists** or **dusts,** in which, after ignition has occurred, **combustion spreads** to the entire unburnt mixture*

- *With **dusts**, **layers** and **deposits** constitute an **additional state** for combustion propagation that satisfies the ATEX definition of an **explosive 'atmosphere'***

Unfortunate combination of dust and gas standards for design of electrical apparatuses within the IEC/ATEX-domain

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Overall argument used by manufacturers to defend gas/dust alignment

- *The **same** electrical **apparatus** can be used both for **gases** and **dusts***
- *Argument **useful** for **producers** of electrical apparatuses, but **invalid** in **objective safety standardization**, and **not optimal** for **users***

IEC ‘pressurisation’ standard for dusts

- *The standard is an **edited copy** of the corresponding IEC **gas standard** (Ex ‘p’)*

<u>Erratic inherent assumption</u>

***Dust particles** that enter the interior of electrical apparatus through **narrow holes/gaps** in the enclosure wall can **accumulate** to form an **explosive dust cloud inside** the enclosures’ in the same way as combustible gas molecules can form an explosive gas mixture*

New IEC dust 'moulding' standard

- *This standard is an edited copy of the corresponding IEC gas standard. But, a special **dust 'moulding' standard** seems **unnecessary***

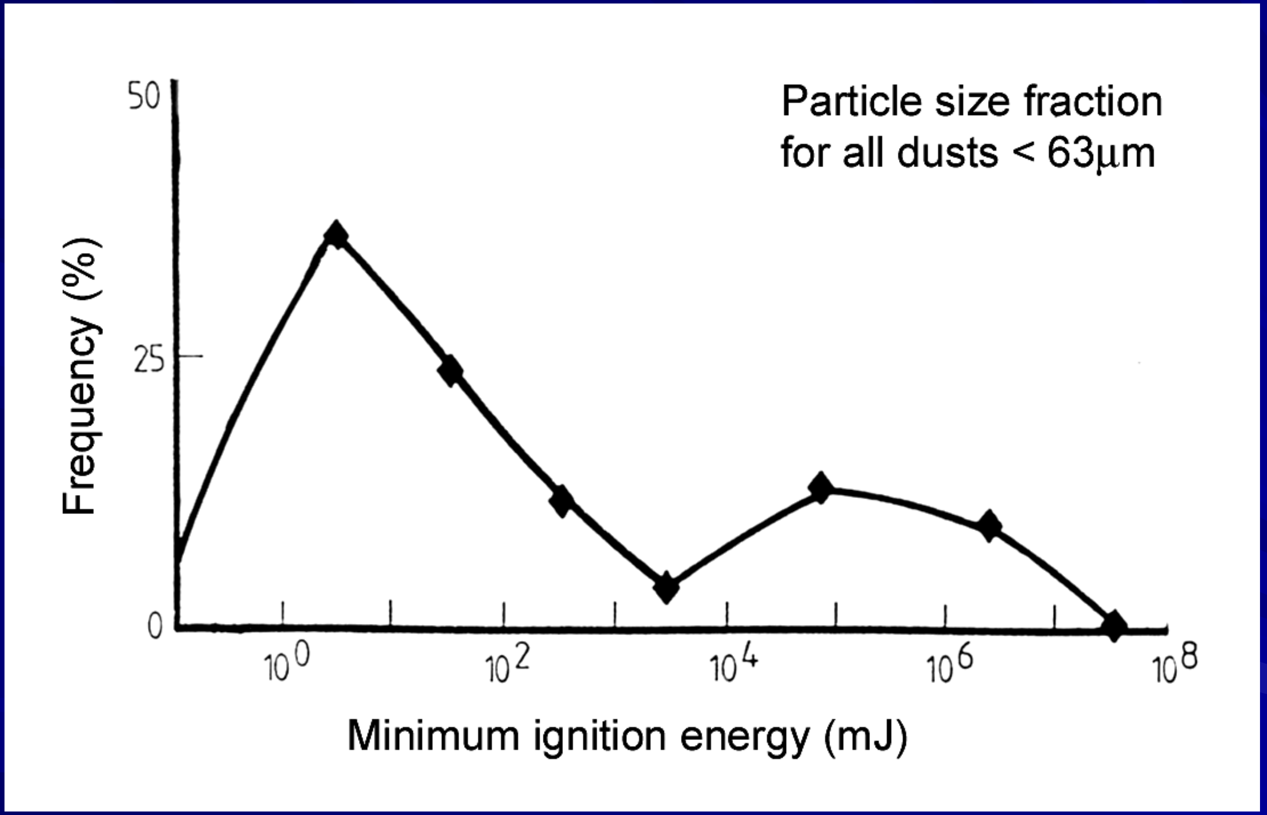
*Note: **EN 50281-1-1** (construction and testing of electrical apparatus protected by enclosures) contains a paragraph on **'materials used for cementing'**, which may be expanded to cover any aspects of encapsulation by moulding that may be relevant for dusts*

New ‘intrinsic safety’ standard for dusts

- *In a few **special cases** genuine **Ex'iD’** apparatuses are needed (e.g. some capacitive level detectors for silos)*

- *However, the new IEC (2004) standard has **no differentiation IIB gas** requirements (MIE = 0.06 mJ) for **all dusts***

*However, **MIEs for dusts** cover about **8** orders of magnitude, and current **standard MIE test method** for dusts offers a simple means for obtaining the required **differentiation***



Frequency of occurrence of MIEs of dusts
From Bartknecht (1993)

New *'flame proof"* (Ex 'd') standard also covering *dusts*

- *When the basic principle of the 'flame proof' concept is explained, only **gases** and **vapours** are **mentioned***
- *Possible reason: **Not very sensible to include dusts** (and sprays/mists) in this explanation*

- *According to the standard, the* ***testing*** *of flameproof enclosures to be used in explosive* ***dust clouds*** *should be done with explosive* ***gas*** *mixtures,* ***not*** *with* ***dusts***
- *The reason given is that testing with gases is* ***'simpler'.*** *The real reason rather seems to be that* ***testing with dusts would not make much sense***

Necessary adjustment of ATEX "user" directive

- *The term **'source of release of dust'** should be replaced by a more relevant term for dusts, e.g. **'area of dust cloud generation'***
- ***Dust layers/deposit** to be classified in their own right with because of possible **dust fires***
- *The issue of **dust layers** outside process equipment being a source **secondary** dust **explosions** is **not a concern** of conventional area classification. The Directive should express clearly that this is to be considered in a QRA in the context of explosion **consequences***

Necessary adjustment of ATEX "appartus" directive

- *A revised directive should express clearly that the* ***ways*** *in which* ***gas/vapour*** *clouds, and* ***dust*** *clouds, are* ***generated, sustained****, and* ***migrate****, are* ***basically different***

Nano-particle dust clouds

- *Does **ignition sensitivity** and **explosion violence** increase systematically with decreasing particle size right down to the **nano-particle** range?*

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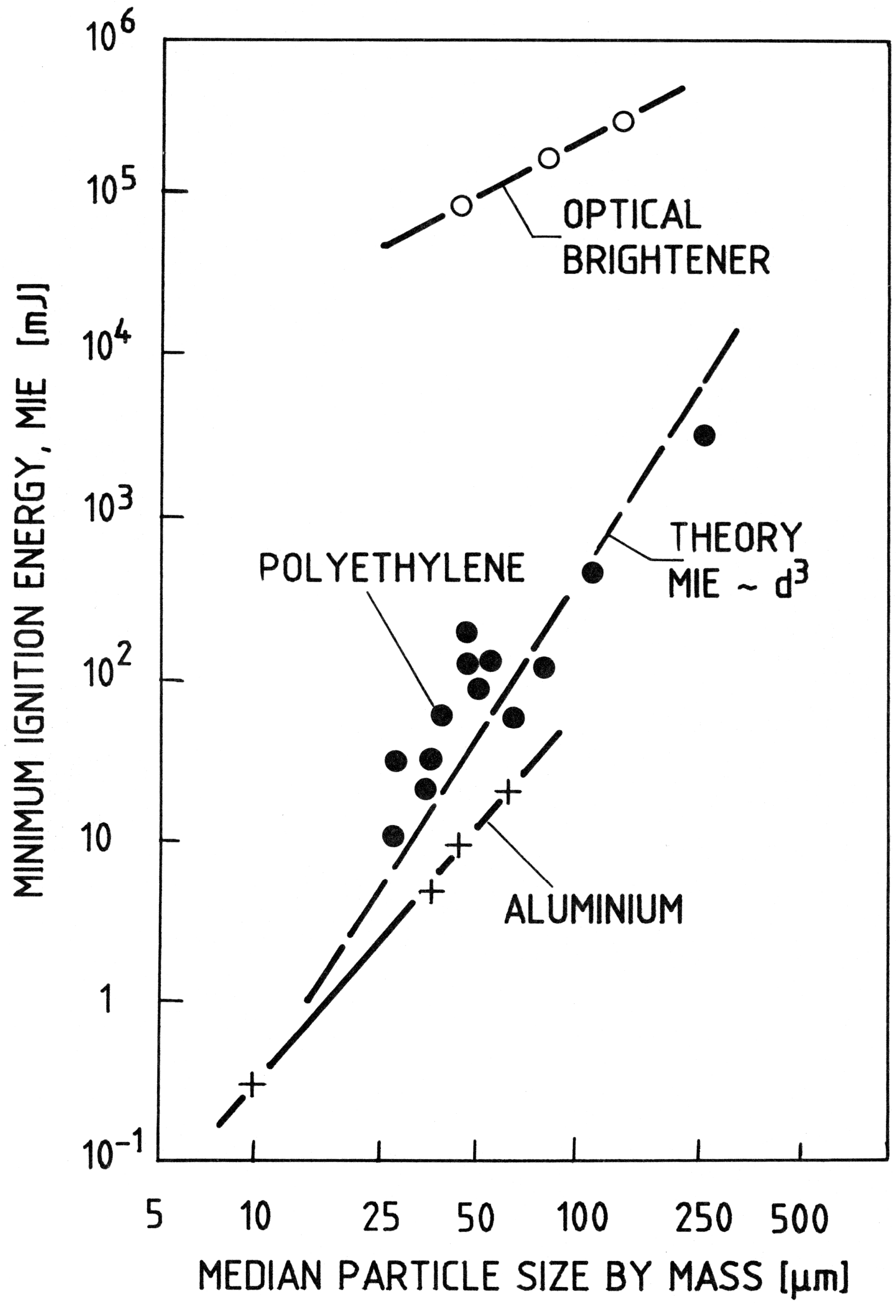
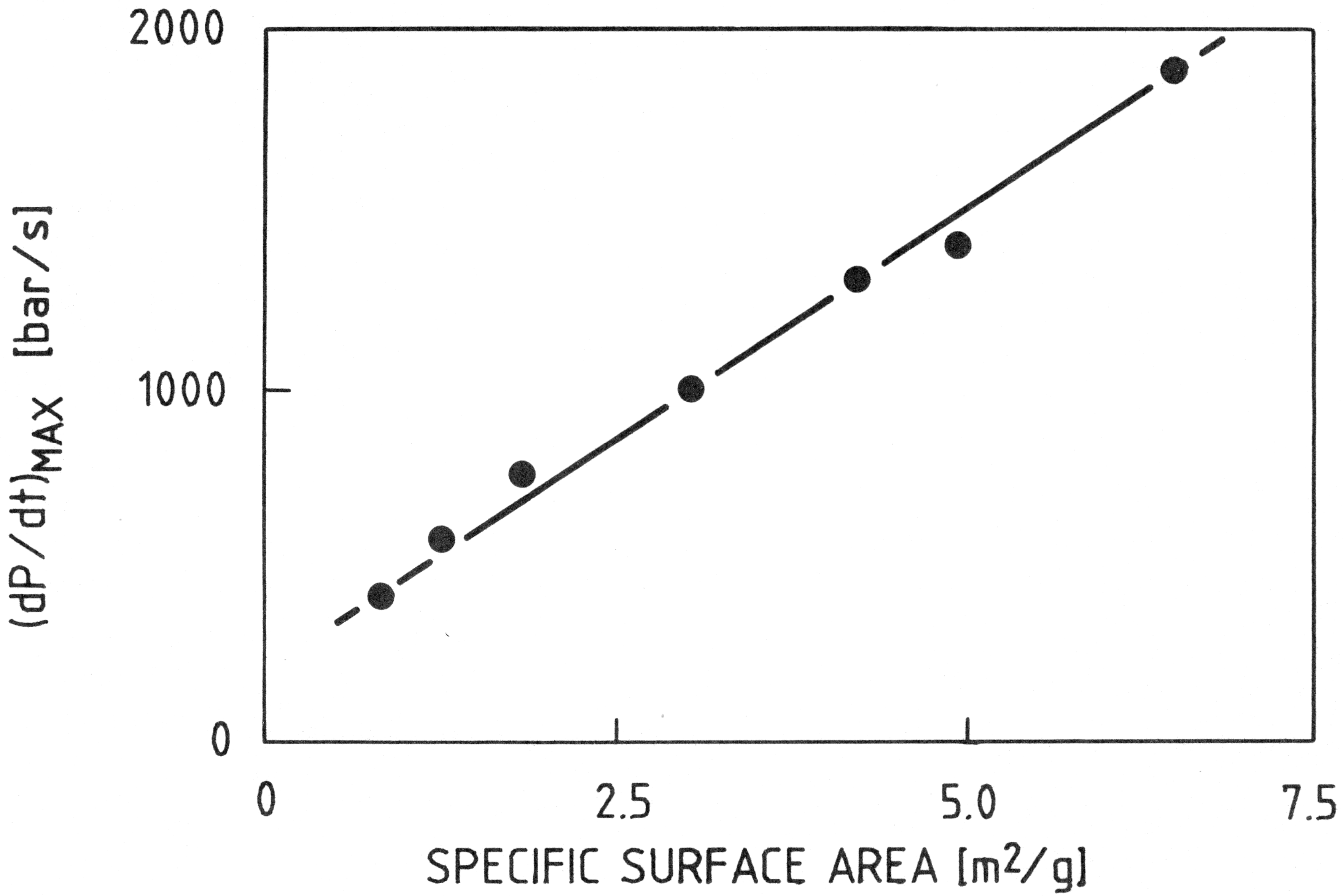


10^6
10^5
10^4
10^3
10^2
10
1
10^-1
MINIMUM IGNITION ENERGY, MIE [mJ]
OPTICAL
BRIGHTENER
THEORY
MIE ~ d^3
POLYETHYLENE
ALUMINIUM
5
10
25
50
100
250
500
MEDIAN PARTICLE SIZE BY MASS [µm]


2000
1000
0
(dP/dt)MAX [bar/s]
0
2.5
5.0
7.5
SPECIFIC SURFACE AREA [m2/g]

- *Ongoing research on nano-particle dust explosions will be discussed later this morning by Paul Holbrow*

Some important concerns

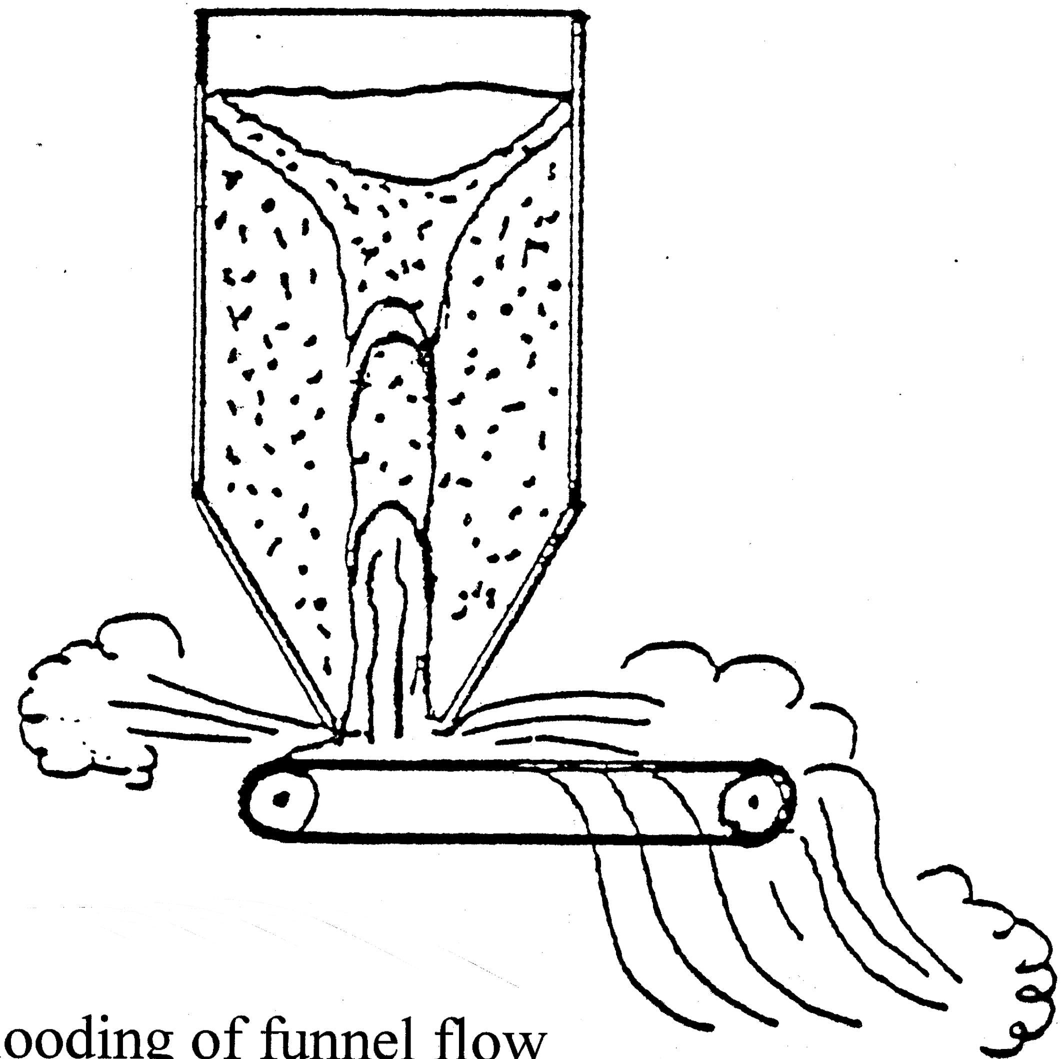
- ***Dispersion*** *of powder deposits of nano-particles to clouds of primary particles, is very difficult in practice (very strong inter-particle forces)*
- *Clouds of* ***primary nano-particles*** *of mass concentrations within the* ***explosive range*** *will* ***coagulate*** *very rapidly to form clouds of* ***agglomerates****, i.e. of much larger effective particle sizes than the sizes of primary nano-particles*
- ***Delay between dispersion and ignition*** *important for ignition sensitivity and explosion rate*

Inherently safer plants

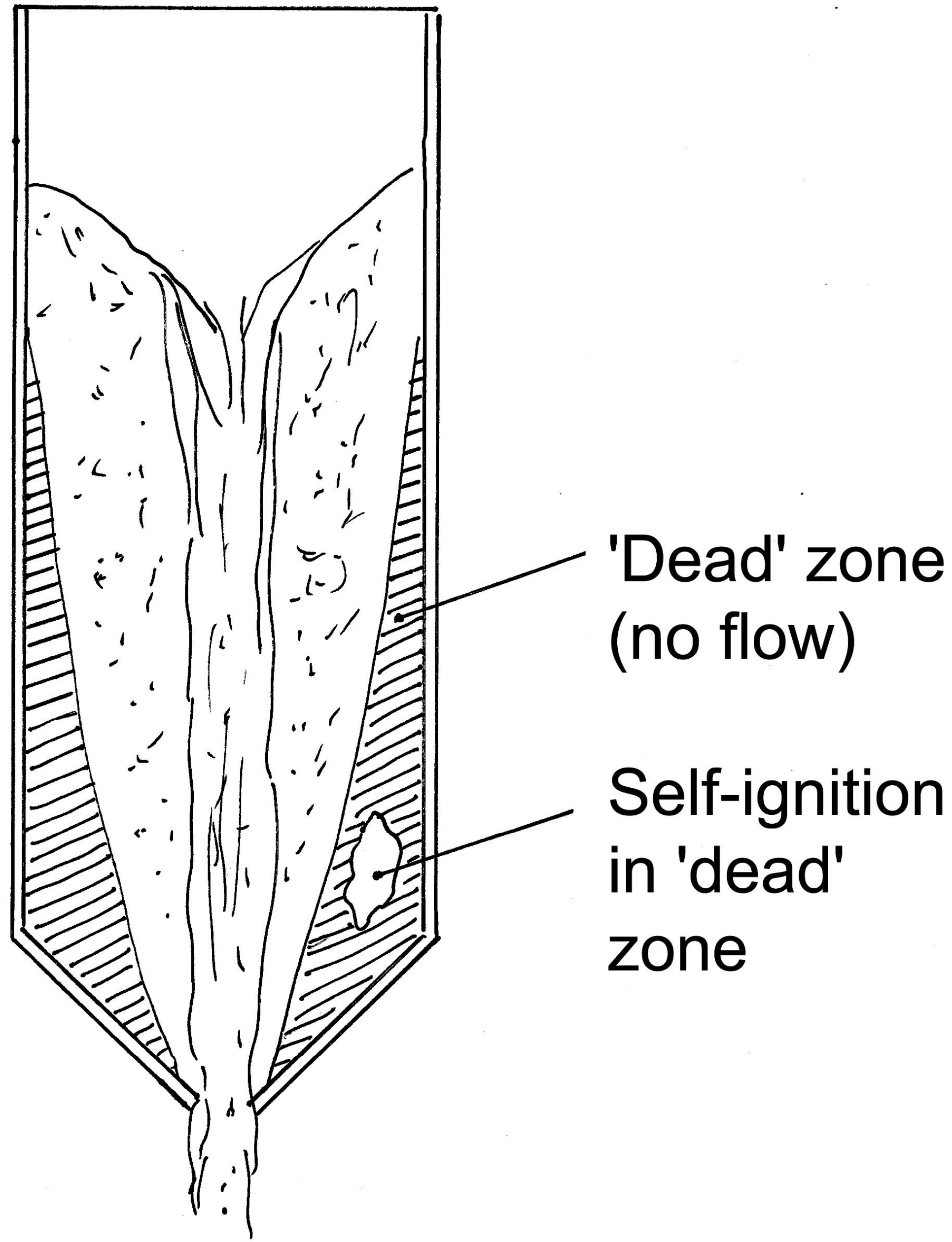
- *Central role of* ***powder science and technology*** *in plant design*

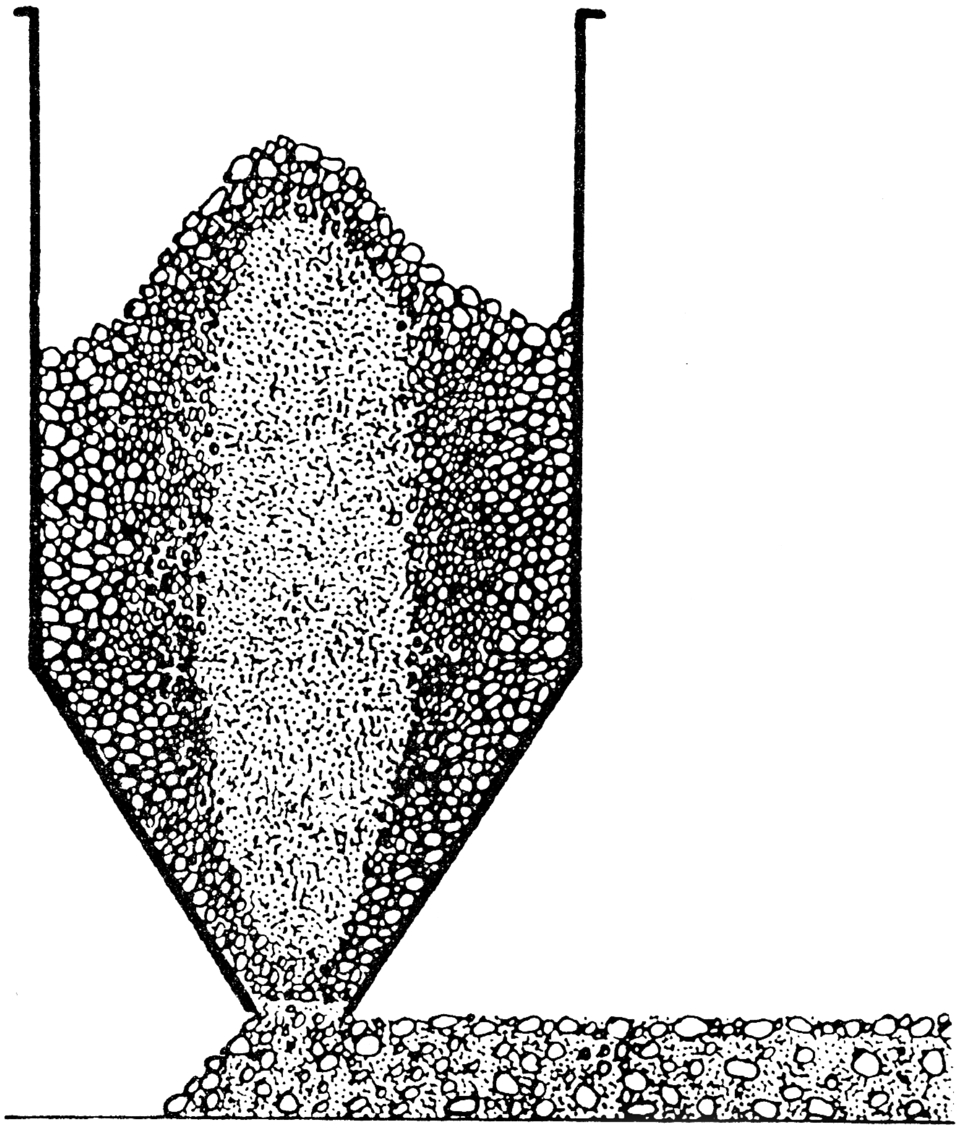
- *<u>Four basic principles</u> (Kletz/Amyotte):*
  - Minimization of undesired dust clouds and layers
  - Substitution of process equipment and procedures
  - Moderation/modification of raw materials, processes and products
  - Simplification of processes and operations

Design of silos and hoppers



Flooding of funnel flow silo due to uncontrolled powder flow


'Dead' zone
(no flow)
Self-ignition
in 'dead'
zone



Mass flow silo

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Casting of MgFeSi alloys

***Old* casting method:**

- *Large flakes of solidified alloy formed*
- *Substantial segregation of Mg during solidification*
- *Regions of high Mg content was most brittle and created most and finest dust*

Therefore:

- *More very fine dust than necessary was produced*
- *Twice as much Mg in the fine dust than average in product*
- *Because MIE decreased with both decreasing particle size and increasing Mg content, excessive amounts of dust of very low MIE were generated*

Casting of MgFeSi alloys

New casting method:

- *Small rectangular solidification flakes*
- *Markedly reduced Mg segregation, i.e. less fine dust and less Mg in finest dust*

Result:

- *A more homogeneous main product, and*
- *a reduced dust explosion hazard*

Education and training

- *Proper motivation and dedication is essential for establishing and maintaining optimal safety culture*
- ***Real experiments*** *are an effective means of promoting genuine understanding, dedication and motivation*

Film av støvekspl.i lab.app.MOV

Thank you very much for your attention !

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