



Introduction to Fire and Explosion Hazards

Module 7

ENG 431: Safety Chemical Processes

Annik Nanchen

Agenda



1	Introduction to fire & explosion hazards
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2	Explosion dynamics
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3	Explosion prevention
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3.1	Limit fuel concentration
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3.2	Limit oxidant concentration
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3.3	Avoidance of ignition sources
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4	Risk based prevention: Zoning
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5	Explosion protection
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Major Accidents

Flixborough, 1974



Vapor Cloud Explosion (VCE)
28 killed and 104 injured, explosion of a
cyclohexane/air-mixture

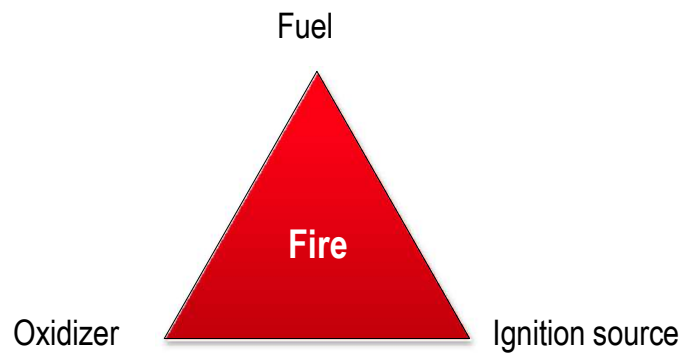
Imperial Sugar, 2008



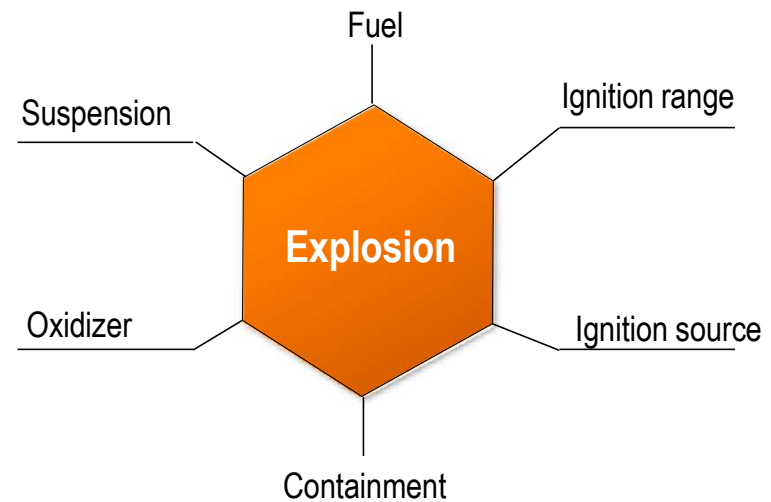
Dust explosion of sugar, 14 killed, 38 injured
including 14 with serious and life-threatening
burns.

Conditions for creating an explosion

Fire Triangle

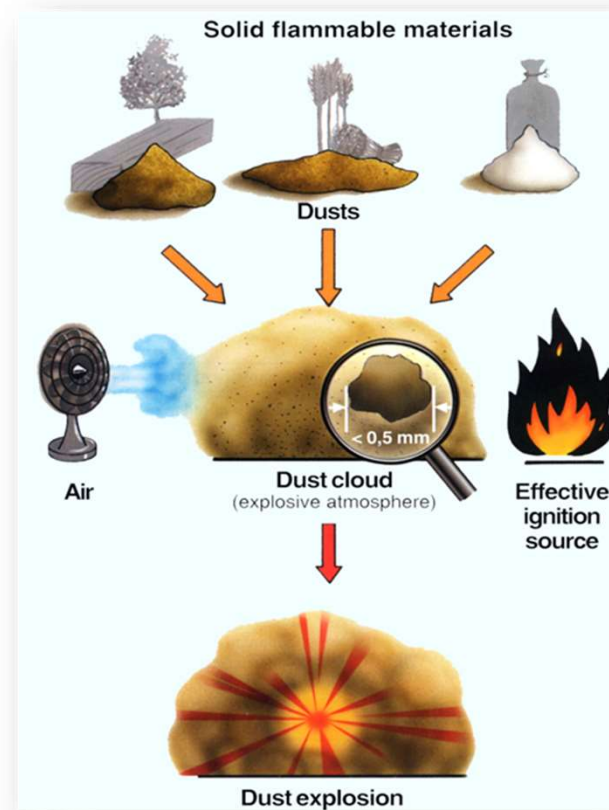
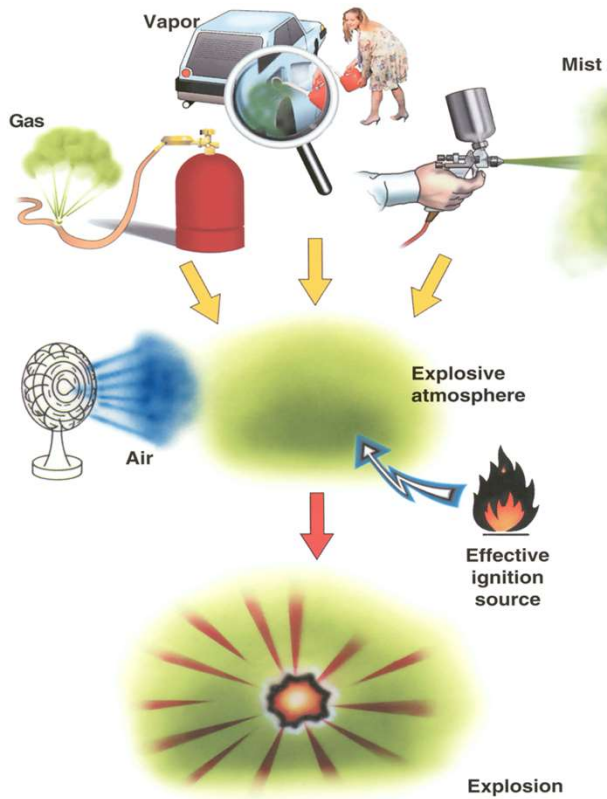


Explosion Hexagon



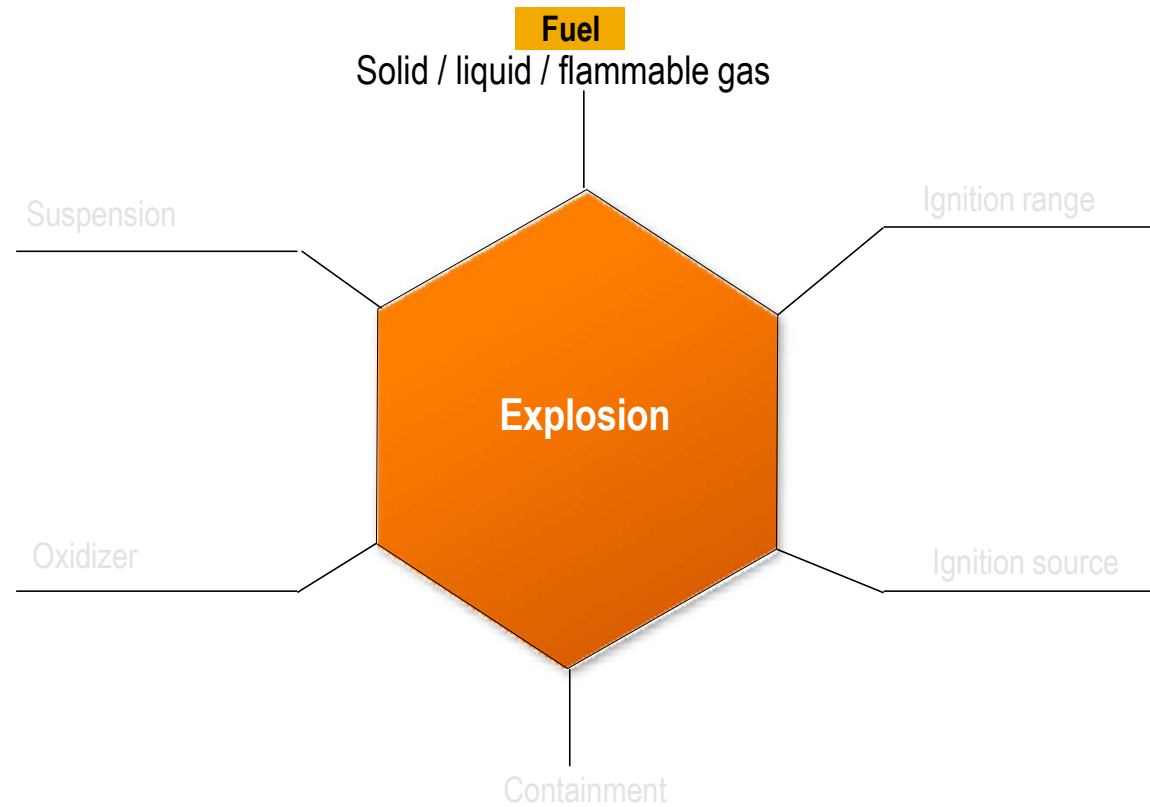
Explosion prevention aims to remove at least one of the explosion hexagon components.

Prerequisites for the occurrence of explosions



Sources: ISSA, Dust Explosions (2003) and Gas Explosions (2000)

Conditions for creating an explosion



Fuel – State of matter and flammability

Gas:

- Flammable mixtures can form at any temperature

Vapor:

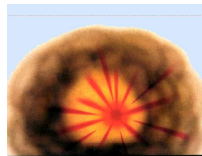
- Flammable vapor atmospheres occur at, or above, the flash point temperature of the liquid

“Liquid droplets”:

- Fine droplet mist can be flammable below the flash point of the liquid

Solids:

- Dust layer
- Dust cloud



Fuel: Flash point

- The flash point of a flammable liquid is the lowest temperature corrected to a barometric pressure of 101.3kPa, at which application of a test flame causes the vapour of the liquid to ignite momentarily and the flame to propagate across the surface of the liquid.
- Closed cup (c.c.) and open cup (o.c.) measurements can be performed. Flash point measured with o.c. are 10-20°C higher → only use c.c. data

Compound	Flash point
Acetone	-18°C
Ethanol	12°C
Diesel	>52°C
Toluene	4°C
Petrol/gas	~43°C

Flash point

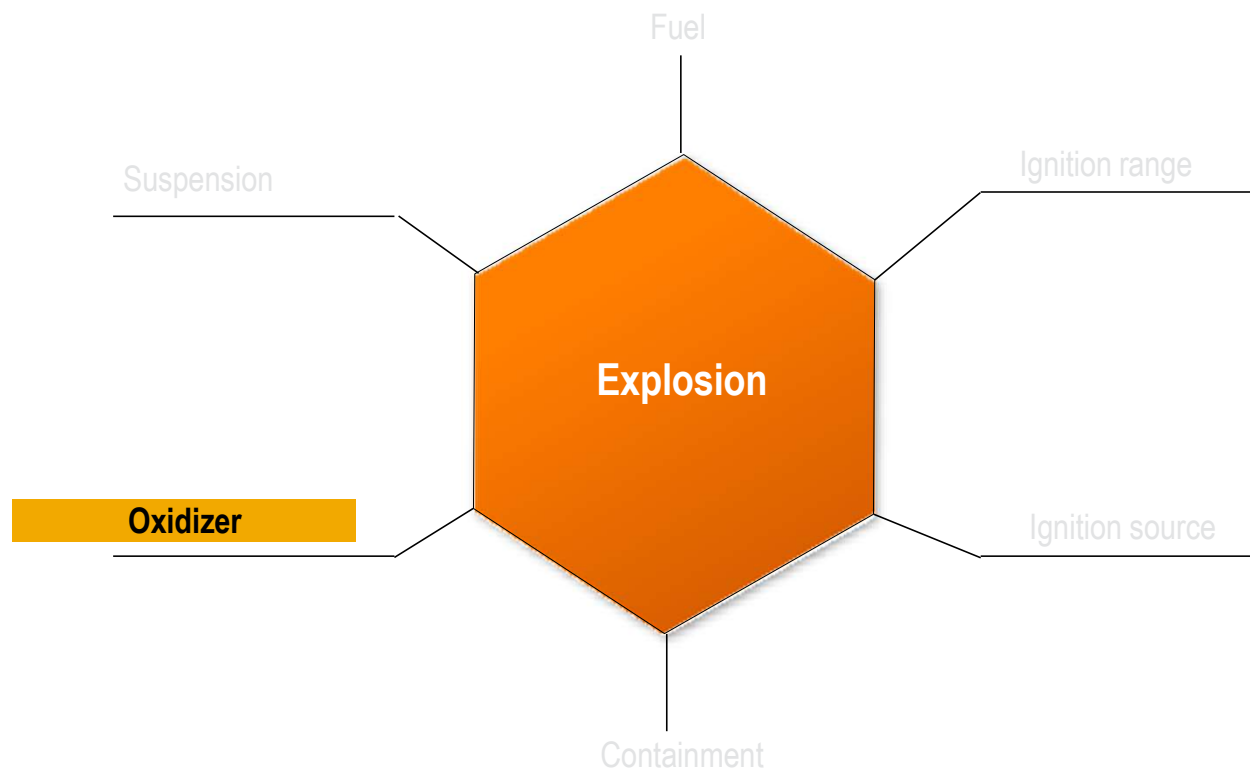


Fuel: Flash point, fire point, auto-ignition

- Flash point: momentary ignition when ignited
- Fire point: continuous burning when ignited (continues burning for at least 5s when removes the ignition source) (generally estimated to be 10°C higher than flash point, but can vary much more)
- Auto-ignition: liquid ignites spontaneously
- Relevant for Process Safety: flash point and autoignition.
 - Flash point used to characterize fire/explosion hazard
 - Autoignition: to assess ignition source hot surfaces

Compound	Flash point	Fire point	Autoignition
Acetone	-18°C		528°C
Ethanol	12°C	22°C	400°C
Methanol	9°C	17°C	440°C
Toluene	4°C		535°C

Conditions for creating an explosion



Conditions for creating an explosion - True or False

Fuel can ignite without an oxidizer

False

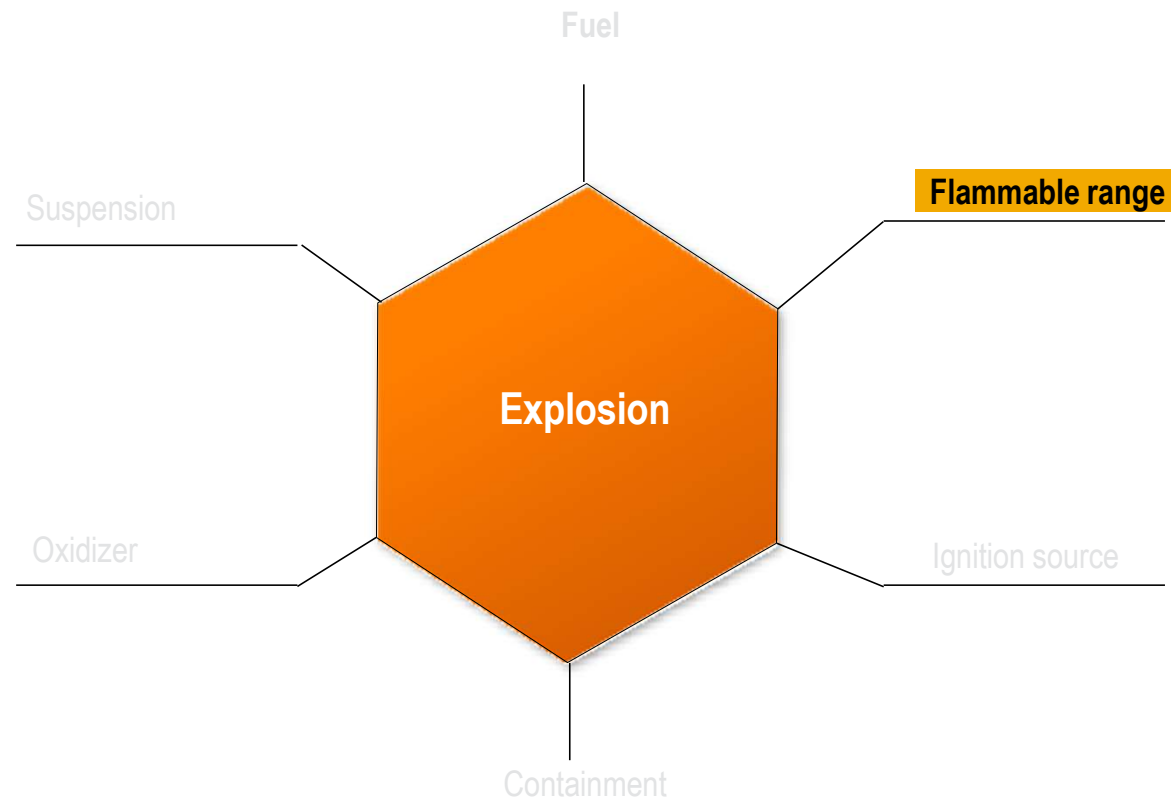
Can an explosion occur without oxygen (inert atmosphere) ?

True

Oxidizers

- Air
- Substances/reactions that can produce O_2 (e.g. use of peroxides)
- Chlorine
- Fluorine
- NO , NO_2 , N_2O_4 etc (various oxides of nitrogen)
- O_2F
- Cl_3F

Conditions for creating an explosion



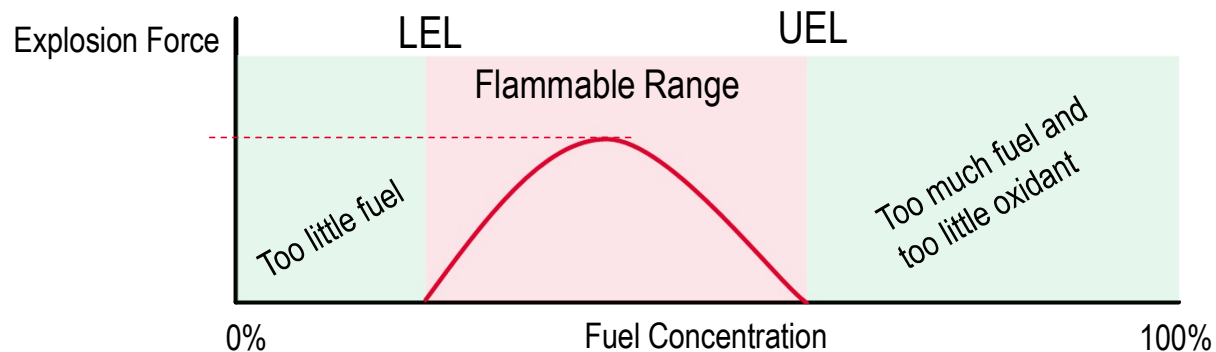
Fuel Concentration: Fire & Explosion Limits

There is a certain concentration range over which materials are flammable/explosive
(LEL= Lower Explosion Limit also known as MEC=Minimum Explosion concentration; UEL= Upper Explosion Limit)

Usually expressed as

- Gases and vapors: volume % with respect air (% v/v)
- Dusts clouds: g/m³ air

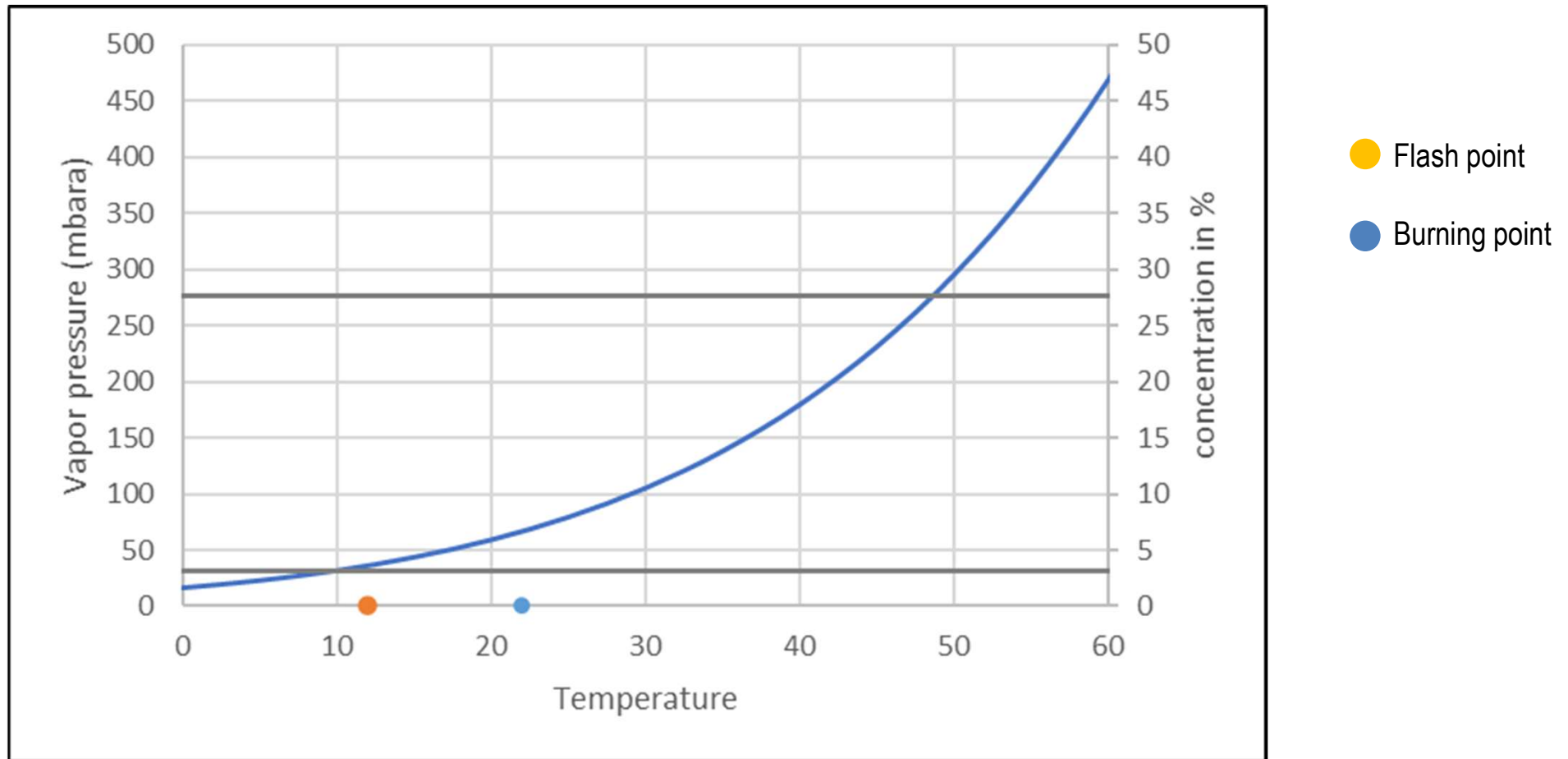
The range varies from material to material.



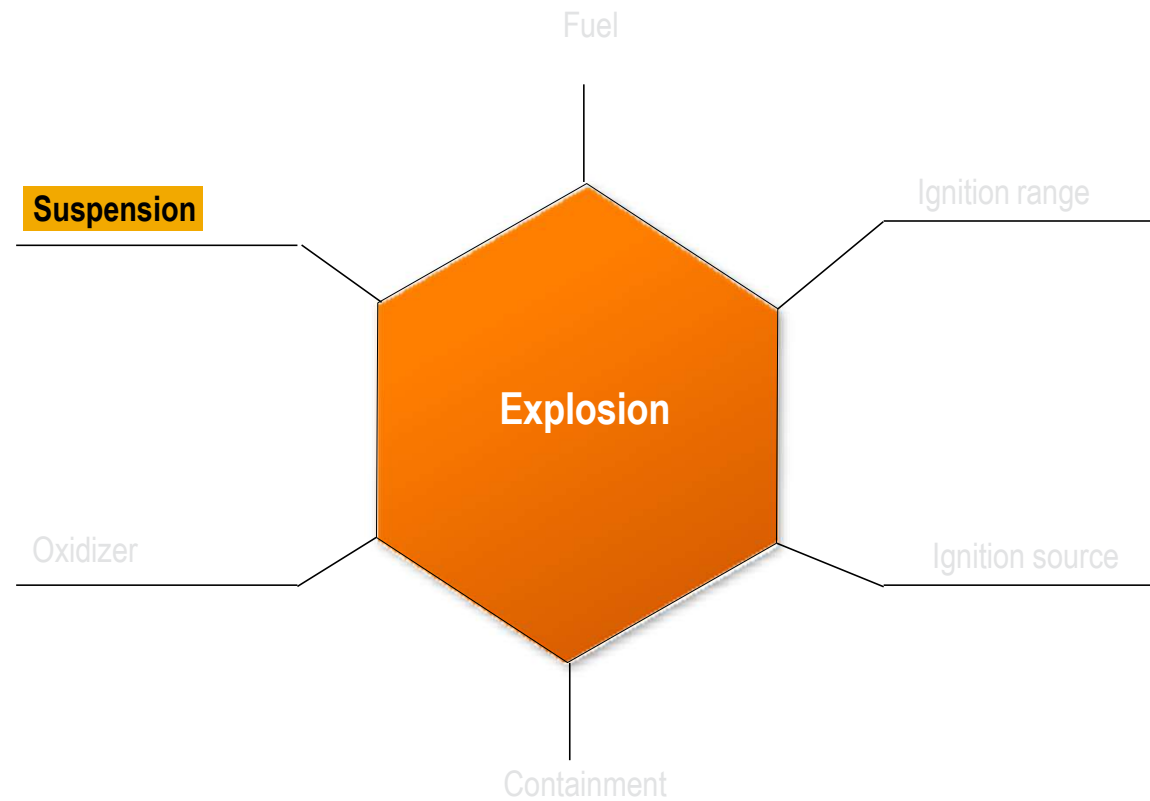
Fuel Concentration: Fire & Explosion Limits

Compound	Flash point	LEL (%)	UEL (%)	Autoignition
Acetone	-18°C	2.5	14.3	528°C
Ethanol	12°C	3.1	27.7	400°C
Methanol	9°C	6	50	440°C
Toluene	4°C	1	7.8	535°C
Hydrogen		4	77	560°C
Ethylene oxide	-47°C	2.6	100	435°C

Fuel Concentration: Ethanol

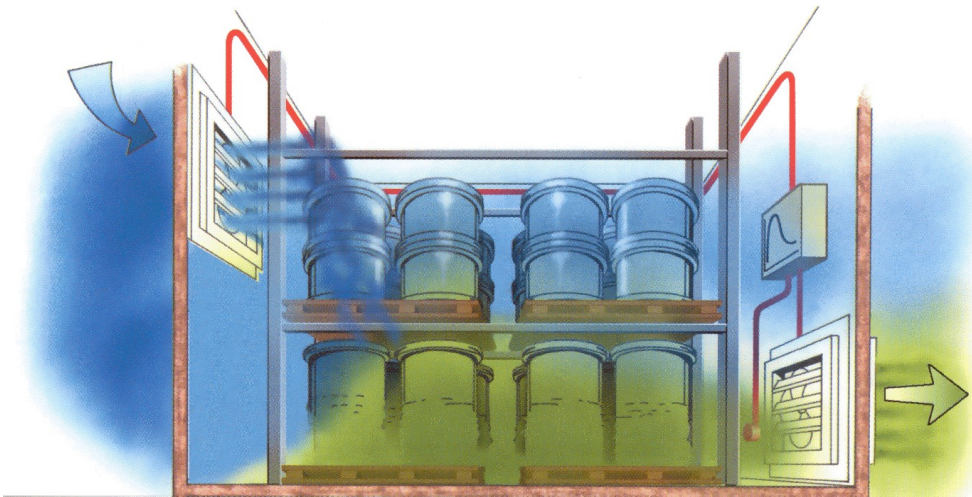


Conditions for creating an explosion



Gases / vapour ...

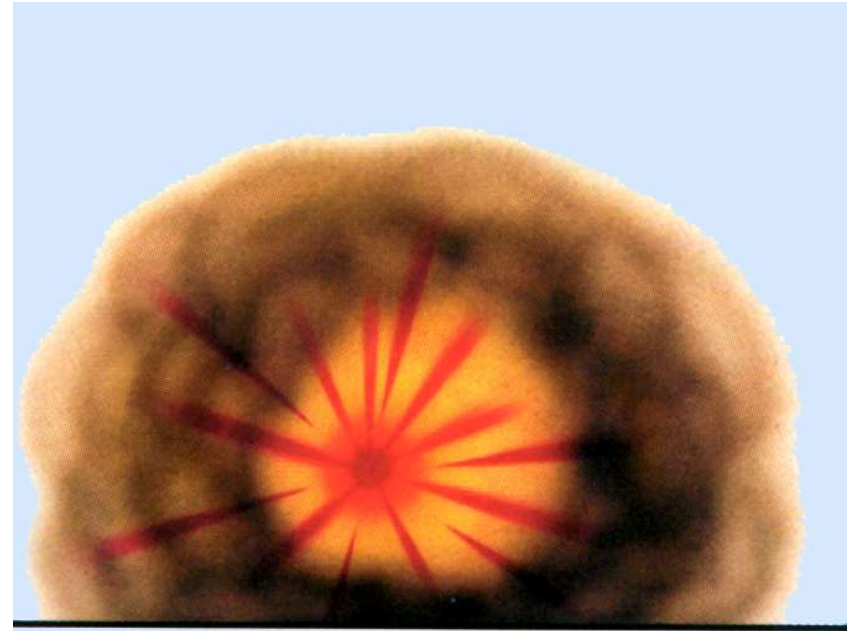
- **Ventilation is important, but note:**
- **Most solvent vapors are heavier than air**
- **Hydrogen is much lighter than air**



Dusts...



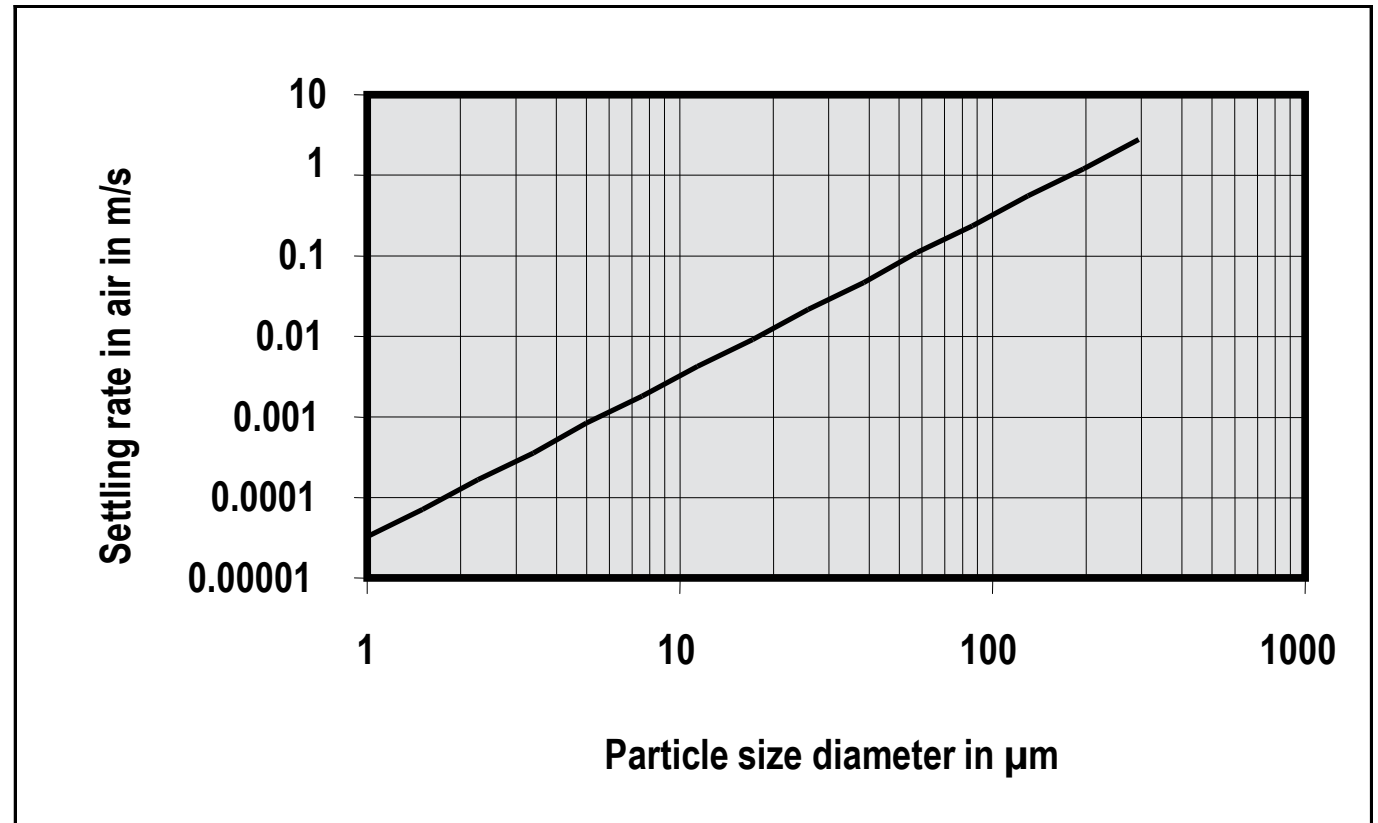
Dust layer → Fire



Dust cloud → Explosion

Dusts...

Settling rate as a function of the particles size diameter (density 10^3 kg/m^3)



Fire & Explosions

- **The majority of materials used in chemical processes are flammable or** are capable of becoming flammable under the process conditions used.
- It is much safer to use low flammability (or non-flammable) materials if at all feasible (an inherent safety consideration that should be taken at early development stage – if it is feasible to use them then do so).
- Occurrence of flammable conditions e.g. in air depends on:
 - Presence of flammable materials.
 - The concentration of the flammable material(s).
 - The dispersion of the flammable mixture.

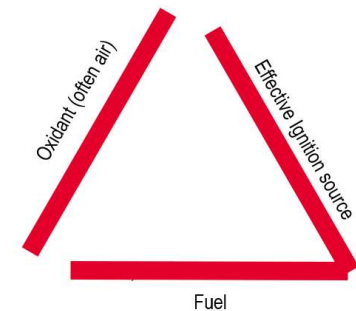
Explosion Prevention vs Protection

- **Prevention**

- Controlling/limiting the available fuel concentration
- Limit the oxidant concentration (e.g. air, chlorine, NO_x)
- Avoidance of effective ignition sources
(e.g. open flames, electrical equipment - static electricity, friction during grinding, exothermic decomposition reactions)

- **Protection**

- Explosion resistant vessel design
- Pressure relief
- Explosion suppression
- Equipment isolation



Take one of the components away from the 'fire triangle' and the hazard is removed.

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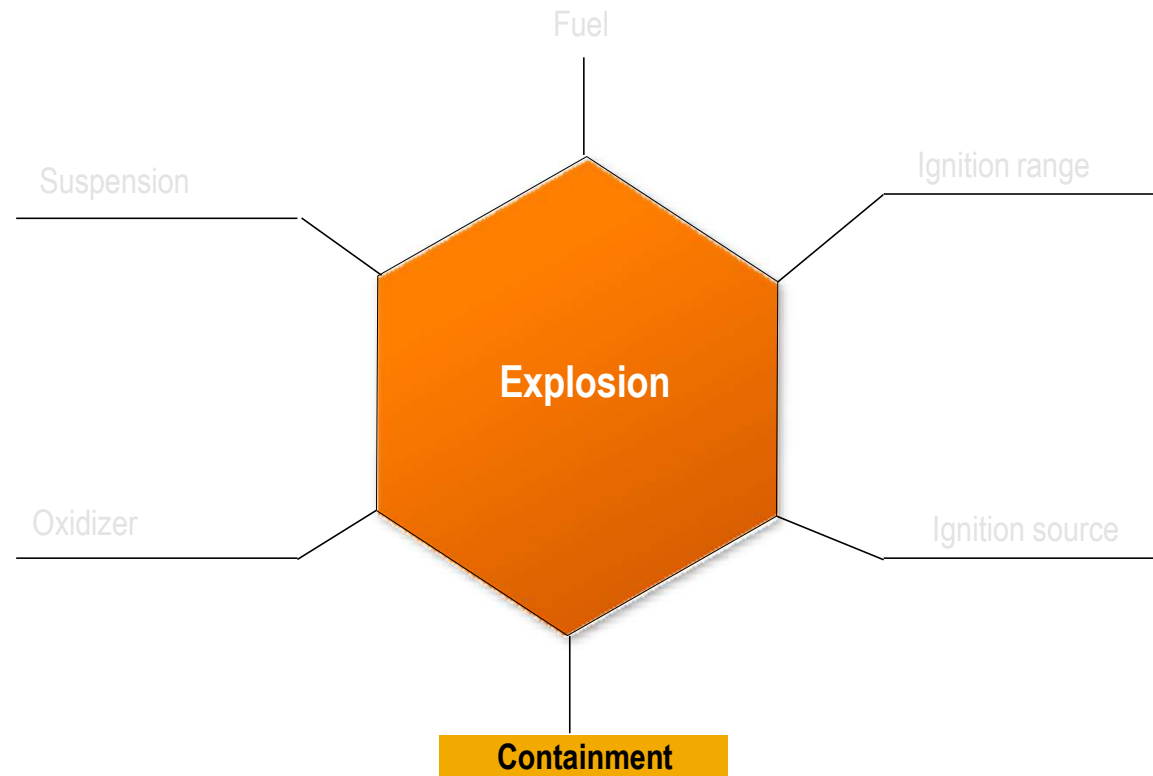
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Conditions for creating an explosion



Explosion Dynamics (unconfined space)



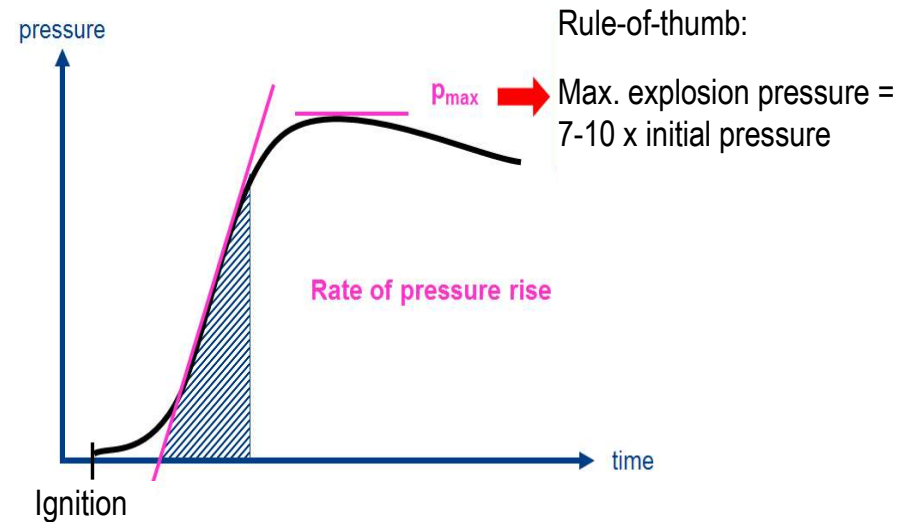
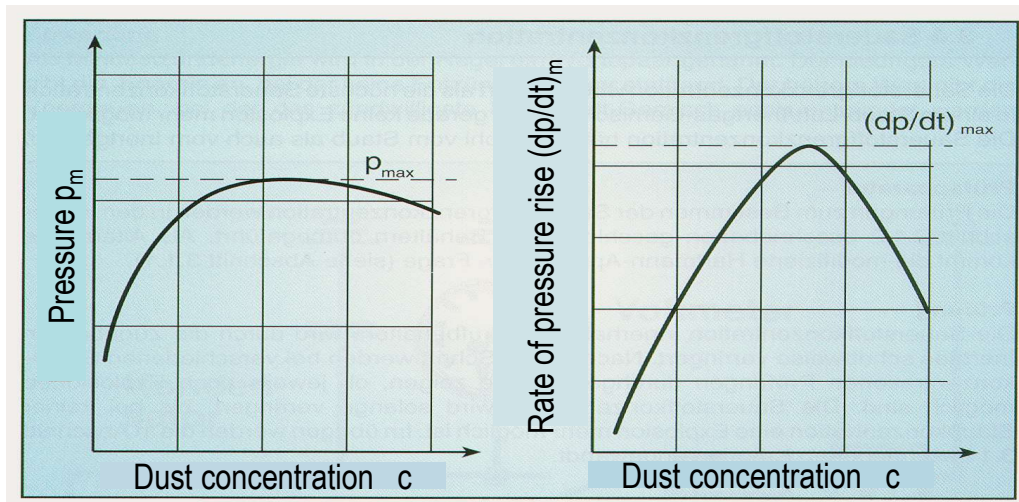
Explosion Dynamics (confined space)



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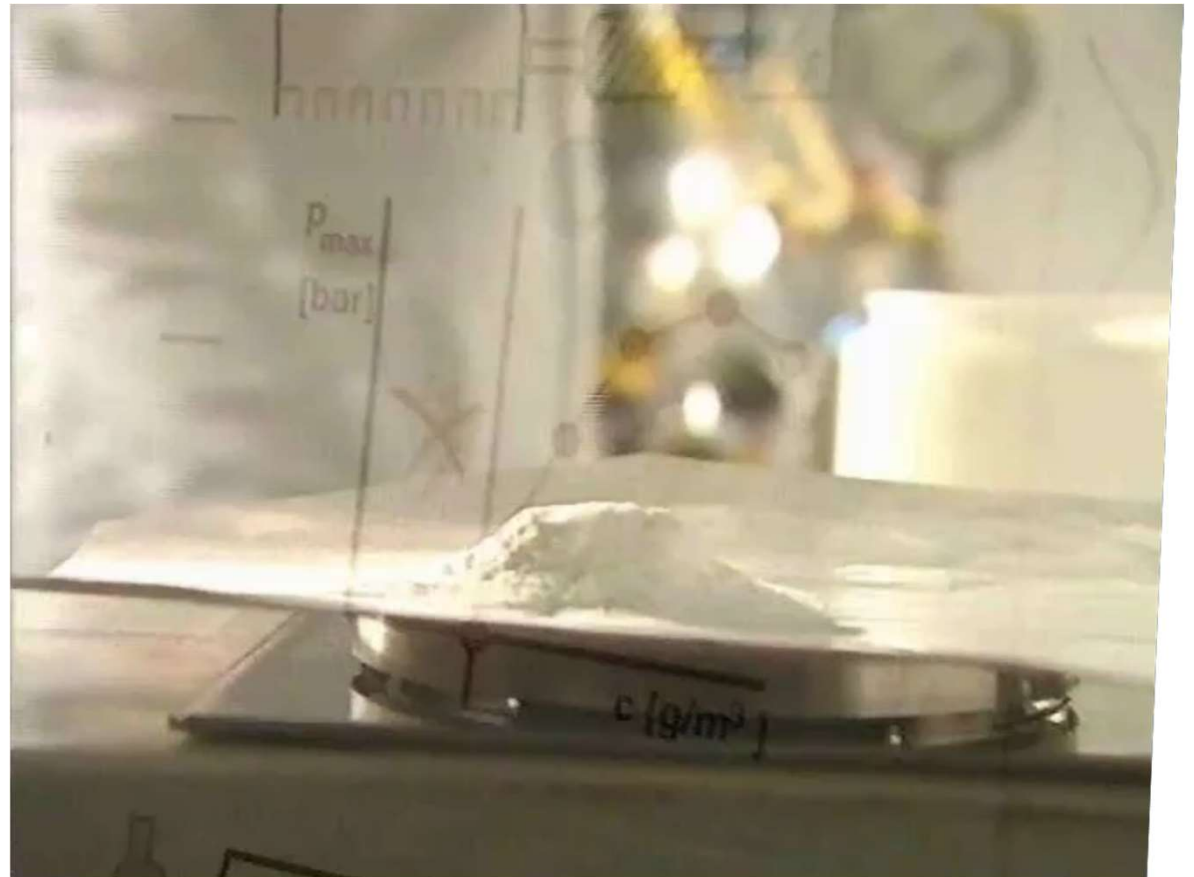
Dependence on concentration

- Explosion pressure
- Rate of pressure rise



Explosion dynamics: measurement

- Powders : 20 L sphere
- Vapors and gaz: 5 L



Explosion Dynamics (confined space)

Influence of volume in case of spherical, cubical or cylindrical (H/D approx. 1:1) containers

- No influence on the maximum explosion pressure $P_{\max}$

$$P_{\max} = \text{constant}$$

- Influence on the rate of pressure rise $(dp/dt)_{\max}$: Cubic law

$$(dp/dt)_{\max} V^{1/3} = \text{constant} = K \quad (K_{\max}, K_G, K_{St})$$

- For dusts: Explosion class
 - St 1 $K_{St} < 200 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1}$
 - St 2 $200 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1} < K_{St} < 300 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1}$
 - St 3 $300 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1} < K_{St}$
- Explosion class St 3 indicates a higher severity in case of explosion: often (if the material amount is sufficient)

Chemical	$K_{\max}$ bar·m·s ⁻¹	$P_{\max}$ barg
H ₂	800	7.0
CH ₄	68	7.2
CH ₄ +10% H ₂	293	7.2

Material	$K_{\max}$ bar·m·s ⁻¹	$P_{\max}$ barg	St class
Coal dust	85	6.4	St 1
Flour	63	9.7	St 1
Sugar	138	8.5	St 1
Wood dust	224	10.3	St 2
Polypropylene (25µm)	101	7.4	St 1
Al dust (29µm)	415	11.4	St 3

Explosion Dynamics

Influence of initial pressure P_0 :

- $P_0 \uparrow$: widens the flammable range (reduced LEL, increased UEL)
- $P_0 \uparrow$: increases final explosion pressure
- Typical combustion explosion from atmospheric pressure reaches 7-10 bara
- Maximum over-pressure is proportional to the initial absolute pressure
- Explosion under vacuum (< 100 mbar) would normally not generate any overpressure, the final pressure being still under atmospheric. In the reality, such an atmosphere could not be easily ignited (if possible at all)

Initial Pressure (bara)	Explosion Pressure (bara)
1	~8
6	~48
11	~88

Characteristic parameters

Consequences of an explosion

On people

$P_{\max} < 70$ mbar: low risks

$150 < P_{\max} < 200$ mbar: dizziness / Projection of a person on the ground

$P_{\max} > 1000$ mbar: Organ damage

On facilities

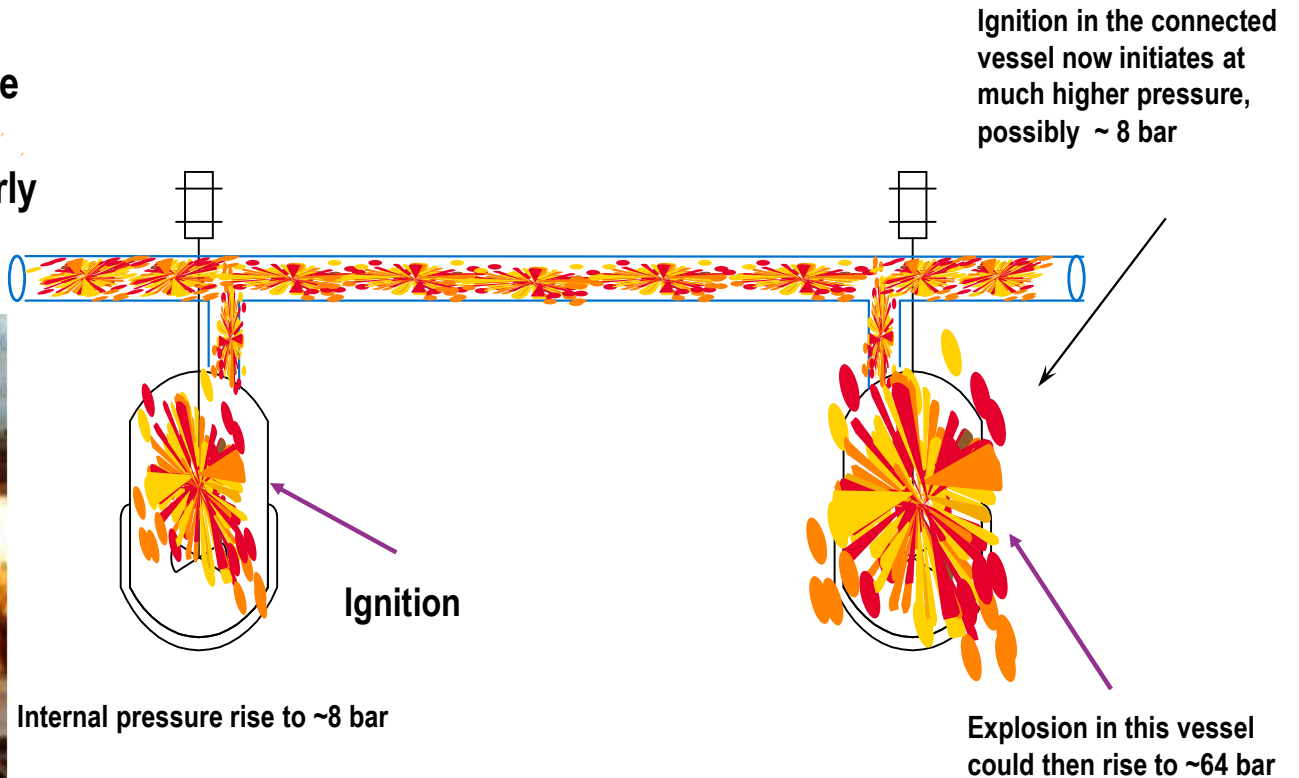
20 mbar: glass fragments

500 mbar: rupture of 25 cm thick brick walls

700 mbar: destruction of the building

Explosion Dynamics – Pressure piling

Connected pipe-work containing flammable vapor/gas can result in flame propagation with dramatic effects. (Ventilation pipe-work can be particularly prone to this hazard)



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Ignition Sources

1. **Hot surfaces**
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3. **Mechanically produced sparks**
4. **Electrical equipment**
5. Stray electric currents, cathodic corrosion protection
6. **Discharges of static electricity**
7. **Lightning strike**
8. Electromagnetic radiation in the range $9 \text{ kHz} \leq \nu \leq 300 \text{ GHz}$ (radio, TV)
9. Electromagnetic radiation in the visible spectral range
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11. Ultrasonic waves
12. Adiabatic compression and shockwaves
13. **Chemical reactions**

Note: ignition sources in bold are responsible for about 98% of all ignitions

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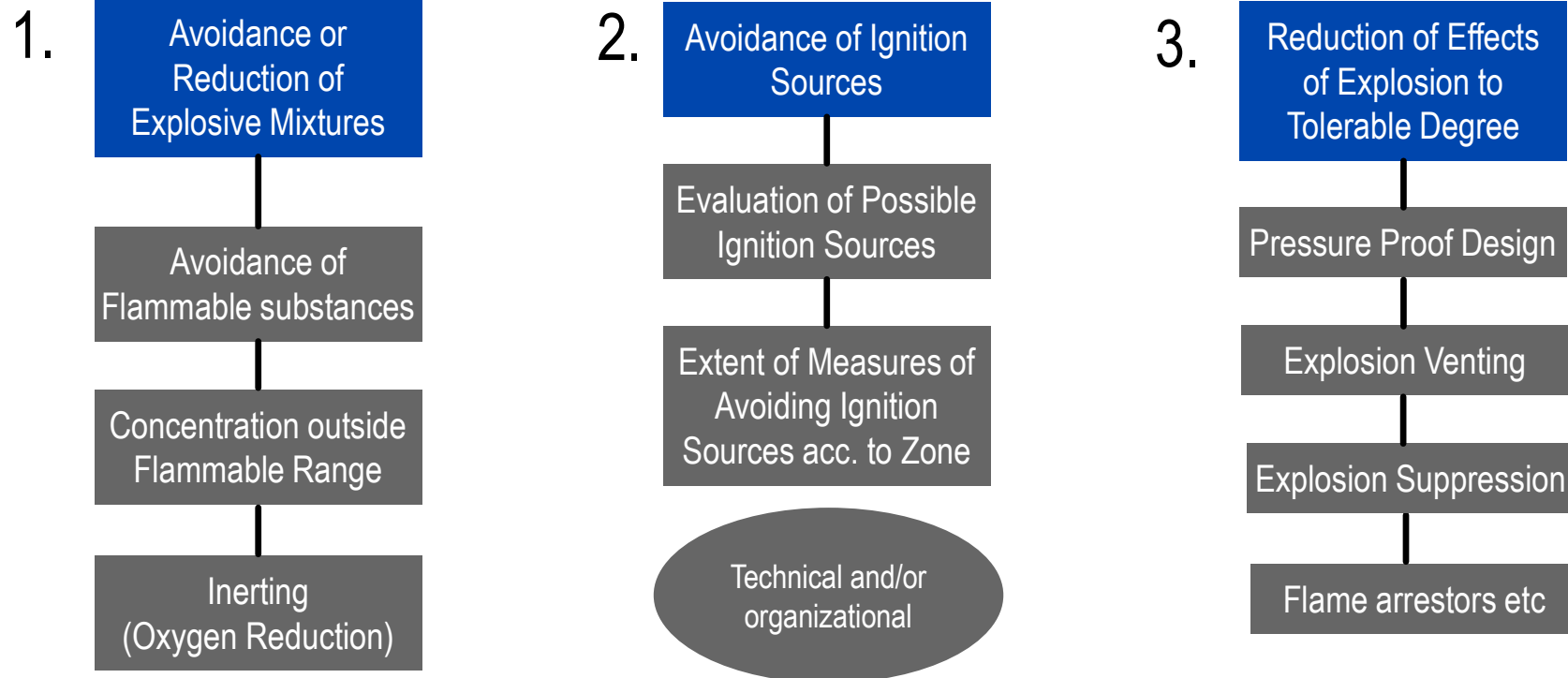
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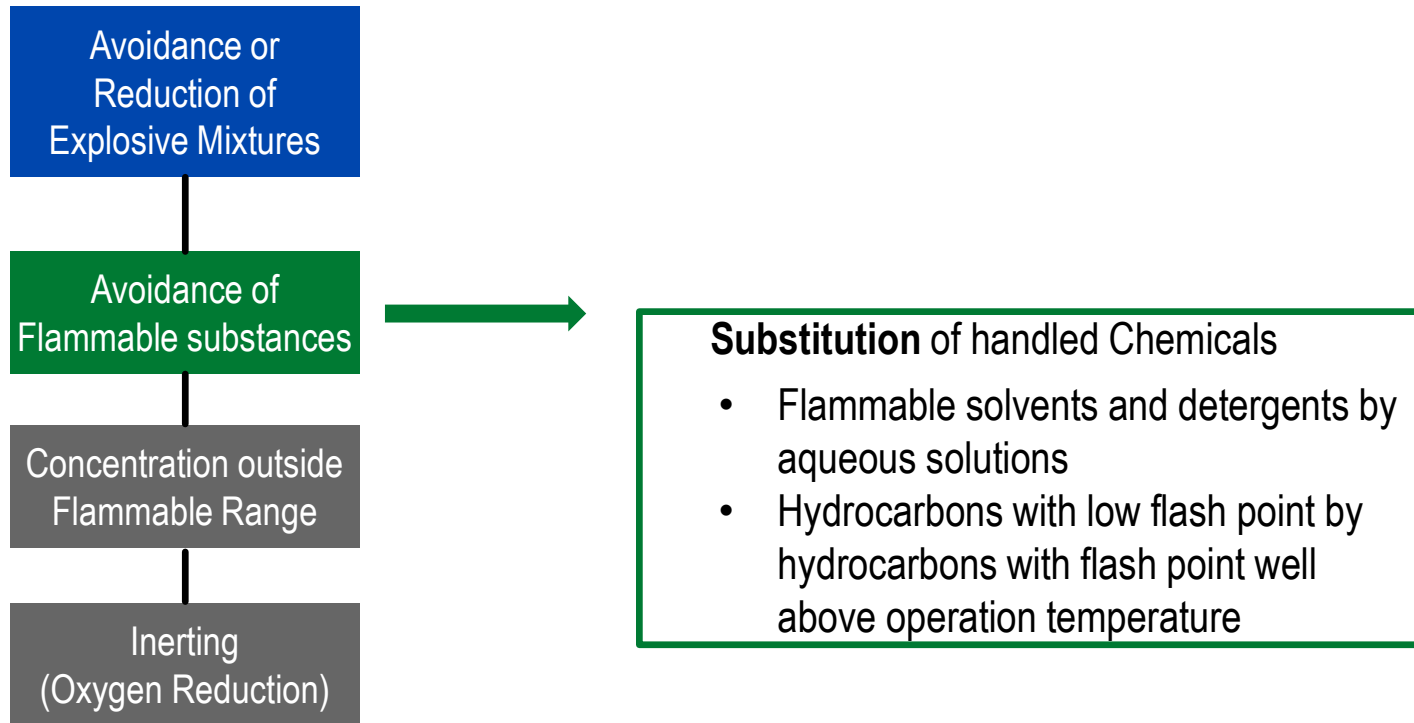
Basic approach to discuss explosion prevention and protection



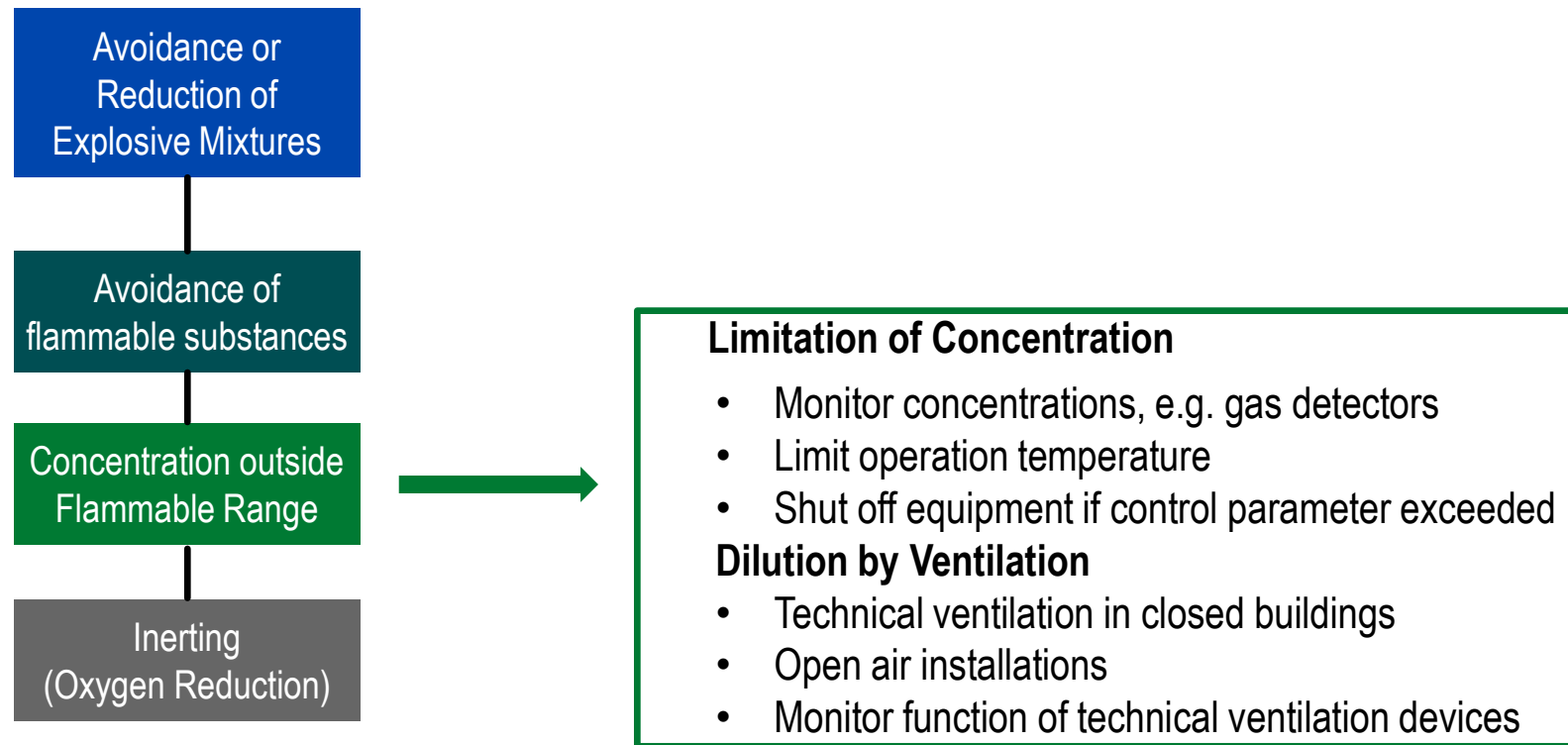
Priority for explosion prevention and protection

- In presence of an explosion risk, the following order should be respected:
 - 1. **Remove the explosive atmosphere**
 - Increase ventilation, dilution
 - Lower temperature below flash point
 - Ensure cleaning and exhaust of dust
 - Change of process (alternative mode of feeding of solvents or powders)
 - Change the solvent
 - If 1. is not possible/reasonably feasible, then 2. Preventive measures
 - Avoidance of ignition sources (ATEX rules)
 - If 2. is not possible/reasonably feasible OR if the severity of the explosion is too high, then 3. Protective measures
 - Equipment isolation
 - Equipment protection

Basic approach to discuss explosion prevention



Basic approach to discuss explosion prevention



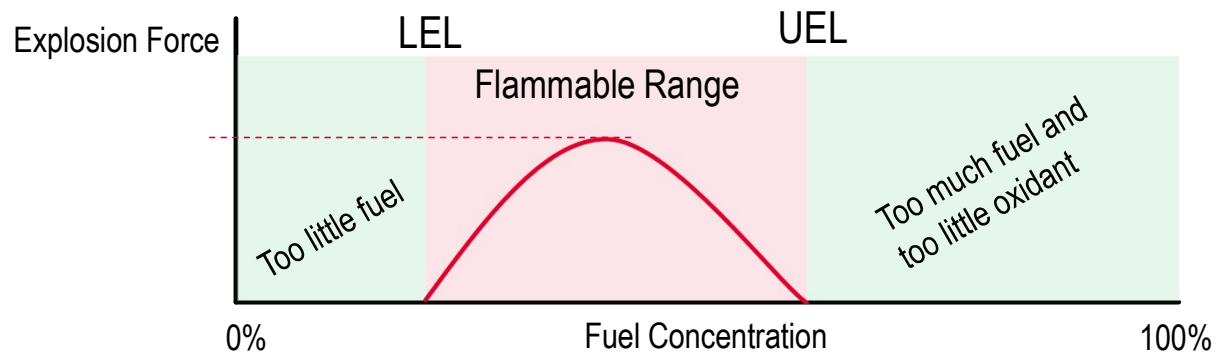
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Usually expressed as

- Gases and vapors: volume % with respect air (% v/v)
- Dusts clouds: g/m³ air

The range varies from material to material.



Fuel Concentration: Fire & Explosion Limits

Gases / Vapor (data are generally available in open literature):

From very narrow ranges
(for example).

To almost all possible
concentrations of certain
materials.

Material	LEL (% v/v)		UEL (%v/v)
Methane	5	29 g/m ³	15
Ethane	3		12.4
Propane	2.1	31 g/m ³	9.5
Butane	1.8		8.4
Octane	0.8		6.5
Toluene	1.0	29 g/m ³	7.8
Ammonia	15		28
Carbon Monoxide	12		75
Hydrogen	4	3.4 g/m ³	75
Ethylene Oxide	3		100
Acetone	2.5	60 g/m ³	12
Isopropanol	2		12.1
Ethanol	3.5		15
Ethyl Acetate	2		11

Solids: Most dusts have LELs between 20 g/m³ to 125 g/m³, typical value ~30 g/m³.

Gas/vapor explosion example

Room area: 20 m² (215 ft²)
Room height: 2 m (6.5 ft)
Room volume: 40 m³ (1412 ft³)

Amount of octane vapor required for an explosion:

$$40 \text{ g/m}^3 \times 40 \text{ m}^3 = 1600 \text{ g} = \text{ca. 2 Liters (1/2 gal) liquid}$$

LEL octane: ~40 g/m³



Gas/vapor explosion example

Explosion in fridges (Pictures:
Process Safety Beacon 2008)

Small amounts of vapors, ignition
sources (light, light switch,
temperature measurement etc)



Dust Explosion

Dust deposits

Room area: 20 m² (215 ft²)
Room height: 2 m (6.5 ft)
Room volume: 40 m³ (1412 ft³)

Amount of dust required for an explosion:
 $30 \text{ g/m}^3 \times 40 \text{ m}^3 = 1200 \text{ g} = 1.2 \text{ kg}$

Dust deposit:
 $2 \cdot 10^{-4} \text{ m} \times 20 \text{ m}^2 \times 500 \text{ kg/m}^3 = 2 \text{ kg}$

0.2 mm (as ref: copy paper thickness ~0.1 mm)

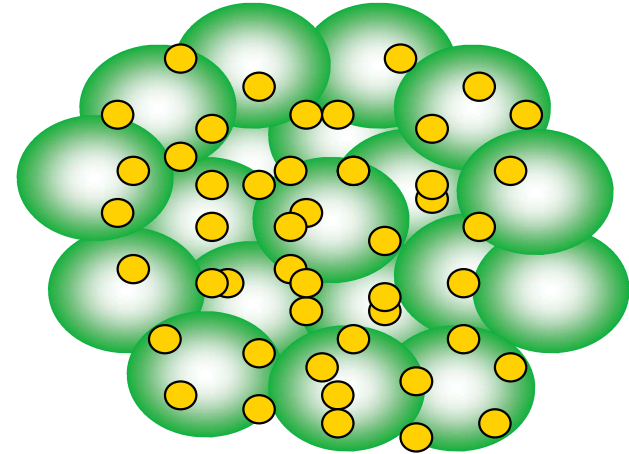
dust LEL: 30 g/m³



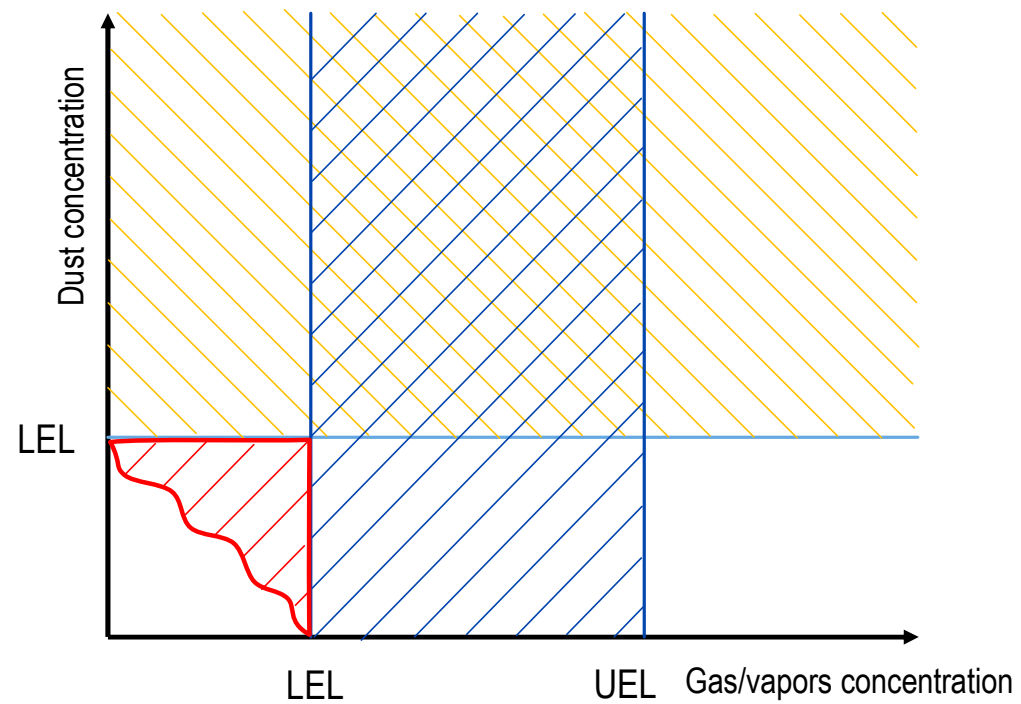
Dusts: Special precautions



- Dust deposited on the floor may be dispersed in air
- In the presence of flammable gases or vapours hybrid mixtures may be formed

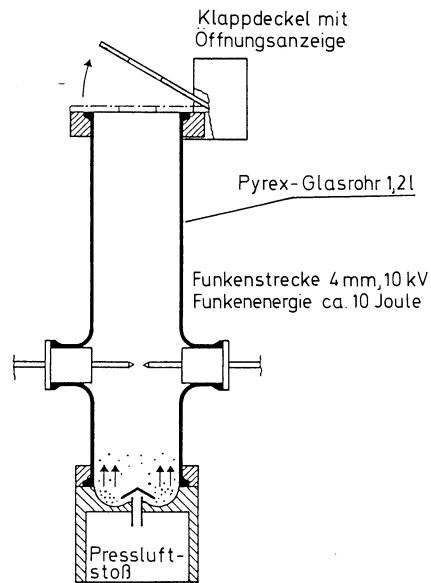


Hybrid mixtures



Determining whether the dust has a dust explosion potential

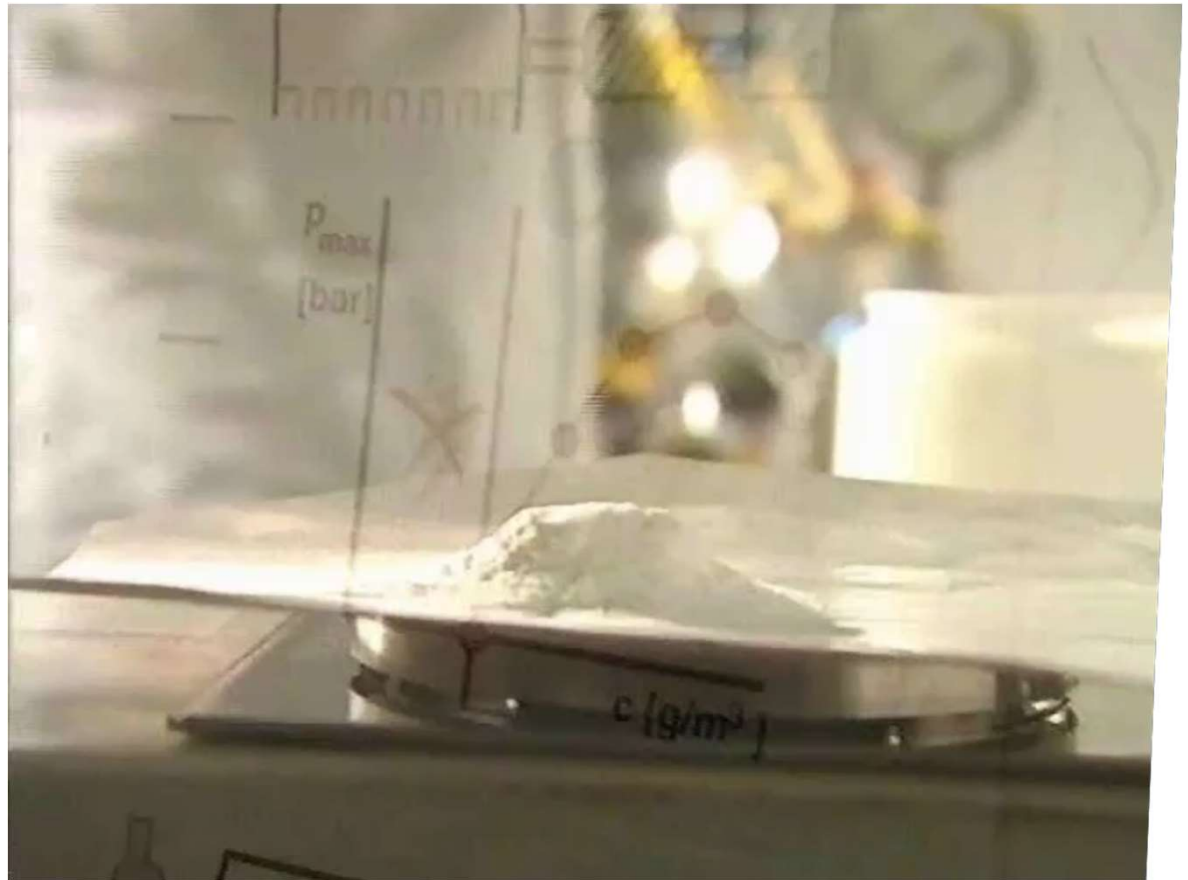
- Screening test: modified Hartmann tube



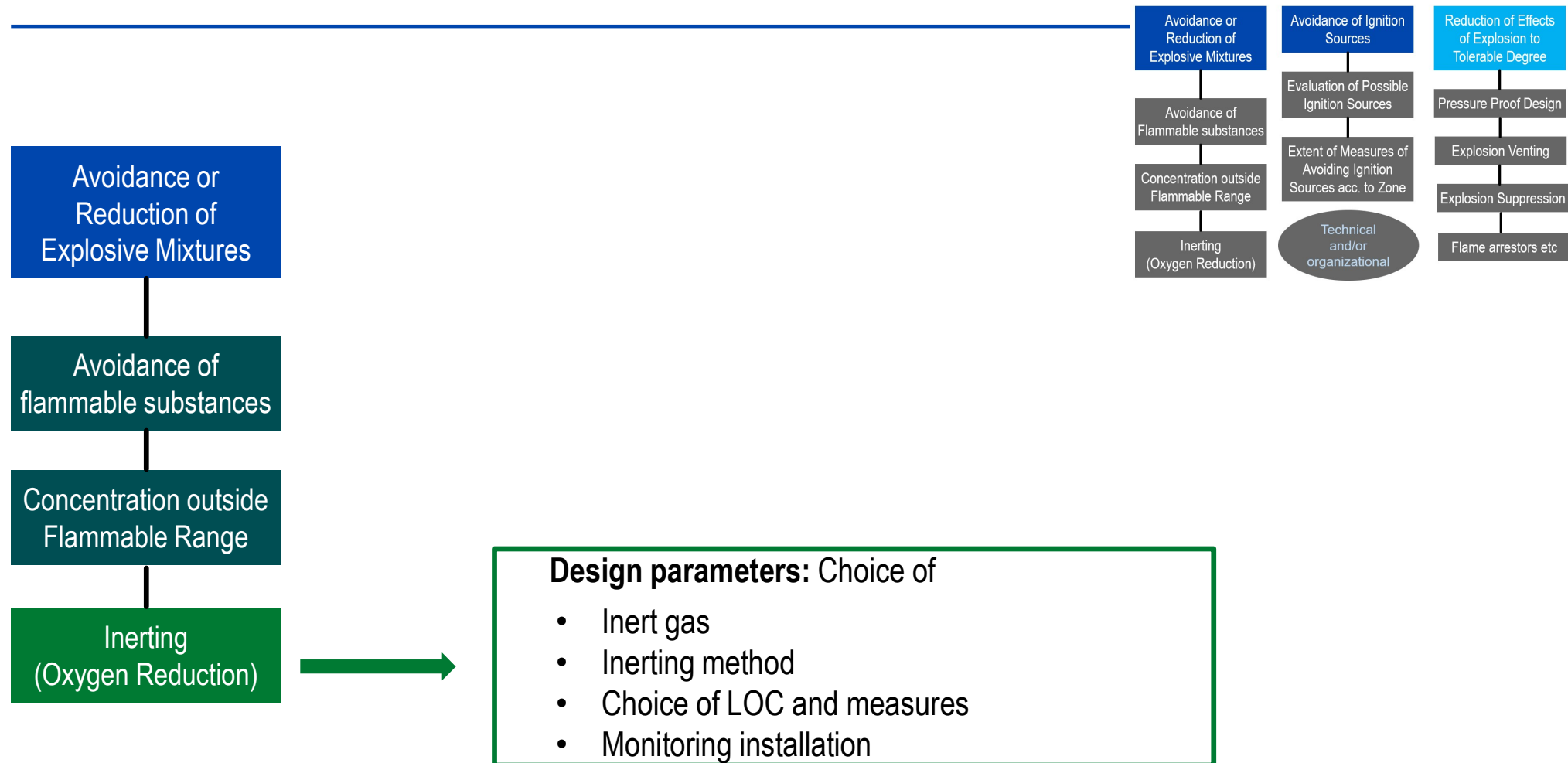
Determining whether the dust has a dust explosion potential

- Powders : 20 L sphere

This test should only be performed with dusts with a median particle size distribution of $< 63 \mu\text{m}$ (US: $< 75 \mu\text{m}$)



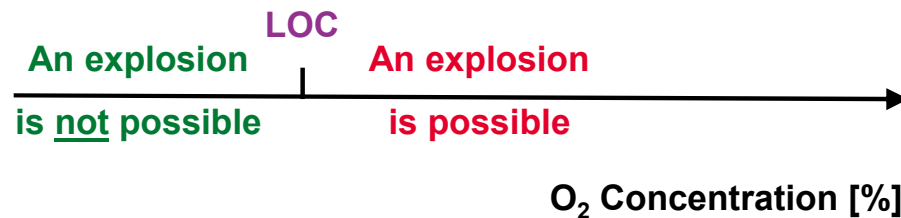
Basic approach to discuss explosion prevention



Oxidant limitation

Limiting oxidant concentration for combustion (LOC)

- LOC is the minimum concentration of oxidant (usually oxygen) that can support combustion of the fuel
- Below the LOC no combustion will occur.
- Most volatile organic compounds will not combust if oxygen content is reduced to below 10% v/v with nitrogen

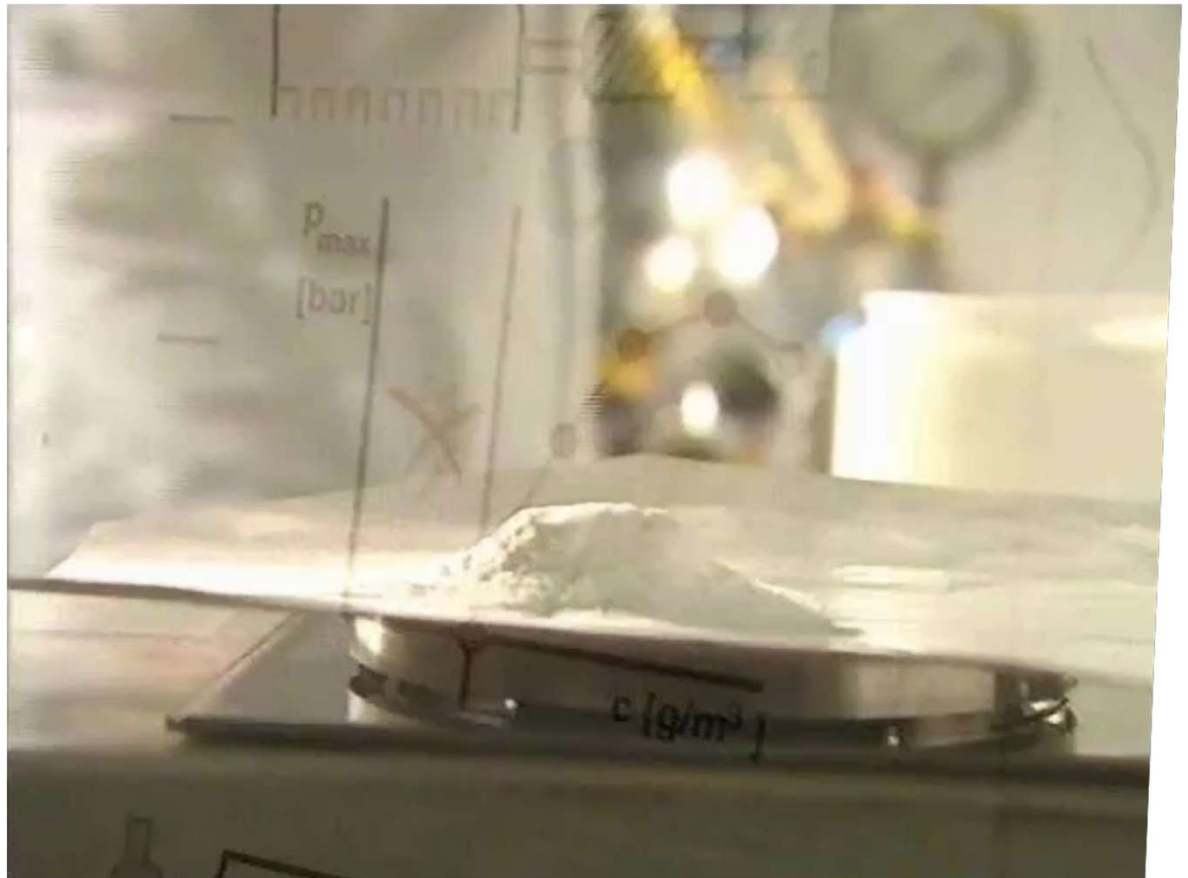


	LOC (% Oxygen) (N ₂ as inert)
Acetone	13.5
Methanol	10.0
Ethanol	10.5
Carbon Monoxide	5
Hydrogen	5
Hydrogen Sulphide	7.5
1,3 Butadiene	10.5
Styrene	9.0

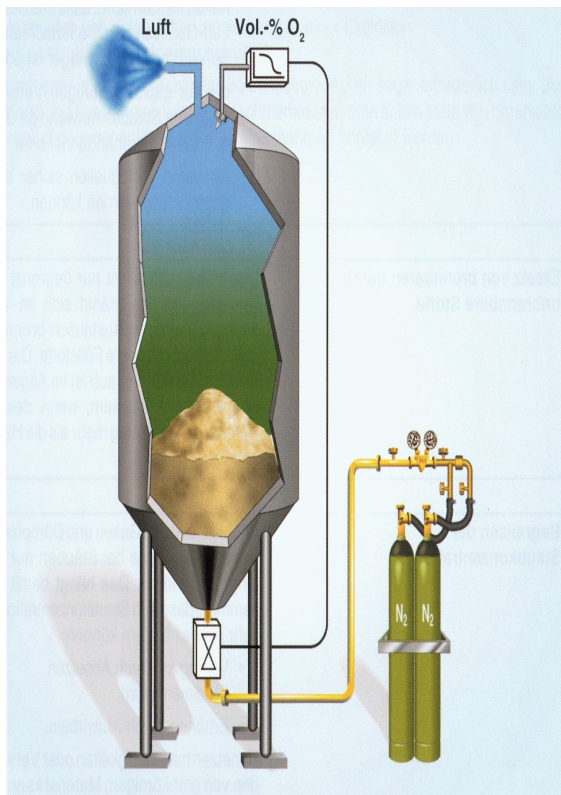
- This is the basis for inert gas blanketing as a method of explosion prevention

LOC determination

- Powders : 20 L sphere
- Vapors and gaz: 5 L



Inerting (CEN/TR 15281)



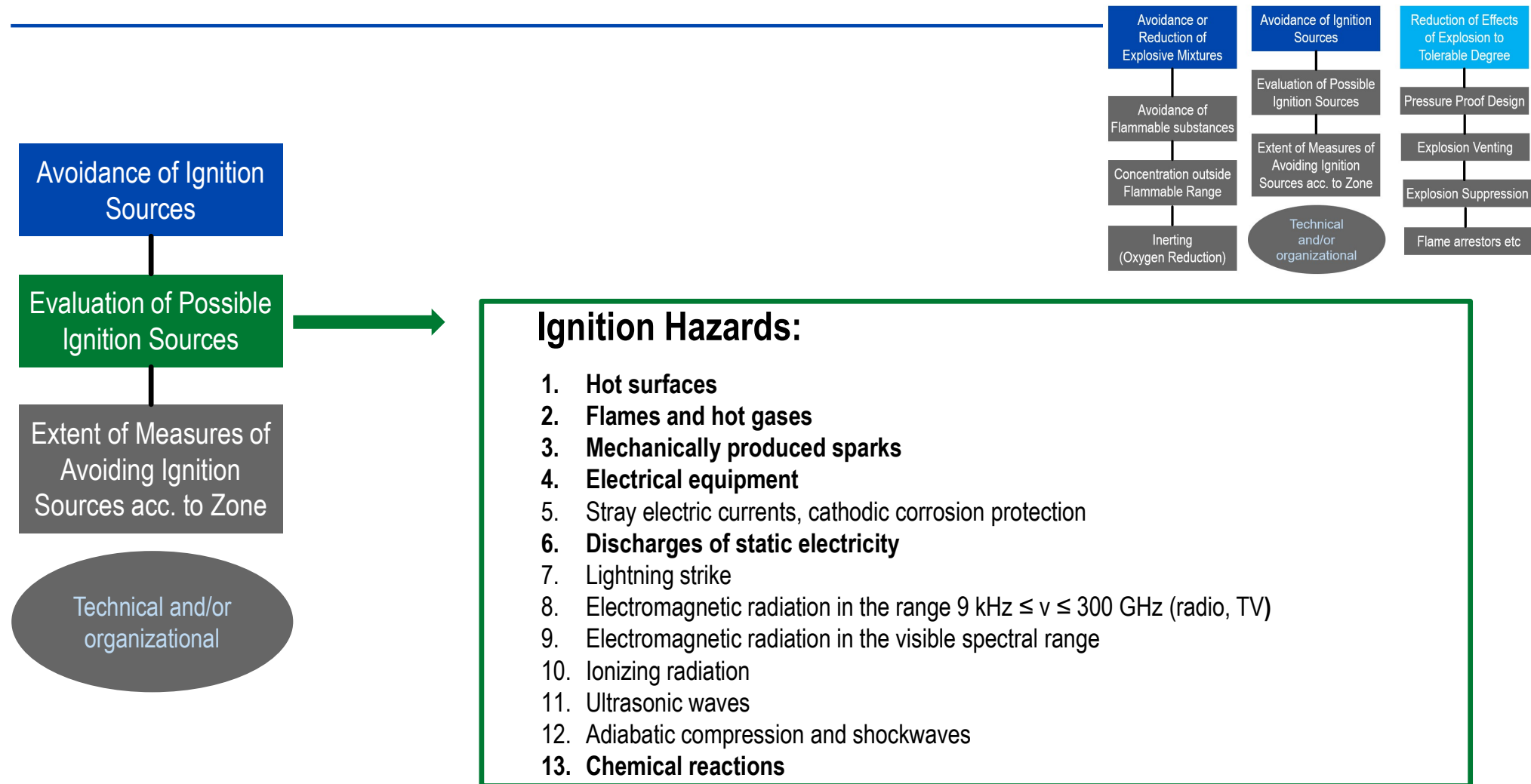
- Total: reducing the oxygen level < **LOC of the flammable material**
 - LOC: mostly 8-12% v/v
 - Ensure safety: use < 5% v/v (for sensitive material like hydrogen < 2% v/v)
- Partial (lean air): explosion characteristics modified to acceptable level
- Methods:
 - Vacuum swing
 - Pressure swing
 - Purge
- Note, nitrogen blankets are quickly lost when opening vessels

Inerting - Limitations

- Open/closed apparatus and equipment (an inert blanket can be lost in 5 minutes in a vessel with the manhole open)
- Processes producing oxygen (chemically or desorption)
- Processes producing other oxidizing chemicals (e.g. Cl_2 , NO_x)
- **Hazard of asphyxiation**

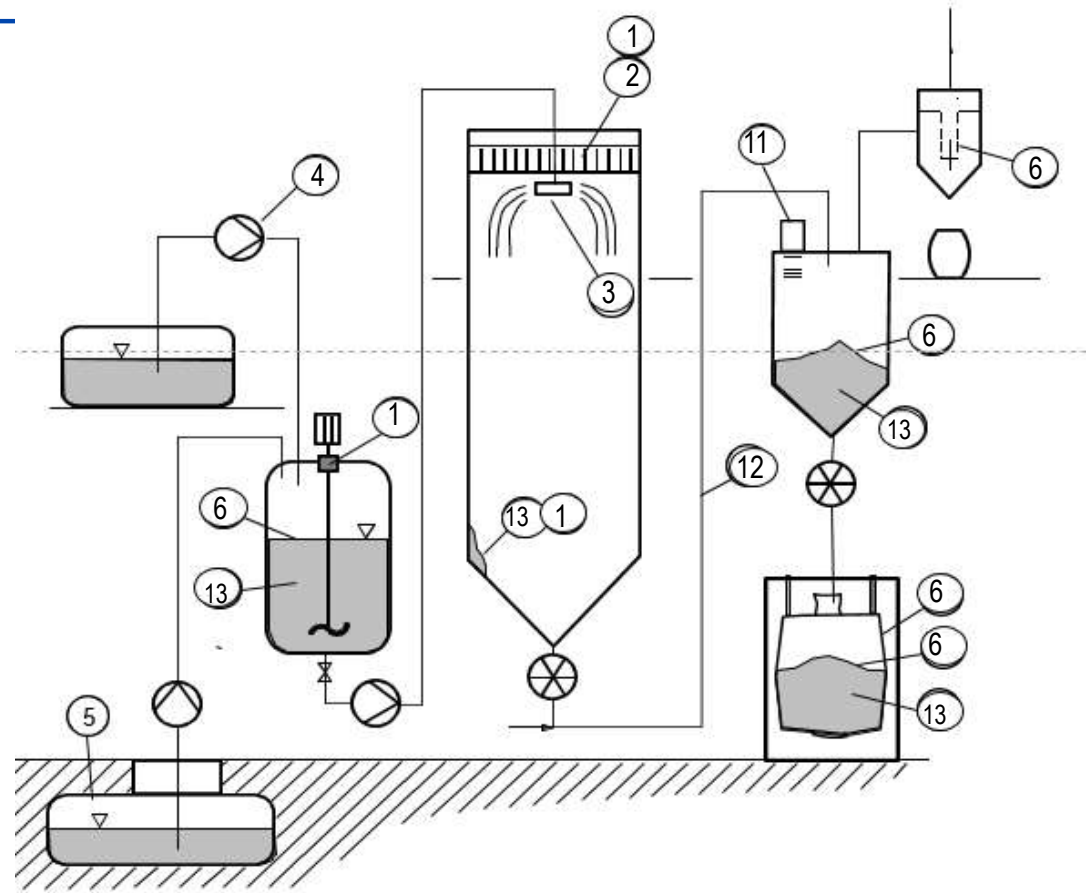


Basic approach to discuss explosion prevention



Ignition Sources

1. **Hot surfaces**
2. **Flames and hot gases**
3. **Mechanically produced sparks**
4. **Electrical equipment**
5. Stray electric currents, cathodic corrosion protection
6. **Discharges of static electricity**
7. **Lightning strike**
8. Electromagnetic radiation in the range $9 \text{ kHz} \leq \nu \leq 300 \text{ GHz}$ (radio, TV)
9. Electromagnetic radiation in the visible spectral range
10. Ionizing radiation
11. Ultrasonic waves
12. Adiabatic compression and shockwaves
13. **Chemical reactions**

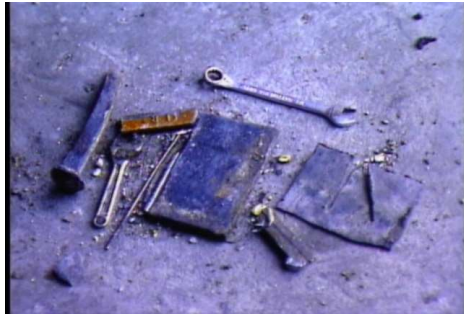


Note: ignition sources in bold are responsible for about 98% of all ignitions

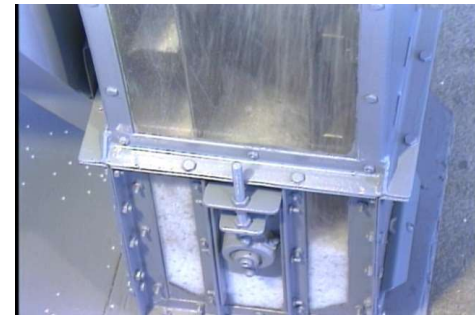
Avoidance of ignition sources



Welding & cutting



Foreign materials



Overheated bearing



Open fire

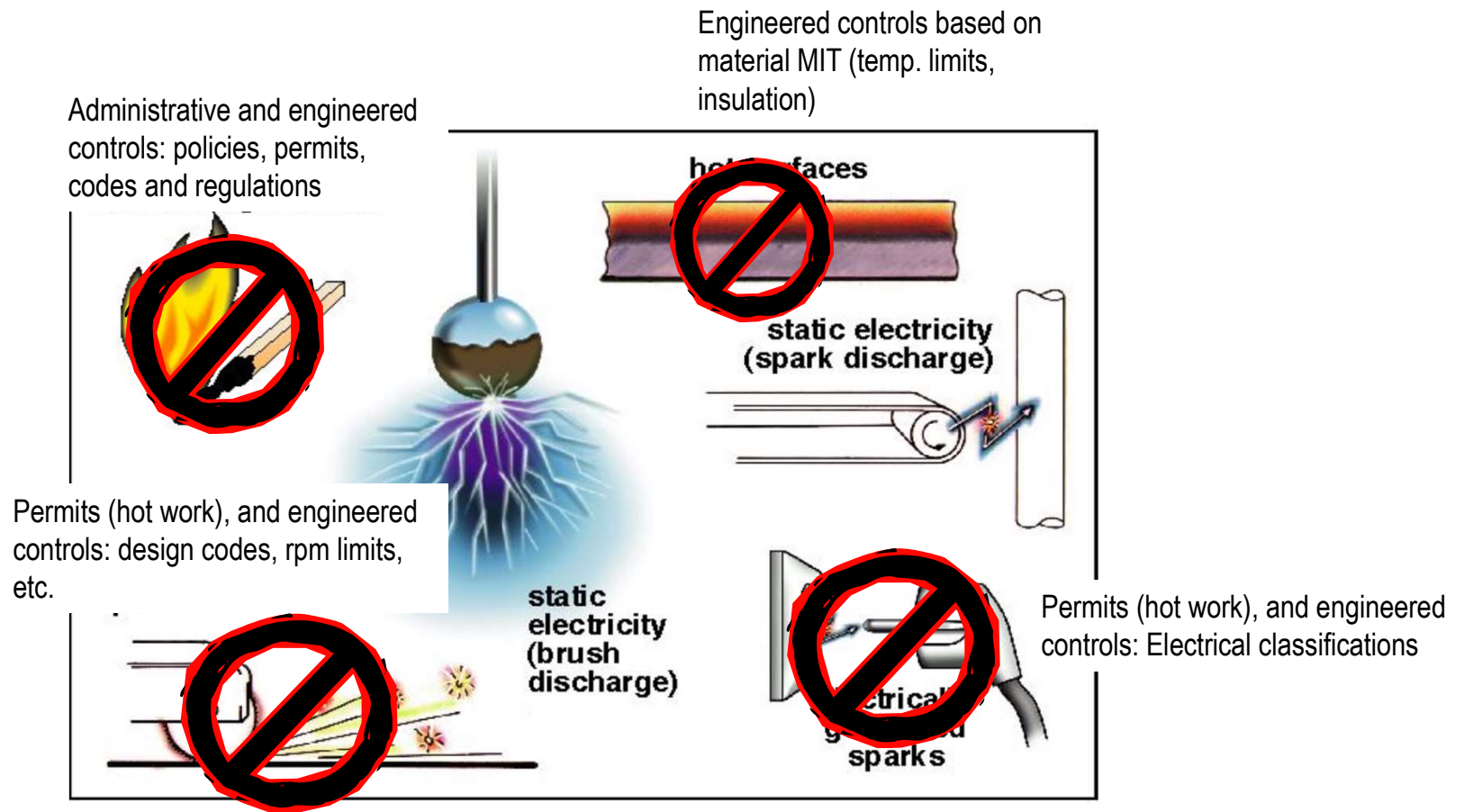


Friction & shock



Electrical malfunctions

“Avoidance” of ignition sources



Sources: ISSA, Gas Explosions (2000)

Ignition from electrical and mechanical equipment

- Ensure equipment is adequate for explosive atmospheres (ATEX certification)
 - Protection of equipment will depend on frequency of explosive atmosphere (zone)
 - Nature of explosive atmosphere
 - Gas/vapor
 - Dust
 - Sensitivity of gas/vapor and dusts



Group		Type of Hazardous Material and Location of Atmosphere
Group I		Mines susceptible to firedamp (flammable mixture of gases naturally occurring in a mine).
Group II		Explosive gas atmosphere other than mines susceptible to firedamp. Group II equipment is subdivided into three subgroups.
	A	Atmospheres containing propane, acetone, benzene, butane, methane, petrol, hexane, paint solvents or gases and vapors of equivalent hazard.
	B	Atmospheres containing ethylene, propylene oxide, ethylene oxide, butadiene, cyclopropane, ethyl ether, or gases and vapors of equivalent hazard.
	C	Atmospheres containing acetylene, hydrogen, carbon disulphide or gases and vapors of equivalent hazard.
Group III		Explosive dust atmosphere. Group III equipment is subdivided into three subgroups.
	A	Atmospheres containing combustible flyings.
	B	Atmospheres containing non-conductive dust.
	C	Atmospheres containing conductive dust.

Hot surface

- Auto-ignition of liquids (AIT)



Hot surface

- Minimum ignition temperature of dust cloud (MIT)

The minimum ignition temperature is defined as the lowest temperature of a heated surface at which the most readily ignitable dust/air mixture is just ignited.



- Layer Ignition temperature (LIT)

The smouldering temperature or the AIT of a dust layer is the lowest temperature of a hot surface at which a dust layer of 5 mm thickness starts to burn or smoulders. This value is only valid for dust layers ≤ 5 mm.



Temperature (hot surfaces) classification

- Use data (AIT, MIT, LIT) and take safety margin
- Temperature classes are defined for equipments, which define the maximum surface temperature.
- If an apparatus can be covered by a layer of powder, the maximum surface temperature allowed is given by $AIT_{\text{layer}} - 75\text{ °C}$
- If an explosive dust cloud (ATEX zones 20, 21 or 22) is present, the Auto-Ignition in Cloud (BAM oven) should be considered; Maximum surface temperature $\frac{2}{3} \times AIT_{\text{cloud}}\text{ (°C)}$

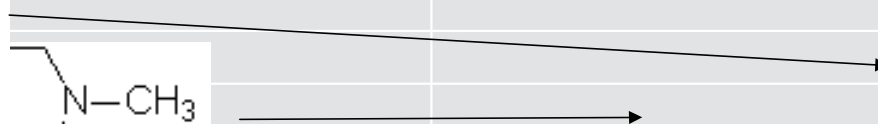
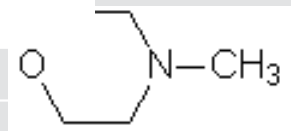
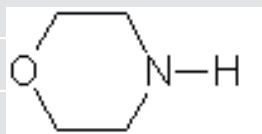
Temperature class	Maximum surface temperature
T1	450°C
T2	300°C
T3	200°C
T4	135°C
T5	100°C
T6	85°C

Auto-ignition temperature (AIT)

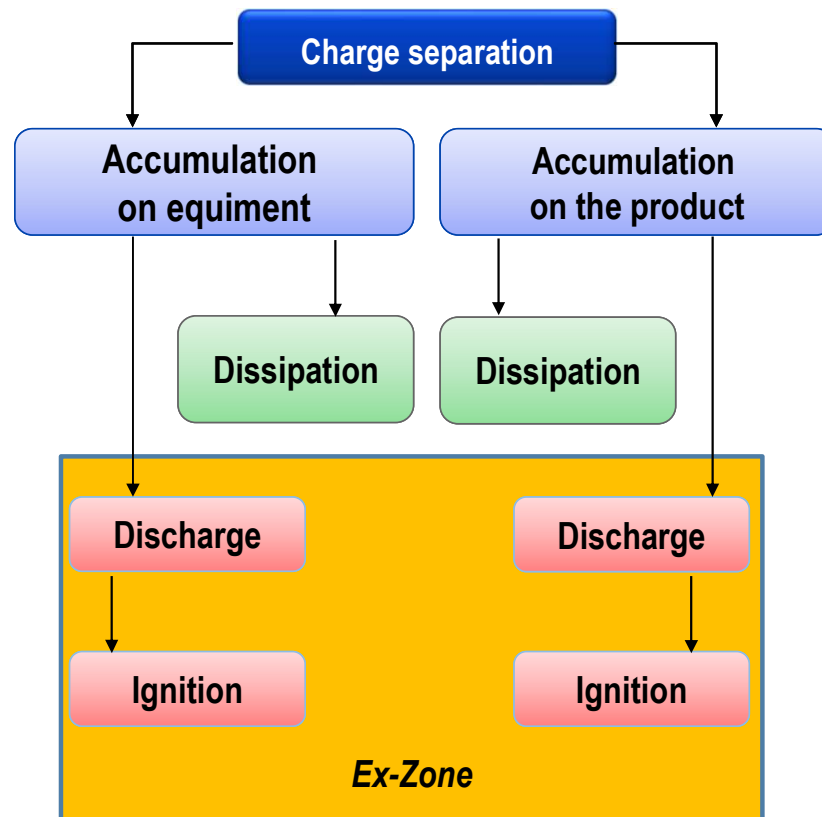


Chemical	AIT / °C
Acetone	527
Toluene	535
Methanol	440
Isopropanol	425
THF	230
Diethyl ether	175
Butadiene	415
Acrylonitrile	480
Styrene	490
Ammonia	630
Morpholine	275
Methyl morpholine	165
Butylacrylate	275
Acetic acid 80%	550
Methacrylic acid	400
Hexane	230
Divinylbenzene	494

AIT estimations based on structural similarity are dangerous!



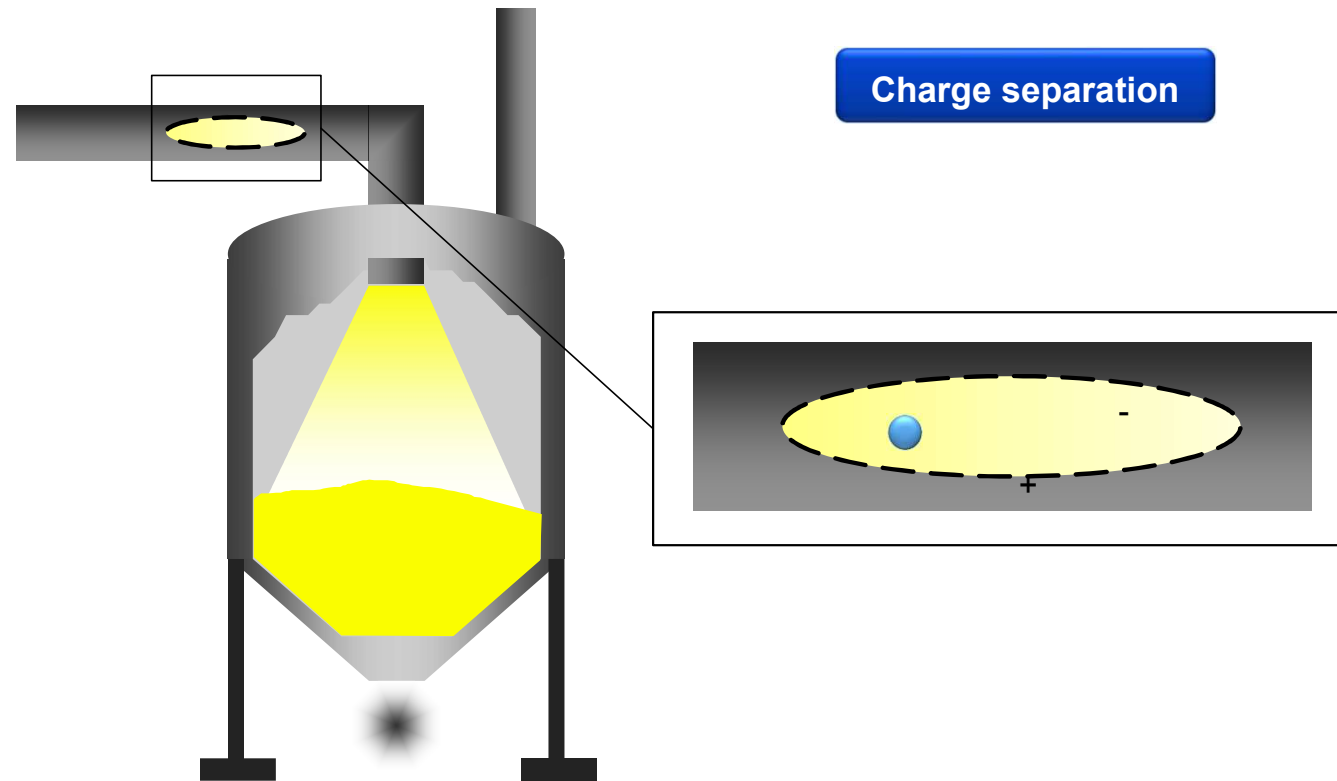
Electrostatic ignition source



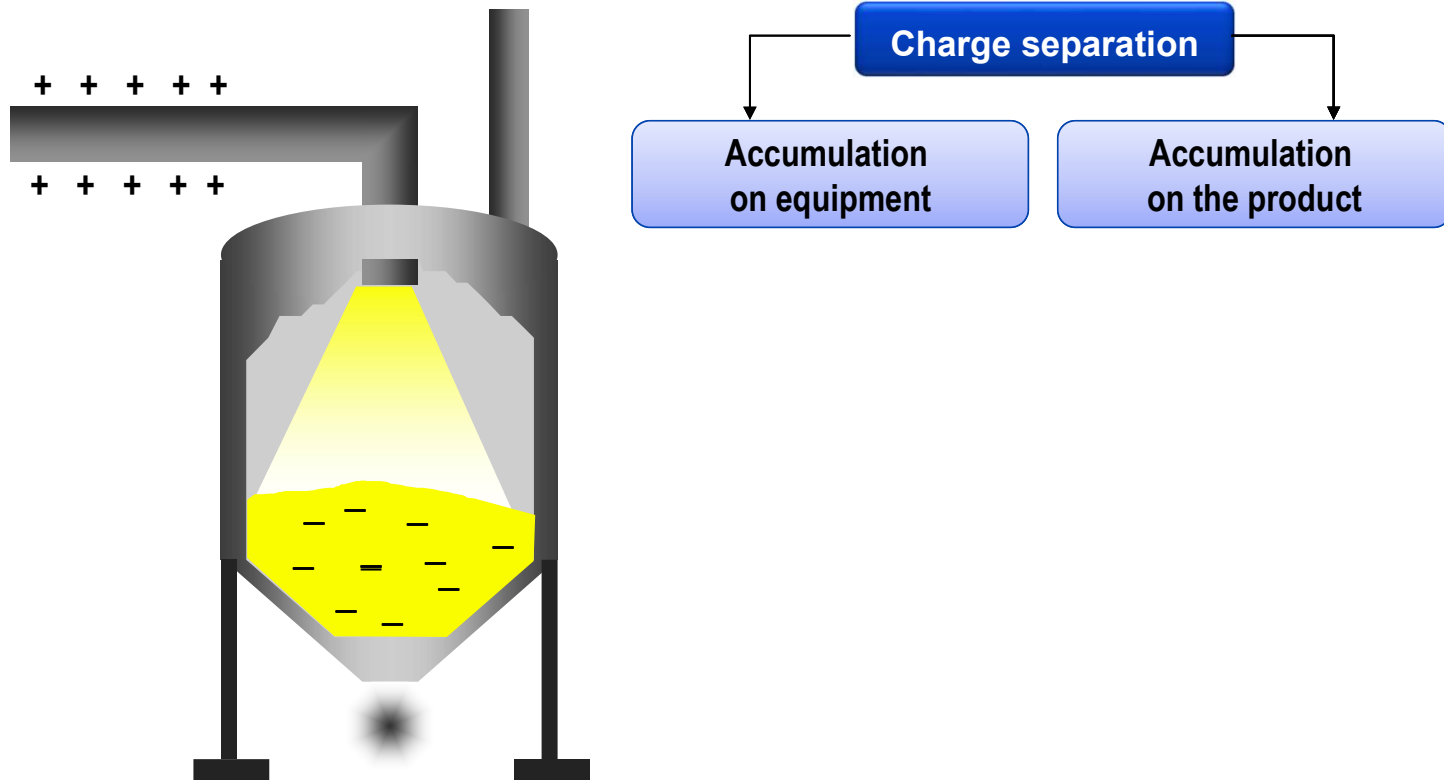
Electrostatic ignition source / charging

- Charging by friction and separation
 - Contact and separation of two surfaces
- Charging by double-layer
 - Transport of liquids through pipes
- Charging by influence
 - Person not grounded near a loaded FIBC
- Charging by charge transfer
 - Filling charged conductive products into a non-earthed metal drum

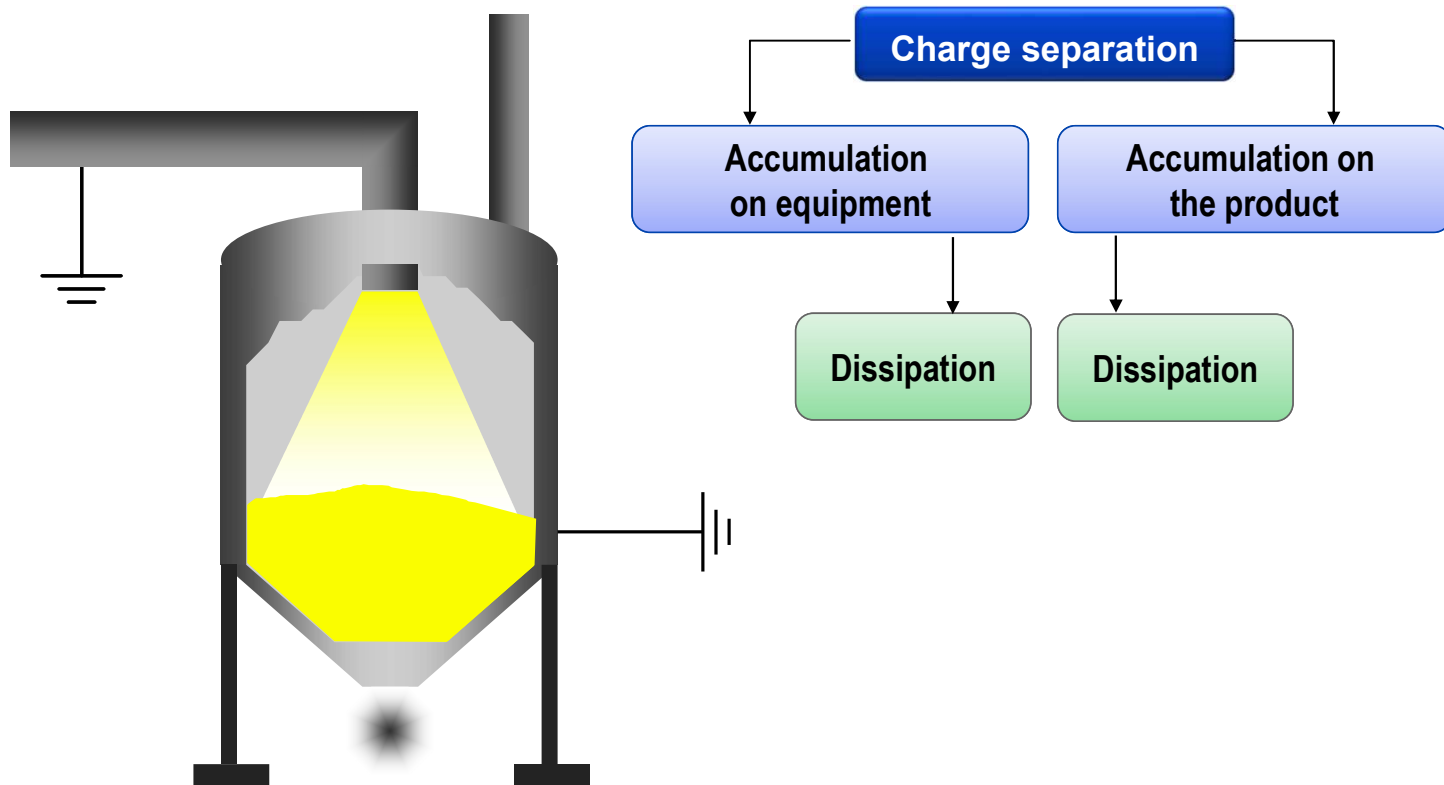
Electrostatic ignition source



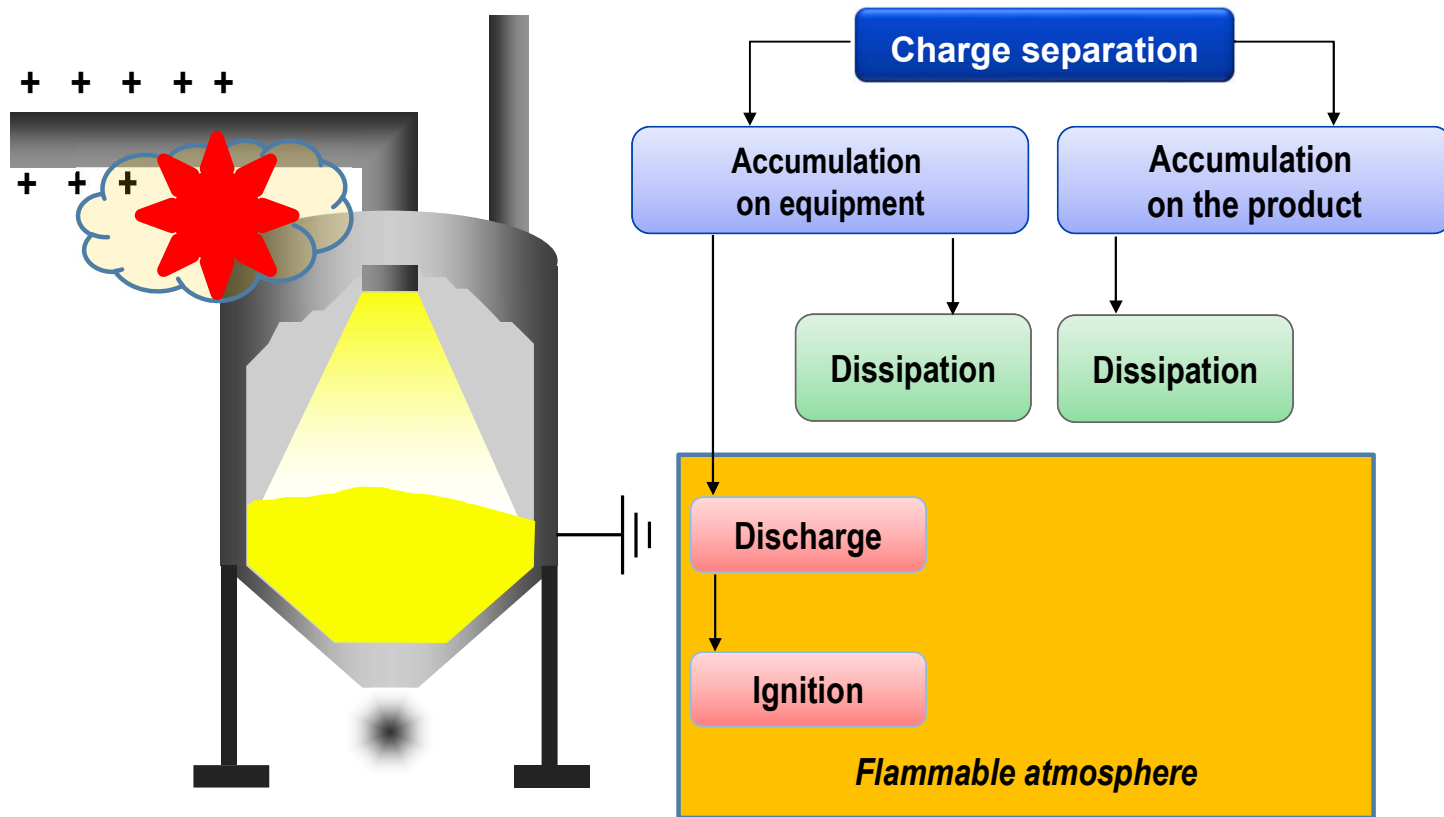
Electrostatic ignition source



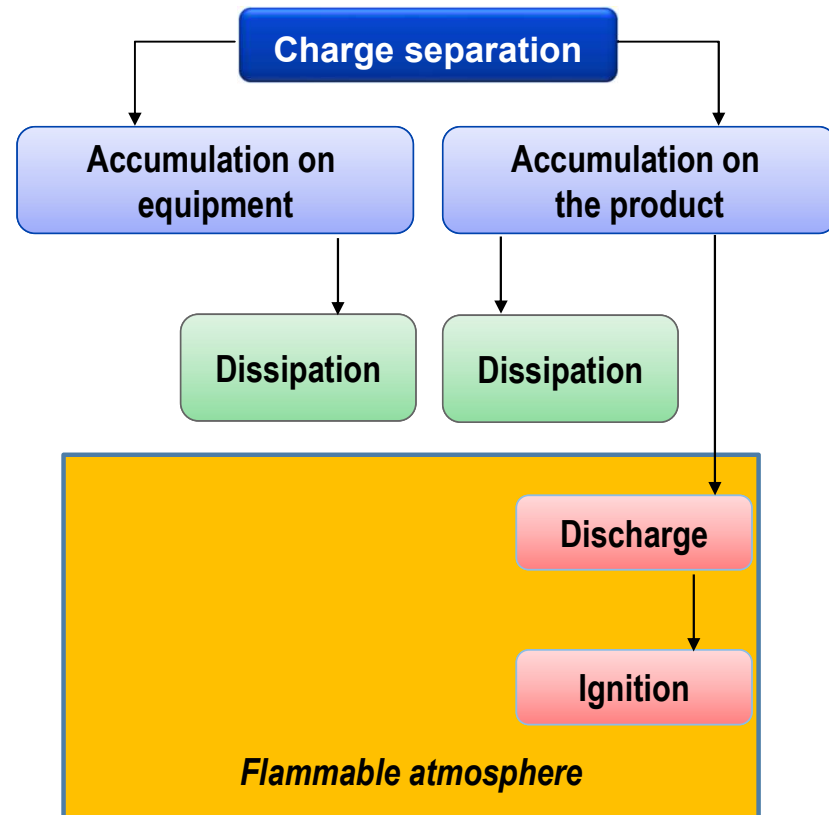
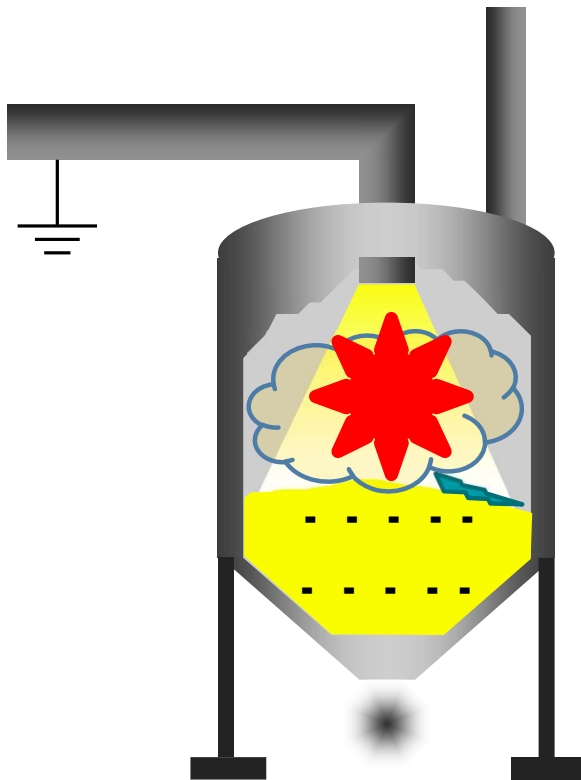
Electrostatic ignition source



Electrostatic ignition source



Electrostatic ignition source



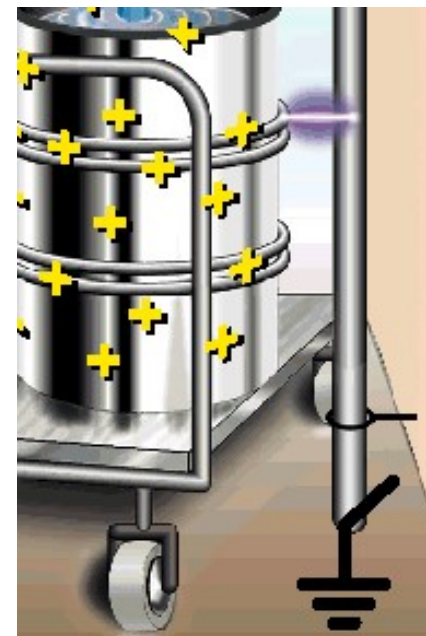
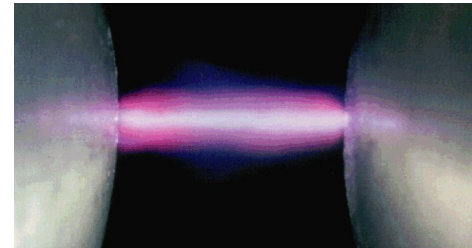
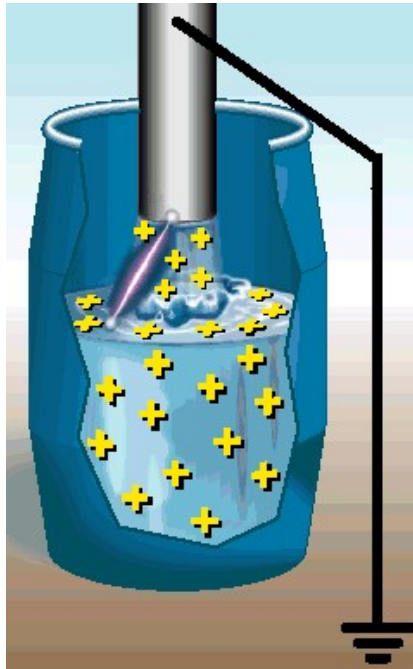
Electrostatic ignition sources

- Spark: electrostatic discharge between 2 conductors
- Brush discharge: electrostatic discharge from an insulating surface
- Propagating brush discharge: electrostatic discharge involving high transport speeds, insulating powder or liquid and insulating surface.
- Cone discharge: electrostatic discharge involving solids with a minimum size, highly insulating and loaded at high speed in silos or containers
- Corona discharge: electrostatic discharge from a very thin electrode.

Electrostatic ignition sources / loading

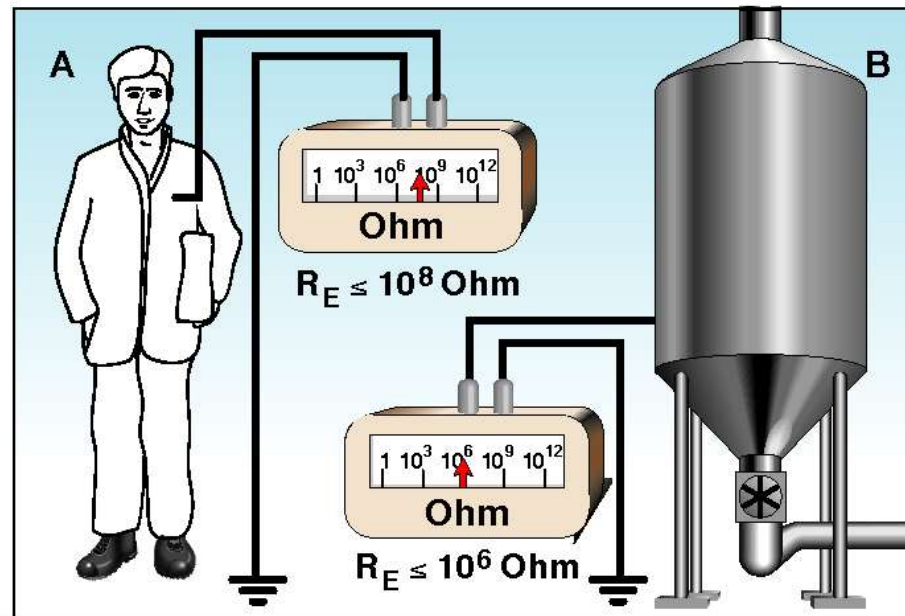
Electrostatic sparks

- Between two conductive entities



Electrostatic ignition source / sparks

- Safety measures to be taken
 - Connect and earth all conductors
 - Ground the people



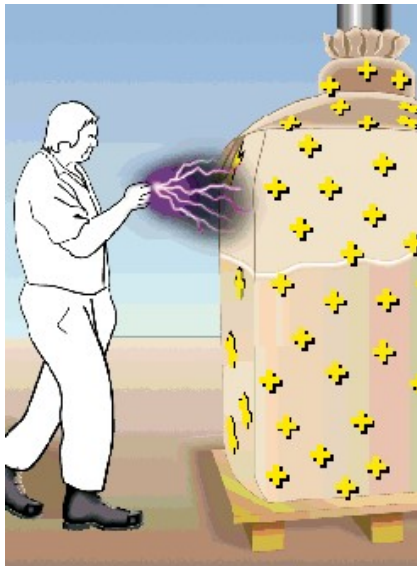
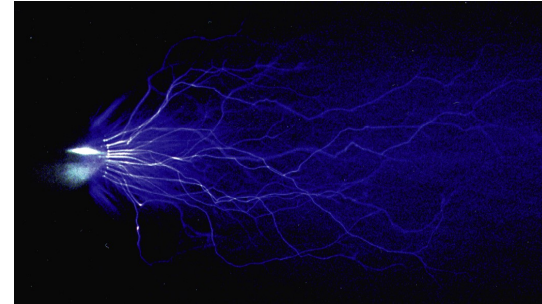
Spark discharge



Electrostatic ignition source

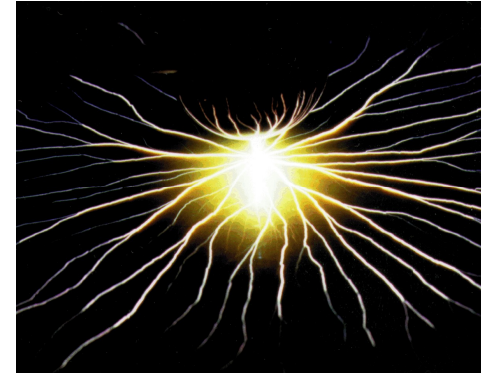
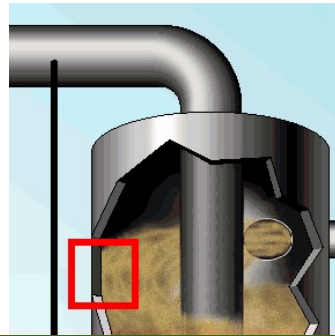
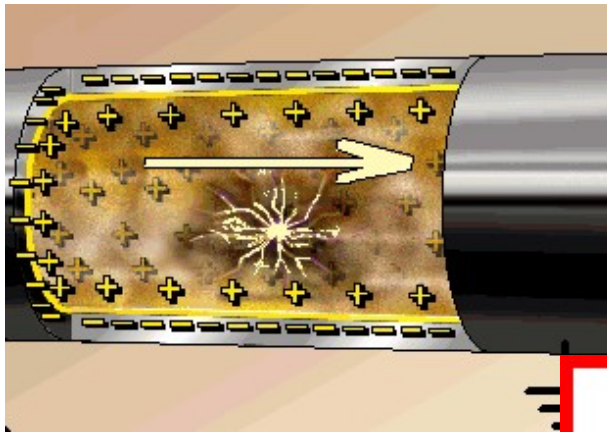
Brush discharge

- Between charged non-conductive material and conductors
- Energy < 5mJ
- Generally, non-efficient on combustible powders



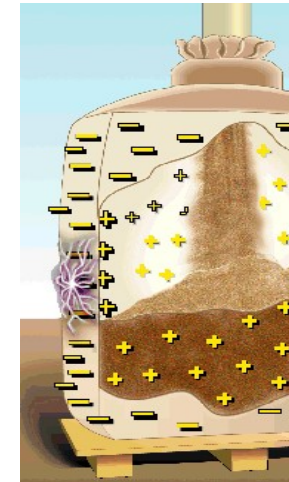
Electrostatic ignition source

Propagating brush discharge



Typically, at the inner surface of an isolating pipe or an isolating coating of a conductive pipe, if an isolating liquid flows very quickly.

Highly energetic, values $>1\text{J}$ are typical



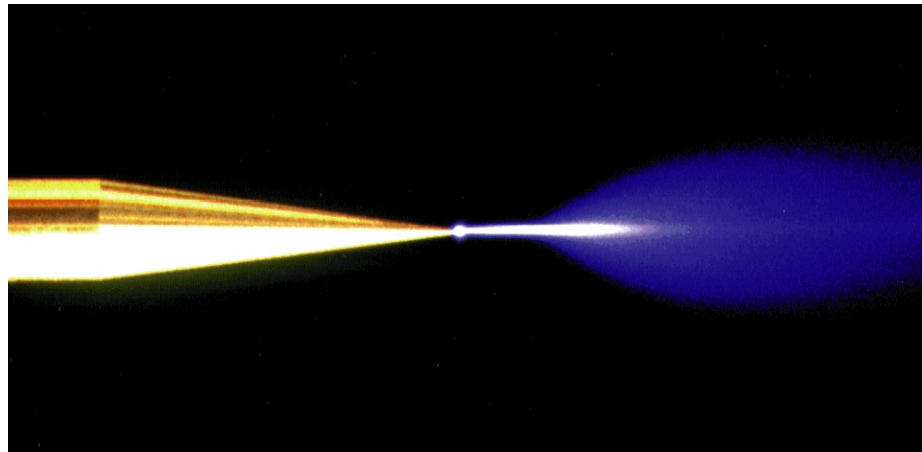
Propagating brush discharge



Electrostatic ignition source

Corona discharges

- Atomization of charges at specific locations during high electric fields
- Ignition source relevant for the most flammable gases (IIC)
- Corona discharges cannot ignite combustible powders.

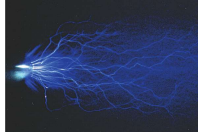
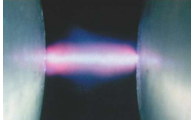
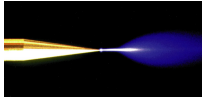


How to minimize the electrostatic risk ?

- Increasing the conductivity of the bulk material, e.g. by coating
- Replace insulating equipment by earthed conductive equipment
- Humidification of powders (with non-flammable liquids)
- Ionisation
- Reducing the quantity of fines in the bulk, e.g. avoiding fine fractions caused by wear and abrasion
- Reducing the conveying speed, throughput or air velocity
- Avoiding big heaps of bulk material
- Preferring gravity transport to pneumatic transport
- Using conductive or antistatic hoses for pneumatic transport.

Source: IEC 60079-32-2

Static electricity – Discharge Energies

Ignition Sources		
Brush discharge		$\leq 3 - 4 \text{ mJ}$
Bulk surface discharge (Cone discharge)		$< 1 \text{ J}$ ($D = 3 \text{ m}$)
Spark discharge		$\leq 1 \text{ J}$
Propagating brush discharge		1 J and more ($< 10 \text{ J}$)
Corona		$\leq 0.03 \text{ mJ}$

Ignition Sensitivity – Minimum Ignition Energy values

- Very sensitive atmospheres:
 - H_2 , C_2H_2 , CS <0.02mJ

- Sensitive atmospheres
 - Solvent vapours: 0.2mJ
 - Very rare dusts: 0.2mJ

- Dust clouds
 - Very sensitive dusts: < 1mJ
 - Sensitive dusts: <10mJ
 - Other dusts: >10mJ

Physiological effect of static discharges

- < 0.25mJ : Undetectable
- 1mJ : Just detectable
- 10mJ : Prickling sensation
("normal" discharge)
- 100mJ : Slight muscular contraction
- 1000mJ : Sharp muscular contraction

Question ?

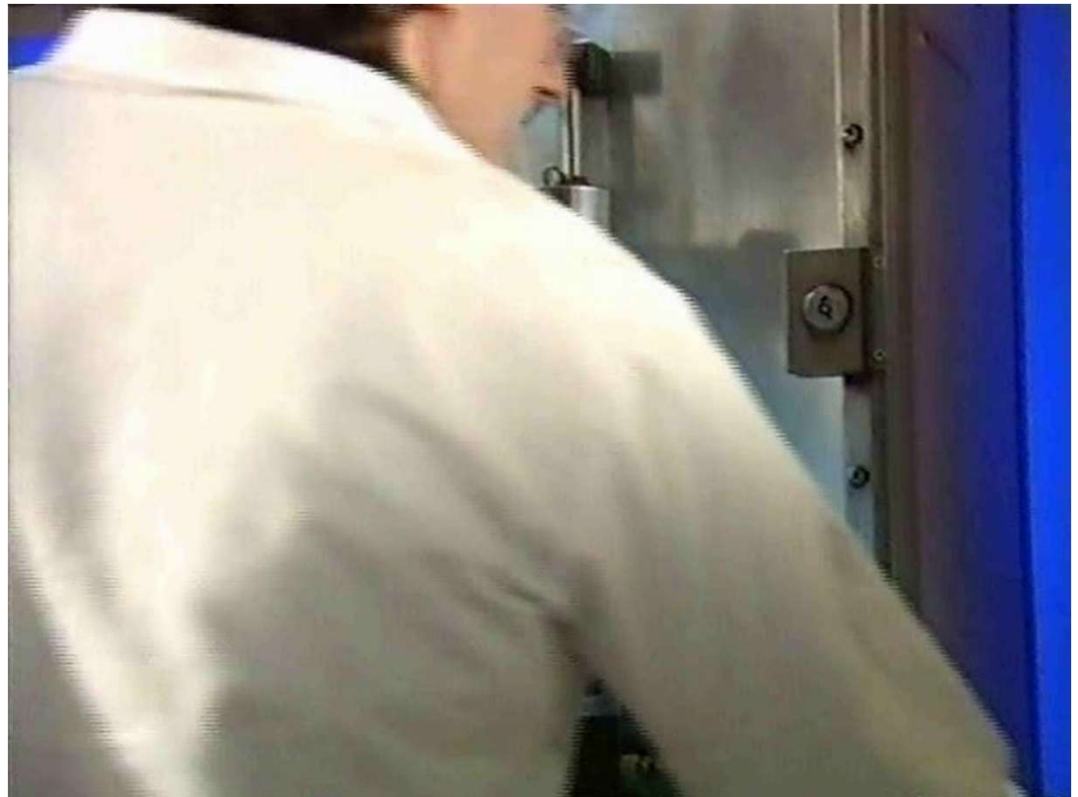
- Can those discharges ignite gases/vapors or dusts atmospheres ? YES or NO ?

Type of discharge	Gas/Vapors	Dusts
Brush discharges		
Spark discharges		
Propagating brush discharges		
Cone discharges		
Corona discharges		

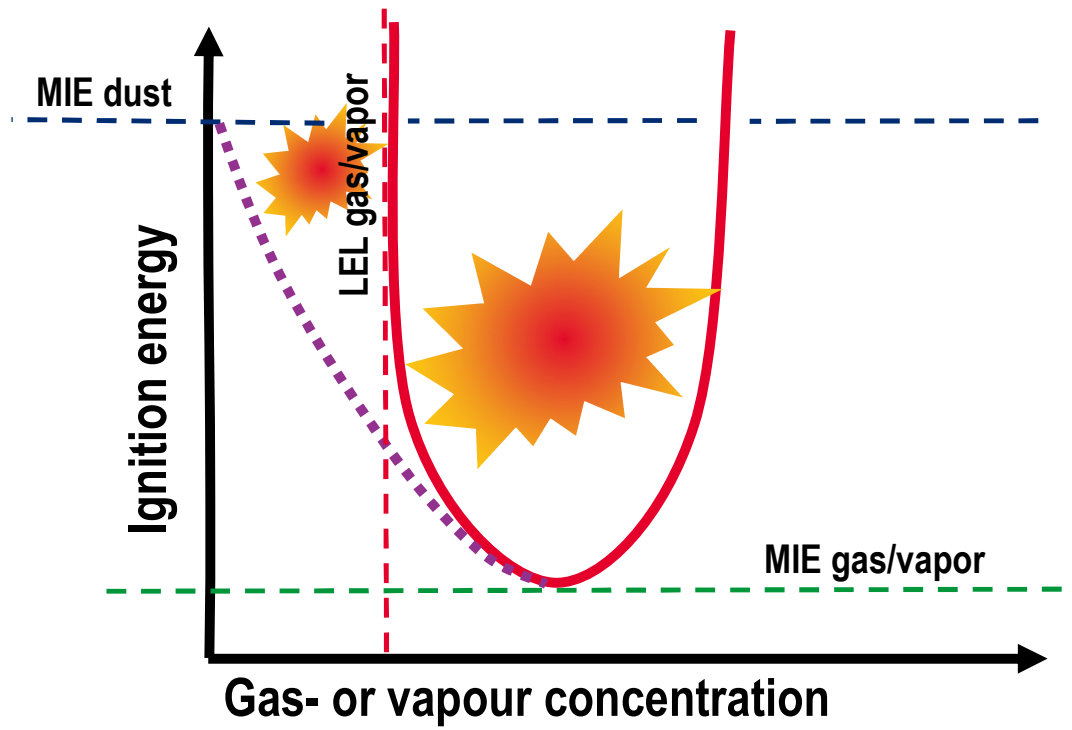
Minimum ignition energy test

- The minimum ignition energy is the lowest value of electrical energy stored in a capacitor which is just sufficient to ignite a dust/air mixture in case of discharging

MIE	classification
$\geq 10\text{mJ}$	Normal ignition sensitive
$\geq 3\text{mJ}$ and $< 10\text{mJ}$	Particular ignition sensitive
$< 3\text{mJ}$	Extremely ignition sensitive



Hybrid mixtures - MIE



Fire at a gas station...



Lightning effects from static electricity

Eruption of the Eyjafjallajökul in Island



Source: www.spiegel.de

Eruption of the Puyehue-Cordón Caulle in Chile



Agenda



1	Introduction to fire & explosion hazards
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2	Explosion dynamics
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3	Explosion prevention
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3.1	Limit fuel concentration
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3.2	Limit oxidant concentration
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3.3	Avoidance of ignition sources
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4	Risk based prevention: Zoning
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5	Explosion protection
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Introduction to ATEX directives

ATEX = ATmosphères EXplosives

ATEX 137 for the users of equipment (employers)
Directive 1999/92/UE, 16.12.1999 (applicable since 1st July 2003)



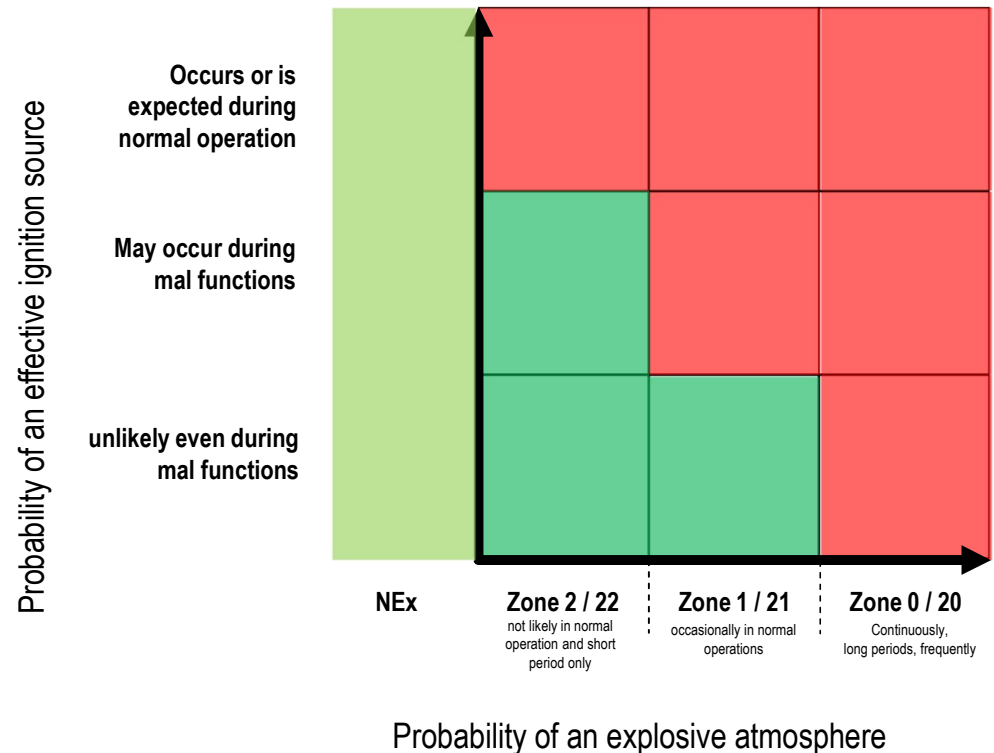
ATEX 95 for manufacturers
Directive 94/9/UE, 23.03.1994 (applicable until 19.04.2016)



---> ATEX 2014 for manufacturers
Directive 2014/34/UE, 26.02.2014 (applicable from 20.04.2016)

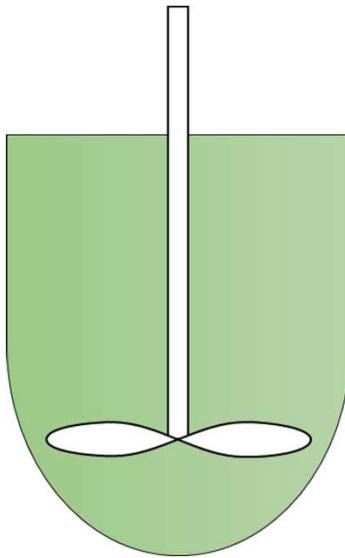
Zoning – “Risk Matrix”

- Electrical components can be an ignition source.
- Electrical components installed in and around areas handling flammable materials must be designed to minimize the possibility of fire or explosion



Zoning

Never

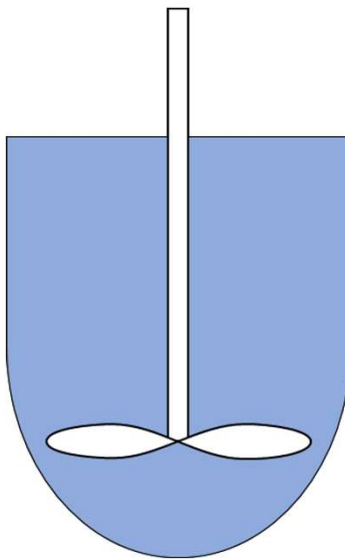


Non-Hazardous Zone

No flammable zone is expected regardless of the operating conditions and possible deviation.

Zoning

Only during deviations from the process – accidental cases

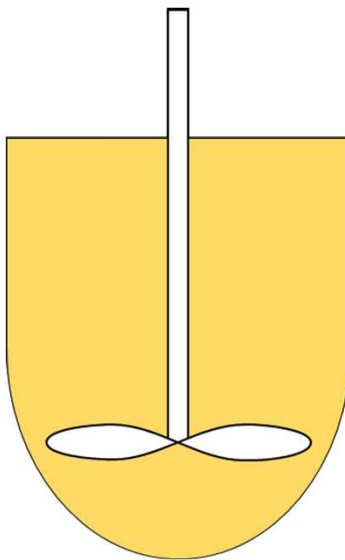


Zone 2 (gases and vapours) or Zone 22 (dusts)

Where, in a volume, a flammable atmosphere cannot occur under normal process conditions but only during a deviation, that volume is defined as Zone 2 when the flammable atmosphere is generated by gases or vapours and Zone 22 when it is generated by dust. For example, in an inert reactor or in the surroundings of a pump.

Zoning

Occasionally under normal process conditions

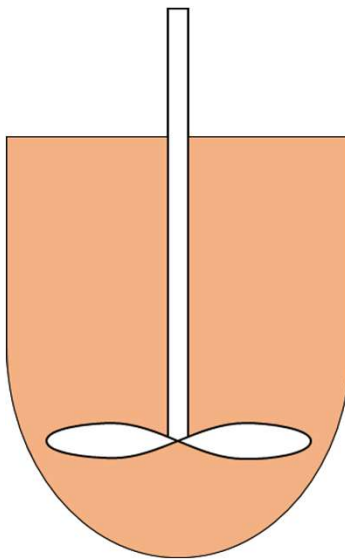


Zone 1 (gases and vapours) or Zone 21 (dusts)

Where, in a volume, a flammable atmosphere may occasionally occur under normal process conditions, that volume is defined as Zone 1 when the flammable atmosphere is generated by gases or vapours and Zone 21 when it is generated by dust. For example, in the surroundings of a manhole or in an IBC.

Zoning

Permanently or very frequently under normal process conditions

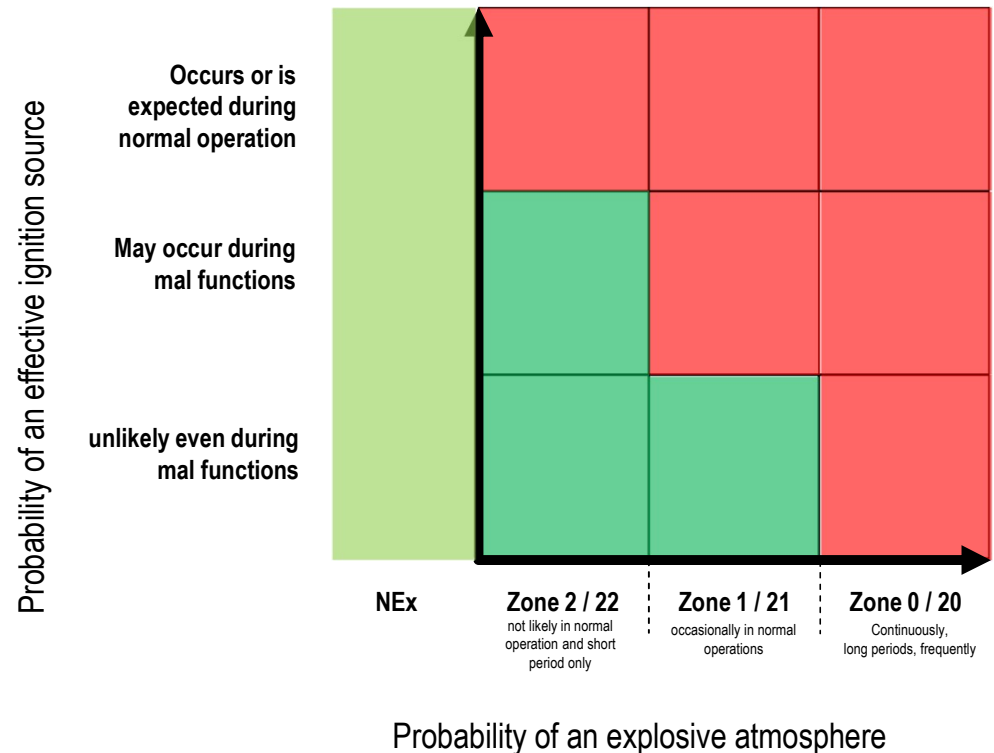


Zone 0 (gases and vapours) or Zone 20 (dusts)

Where, in a volume, a flammable atmosphere occurs frequently or continuously under normal process conditions, that volume is defined as Zone 0 when the flammable atmosphere is generated by gases or vapors and Zone 20 when it is generated by dust. For example, in an inert reactor or a shredder.

Zoning – “Risk Matrix”

- Electrical components can be an ignition source.
- Electrical components installed in and around areas handling flammable materials must be designed to minimize the possibility of fire or explosion



ATEX/IECEx marking for electrical equipment

- Electrical equipment as ignition source: e.g. motors, switches, lights
- Electrical equipment need to conform to the surrounding zone

Zone	ATEX category	Equipment protection level (EPL)
Gas / Vapor		
Zone 0	1G	Ga
Zone 1	2G or 1G	Gb or Ga
Zone 2	3G, 2G or 1G	Gc, Gb or Ga
Dust		
Zone 20	1D	Da
Zone 21	2D or 1D	Db or Da
Zone 22	3D, 2D or 1D	Dc, Db or Da



II	= no mines
2G	= category 2 gas (zone 1)

Ex	= Explosion protection
db	= Flameproof enclosure for use in zone 1 and 2
IIC	= gas group (e.g. H ₂)
T6	= temperature class, max. surface temp. 85°C
Gb	= EPL for use zone 1 and 2

Basic approach to discuss explosion prevention and protection

3.

Reduction of Effects
of Explosion to
Tolerable Degree

Pressure Proof Design

Explosion Venting

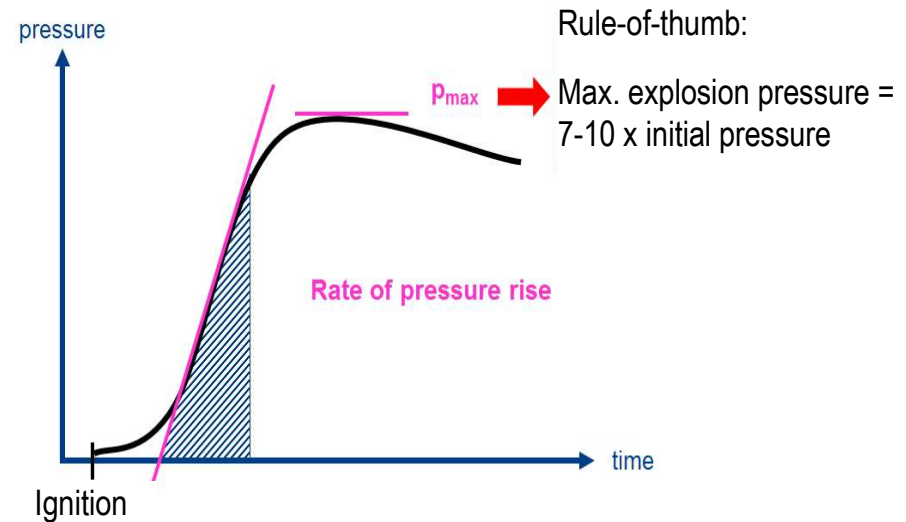
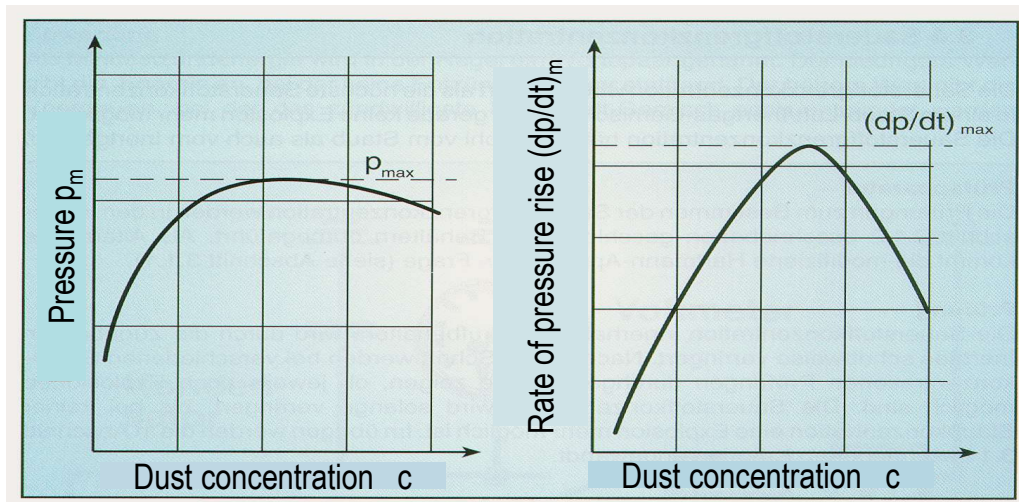
Explosion Suppression

Flame arrestors etc

Explosion Dynamics (confined space)

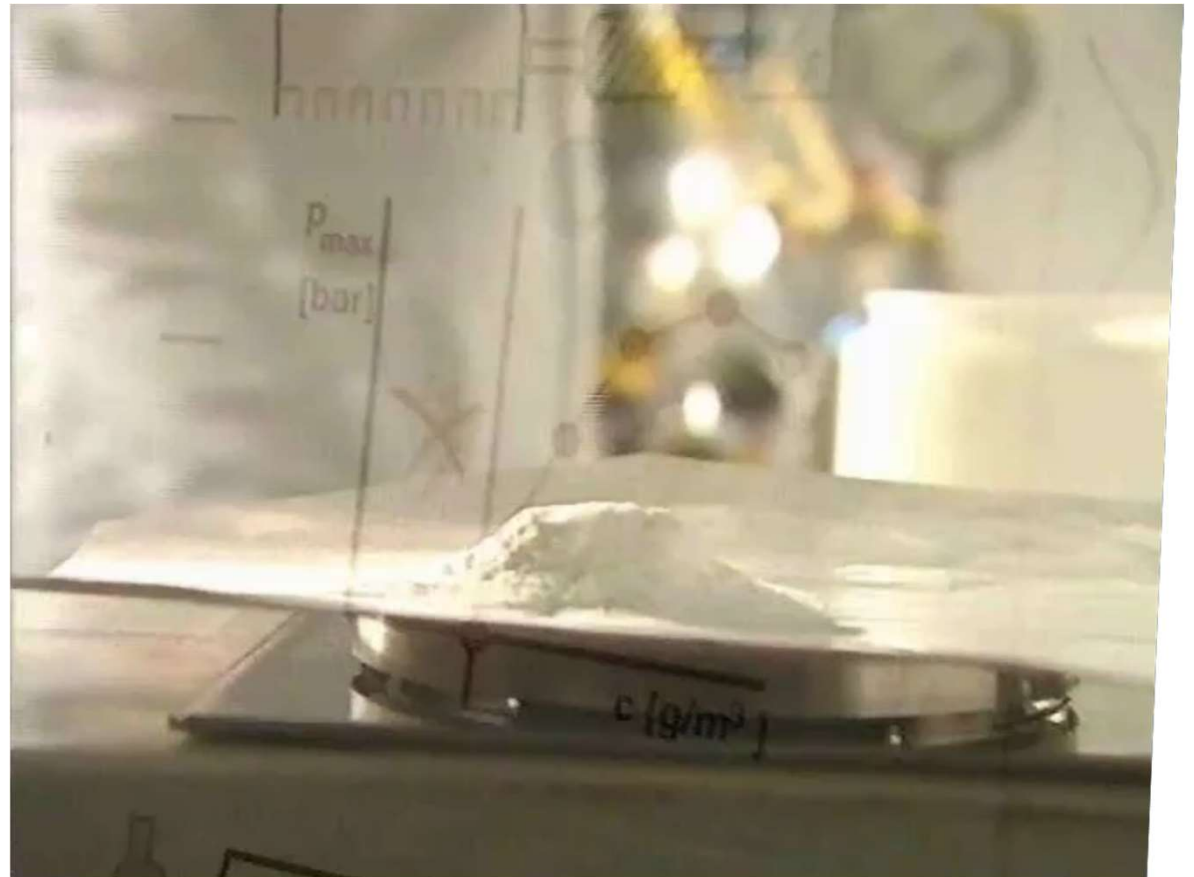
Dependence on concentration

- Explosion pressure
- Rate of pressure rise



Explosion dynamics: measurement

- Powders : 20 L sphere
- Vapors and gaz: 5 L



Explosion resistant designs

Apparatus is constructed to withstand an internal explosion without rupturing ("explosion resistant design").

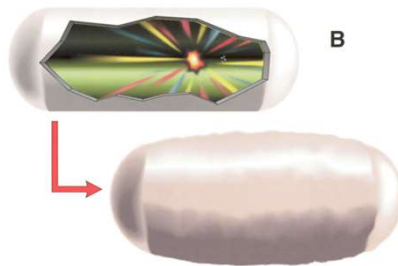
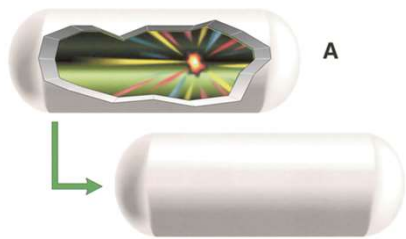
Explosion-resistant design

Explosion-pressure-resistant design

Explosion-pressure-shock resistant design

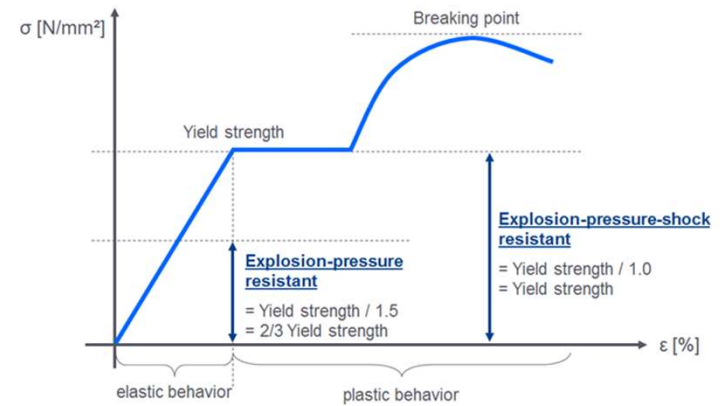
No deformation

May deform

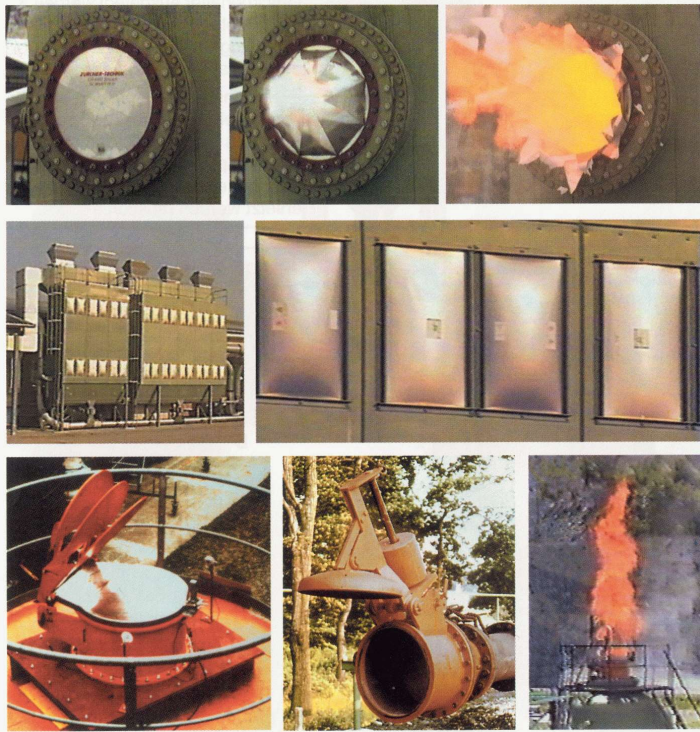


$$P_{design} = \text{Yield strength} / 1.5$$

$$P_{design} = \text{Yield strength} / 1.0$$



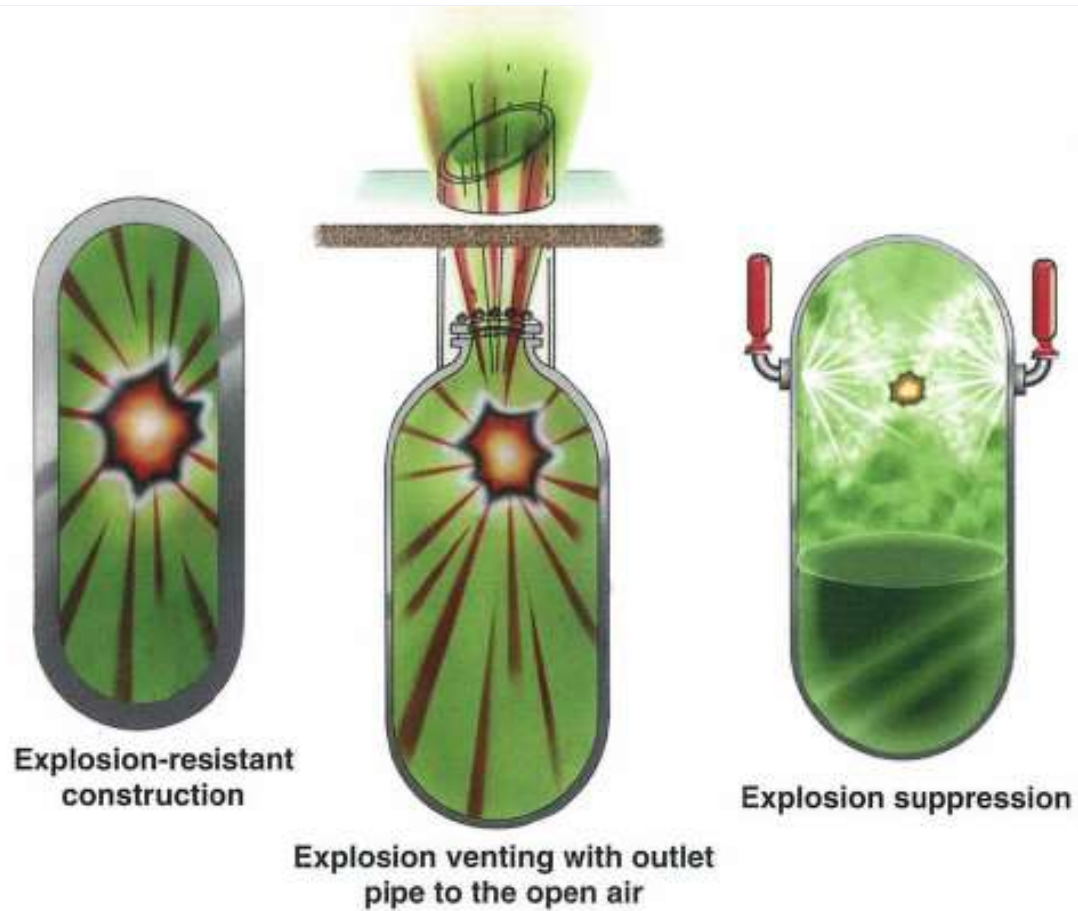
Pressure venting



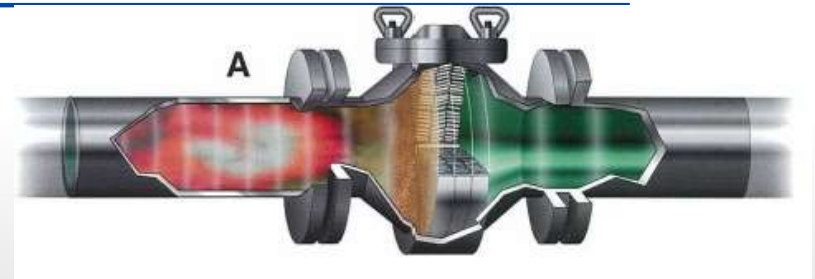
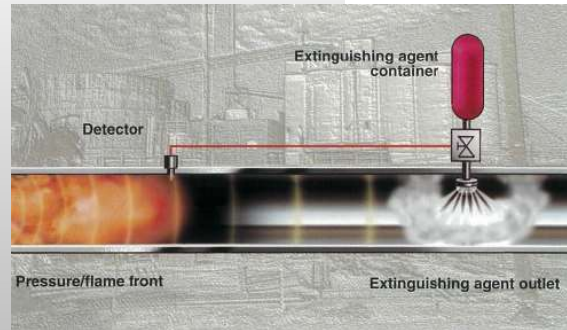
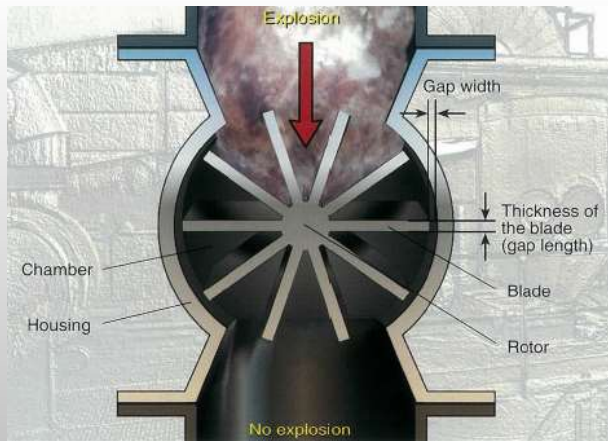
Explosion venting



Explosion Protection



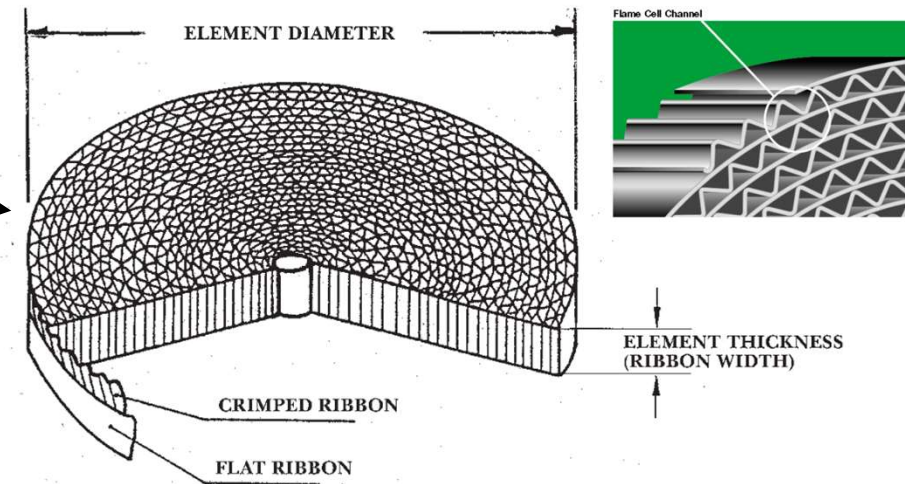
Equipment isolation



Sources: ISSA, Dust Explosions (2003) and Gas Explosions (2000)

Flame Arresters: Types

- Crimped Metal Ribbon (very widely used)
- Parallel plate
- Perforated plate
- Wire gauze
- Expanded metal cartridge
- Sintered metal
- Ceramic balls / metal shot



- Different geometries with the same function: provide a narrow gap while allowing flow of the gas (reducing pressure loss)
- The high temperature lasts an extremely short amount of time. As a result, conduction plays a small role
- Flame arrester elements can be made from materials other than metal, but compatibility with process gases and conditions have to be ensured (corrosion, fouling)
- If the point of ignition is downstream of the arrester, a flame could stabilize on the element. Therefore endurance burn tests must be carried out to test the burnback resistance
 - Temperature monitoring can help detect a stabilized flame

Common mistakes

- Flame arresters do not work if they are

dirty



corroded



blocked



Installed incorrectly
(vertical)

