Dust: Knowledge and key gaps

35th Anniversary UKELG Discussion Meeting

DNV GL Spadeadam Testing and Research Centre

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Overview

- Review of current knowledge
  - Dust explosion phenomenon
  - Combustion in dust explosions
  - Factors affecting dust explosions
  - Consequences
  - Current legislation
  - Prevention and mitigation
  - Incidents and commonly involved industries
- Key gaps
  - Scale and dispersion mechanisms
  - Modelling

Dust explosion phenomenon

COMBUSTIBLE DUST

OXIDANT

IGNITION SOURCE

DISPERSION

CONFINEMENT

Dust explosion

Combustible dust

- Materials that are not stable oxides:
  - Natural organic materials
  - Synthetic organic materials
  - Coal
  - Metals
- Dispersed dust will explode within certain flammable concentration limits (LEL-UEL)
- Typically tenths of g/m^3 to thousands of g/m^3.

Ignition source

- Typically:
  - Smouldering nests
  - Open flames
  - Hot surfaces
  - Heat from mechanical impact
  - Electrical discharges
- Ignition energy required generally higher than for gas clouds (>0.1 mJ as opposed to >0.01 mJ).

Dispersion

- Typically through turbulence or gravity.

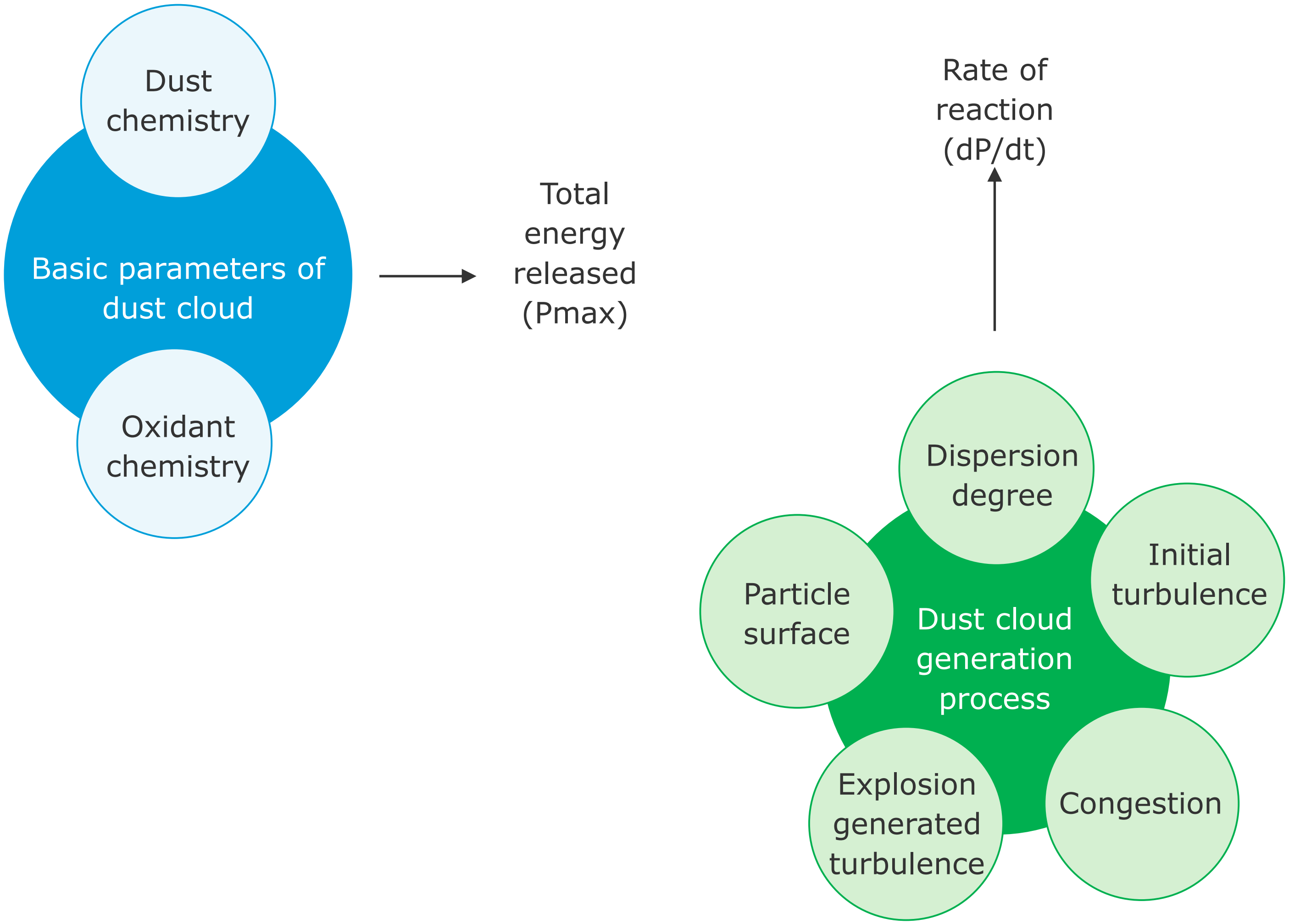
Confinement

- No confinement results in flash fire
- Confinement and congestion will result in rise of pressure. P_{max}
- High rates of pressure rise result in more violent explosions (dP/dt)

Combustion in dust clouds

- Rate of combustion and ease of ignition strongly influenced by:
  - Concentration
  - Degree of dispersion
  - Dynamic state of the cloud
- K_{St} was introduced to quantify explosion severity as opposed to burning velocity.
- $K_{St} = \left(\frac{dP}{dt}\right)_{max} \cdot V^{\frac{1}{3}}$
- This is because laminar dust flames are difficult to achieve.
- Combustion of dust particles varies with dust type.
- Most research into combustion mechanism conducted in closed vessels.
- Flame acceleration occurs in the same way as with gas flames.
- Dust explosions can escalate through dust lifting ahead of the flame (secondary explosions) and pressure piling.

Factors affecting dust explosion



Consequences

- Dust explosions can result in overpressure, thermal radiation and noise:
  - Loss of life/Injury
  - Destruction of buildings and plant (due to overpressure/fire)
  - Fire
  - Fireball
  - Secondary explosions

Current legislation

- Main legislation covering occupational health and safety HSW Act 1974
- Number of regulations were made under the Act to implement EU directives

	Health	Safety	
EU Directive	98/24/EC (risks related to chemical agents)	99/92/EC Risks from explosive atmospheres	ATEX 94/9/EC (Now replaced by New ATEX directive (2014/34/EU)
UK Implementation	COSHH (2002) Control of Substances Hazardous to Health	DSEAR (2002) Dangerous Substances and Explosive Atmospheres Regulations	EPS (1996) Equipment and Protective Systems Intended for use in potentially explosive atmosphere regulations

Prevention of dust explosions

Elimination ignition sources

- Temperature control
- Cooling
- Infrared detection
- Prohibitions (smoking, hot work)
- ATEX equipment
- Removal of foreign objects
- Earthing

Prevent formation flammable cloud

- Inerting
- Dust extraction

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Mitigation of dust explosions

Isolation

- Limits spread of explosion
- Prevents acceleration and pressure piling

Pressure resistant design

- Pressure rated enclosures/structures
- Costly and conservative solution

Venting

- Relief panels activate (break) at a set pressure.
- Standard guidance for sizing vent panels
- BS EN 14491:2012
- NFPA 68
- Size of panels depends on:
- Enclosure volume
- Enclosure strength
- Vent cover strength
- Burning rate of dust (K_{St})
- **Consideration must be given to:**
- Toxic/corrosive combustion products
- Emission of objects, external overpressure
- Reaction forces
- Application outside correlation limits

Suppression

- Systems can detect pressure or flame.
- Fast opening valve is activated on detection of pressure or flame to release a permanently pressurised extinguishing agent.

Incidents

- Records of industrial explosions start as early as 17th century
- Small percentage of total incidents recognised as a dust explosion

Most frequently involved dusts	Most frequently involved equipment	Frequent triggers
• Wood • Feed/food • Metals • Plastic • Coal • Chemical	• Mills • Grinders • Filters • Dryers • Silos Hoppers • Ducts	• Friction sparks • Smouldering nests • Mechanical heating

- Inadequate housekeeping
- Increased risk during maintenance/modification activities

Key gaps

- Combustion mechanisms
- Modelling
- Scale and dispersion mechanisms

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Combustion mechanisms

- Most research conducted in closed vessel tests.
  - Limited knowledge of flame structure and flame thickness
- Effect of radiative heat transfer on particles surrounding flame.

Modelling

- Numerical simulations are based on existing codes for gas explosions
- A number of areas require further work:
  - How the flow of suspended particles is represented
  - Application of gas correlations
  - Development of quenching and re-ignition models

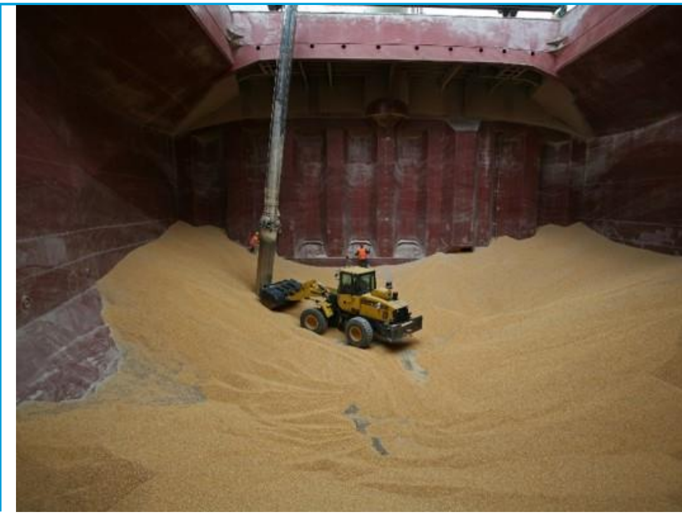
Scale and dispersion mechanisms

- Most testing has been done in relatively small volumes.
  - Uncertainty in extrapolating current correlations beyond the scale of original experiments used to derive them.
- Dust cloud formation processes are affected by the geometry and volume of enclosures.
  - Little quantitative knowledge of dust cloud formation
  - Potential for formation of flammable clouds and escalation in real scenarios is uncertain.

RESOLVE: research into large-volume dust explosions

CHALLENGE

Combustible dusts pose explosion hazards in a wide range of industrial facilities. Current guidelines for the design of explosion protection systems are unsuitable for the increasingly large facilities available. There is a need to understand the effects of scale on the potential for flammable atmospheres to be formed and the effectiveness of current guidance in the mitigation of dust explosion hazards.



SOLUTION

- Conduct large-scale experiments under both idealized and realistic conditions combined with modelling activities.
- Validate methodologies for modelling dust explosions using CFD.

BENEFITS

- Determination of the potential for dust build-up, escalation or effects due to the variability of feedstocks.
- Safe and cost-effective explosion protection systems.
- Industry guidance.

VALUE

NOK 8.5 million through the prevention of fire and explosion incidents*

* Factory Mutual Insurance Company estimated in 2011 that dust-related incidents resulted in losses of over USD 1 million

Contact: clara.huescar@dnvgl.com / +44 (0)2038164933

Region: UK

JIP I.D.: 2017-105

Comments/Questions?

Clara Huéscar
clara.huescar.medina@dnvgl.com
+44 (0)2038164933

www.dnvgl.com

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