Chapter 12 Fire and Explosion Hazards of Fine Powders

12.1 Introduction

Explosion

- Flammable gas: fuel concentration, local heat transfer conditions, oxygen concentration, initial temperature
- Dusts: + particle size distribution, moisture content

* Powders - High surface area / small size (small heat capacity)

Combustible powders → can be explosible

e.g. agricultural/chemical/coal/foodstuffs/metals/pharmaceuticals/plastics/woodworking

- Organic dust :
  heating → emission of combustible gases → explosion
- Metals :
  protective oxide films → breaking by sudden heating

12.2 Combustion Fundamentals

(1) Flames

- Flammable materials + oxygen + ignition source
- Stationary flame vs. explosion flame
  according to the behavior of flame front

(2) Explosion and Detonation

- Generation of gaseous combustion products
  → rapid gas expansion or
  → rapid pressure increase
- Detonation vs.deflagration
  Determined by flame speed (< or > speed of sound) which is

governed by heat of combustion

degree of turbulence

ignition energy

* Primary vs. secondary explosion

↓

compression wave of small explosion → increase in resuspending particles

∵ Compression wave precedes the flame.

(3) Ignition - Simple Analysis for Ignition

Energy balance for fuel-air mixture:

$$Q_{input} + (-\Delta H)\left[Z\exp\left(-\frac{E}{RT}\right)\right]C\rho_{m,\,fuel} =$$

Heat input Heat generated

$$V[C\rho_{m,\,fuel}C_{p,\,fuel} + (1-C)\rho_{m_{air}}C_{p,\,air}]\frac{dT}{dt} + hA(T-T_s),\ J/s$$

heat accumulation heat dissipated

where C: volumetric concentration of fuel

ρ: molar density

V: volume of fuel-and-air mixture element

A: surface area of the element

* Figure 12.1

T_B→ *Ignition* temperature

Explosion → "*Runaway*" reaction

Figure 12.2 Effect of heat input

Figure 12.3 Autoignition(spontaneous ignition)

(4) Flammability Limits

- Upper and lower flammability limit, C_{fL}, C_{fU}

in volume % fuel

- Minimum oxygen for combustion

For C_3H_8 $C_{fL} = 2.2\%$ *by volume*,

$$MOC = C_{fL} \cdot \left[\frac{moles\ O_2}{moles\ fuel} \right]_{Stoich}$$

$$= 2.2 \cdot 5 = 11\%\ O_2\ by\ volume$$

Worked Example 12.1

Worked Example 12.2

12.3 Combustion in Dust Clouds

(1) Fundamental to Specific to Dust Cloud Explosion

$$(-\Delta H)\left[Z\exp\left(-\frac{E}{RT}\right)\right] Cp_{m,\,fuel}$$

$$(-\Delta H) rV \qquad \rightarrow (-\Delta H) r''S \cdot \left(\frac{surface\ fuel}{volume\ fuel}\right) = (-\Delta H) r''S \cdot \frac{6}{x}$$

* Particle size : very important

- *Dispersion*
- *Surface area for reaction*
- *Specific heat of reaction*
- *Heat up rate*

(2) Characteristics of Dust Explosion

little data on powder properties

- *Minimum dust concentration*
- *Minimum oxygen for combustion (MOC)*
- *Minimum ignition temperature*
- *Minimum ignition energy*
- *Maximum explosion pressure*

- *Maximum rate of pressure rise*

$$\left(\frac{dp}{dt}\right)_{\max} V^{1/3} = K_{ST}$$

As close as possible to plant conditions

Table 12.1

Table 11.2 - Explosion class (K_{ST})

(3) Apparatus for Determination of Dust Explosion Characteristics

- Ignition source
- Dust dispersion

- Vertical tube apparatus Figure 12.4

  (max.dust concentration, min. energy for ignition, MOC)
- Sphere apparatus Figure 12.5

  (max. explosion pressure and max. rate of pressure rise)
- Godbert-Greenwald furnace apparatus (min. ignition temperature)

12.4 Control of the Hazard

(1) Introduction

- Change the process to eliminate the dust
- Design the plant to withstand the pressure generated by any explosion
- Remove the oxygen to below MOC
- Add moisture to the dust
- Add diluent powder to the dust

(2) Ignition Sources

Flames / Smouldering / hot surfaces / welding and cutting / friction and impact / electric spark / spontaneous heating

(3) Venting

- Simple and inexpensive method

Figure 12.6

Worked Example 12.3

(4) Suppression

- Discharging a quantity of inert gas and inert powder into the vessel

* Suppression systems

Automatic venting/advance inerting/automatic shutdown

(5) Inerting

- N_2 and CO_2
- Oxygen concentration < MOC

(6) Minimize Dust Cloud Formation

- Use of dense phase conveying
- Use cyclone and filters instead of settling vessels
- Dot not allow the powder stream to fall freely through the air

(7) Containment