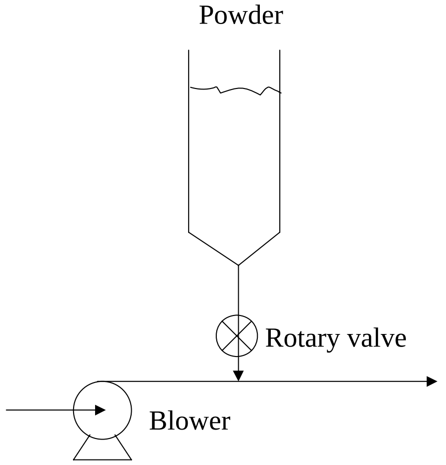
Chapter 6 Pneumatic Transport and Standpipes

6.1 Pneumatic Transport

Use of a gas to transport a particulate solid through pipeline



Three major variables for pneumatic conveying

- solid mass flow rate
- gas mass flow rate
- pressure gradient(pressure drop per unit length)

(1) Dilute-Phase and Dense-Phase Transport

Dilute-Phase	Dense-Phase
High gas velocity (> 20 m/s)	Low-gas velocity (1-5 m/s)
Low solids concentration (< 1 % by volume)	High solids concentration (> 30 % by volume)
Low pressure drop (<5 mbar/m)	High pressure drop (> 20 mbar/m)
Short-route, continuous transport(< 10 ton/h)	Batch or semibatch transport
Capable under negative pressure	
Particles behave as individuals	
Fully suspended in gas	Not-fully suspended in gas
Fluid-particle : dominant	Much interaction between particles and between particle and wall

(2) The Choking Velocity in Vertical Transport

Figure 6.1 - $\Delta p/\Delta L$ vs. U (gas superficial velocity)
at various solids flow flux G

Static head of solids → friction resistance

Choking velocity, U_{CH}

The lowest velocity at which the dilute-phase transport can operate at G given

Punwani et al (1976)

$$\frac{U_{CH}}{\varepsilon_{CH}} - U_T = \frac{G}{\rho_p(1-\varepsilon_{CH})}$$

$$\rho_f^{0.77} = \frac{2250D(\varepsilon_{CH}^{-4.7}-1)}{\left[\frac{U_{CH}}{\varepsilon_{CH}} - U_T\right]^2}$$

(3) Saltation Velocity in Horizontal Transport

Figure 6.2 - $\Delta p/\Delta L$ vs. U(gas superficial velocity)
at various solids flow flux G

Saltation velocity, U_{SALT}

The gas velocity at which the solids to begin to settle out

Boundary between dilute phase flow and dense phase flow

Rizk(1973)

$$\underbrace{\frac{M_p}{\rho_f U_{SALT} A}}_{\text{solid loading}} = \left\{\frac{1}{10^{(1440x+1.96)}}\right\}\underbrace{\left\{\frac{U_{SALT}}{\sqrt{gD}}\right\}^{(1100x+2.5)}}_{\text{Froude number at saltation}} \text{ in SI}$$

where M_p : particle mass flow rate

D : pipe diameter

(4) Fundamentals

Gas and particle velocity

Superficial velocity

$$U_{fs} = \frac{Q_f}{A} \quad \text{and} \quad U_{fp} = \frac{Q_p}{A}$$

Actual velocity

$$U_f = \frac{Q_f}{A\varepsilon} = \frac{U_{fs}}{\varepsilon} \quad \text{and} \quad U_p = \frac{Q_p}{A(1-\varepsilon)} = \frac{U_{ps}}{1-\varepsilon}$$

* Slip velocity U_{slip}

$$U_{rel} = U_f - U_p \equiv U_{slip}$$

Continuity

Gas mass flow rate

$$M_f = A U_f \varepsilon \rho_f$$

Particle mass flow rate

$$M_p = A U_p (1-\varepsilon) \rho_p$$

Solid loading

$$\frac{M_p}{M_f} = \frac{U_p(1-\varepsilon)\rho_p}{U_f \varepsilon \rho_f}$$

Pressure drop

From Newton's 2nd law of motion   Figure 6.3

Rate of momentum for flowing gas-solid mixture

= Net force exerting on the mixture

↓

$$p_1 - p_2 = \underbrace{\frac{1}{2}\rho_f \varepsilon U_f^2}_{\text{gas acceleration}} + \underbrace{\frac{1}{2}\rho_p (1-\varepsilon) U_p^2}_{\text{solids acceleration}} + \underbrace{F_{fw} L}_{\text{gas-wall friction}} + \underbrace{F_{pw} L}_{\text{solids-wall friction}}$$

$$+ \underbrace{\rho_f L \varepsilon g \sin\theta}_{\text{gas gravity}} + \underbrace{\rho_p L (1-\varepsilon) g \sin\theta}_{\text{solids gravity}}$$

(5) Design for Dilute Phase Transport

Gas velocity

$U_f \sim 1.5U_{SALT}$ since $U_{SALT} > U_{CH}$

for systems comprising both vertical and horizontal lines

$U_f \sim 1.5U_{CH}$

for vertical line only

Table. Approximate air velocity for powder transport

Powder	U, m/s
Wheat, rice, plastic pellets	16 - 24
Grains, limestone powder	16 - 23
Soda ash, sugar	15 - 20
PVC powder	20 - 26
Carbon powder	18 - 24
Cement	18 - 28
Alumina powder	24 - 32
Sand	23 - 30

Pipeline pressure drop

$$F_{pw}L = 0.057GL\sqrt{\frac{g}{D}}$$ for vertical transport

$$F_{pw}L = \frac{2f_p(1-\varepsilon)\rho_p U_p^2 L}{D} = \frac{2f_p G U_p L}{D}$$ for horizontal transport

where $U_p = U_f(1-0.0638x^{0.3}\rho_p^{0.5})$ and

$$f_p = \frac{3}{8}\frac{\rho_f}{\rho_p}C_D\frac{D}{d_p}\left(\frac{U_f - U_p}{U_p}\right)$$

C_D: drag coefficient (fn of Re_p)

Bend

~ 7.5 m of vertical section pressure drop

* Downflow through vertical-to-horizontal bend :

  - greater tendency for saltation
  - avoided if possible.

※ *Blinded tee bend* : Figure 6.4 with respect to radius elbow

- prolonging service life due to cushioning effect
- with the same pressure drop and solid attrition rate

Worked Example 6.1

Equipment

Figure 6.5 Positive pressure system

Figure 6.6 Negative Pressure system

※ Centrifugal blowers(fan)	vs.	Positive displacement blower
low pressure		high pressure
small amount of dust allowed		no dust is allowed

Some problems in pneumatic transport

	Possible	Avoided by
Blocking	at high concentration region(around solid feeder and bend	feeding at dispersed state sufficient acceleration length and adequate bend curvature
Adhesion	with moisty, low-melting or electrically charged powder	adequate range of gas velocity
Attrition	at bend	- low gas velocity - higher solid load - changing collision angle and bend material.

(6) Dense Phase Transport

Flow Patterns

Horizontal - Figure 6.7

Saltating flow - unstable, bad flow pattern

*Discontinuous dense phase flow**

Dune Flow / Discrete Plug Flow / Plug Flow*

Continuous Dense Phase Flow - requires high pressure

adequate for short-pipe transport

Equipment

Blow tanks : with fluidizing element (Figure 6.13)

without fluidizing element (Figure 6.14)

Plug formation : air knife (Figure 6.10)

air valve (Figure 6.11)

diaphragm (Figure 6.12)

Plug break-up : bypass (Figure 6.8)

pressure actuated valves (Figure 6.9)

Design and Operation

- Use of test facilities + past experience to determine pipe size, air flow rate and type of dense phase system
- Group A, D better than Group B, C for dense phase conveying
- Higher permeability: more suitable for plug flow type conveying
- Higher air retention: more suitable for dune mode flow

6.1S Flow of Liquid-Solid Suspension

(Slurries)

Characteristics of hydraulic transport

Transition velocity

Durand(1953)

$$U_{tr} = 11.9(U_T D)^{1/2} x^{1/4}$$

where D: pipe diameter

Critical(saltation) velocity

Durand(1953)

$$U_c = F_L[2gD(\rho_p/\rho_f - 1)]^{1/2}$$

where F_L: function of d_p and ε

Hanks (1980)

$$U_c = 3.12(1-\varepsilon)^{0.186}\left(\frac{x}{D}\right)^{1/6}[2gD(\rho_p/\rho_f - 1)]^{1/2}$$