Considerable Factors on Designing Dilute Phase Pneumatic Conveyors

1. Acceleration Length

by Rose & Duckworth

$$\frac{L_a}{D} = 5.7\left(\frac{m_p}{\rho_g g^{0.5} D^{2.5}}\right)^{0.36}\left(\frac{d_p}{D}\right)^{-0.16}\left(\frac{\rho_p}{\rho_g}\right)^{0.18}$$

L_a: acceleration length, D: pipe inner diameter, $\dot{m_p}$: solids mass flow rate, ρ_g: gas density, ρ_p: true particle density, d_p: particle diameter, g: gravitational constant

by Enick & Klinzing, Marcus

$$\frac{L_a}{D} = 0.527\left(\frac{D}{d_p}\right)^{-1.26}(1-\emptyset)Re_d$$

Re_d: drag Reynolds number, $\emptyset$: loading ratio

2. Bend Pressure Drop

by Ito for Single Phase Flow

$$\Delta P = \left(\frac{0.029 + 0.304 De^{-0.25}}{\left(\frac{2}{D} r_b\right)}\right)\frac{L_b \rho_g v^2}{2D}$$

r_b: bend radius, L_b: bend length, $300 > De > 0.034$: $De = Re_d\left(\frac{D}{2r_b}\right)^2$

De : Dean Number

If De < 0.034, bend radius is considerably large as a stright length of pipe.

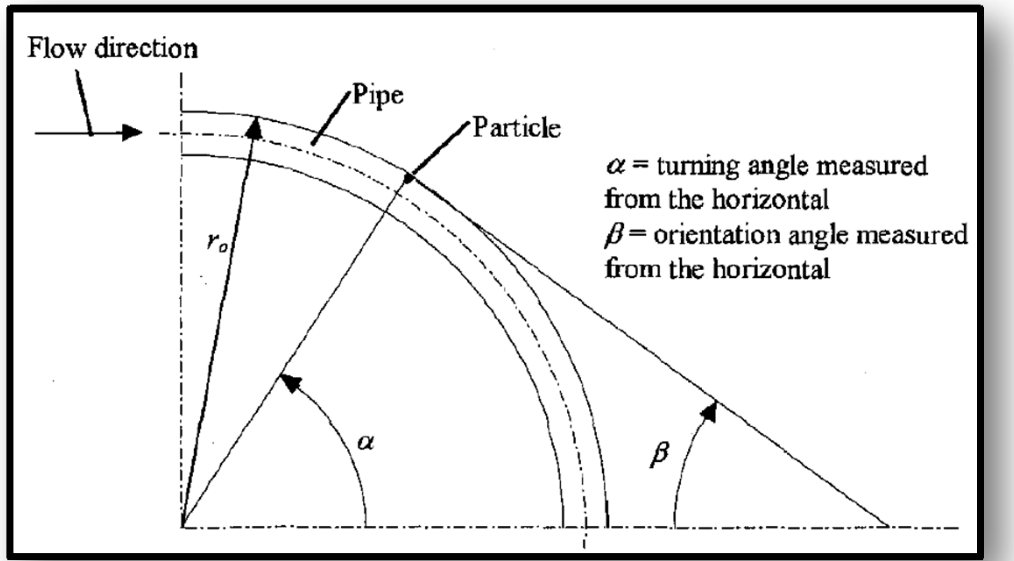
$$\Delta P = \emptyset \rho_g \varepsilon u_{sg}(u_{sa} - u_{so})$$

ε : polocity, u_{sg}: superficial solid velocity, u_{so}: bend outlet solid velocity, u_{sa}: re − accelerated solid velocity after bend

by Fischer

$$\Delta P = \emptyset \frac{L_b f_{slide} \rho_g u_{sg}^2}{r_o}$$

f_{slide} : sliding friction factor, r_o: bend radius to pipe outer wall



Solids Friction Factor for bend in the vertical plane

$$f_{bpv} = 2f_{sl}\left(1 - \frac{\rho_g}{\rho_p}\right)\frac{D}{u_{ig}^2}\left(\frac{u_{ig}^2}{r_o} - g\sin\alpha\ \sin\beta\right)$$

Solids Friction Factor for bend in the horizontal plane

$$f_{bph} = 2f_{sl}\left(1 - \frac{\rho_g}{\rho_p}\right)\frac{D}{r_o}$$

3. Particle Shape Definition

Volume Shape Factor defined by Heywood

$$Z = \frac{V_s}{{d_p}^3} \quad for\ only\ spheric\ solid$$

V_s : particle volume, d_p : projected diameter of particle

Volume Shape Factor defined by Govier & Aziz

$$\psi = \frac{d_{avg}}{\chi d_p} \quad for\ non-spherical\ solid$$

d_{avg}: average particle diameter from a mesh screen analysis
χ : ratio of surface area per mass of particles

The Sphericity defined by Boothroyd

$$\psi = \frac{\pi(\frac{6V_s}{\pi})^{2/3}}{A_{s,ns}} = \frac{surface\ area\ of\ a\ sphere\ of\ equivalent\ volume}{particle\ surface\ area}$$

Material	Sphericity ψ	Shape of material	Sphericity ψ
Sand	0.534-0.861	Octahedron	0.847
Silica	0.554-0.628	Cube	0.806
Pulverised coal	0.696	Prisms	
		a x a x 2a	0.767
		a x 2a x 2a	0.761
		a x 2a x 3a	0.725
Bituminous coal	0.625	Cylinders	
		$h = 3r$	0.860
		$h = 10r$	0.691
		$h = 20r$	0.580
Celite cylinders	0.861	Discs	
		$h = r$	0.827
		$h = r/3$	0.594
		$h = r/10$	0.323
		$h = r/15$	0.254
Iron catalyst	0.578	a = length; h = height; r = radius	
Broken solids	0.63		

4. Drag Coefficient effected by particle shape

Modified Schiller and Naumann's Equation

$$C_{d.s} = \frac{24}{Re_{ds}}\left(1 + 0.15{Re_{ds}}^{0.687}\right) + \frac{0.42}{1 + 4.25 \times 10^4 {Re_{ds}}^{-1.16}} \qquad Re_{ds} < 100,000$$

$C_{d,s}$: Drag coefficient a single spherical particle at an infinite dilution
$Re_{ds} = \frac{\rho_g u_{sg} d_p}{\delta_g}$, δ_g : dynamic gas viscocity, d_p : particle diameter, u_{sg} : superficial gas velocity

by Pettyjohn & Christiansen

$$C_{d,ns} = 0.843 log \frac{\psi}{0.065} C_{d,s} \qquad Re_{ws} < 0.05$$

$C_{d,ns}$: Drag coefficient of a single non-spherical particle at an infinite dilution

Drag Coefficient in the turbulent region

$$C_{d,ns} : 5.31 - 4.88\psi \qquad 2,000 < Re_{ws} < 200,000$$

Marcus에 의해 $C_{d,s}$와의 비율로 표현한 $C_{d,ns}$

$$C_{d,ns} = \left(\frac{1}{0.8431 log \frac{\psi}{0.065}}\right)^2 C_{d,s}$$

5. Drag Coefficient effected by Voidage(=Porocity)

$$C_{d,c} = C_{d,s}\, \varepsilon^{-4.7} \qquad Re_p < 1,000$$

$C_{d,c}$: Drag coefficient of a single particle in a cloud of particles

Pneucon
With Powders Technologies

6. Free fall velocity(or Terminal velocity) of Particles

$$u_t = \sqrt{\frac{4d_p g(\rho_p - \rho_g)}{3\rho_g C_{d,s}}}$$ for spherical particles

7. Solids Friction Factor for Various Models

Investigator	Solids friction factor, $\lambda_Z^*/4$
Stemerding [27]	0.003
Reddy and Pei [28]	$0.046c^{-1}$
Van Swaaij, Buurman and van Breugel [29]	$0.080c^{-1}$
Capes and Nakamura [30]	$0.048c^{-1.22}$
Konno and Saito [31]	$0.0285(gD)^{1/2}c^{-1}$
Yang [32], vertical	$0.00315\frac{1-\varepsilon}{\varepsilon^3}\left(\frac{(1-\varepsilon)w_{fo}}{v_\varepsilon - c}\right)^{-0.979}$
Yang [33], horizontal	$0.0293\frac{1-\varepsilon}{\varepsilon^3}\left(\frac{(1-\varepsilon)v_\varepsilon}{(gD)^{1/2}}\right)^{-1.15}$
Stegmaier [34]	$0.52\mu^{-0.3}Fr^{-1}Fr^{*0.25}(d/D)^{-0.1}$

8. Total Pressure Drop detailed accurately

Advanced Design Equations by Barth

$$\Delta p_{tot} = \Delta p_g + \Delta p_a + \Delta p_s + \Delta p_{grav} + \Delta p_b + \Delta p_{sep} + \Delta p_{blower}$$

Fischer's Equation

$$\Delta p_{tot} = \Delta p_g + \Delta p_a + \Delta p_{horiz} + \Delta p_{grav} + \Delta p_b + \Delta p_{sep} + \Delta p_{blower}$$

Δp_{tot} : Total Pressure Drop

$\Delta p_g = f_g \frac{\rho_g {u_{sg}}^2 L_{tot}}{2D}$: Pressure Drop due to air alone

$\Delta p_a = \emptyset \frac{\rho_g {u_{sg}}^2}{2} = \emptyset u_{sg} \rho_g u_{sp}$: Pressure Drop due to material acceleration at the feed point

$\Delta p_s = \emptyset f_{add} \frac{\rho_g {u_{sg}}^2 L_{tot}}{2D}$: Additional Pressure Drop due to solids in both horizontal and vertical section

$\Delta p_{horiz} = \emptyset \rho_g g f_{slide} L_{horiz}$: Pressure Drop due to horizontal conveying of solids

$\Delta p_{grav} = \emptyset \rho_g L_{vert} = (1-\varepsilon)\rho_p g L_{vert} = \emptyset \frac{\rho_g}{u_{sp} {u_{sg}}^{-1}} g L_{vert}$: Pressure Drop due to gravity for the vertical lift only

$\Delta p_b = \emptyset \frac{L_b f_{slide} \rho_g {u_{sg}}^2}{r_o} = \frac{0.029+0.304De^{-0.25}}{(\frac{2}{D}r_b)} \frac{L_b \rho_g {u_{sg}}^2}{2D} + 210(\frac{2r_b}{D})^{-1.15} \Delta p_s$: Pressure Drop due to bends

Δp_{sep} : Pressure Drop due to the seperating equipment as Cyclone or Bag Filter, Δp_{blower} : Pressure Drop due to air alone from blower to pick up point or duct to vacuum blower after bag filter

f_{add} : Additional Pressure Drop Factor

Table : Available correlations to determine the additional pressure loss factor (ζ).

Equation	Remarks
$\zeta = \frac{\pi}{8}\frac{\lambda_s}{\lambda_a}\left(\frac{\rho_s}{\rho_a}\right)^{0.5}\mu$ [48]	λ_s is called as solid friction factor $\lambda_s = \frac{0.026}{\mathrm{Re}^{0.85}} + \frac{0.0034}{\mathrm{Re}^{0.6}}$
$\zeta = \frac{\lambda_s}{\lambda_a}\frac{v_s}{v_a}\mu$ [49]	v_s is solid velocity
$\zeta = \frac{C_1 m_s}{v_s^2 u_T}$ [50]	C_1 is a factor depend on D and u_T is the free falling terminal velocity of solids
$\zeta = C_2\frac{1}{\mathrm{Re}}\left(\frac{D}{d}\right)^2\frac{\rho_s}{\rho_a}\mu$ [51]	Re is gas phase Reynolds number and C_2 is a constant
$\zeta = \frac{C_3 m_s g}{\rho_a D v_s v_a u_T}$ [50]	A modification to the equation in 3rd row