Pneumatic transport

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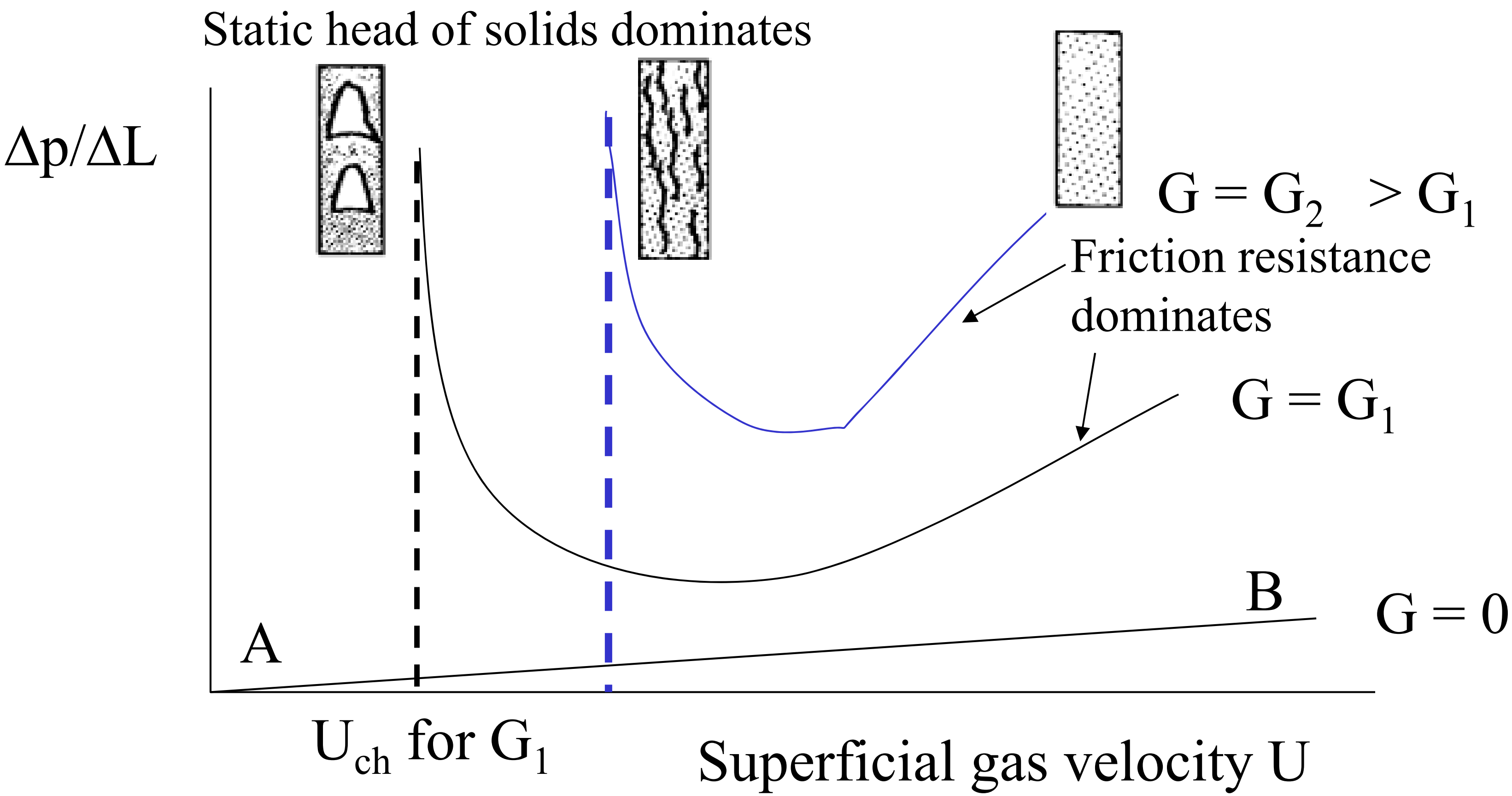
Based on M. Rhodes, Introduction to Particle Technology, 2nd edition, 2008, and material from prof. Ehrman, Univ of Maryland

Pneumatic transport

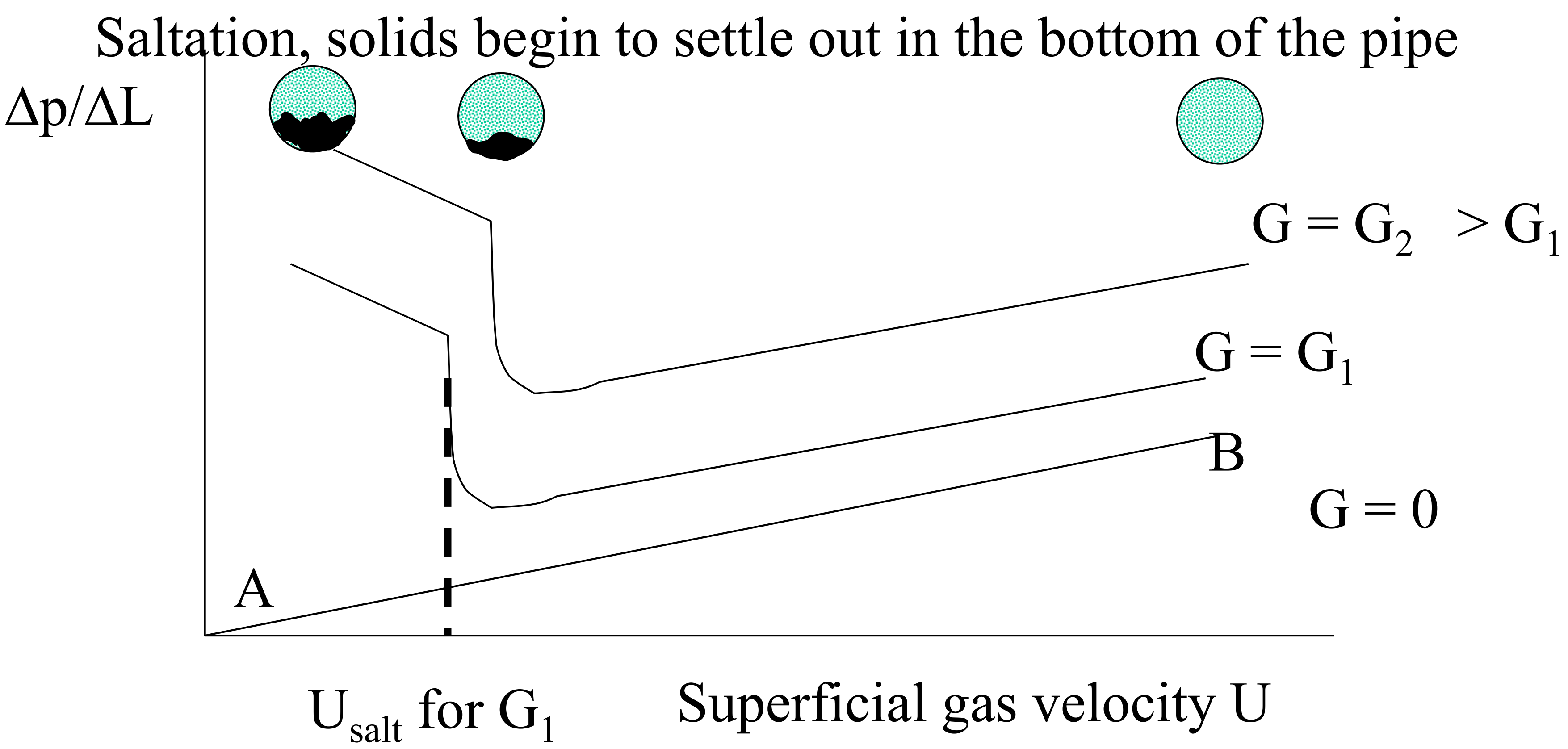
- Basic definition – using gas to transport a particulate solid through a pipeline
  - Ex: grain, flour, plastic, pulverized coal
- Two modes
  - Dilute phase – particles are fully suspended, like entrainment in FB but deliberate, solids less than 1 % by volume, lots of pumping req'd
  - Dense phase – particles not suspended, loading > 30 % by volume, lots of interparticle interactions

Phase diagram for dilute phase vertical pneumatic transport

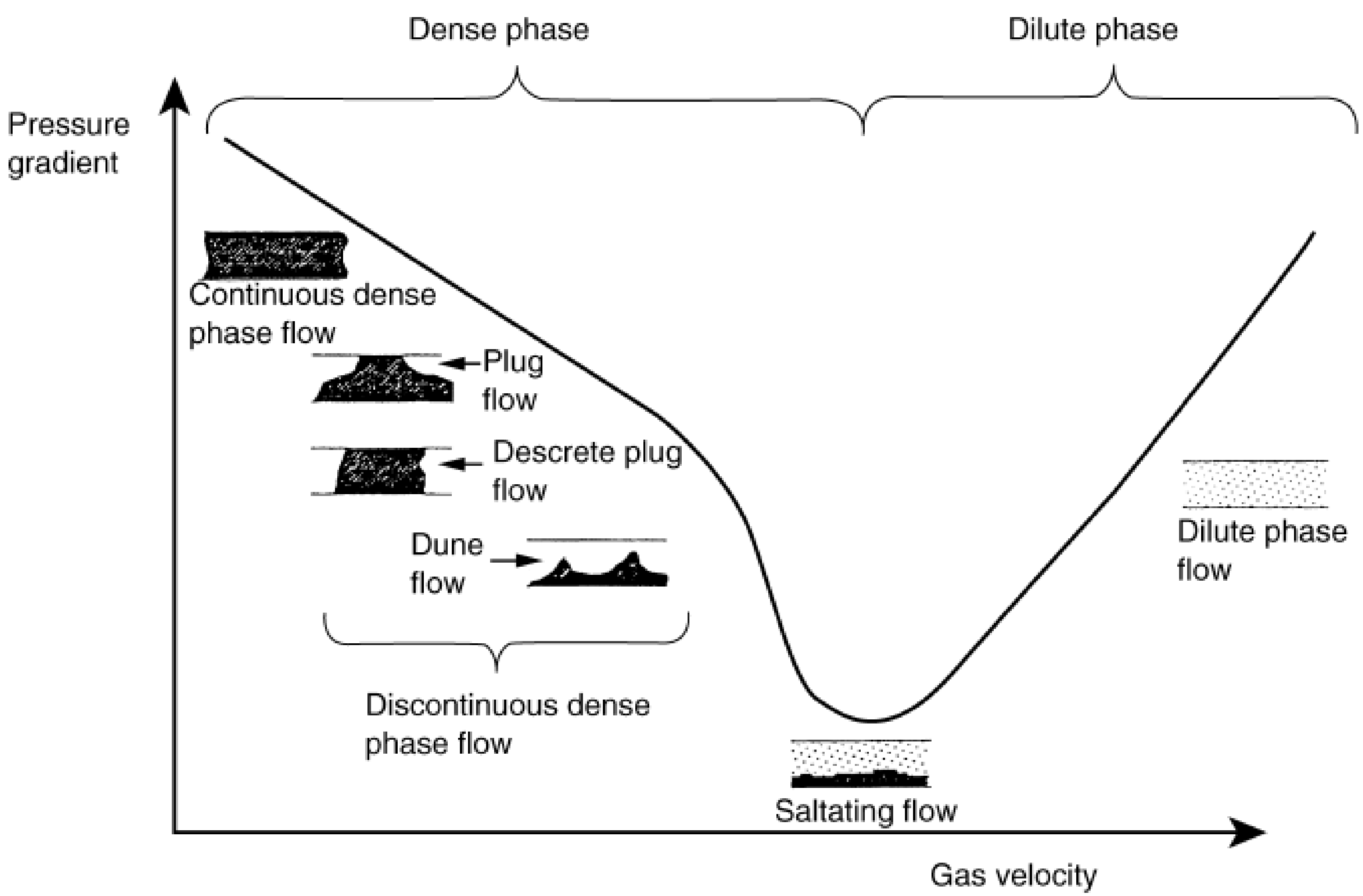


Uch, lowest velocity at which dilute phase transport line can be operated if solids feed rate is G1

Phase diagram for dilute phase horizontal pneumatic transport



Phase diagram for dense phase horizontal pneumatic transport



Definitions

- Superficial gas velocity U_{fs} =

Q_f (gas volumetric flow) /A (cross sectional area of pipe)

- Superficial solids velocity $U_{ps} = Q_p/A$

  (Q_p = volumetric flow of solids)

- Actual gas velocity $U_f = Q_f/A\varepsilon$ (void fraction)

- Actual particle velocity $U_p = Q_p/[A(1-\varepsilon)]$

Important relationships

- Mass flow rate of particles

$$M_p = AU_p(1-\varepsilon)\rho_p$$

- Mass flow of fluid

$$M_f = AU_f\varepsilon\rho_f$$

- Solids loading = M_p/M_f

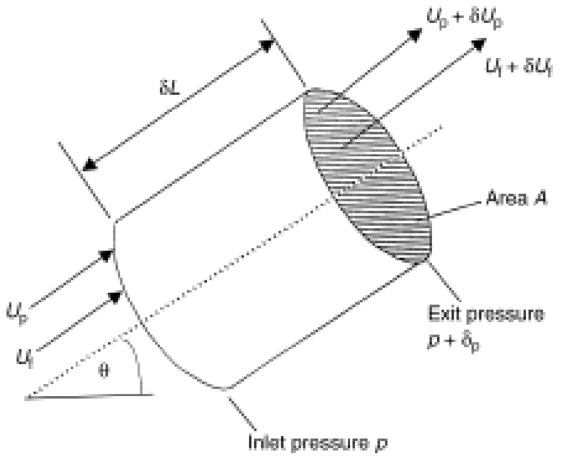
Pressure drop in pneumatic transport

Contributors to pressure drop

1.	Gas acceleration	*gas acting on gas*
2.	Particle acceleration	*gas acting on particles*
3.	Gas/pipe friction	*wall friction*
4.	Solids/pipe friction	*wall friction*
5.	Static head of solids	*fighting gravity*
6.	Static head of gas	*fighting gravity*

Not considered: interparticle forces

Force balance on pipe



Net force acting on pipe contents = rate of increase in momentum of contents

Pressure - gas/wall friction force - solids wall friction force - gravity = rate of increase in momentum of gas + rate of increase in momentum solids

$$(P_1 - P_2) - F_{fw}L - F_{pw}L - \rho_p L(1-\varepsilon)g\ \sin\Theta - \rho_f \mathrm{L}\ \varepsilon\ \mathrm{g}\ \sin\Theta =$$

$$\frac{1}{2}\varepsilon\rho_{\mathrm{f}} U_f^{\ 2} + \frac{1}{2}(1-\varepsilon)\ \rho_{\mathrm{p}} U_p^{\ 2}$$

F_{fw} and F_{pw} are gas to wall and solids to wall friction force respectively, L = pipe length, Θ = angle of pipe with horizontal

What happens for horizontal flow?

Terms and physical meaning

$(P_1 - P_2)$	1. Total pressure drop
$F_{fw}L$	2. Gas acceleration (gas acting on gas)
$F_{pw}L$	3. Particle acceleration (gas acting on particles)
$\rho_p L(1-\varepsilon)g \sin\Theta$	4. Gas/pipe friction — wall friction
$\rho_f \mathrm{L}\ \varepsilon\ \mathrm{g}\ \sin\Theta$	5. Solids/pipe friction — wall friction
$\frac{1}{2}\varepsilon\rho_{\mathrm{f}}U_f^{\ 2}$	6. Static head of solids — fighting gravity
$\frac{1}{2}(1-\varepsilon)\ \rho_{\mathrm{p}}U_p^{\ 2}$	7. Static head of gas — fighting gravity

Tools to calculate pressure drop

Correlations for F_{pw}

For vertical transport [G = solids mass flux, mass particles/(area x time)]

$$F_{pw}\ \mathrm{L} = 0.057\ \mathrm{G\ L}\sqrt{\frac{g}{D}}$$

Horizontal transport

$$F_{pw}\ \mathrm{L} = \frac{2\mathrm{f_p\ G\ U_p L}}{\mathrm{D}}$$

where

$$U_p = U(1 - 0.0638\ \mathrm{x}^{0.3}\rho_p^{\ 0.5})$$

and

$$f_p = \frac{3\rho_f D}{8\rho_p x} C_D \left[\frac{U_f - U_P}{U_p}\right]^2$$

For gas/wall friction pressure drop, calculate with friction factor assuming it is independent of presence of particles.

Simple method for steady state horizontal flow

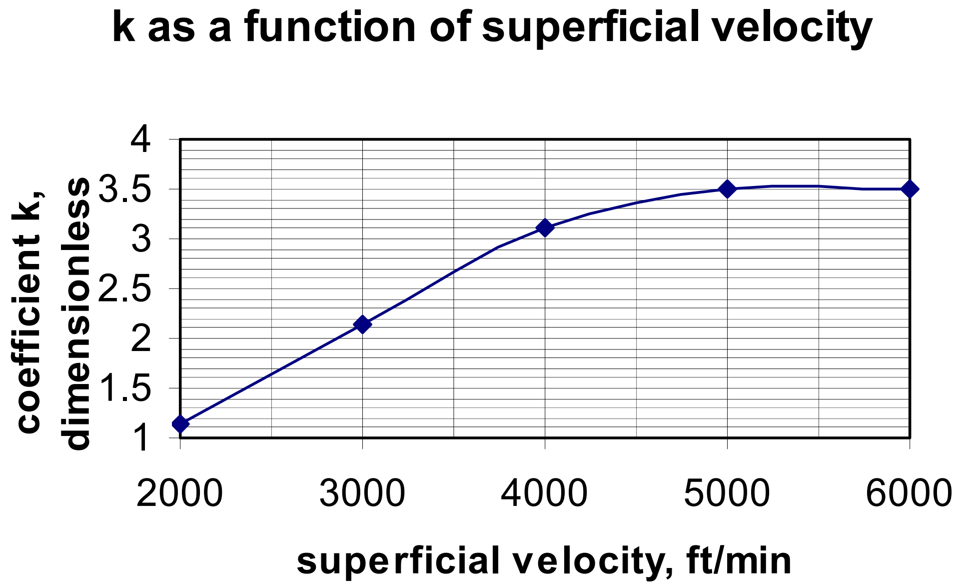
From Particle Technology by Orr (1966)

Ratio of total pressure loss due to solids/air system (ΔPt)
to total pressure loss due to only air flowing (ΔPa)

$$\frac{\Delta P_t}{\Delta P_a} = 1 + \frac{R}{k}$$

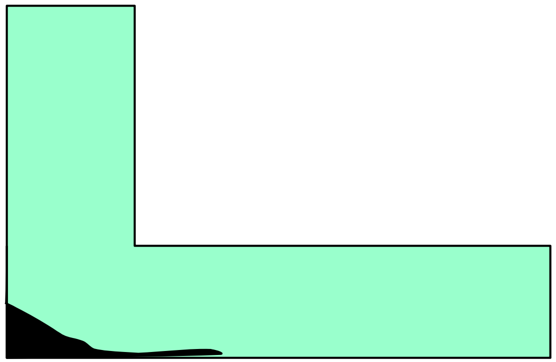
$$R = \frac{\text{mass of solid material}}{\text{mass of air}}$$

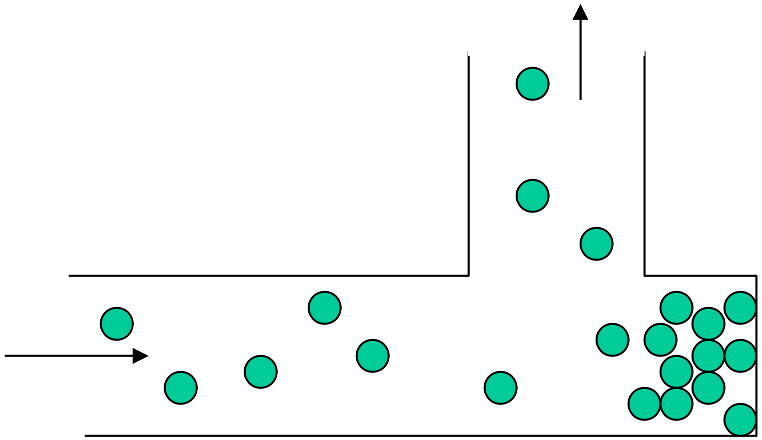
k is an empirically derived coefficient



Bends

Generally problematic. Solids that may be in suspension in vert/horiz transport may salt out as they go around bends. Worst case: vertical going to horizontal

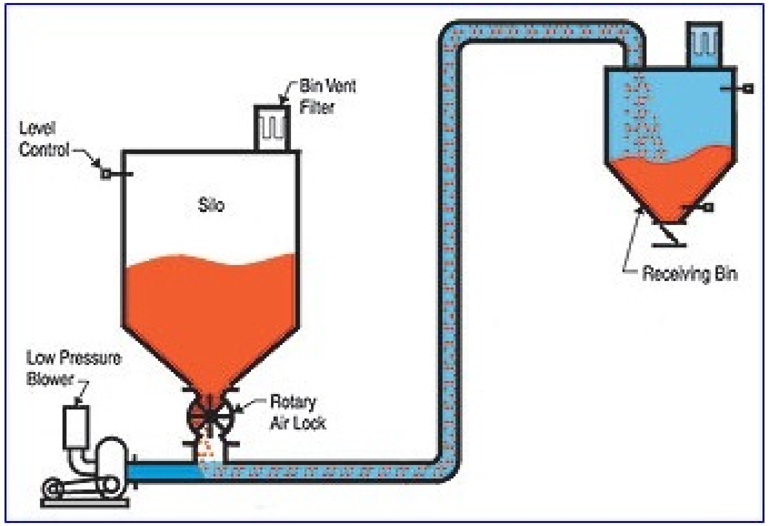




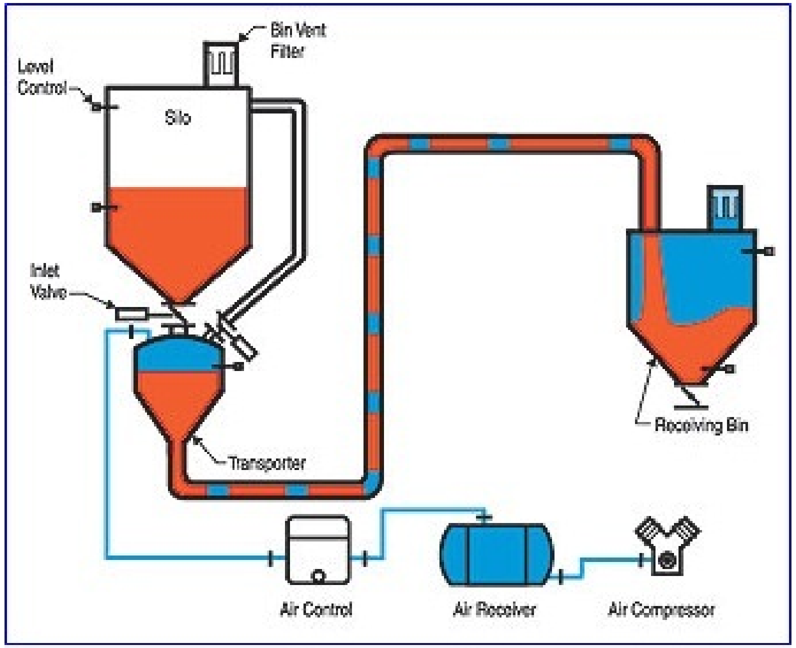
blinded tees recommended if bends are unavoidable

No reliable correlations exist for bend pressure drops.
Only a rough rule of thumb:
Bend $\Delta P = \Delta P$ for 7.5 m of vertical pipe under same flow conditions

Pneumatic conveying systems – Typical designs



Dilute-phase conveying system



Dense-phase conveying system