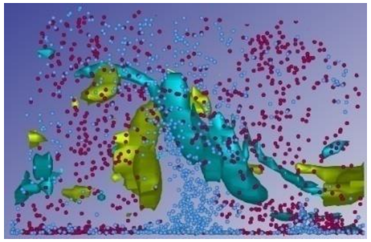
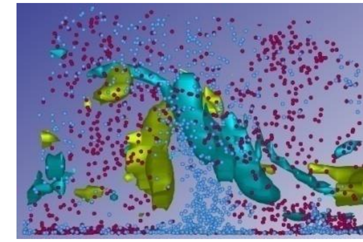
Università degli Studi di Udine
Dip. Politecnico Ingegneria & Architettura



Pneumatic Conveying

M.Campolo

Design of Industrial Plants 2018



Problem

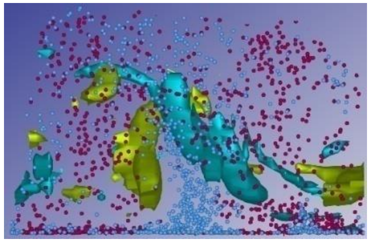
Trasfer particulate solids from one point to another

A boat being loaded at Pier 86 Grain Terminal (Seattle)

Belts conveyor to load/unload suphur

Krupp coal stacker (RTCA Kestrel Mine, Queensland)

Objective



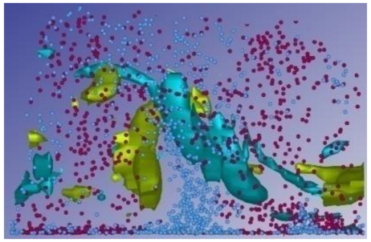
Transfer the solid phase continuously using a flux of air (carrier gas)

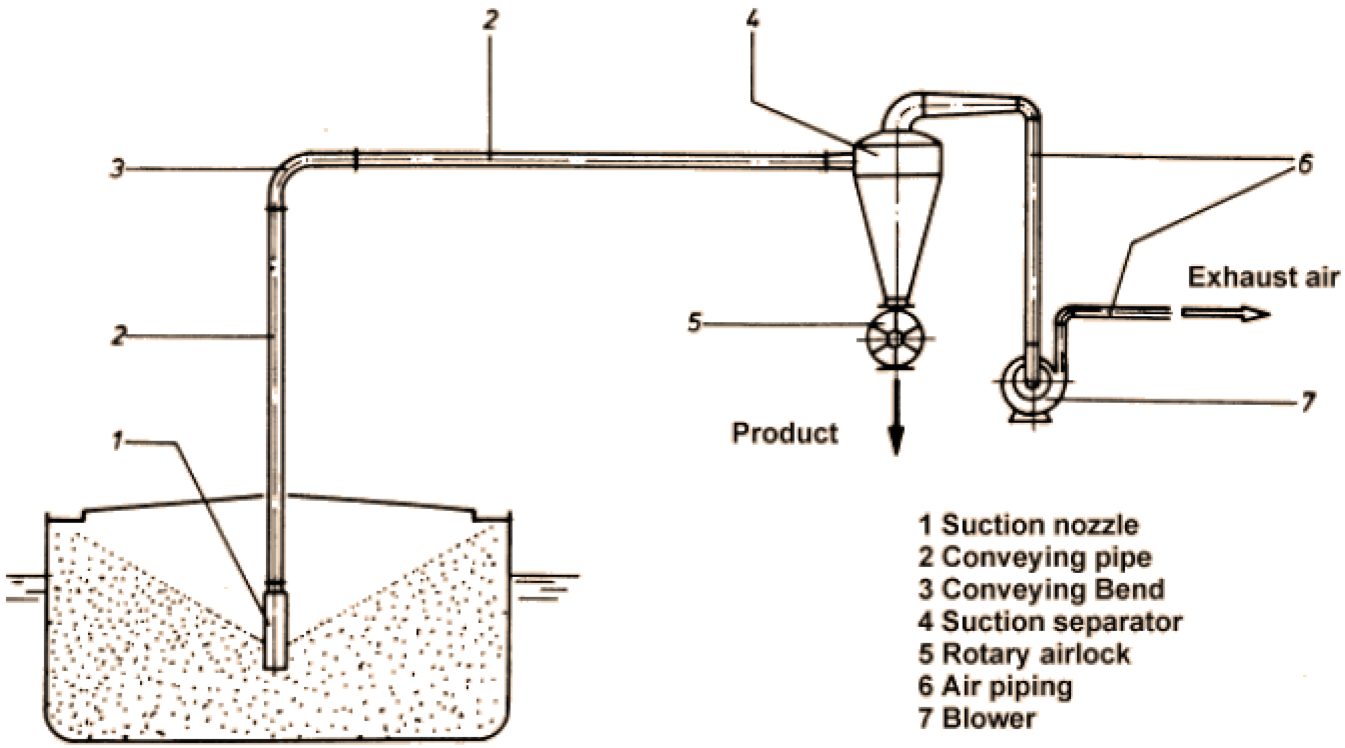
System initially used to load/unload grains, sands, seeds

System presently used to load chemicals, wood fibers, powders

Under which condition the solids can be transported as suspended matter in the flow? How large is the pressure drop?

Transport system: suction mode



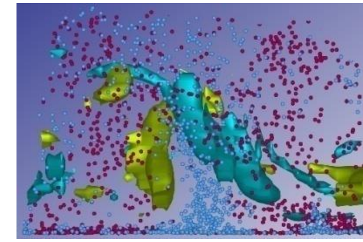


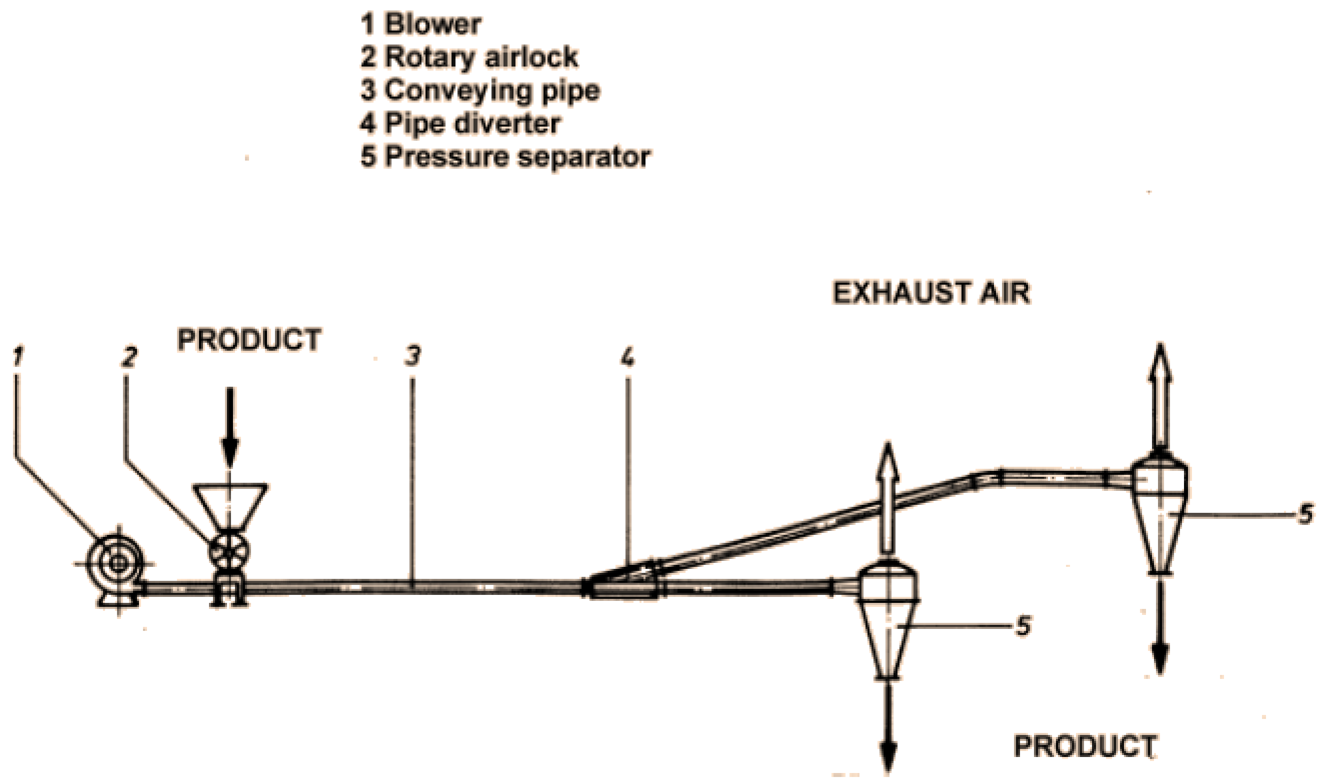
Like in a vacum cleaner…

Pressure in the line < environmental pressure

→ no risk of leakage, limited loading capacity/transport lenght

Transport system: pressure mode

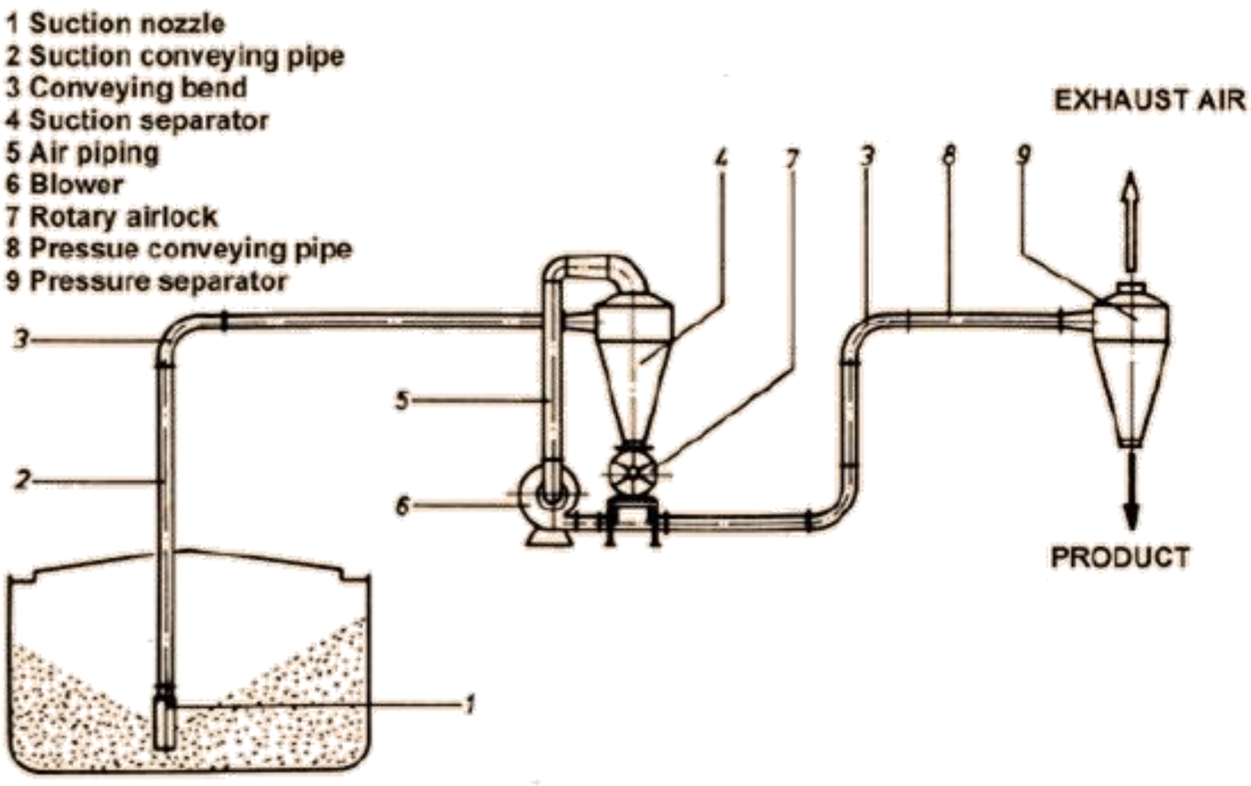


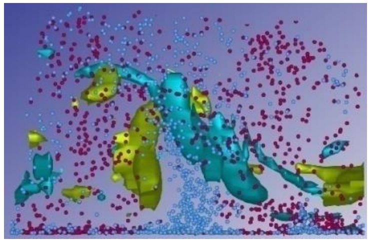


Pressure in the line > environmental pressure

→ Leakage possible, enhanced loading capacity/transport lenght

Transport system: suction-pressure mode





Pipeline characteristics

Pipe diameter: 10 mm – 800 mm

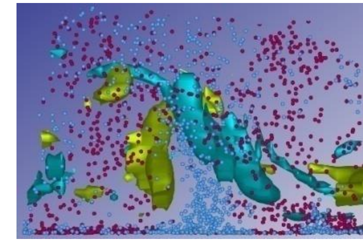
Solid flowrate: 1 kg/h – 1000 t/h

Pipe length: 10 m – 1000 m

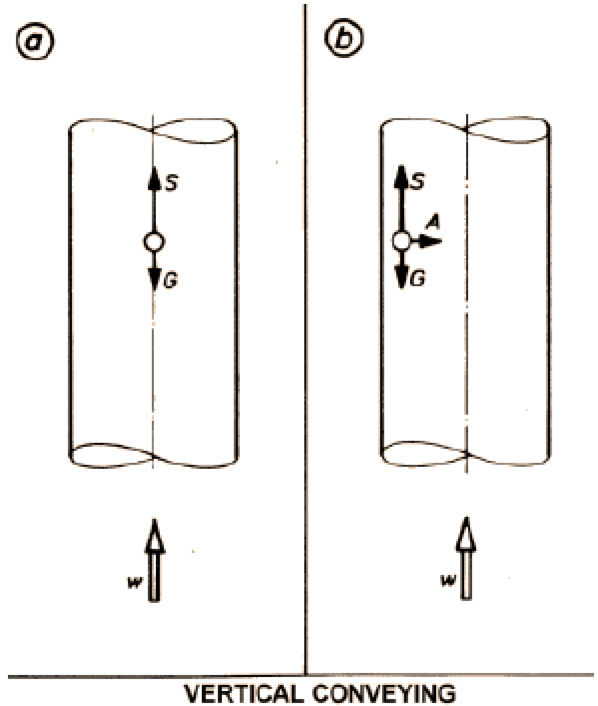
Air velocity: 10 m/s – 30 m/s

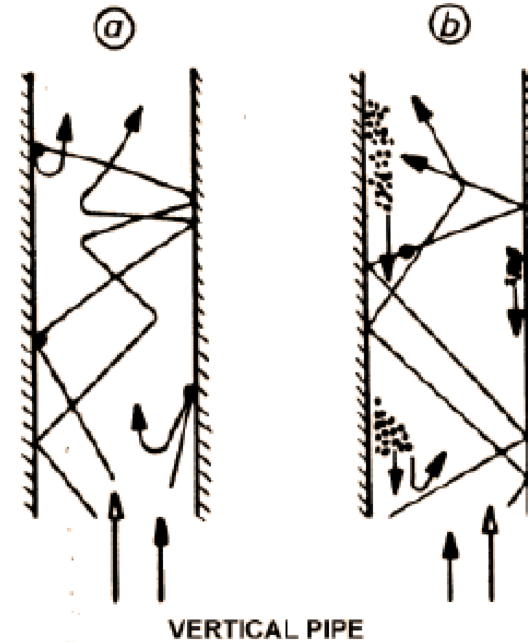
Suction mode: product introduced at a number of points and delivered to a central locations

Pressure mode: product introduced at a single point and delivered to multiple locations (larger throughput)



Flow regimes (vertical pipe)





G: gravity force

S: drag force

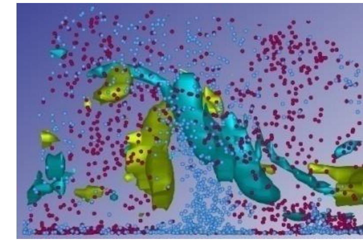
A: lift force

Z →

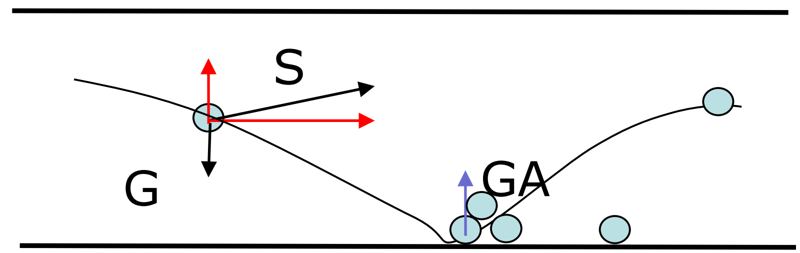
I: inertial force

Fp-p: particle-particle drag

Fp-w: particle-wall drag



Flow regimes (horizontal pipe)



G: gravity force

S: drag force

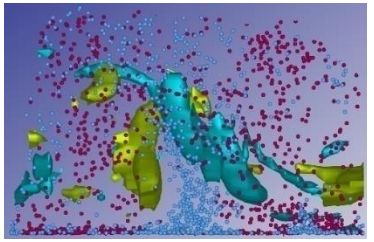
A: lift force

Z →

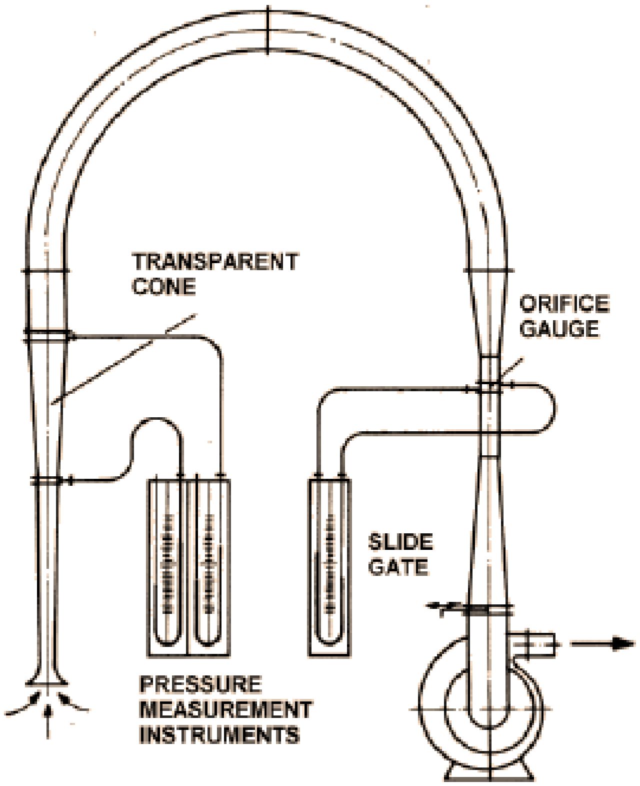
I: inertial force

Fp-p: particle-particle drag

Fp-w: particle-wall drag



Suspension speed: experimental evaluation

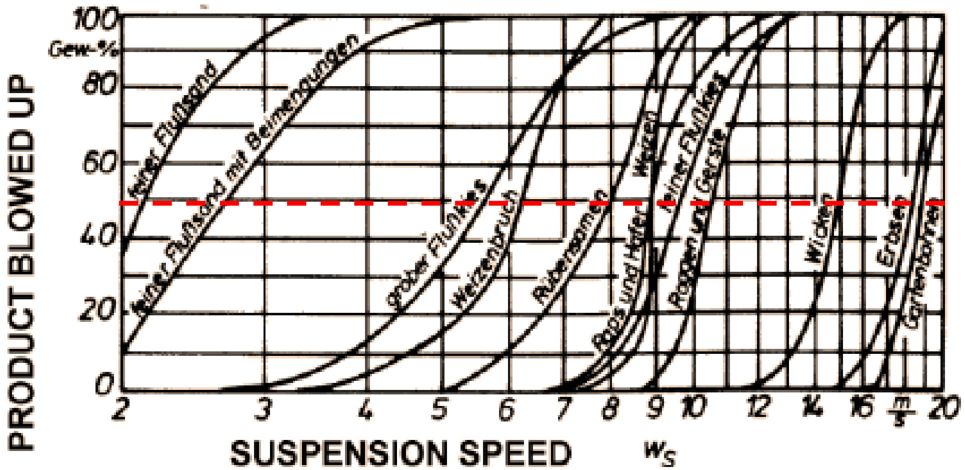


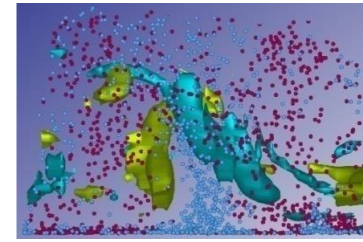
Is a function of:

- Shape
- Size
- Surface roughness (smooth/rough)

Smooth/spherical grains

Fines





Flow regimes (horizontal pipe)

Mass loading (Z)= Solid Mass flow rate/Air mass flow rate

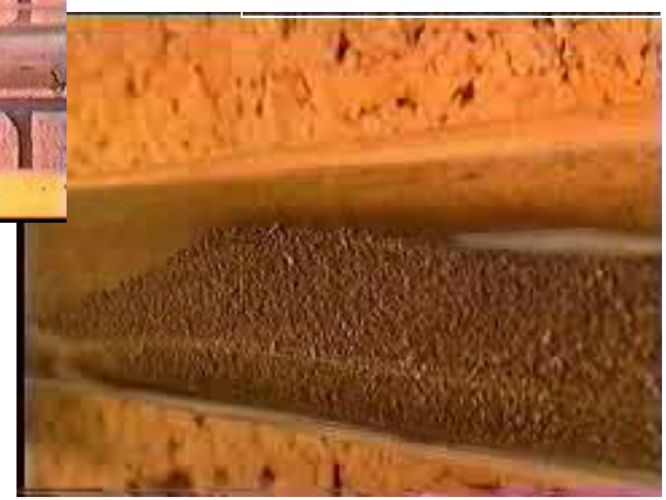
$$Z = \frac{\dot{m}_p}{\dot{m}_g}$$

Dilute regime

Z=5

Dense suspension

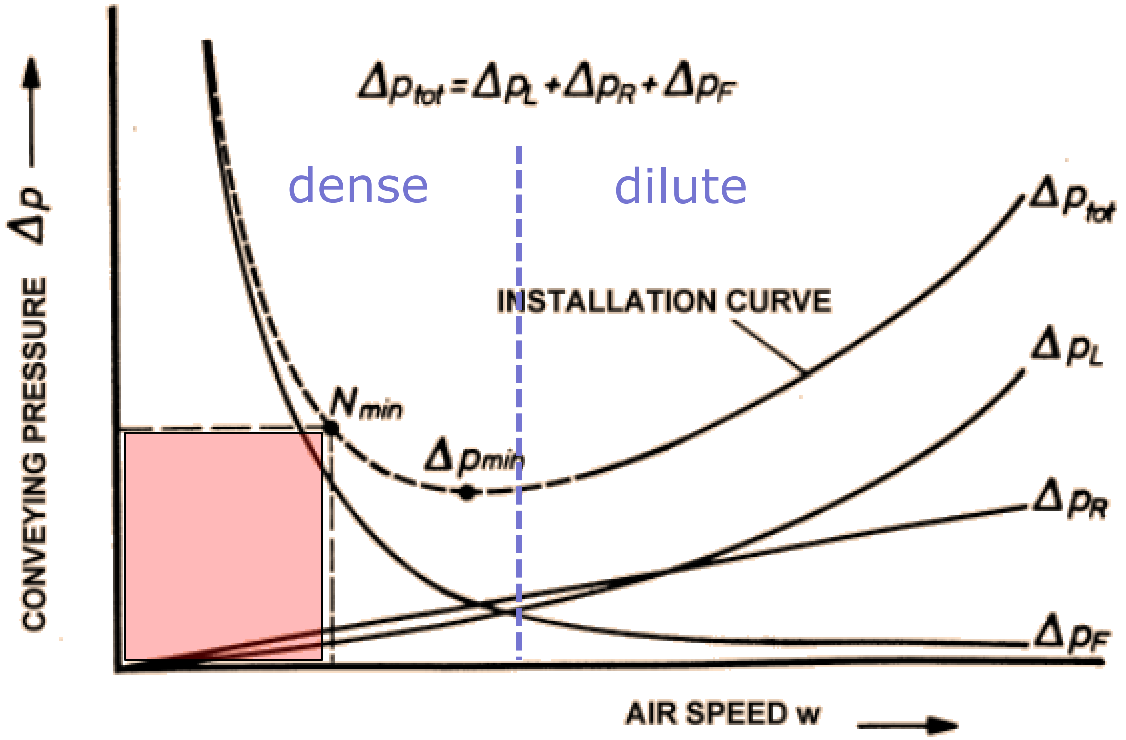
Z=20



Pressure loss

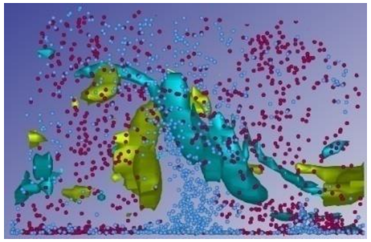
ΔP_{TOT} depends on

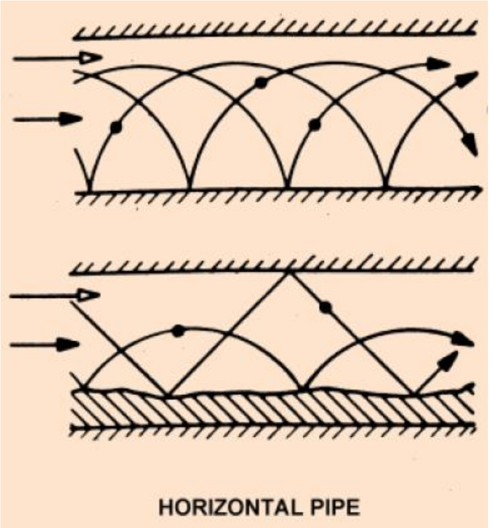
- Gas friction $\Delta P_L \sim w^2$
- Solid acceleration $\Delta P_R \sim \dot{m}_p$ w
- Blocking forces $\Delta P_F \sim 1/w$

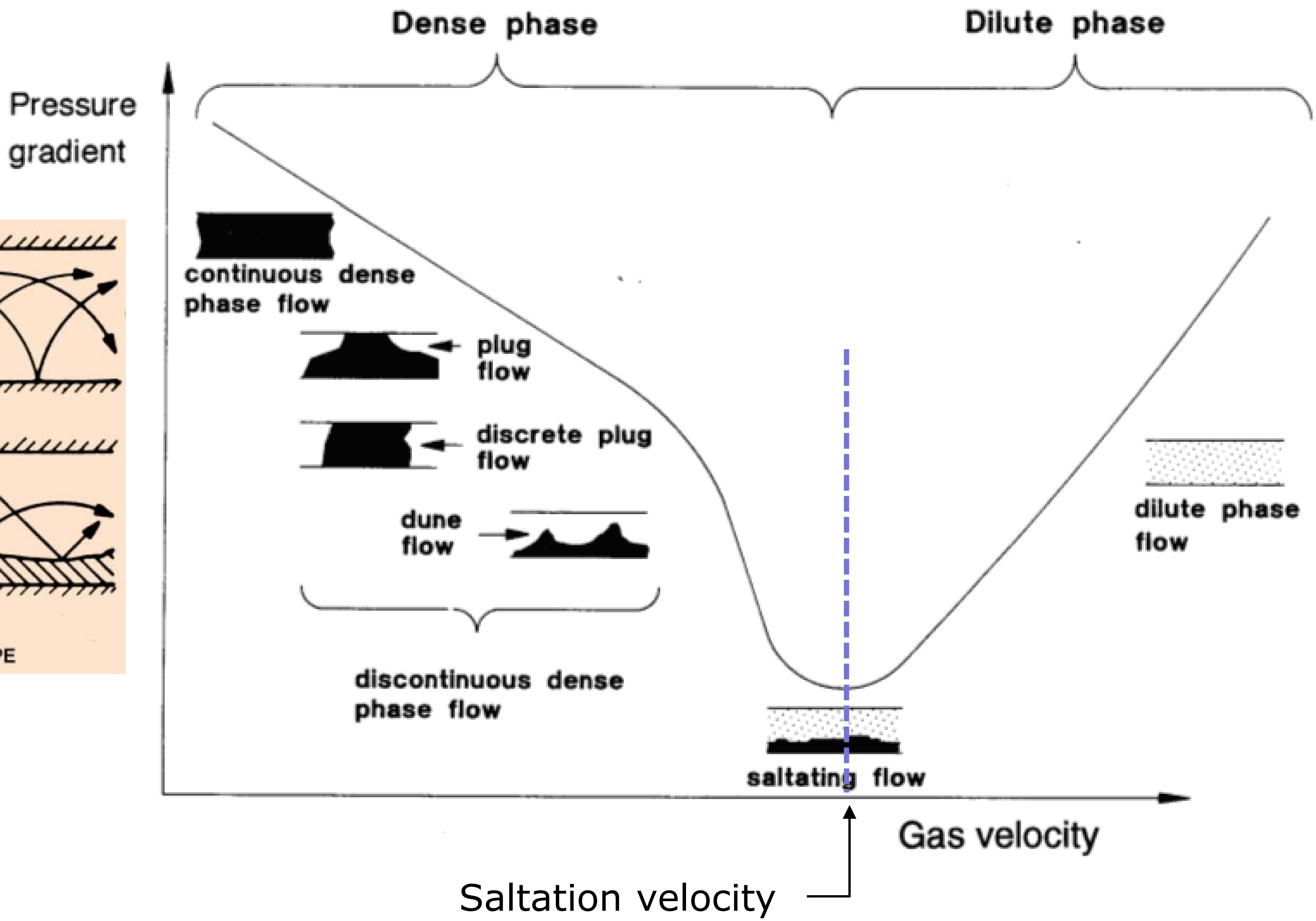


$P = Q \bullet \Delta P_{TOT} \sim w^3$

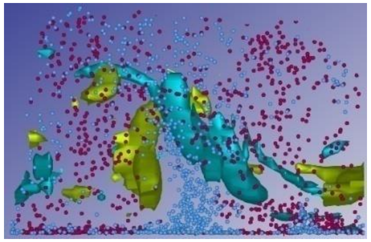
Flow regimes (horizontal)

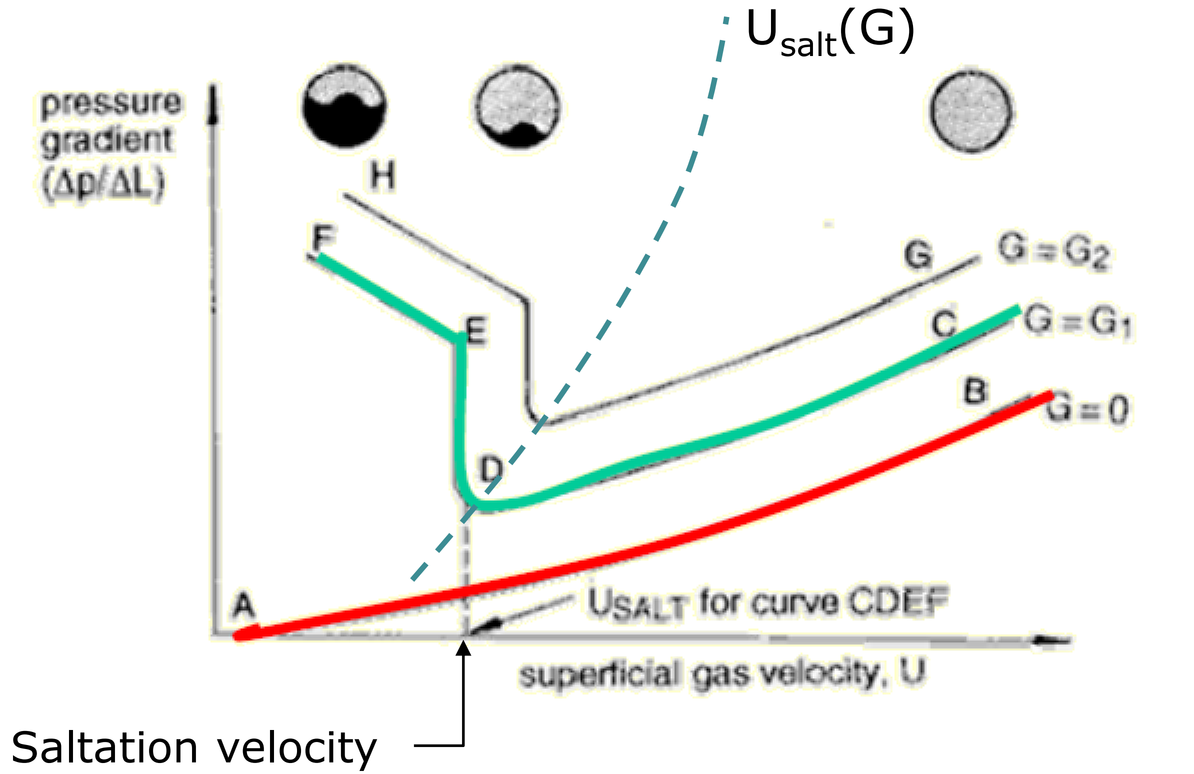






Pressure loss: horizontal pipe





Gas only

Gas + solids

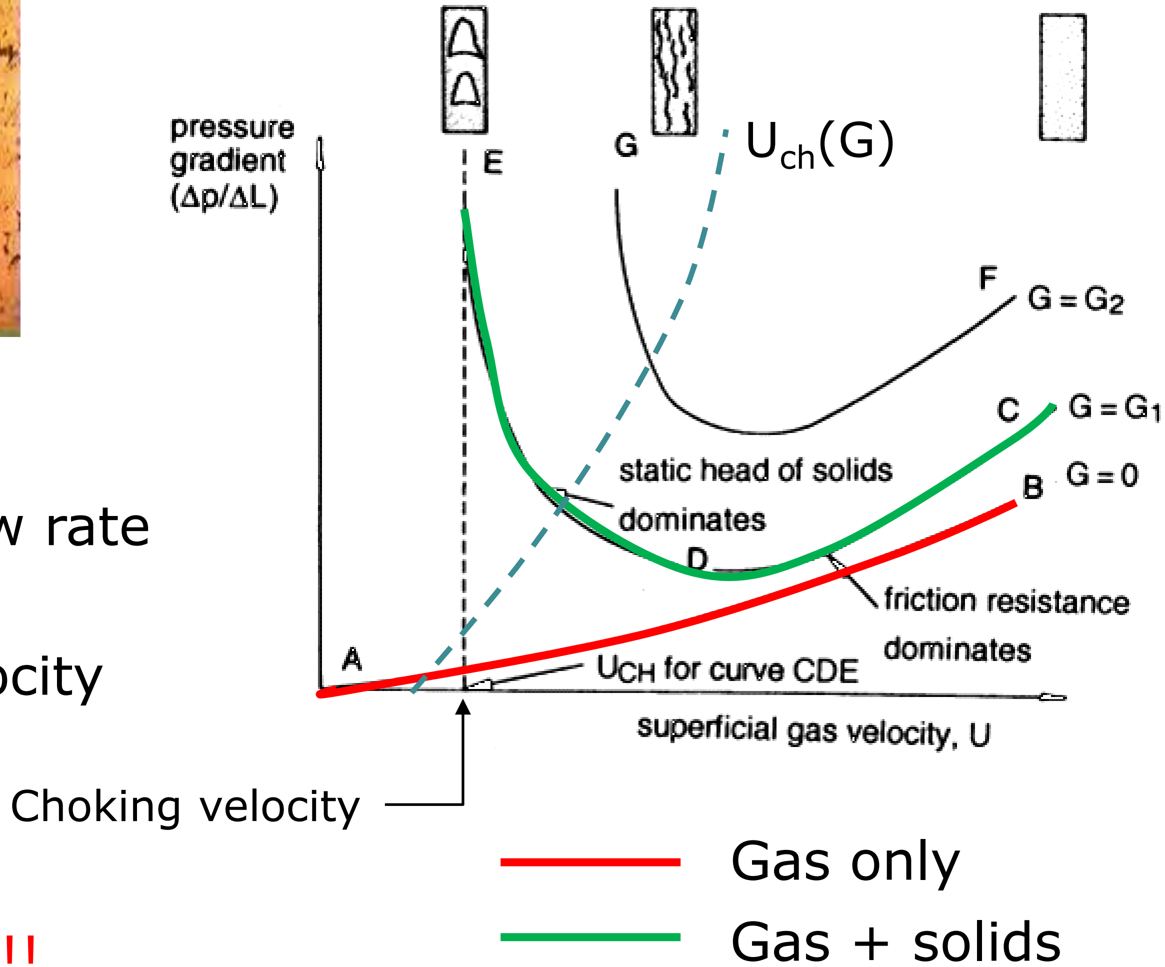
G=$\dot{m}_p$=Solid mass flow rate

U_{salt}= mimimum velocity to prevent deposition

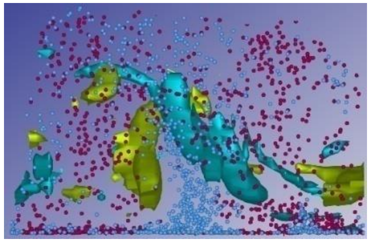
Pressure loss: vertical pipe

G=solid mass flow rate

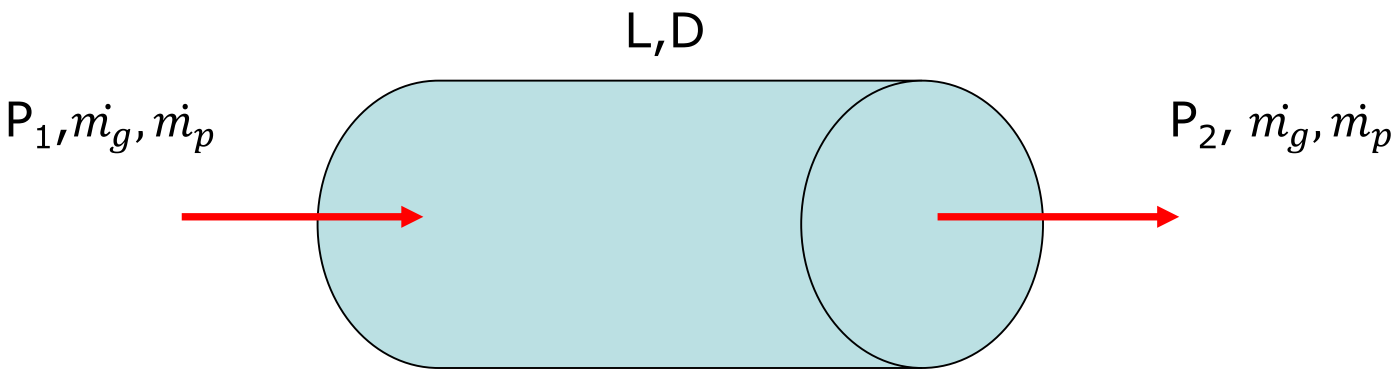
U_{ch}= choking velocity



N.B. $U_{g,salt}>U_{ch}$!!!



Pressure drop calculation

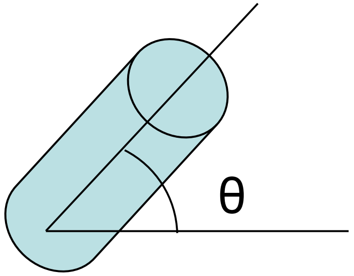


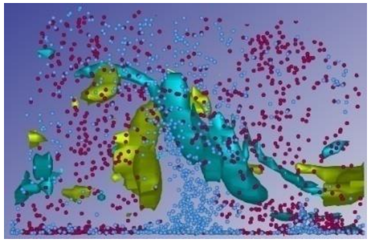
$$P_1 - P_2 = \Delta P_{acc,gas} + \Delta P_{acc,s} + \Delta P_{friction,gas} + \Delta P_{friction,s}$$

$$\left(+\Delta P_{grav,s} + \Delta P_{grav,gas}\right)$$ in vertical flow

$U_{g,sup}$, gas superficial velocity

$U_{p,sup}$, solid phase superficial velocity





Evaluation of pressure drop

1. Problem data

- Gas properties (MM, P, T, μ, ρ)
- Particle properties (ρ_p, D_p)
- Pipeline (L, D)
- Gas and solid flow rates ($\dot{m}_p$, $\dot{m}_g$)

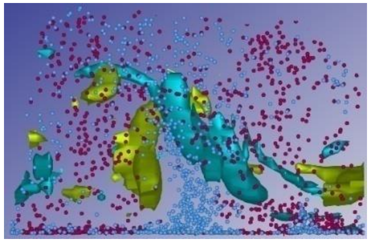
2. Evaluation of saltation velocity

$$Z = \frac{\dot{m}_p}{\dot{m}_s} = \frac{1}{10^{\delta}} Fr^{x}$$

$\delta = 1.44\, D_p + 1.96 \quad D_p$ in mm

x$= 1.1\, D_p + 2.5$

Fr$= \frac{U_{g,salt}}{(gD)^{0.5}} \rightarrow U_{g,salt} \rightarrow \rightarrow select\ U_g > U_{g,salt}$!!!!



Evaluation of pressure drop

3. Evaluation of surface velocity

$$U_{g,sup} = \frac{\dot{m}_g}{A}$$ Gas velocity (if only phase in pipe)

$$U_{p,sup} = \frac{\dot{m}_p}{A}$$ Particle velocity (if only phase in pipe)

4. Evaluation of volumetric fraction

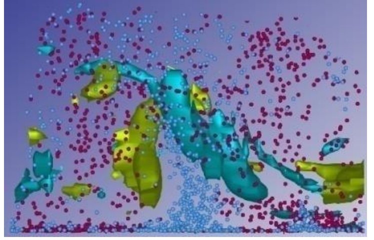
$$Q_g = \frac{\dot{m}_g}{\rho_g} \qquad \varepsilon_g = \frac{Q_g}{Q_g + Q_p}$$ Gas volumetric flowrate & volume fraction

$$Q_p = \frac{\dot{m}_p}{\rho_p} \qquad \varepsilon_p = 1 - \varepsilon_g$$ Particle volumetric flowrate & volume fraction

5. Evaluation of effective velocity

$$U_{g,eff} = \frac{U_{g,sup}}{\varepsilon_g}$$ Actual velocity of gas

$$U_{p,eff} = \frac{U_{p,sup}}{(1 - \varepsilon_g)}$$ Actual velocity of particles



6. Pressure drop for gas and solid acceleration

$\Delta P_{acc,g=}0.5\ \varepsilon_g \rho_g U_{g,eff}^2$

$\Delta P_{acc,p=}0.5\ \rho_p U_{p,eff}^2$

Wall friction

$\Delta P_{friction,g=}2f\,\frac{L}{D}\rho_g U_{g,eff}^2$

Gas wall friction

$f = 0.079\ Re^{-0.25}$

$Re = U_{g,eff}\rho_g D/\mu$

$\Delta P_{friction,p=}f_s Z\,\frac{L}{2D}\rho_g U_{g,eff}^2$

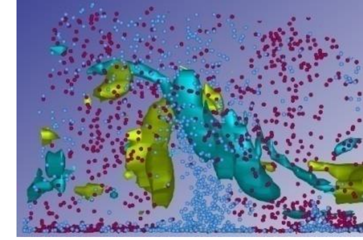
Particle-wall and particle-particle friction

$f_s = 0.082\ Z^{-0.3}Fr^{-0.86}Fr_s^{0.25}\ (\frac{D}{D_p})^{0.1}$

$\mathrm{Fr} = U_{g,eff}/(gD)^{0.5}$

$Fr_s = U_{p,sett}/(gD)^{0.5}$

particle settling velocity $U_{p,sett} = g\rho_p D_p^2/(18\mu)$



Evaluation of pressure drop

7. Extra terms for changes in pipe elevation

$\Delta P_{grav,g=}\varepsilon_g \rho_g L \ \sin\vartheta$ Pressure loss to lift the gas

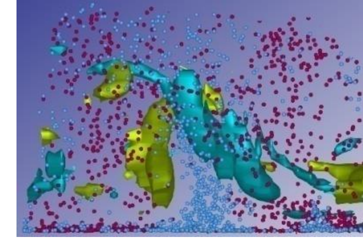
$\Delta P_{grav,p=}(1-\varepsilon_g)\rho_p L \ \sin\vartheta$ Pressure loss to lift the particles

8. Final considerations

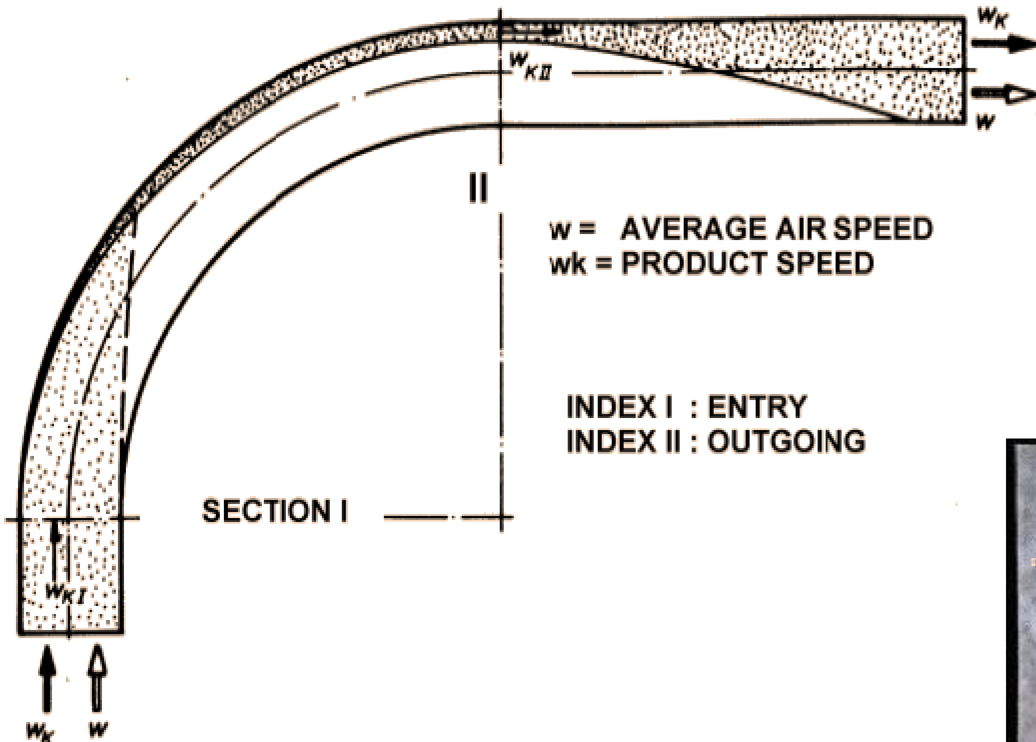
Since $U_{ch} < U_{salt} \rightarrow U_{g,sup} = kU_{salt} > U_{salt} \ \ where\ k > 1$
is enough to produce stable dilute flow

K=1.5÷2 is large enough to account for errors in the evaluation of U_{salt} due to the empirical correlation used

Any larger velocity would be produce dilute flow BUT the pumping power scales with $U_{g,sup}^3$!!!!



Additional pressure loss at bends



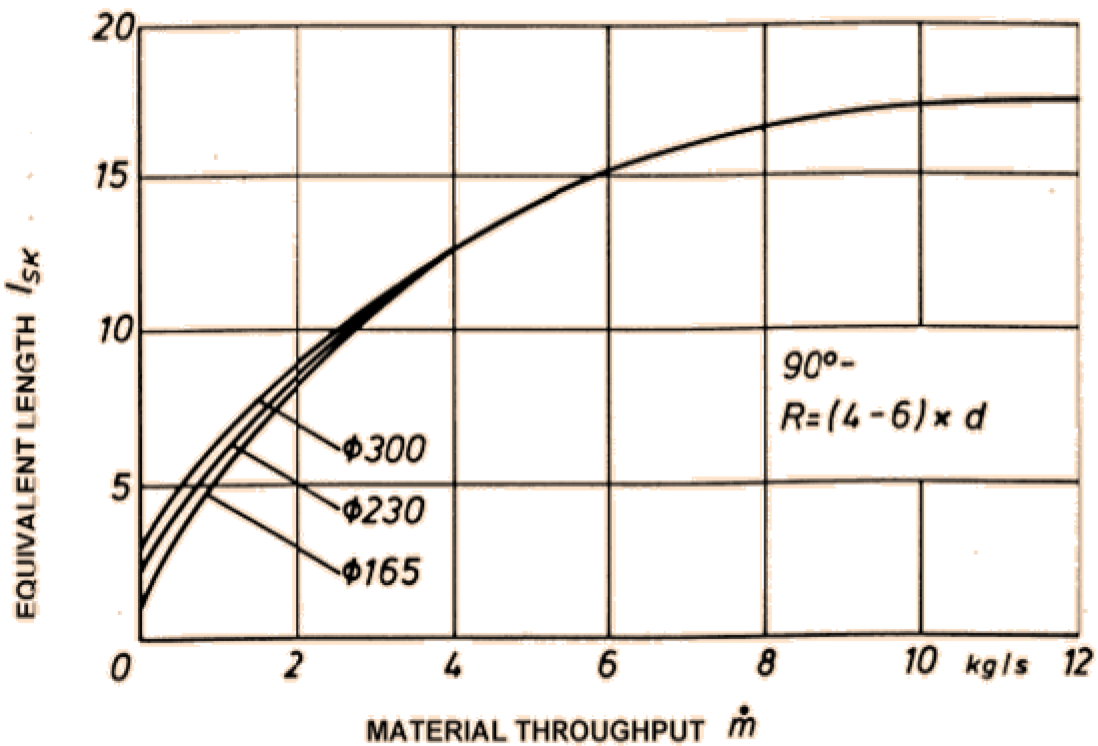
At each bend: due to centrifugal forces particles accumulate on one side of the pipe section, decellerating and loosing energy

Severe erosion may be produces by hard particles

→ Minimise the N° of bends

→ Use large curvature radius

Additional pressure drop due to bends

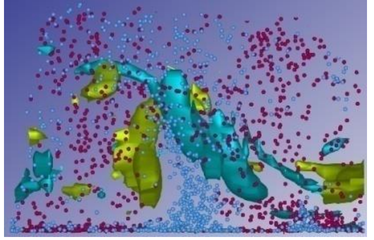


Equivalent length of pipe

R: curvature

D: pipe diameter

$$\Delta P_{Bend} = 2\ f\ Lsk/D\ \rho\ w^2$$



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