Flow in pipes (fully developed) laminar:

$$\Delta P_f \text{ (frictional losses)} = F_F = (P_1 - P_2)_F = 32 \mu \hat{v} (L_2 - L_1) / D^2$$

(laminar only)

$$\therefore F_F = 4 f \Delta L \hat{v}^2 / 2D$$

$$F_{F_{lam}} = 16 / Re$$

(F_f [=] lb·lbf/lb)

Turbulent Flow

Use Friction Factor charts (Moody vs Fanning f)

Problem types. 1. Given pipe info & flow, find losses (ΔP_F, h_f, F_f)

Trial & Error { 2. Given pipe info & ΔP, find flow rate (Q)
3. Given flowrate & losses, design & select pipe.

assume f to start!

In turbulent flow $\quad V_x = V_{x_{max}} \left(\frac{R - r}{R} \right)^n \quad n \simeq 1/7$

but $\quad V_x = f(Re) \xrightarrow{\text{different "n"'s}}$

Loss Terms

1. $\frac{\Delta P_F}{\rho} = \Delta h \frac{g}{g_c}$ [=] ft lbf/lb

2. $\frac{\Delta P_F}{\gamma} = \Delta h$ [=] ft (or m)

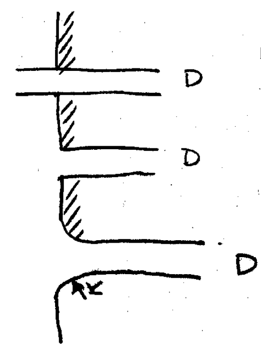
3. ΔP_F [=] atm (or Pa or psi etc)

4. $\frac{g}{g_c} F_F$ [=] $ft \frac{lbf}{lbm} \left(\frac{lbm\ g}{lb_f\ g_c} \right)$ [=] ft

Turb Flow Losses: $\quad h_L = 32 f L g_c Q^2 / \pi^2 g D^5$

Friction losses In Valves & Fittings (Minor losses)

Contractions



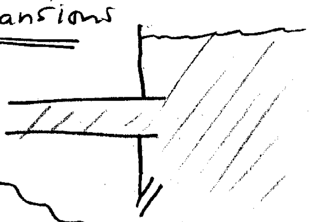
$K_e = 1.0\ \hat{v}^2/2$

$K_e = 0.55\ \hat{v}^2/2$

$K_e = C_1\ \hat{v}^2/2$ where

C_1	r/D
0.55	0.0
0.12	0.1
0.04	0.2

Expansions



$K_{ex} = 1.0 \frac{\hat{V}^2}{2}$

Other

A large variety of other fittings, valves, couplings, T's etc have tabulated coefficients (see Perry's or other fluid ref book)

Noncircular cross-sections ϵ / D_e

$D_e = 4 R_H$ where $R_H = \frac{\text{crosssectional area (flow)}}{\text{wetted perimeter}}$

for circular $D_e = D$
annular $D_e = D_1 - D_2$
rectangular $D = \frac{2ab}{a+b}$

Drag forces. $C_D \equiv \frac{F_D / A_{proj}}{\rho V_0^2/2}$ $\therefore F_D = C_D A_p \rho V_0^2 / 2$

for creeping flow (stokes flow) $Re < 0.1$ $C_D = 24/Re$
$F_D = 3\pi \mu D \rho V_0$

other regimes
$C_D = 0.2$ $Re > 5 \times 10^5$
$C_D = 0.44$ $10^3 < Re < 2 \times 10^5$

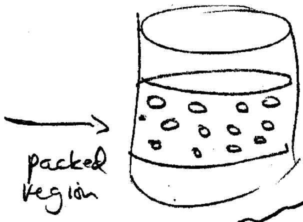
Other Re: use C_D vs Re charts

$A_p(\text{sphere}) = \pi D^2/2$
$A_p(\text{cyl} \perp \text{flow}) = L D_p$

$Re = \frac{DG}{\mu}$

Drag on flat plates
$F_D = C_F A_{shear} \rho V^2/2$ use graphs for C_F vs Re values.

Packed Beds (not fluidization)



Defs: ϵ = void fraction = vol of voids / vol of bed

a_v = spec. area of particles

$= \dfrac{S_p}{v_p} = \dfrac{\text{surface area sphere}}{\text{vol of particles}}$ $[=]\ ft^{-1}$

$a_v(\text{sphere}) = 6/D_p \quad m^{-1}$

$1-\epsilon$ = Solids fraction

$a_L = a_v(1-\epsilon) = 6/D_p\,(1-\epsilon)$

$\uparrow$ total area of bed

v = average interstitial velocity

v' = superficial velocity $= v\epsilon$

$v' = Q/A_{bed(empty)}$

$G' = \dfrac{\dot m}{A} = \rho\dfrac{VA}{A} = \rho V$

$R_H = \dfrac{\epsilon}{a} = \dfrac{\epsilon D_p}{6(1-\epsilon)}$

$N_{Re} = \dfrac{4 D_p v' \rho}{6(1-\epsilon)\mu}$

Pressure drop in packed beds

$\Delta P = \dfrac{32 v \Delta L}{(4R_H)^2} = \dfrac{150\,\mu v' \Delta L (1-\epsilon)^2}{\epsilon^3 D_p}$ $\quad Re < 10$ (laminar)

$\Delta P = 1.75\,\dfrac{\rho v'^2 \Delta L (1-\epsilon)}{D_p\,\epsilon^3}$ $\quad Re \geq 1000$

All purpose $\quad \dfrac{\Delta P \rho}{G'^2}\,\dfrac{D_p}{L}\,\dfrac{\epsilon^3}{(1-\epsilon)} = \dfrac{150}{N_{Re,p}} + 1.75$

Non-spherical particles

mixtures: of different particles

$$\frac{1}{x_1/\phi_{s_1}D_{p_1} + x_2/\phi_{s_2}D_{p_2} + \dots} = D_{pm}$$

x: fraction

Sphericity $\phi_s = \dfrac{\text{surf area of sphere with } D_p}{\text{surf area of particle}}$

$a_v = 6/\phi_s D_p \qquad a = 6/\phi_s D_p\,(1-\epsilon)$

Pumps, Fans, Blowers

ΔP: (pump) $\quad \frac{P_1}{\gamma} + z_1 + \frac{\hat{V}^2}{2g} + \eta h_p = \frac{P_2}{\gamma} + z + \frac{\hat{V}^2}{2g}$

losses here

elevation changes usually small.

Use of pump curves

C_Q = discharge coeff = Q/nD^3

C_H = head coeff = $\Delta H/(D^2 n^2/g)$

C_P = power coeff = $P/\rho D^5 n^3$

$$-W_{s\,pump} = \left.\begin{array}{l} Hg \quad \text{or} \\ Hg/g_c \end{array}\right\}$$ depending on work units.