Chemical Engineering 374

Fluid Mechanics

Minor/Fitting Losses

A good scientist is a person with original ideas. A good engineer is a person who makes a design that works with as few original ideas as possible. There are no prima donnas in engineering.
--Freeman Dyson (theoretical physicist and mathematician).

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Recap

- ΔP → f, Re, f = f(Re, ε/D)
- Relate, ΔP, L, D, v.
- Colbrook Eqn. gives f(Re, ε/D)
  - Implicit equation
  - Haaland is explicit
  - 3 problem types: ΔP, D, flow rate (v)
    - Swamee & Jain relations
- Note: 2 friction factors
  - Darcy (our book)
  - Fanning = ¼ Darcy
- Moody Diagram plots the Colbrook Equation
  - f drops with Re
  - Transition region in grey
  - Turbulent f >> laminar f
  - Curves flatten, become independent of Re at high Re (fully rough flow)

- Write $\left(\frac{\Delta P}{\rho}+\frac{\Delta v^2}{2}+g\Delta z\right)=-F$ $\quad F=\frac{fLv^2}{2D}$
  - SS, no Heat transfer, no Shaft work
  - Mechanical losses due to friction
    - Pipes
- Pipelines consist of more than just pipes
  - Valves, fittings, bends, elbows, flow meters, expansions, etc.
  - All cause losses
    - Generally small (hence "minor" losses)
    - Provided have long pipes and few fittings
- Two methods to account for losses
  - Loss Coefficient: K_L
  - Equivalent Pipe Length

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Loss Coefficient

$$K=\frac{\Delta P_L}{\frac{1}{2}\rho v^2}$$

$$\left(\frac{\Delta P}{\rho}+\frac{\Delta v^2}{2}+g\Delta z\right)=-F=-K\frac{v^2}{2}=-W_L$$

$$E_L=F=K\frac{v^2}{2}$$

$$\Delta P_L=\rho F=K\frac{\rho v^2}{2}$$

$$h_L=\frac{F}{g}=K\frac{v^2}{2g}$$

- 3 forms:
  - Energy, pressure, head
- Constant times:
  - Kinetic energy
  - Dynamic pressure
  - Velocity head

- Rewrite with pipe losses and minor losses

Energy: $-E_L$ $\quad \left(\frac{\Delta P}{\rho}+\frac{\Delta v^2}{2}+g\Delta z\right)=-\frac{fLv^2}{2D}-\frac{K\ v^2}{2}$

Pressure: $-\Delta P_L$ $\quad \left(\Delta P+\frac{\rho\Delta v^2}{2}+\rho g\Delta z\right)=-\frac{fL\rho v^2}{2D}-\frac{K\ \rho v^2}{2}$

Head: $-h_L$ $\quad \left(\frac{\Delta P}{\rho g}+\frac{\Delta v^2}{2g}+\Delta z\right)=-\frac{fLv^2}{2Dg}-\frac{K\ v^2}{2g}$

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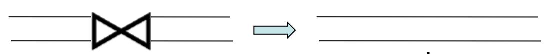
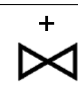
Equivalent Length

- Head Loss Form.
- Compare pipe term $\frac{fLv^2}{2gD}$ and fitting term $\frac{Kv^2}{2g}$
- Put the fittings loss in terms of the pipe loss
  - Set equal, then $K = \frac{fL_{eq}}{D}$
  - Or $L_{eq} = \frac{D}{f}K$
- Given fitting K, solve for Leq and increase the pipe length by this amount.
- Note the definition of K:

  - Don't subtract out the length of the valve

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Losses

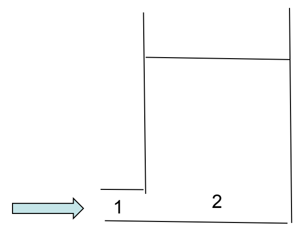
- Losses are due to complex flow path
  - Swirling, turbulent eddies where stresses are higher than regular pipe flow.
- May persist downstream → not just localized at the fitting
- Place flowmeters 10-20 D away to minimize fittings effects & better agree with manufacturers calibrations
- Types of fittings/losses
  - Expansions
  - Contractions
  - Bends
  - Valves
- Determine Experimentally
- Use the velocity in the smaller of two pipe sections (e.g. expansions, contractions)

Expansions

- Consider pipe into a tank
- Without losses:
  - v_2 is small
  - P_2 increases, recovering KE drop as pressure rise
- Actually, all KE is converted to friction, as flow enteres and eddies around
  - Then $P_1=P_2$
  - Note α included (~1)
  - K = α
  - This is as bad as it gets.
- Expansion with finite area ratio:

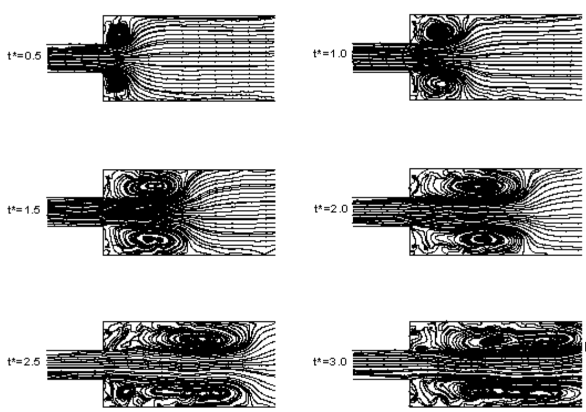
  $K = \alpha(1-A_1/A_2)^2$

  $A_1=A_2 \rightarrow K=0$; $A_2 >> A_1 \rightarrow K=\alpha$



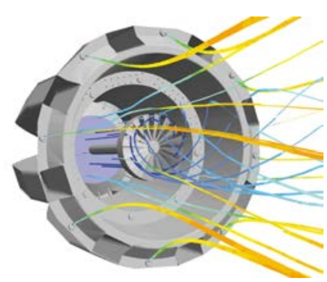
$$\frac{\Delta P}{\rho} + \frac{\alpha v_2^2 - \alpha v_1^2}{2} = -\frac{K v_1^2}{2}$$

Sudden expansion



Sudden expansion, Reynolds number=3000

http://www.bhrc.ac.ir/Profile/Heidarinejad/Images/expan.gif



http://www.fluent.com/solutions/examples/img/x165i1_lg.gif

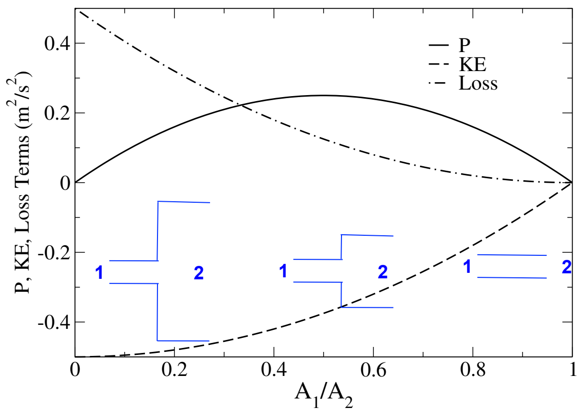
Sudden Expansion

P | KE | Loss

$$\frac{P_2 - P_1}{\rho} + \frac{v_1^2}{2}\left(\frac{A_1^2}{A_2^2 - 1}\right) = -\frac{K_L v_1^2}{2} = -\frac{\alpha v_1^2}{2}\left(1 - \frac{A_1}{A_2}\right)^2$$

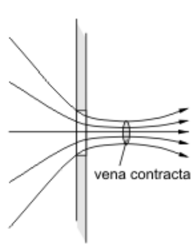
- ➢Vary the area ratio,
- ➢Compare terms:
  - •Pressure,
  - •Kinetic Energy
  - •Loss

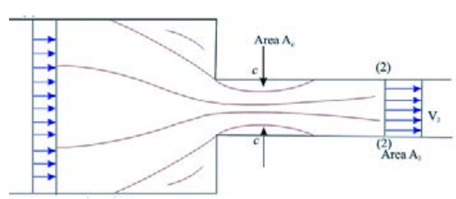
<u>Take</u>
ρ=1,
v_1=1,
P_1=0,
A=1



Contraction

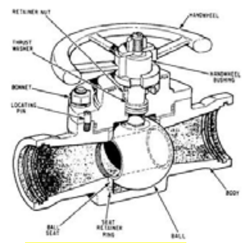
- Sharp edges → flow can't make the turn and separates.
- Flow is squeezed through the "vena contracta"
- Recirculation → losses.
- Rounding edges makes a big impact.
  - – Square → K = 0.5
  - – Round → K = 0.03 (r/D=0.2)
  - – Round → K=0.12 (r/D=0.12)
- Gradual expansion/contraction helps
- **SEE TABLE 8.4 FOR MORE DETAILS**



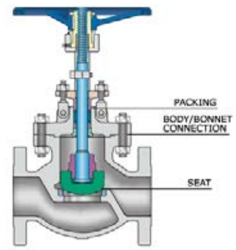


Valves

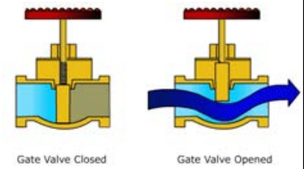
Ball Valves



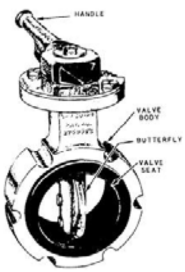
Globe Valves

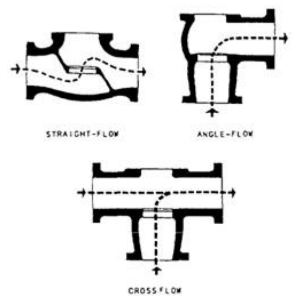


Gate Valves

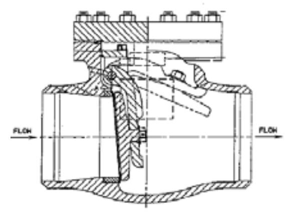


Butterfly Valves

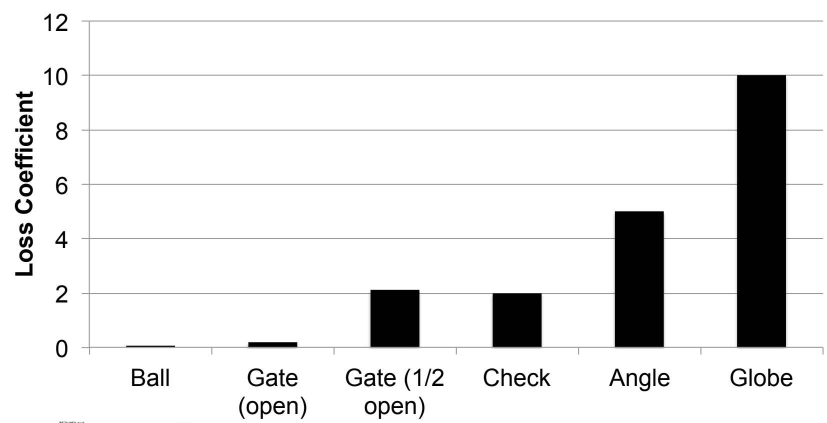


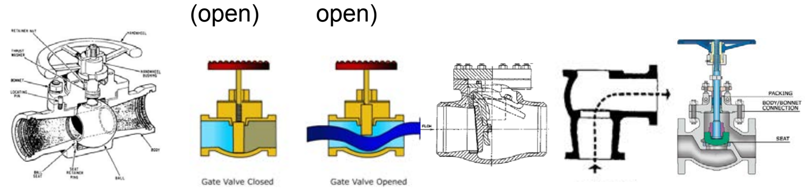


Check Valve



Relative Valve Losses



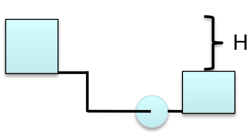


How important are the minor losses?

- Leq = KD/f → L/D = K/f
- Take smooth pipe with Re=10,000 → f=0.03
  - L/D
    - Open globe valve → 400
    - Open ball valve → 1.7
    - Sharp contraction → 16
    - Smooth contraction → 1
    - Expansion → 33
    - 90 deg. Smooth bend →10
    - 90 deg. Sharp bend →36
- As Re increases, f decreases, and L/D increases

Quiz (not graded)

- Water flows from a reservoir, into a **sharp-edged pipe** (K_L=0.5), through a couple of **90° miter bends** (K_L=1.1) to a lower reservoir as shown in the figure. The difference in the levels of the reservoirs is **H=100 m**. The water flows through a pipe of length **L=200 m** and relative roughness **e/D=0.002**. The velocity in the pipe is **v=10 m/s**, giving a very **high Re**. If the power generated by the turbine is **W_t=4,437,500 J/s**, **Find the required pipe diameter**.



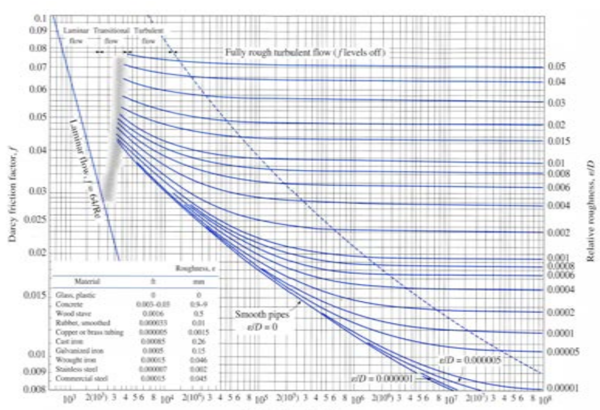


FIGURE A–12

The Moody chart for the friction factor for fully developed flow in circular pipes for use in the head loss relation $h_L = f\frac{L}{D}\frac{V^2}{2g}$. Friction factors in the turbulent flow are evaluated from the Colebrook equation $\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$.