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).

ChE Alumni Banquet

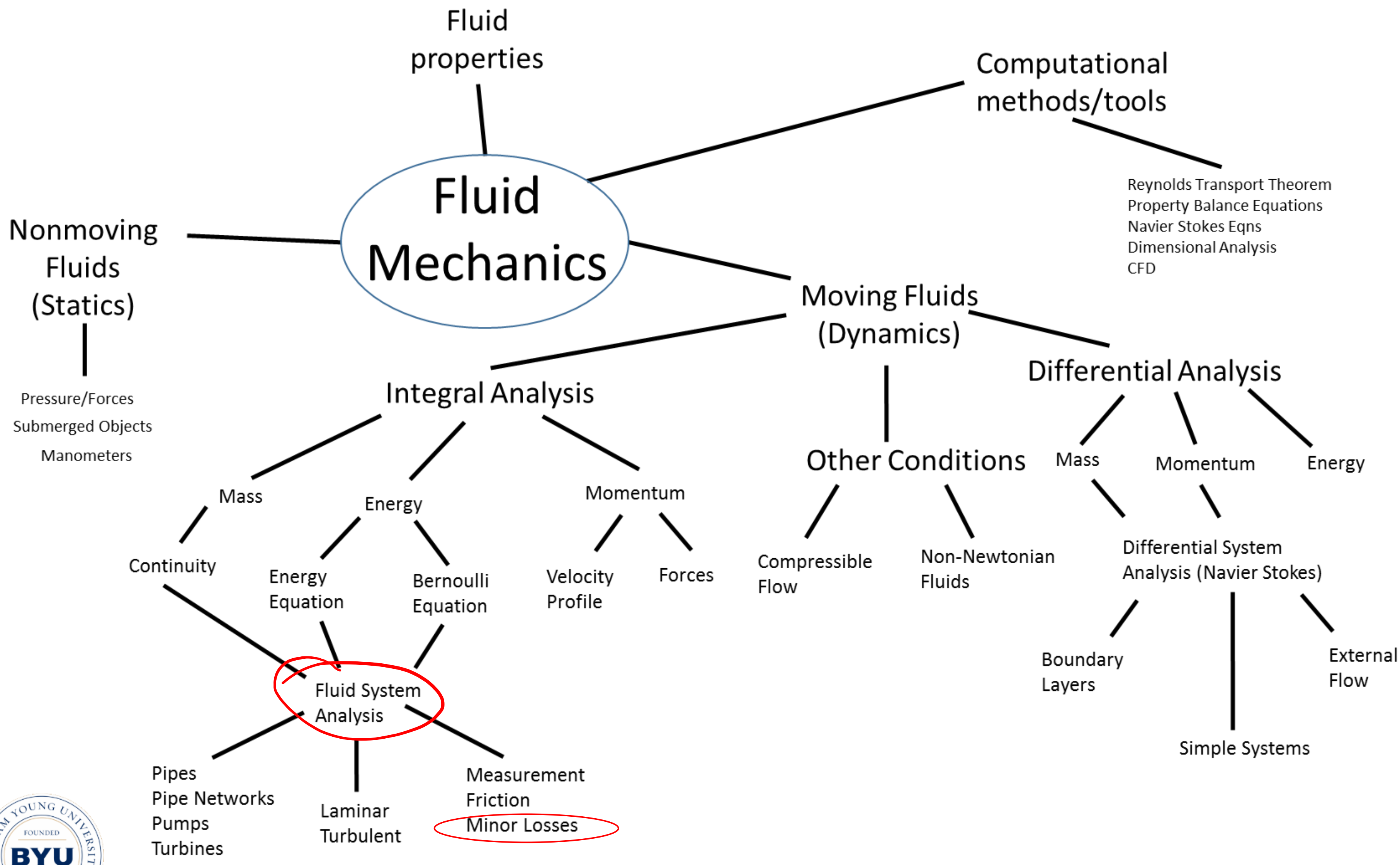
- Need 4-5 Students (or spouses) to help
  - Come to Clyde Stepdown at 5:15PM this Saturday (October 15th)
    - Set up tables/chairs/flatware
    - Serve food (Maglebey's)
    - Prep/Serve ice cream (BYU Creamery)
    - Eat leftovers (Free dinner!)
  - Business Casual Dress (no suit coats)
  - Volunteers?

Spiritual Thought

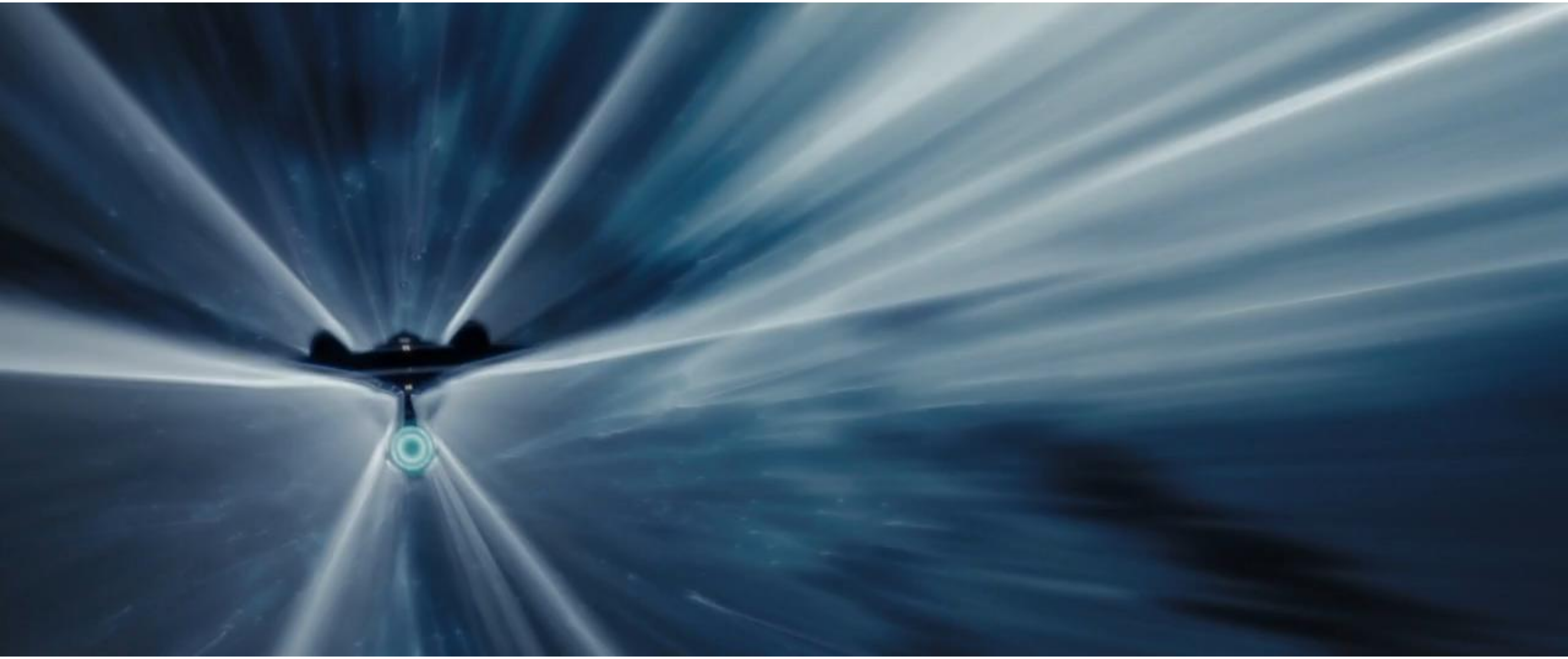
"We don't always know the details of our future. We do not know what lies ahead. We live in a time of uncertainty. We are surrounded by challenges on all sides. Occasionally discouragement may sneak into our day; frustration may invite itself into our thinking; doubt might enter about the value of our work. In these dark moments Satan whispers in our ears that we will never be able to succeed, that the price isn't worth the effort, and that our small part will never make a difference. He, the father of all lies, will try to prevent us from seeing the end from the beginning."

President Dieter F. Ucthdorf

Fluids Roadmap



OEP 6 Clip



OEP 6

Open Ended Problem #6

Turbine Trouble

INDIVIDUAL Work ONLY, Due 10/19/16 at beginning of class

- Amazingly, Kirk and Scotty were able to beam aboard the enterprise while it was traveling at warp speed (thanks to Scotty's theory on trans-warp transportation). However, it appears that Scotty was beamed into a tank that leads to the turbine powering the ships systems. In transporting into that tank (which was water-solid) no water atoms were eliminated, just displaced, and this resulted in an increase in pressure (which for simplicity, persists throughout the time Scotty is in the pipes, which tripped the turbine system. What is the rate of energy (power) derived by the turbine system?

OEP 6 (continued)

Open Ended Problem #6

Turbine Trouble

INDIVIDUAL Work ONLY, Due 10/19/16 at beginning of class

7. Verify your answer... Does it look reasonable? Anything odd about the calculation?

a) Is it reasonable to assume that Scotty could survive the pressure spike from his beaming into the tank?

b) Based on the distance and calculated velocity, could he hold his breath that long?

c) Let's suppose that rather than a sudden pressure spike from Scotty's mass displacing fluid, this same pressure difference is the constant dP for the turbine system on the enterprise. How much energy does this provide the ship?

d) Is this reasonable? If not, how many such turbines should be used to power the starship?

Recap

Re=? D or L?

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

simple (B.E.) → complex

- 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)
- 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)

pipe + minor

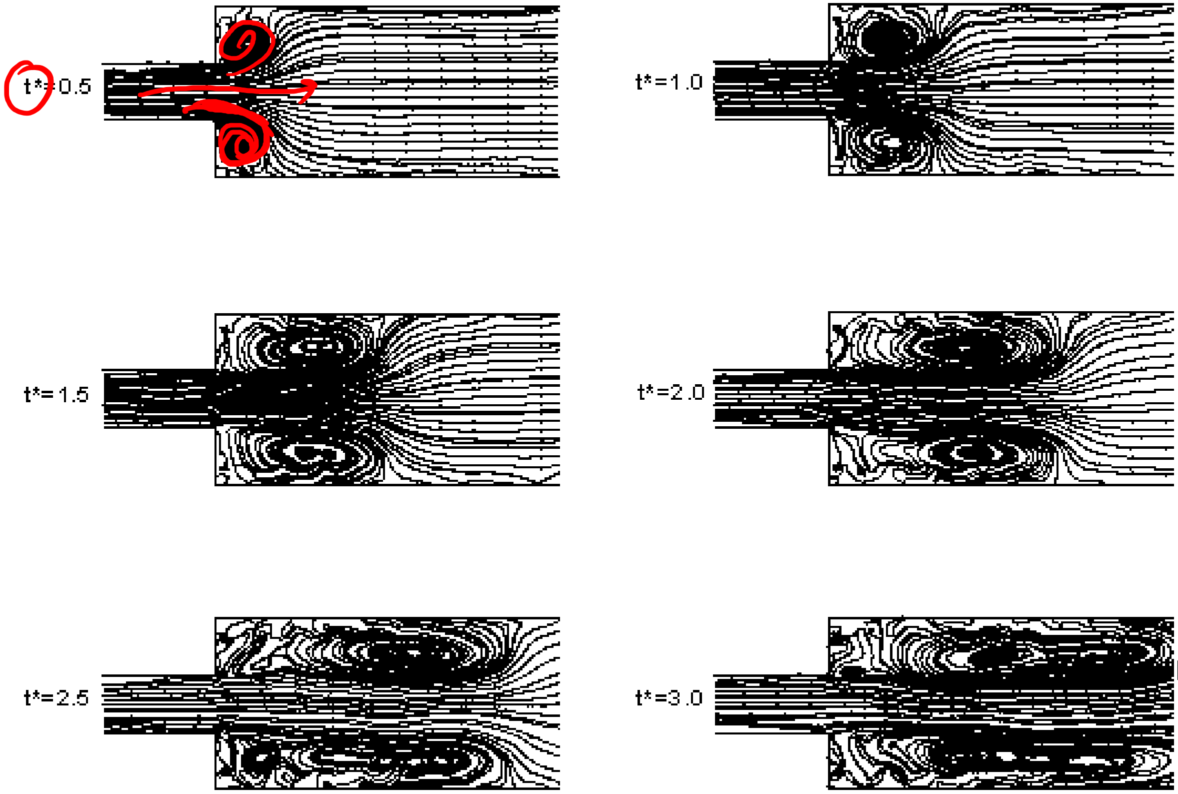
- Write $\left(\frac{\Delta P}{\rho} + \frac{\Delta v^2}{2} + g\Delta z\right) = -F$ $\qquad F = \frac{fLv^2}{2D}$
  - SS, no Heat transfer, no Shaft work
  - Mechanical losses due to friction
    - Pipes
- Pipelines consist of more than just pipes
  - Valves, fittings, bends, elbows, flow meters, expansions, etc.
  - All cause losses
    - Generally (but not always!) small (hence "minor" losses)
    - Typically long pipes and few fittings
- Two methods to account for losses
  - Loss Coefficient: K_L
  - Equivalent Pipe Length

Losses

- Losses are due to complex flow path

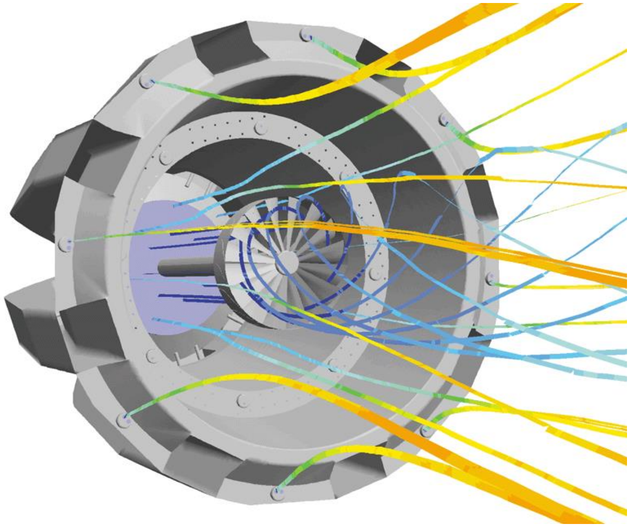
  - Swirling, turbulent eddies where stresses are higher than regular pipe flow.
- May persist downstream → not just localized at the fitting
- Place flowmeters 10-20 D away to minimize fittings effects & better agree with manufacturers calibrations
- Types of fittings/losses
  - Expansions
  - Contractions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

Sudden expansion



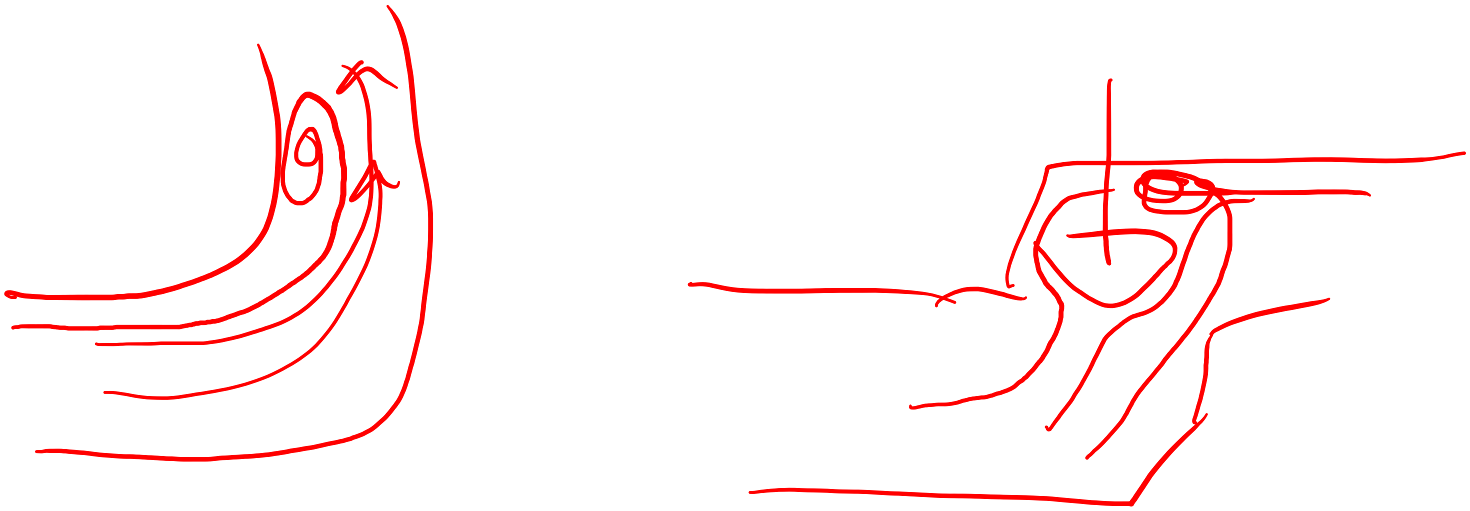
Sudden expansion, Reynolds number=3000

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



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

Valves/Bends



Loss Coefficient

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

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

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

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

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

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

Note: For two different pipe areas, use smaller D for minor loss calculation!

- Rewrite with pipe losses and minor losses

Energy: -E_L

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

Pressure: -ΔP_L

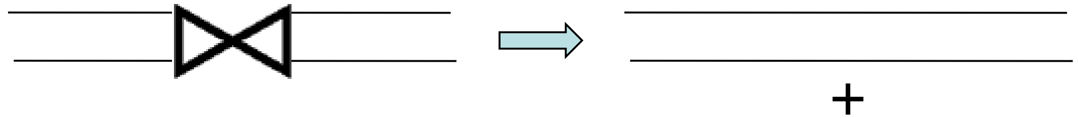
$$\left(\Delta P+\frac{\rho\Delta v^2}{2}+\rho g\Delta z\right)=-\frac{fL\rho v^2}{2D}-\frac{K\ \ \rho v^2}{2}$$

Head: -h_L

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

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:



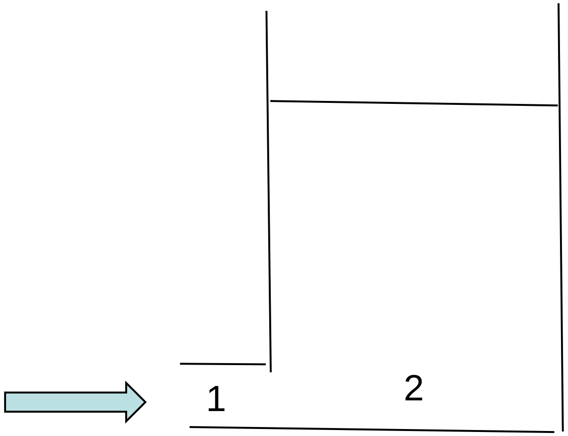
  - Don't subtract out the length of the valve

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 enters and eddies
  - Then $P_1=P_2$
  - Note α included (~1)
  - $K = \alpha$
  - This is as bad as it gets.
- Expansion with finite area ratio:

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

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



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

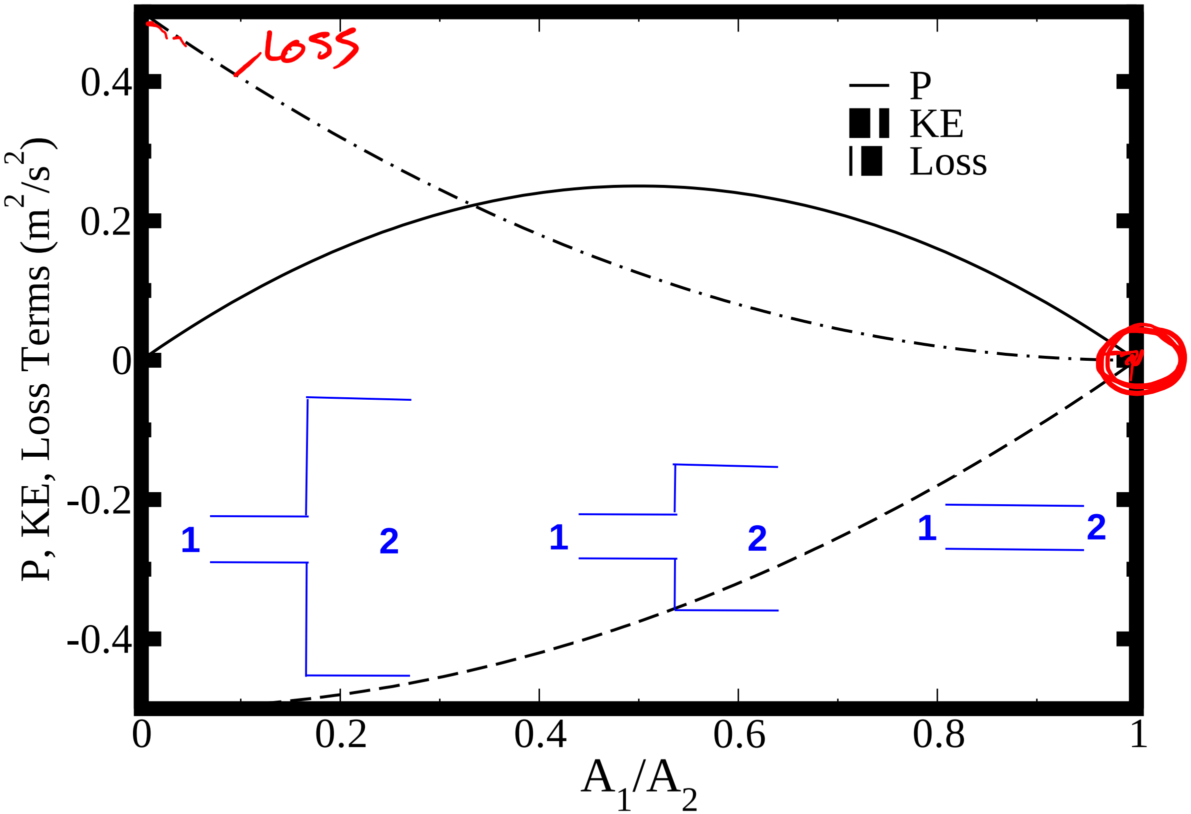
Sudden Expansion

$$\underbrace{\frac{P_2 - P_1}{\rho}}_{\text{P}} + \underbrace{\frac{v_1^2}{2}\left(\frac{A_1^2}{A_2^2 - 1}\right)}_{\text{KE}} = \underbrace{-\frac{K_L v_1^2}{2}}_{\text{Loss}} = -\frac{\alpha v_1^2}{2}\left(1 - \frac{A_1}{A_2}\right)^2$$

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

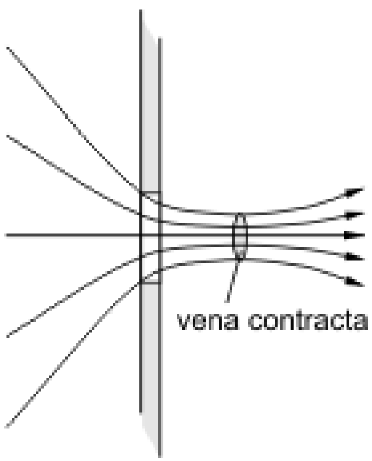
<u>Take</u>

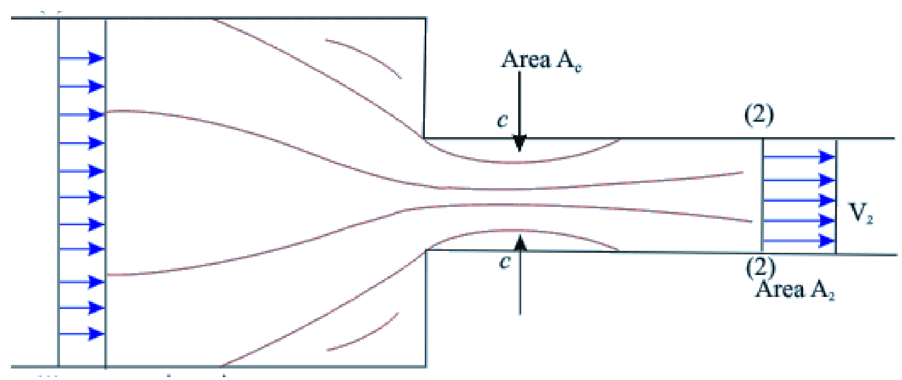
$\rho=1$,
$v_1=1$,
$P_1=0$,
A=1



Contraction

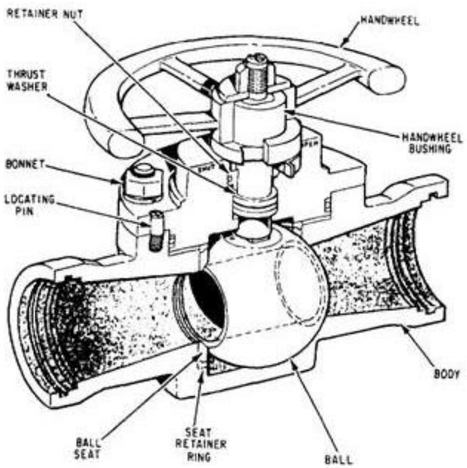
- Sharp edges → flow can't make the turn and separates.
- Flow is squeezed through the "vena contracta"
- Recirculation → losses.
- Rounding edges makes a big impact.
  - Square → K = 0.5
  - Round → K = 0.03 (r/D=0.2)
  - Round → K=0.12 (r/D=0.12)
- Gradual expansion/contraction helps
- **SEE TABLE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



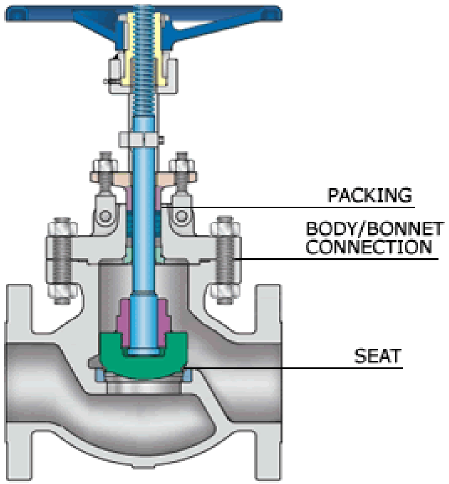


Valves

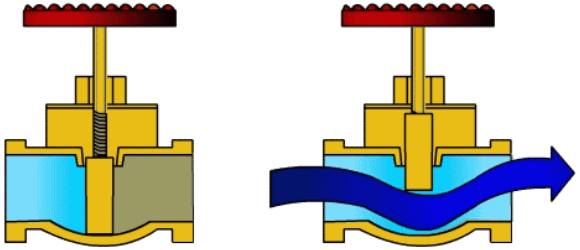
Ball Valves



Globe Valves



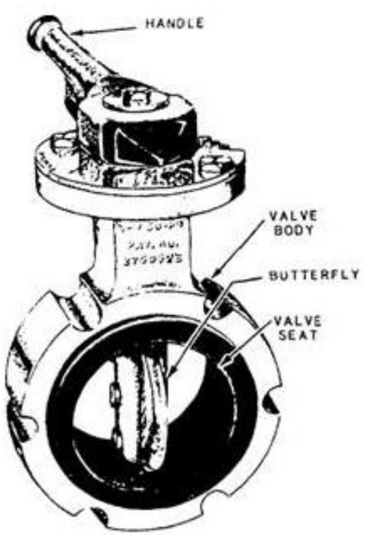
Gate Valves

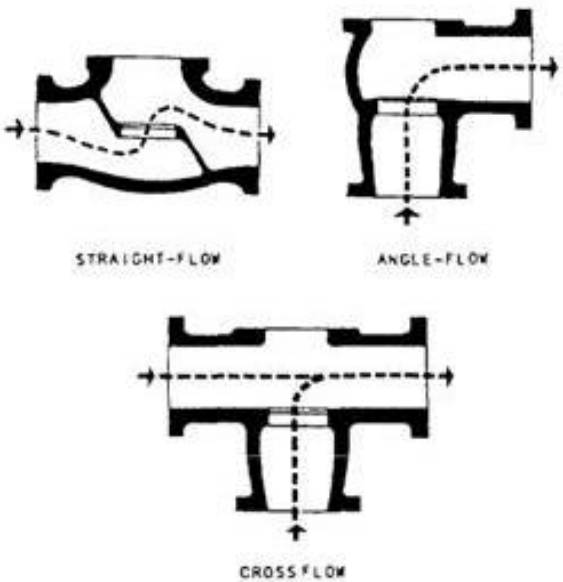


Gate Valve Closed

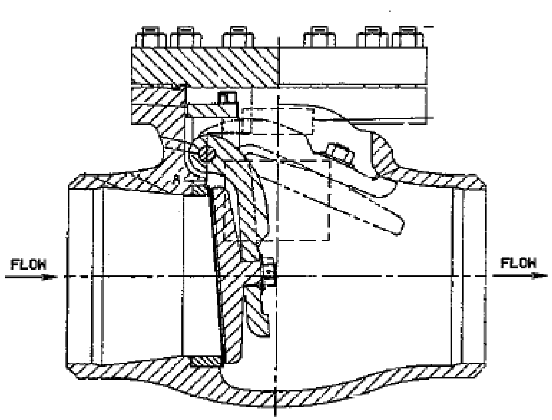
Gate Valve Opened

Butterfly Valves

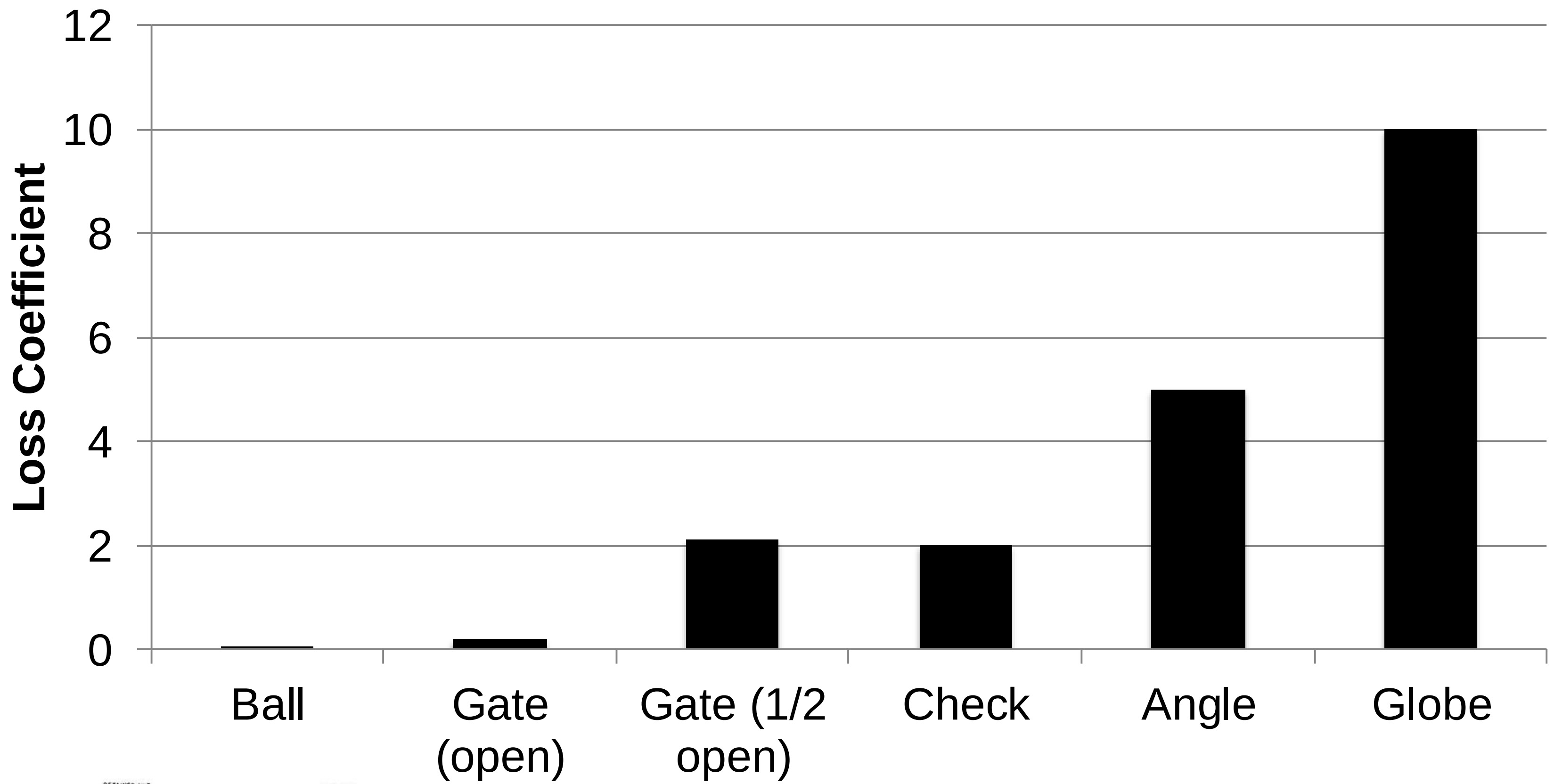


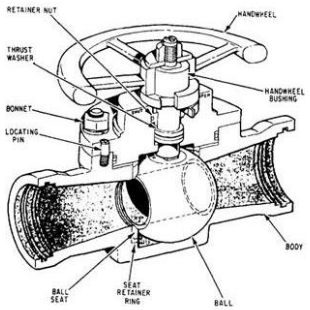


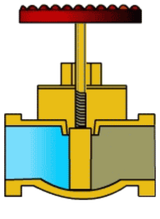
Check Valve



Relative Valve Losses

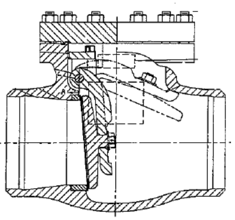


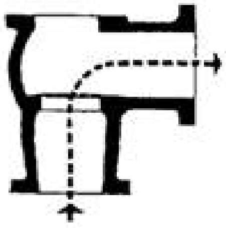


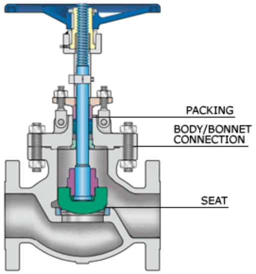


Gate Valve Closed

Gate Valve Opened







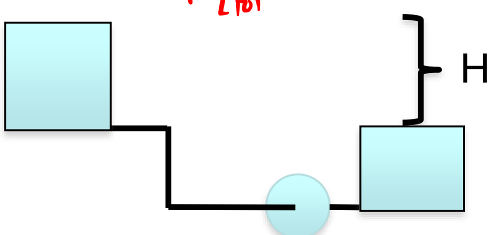
How important are the minor losses?

- 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

Example

- Water flows from a reservoir, into a **sharp-edged pipe** (K_L=0.5), through a couple of **90º 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**.

$K_{L\,tot} = 0.5 + 1.1(2) = 2.7$



$$\frac{\Delta p}{\rho} + \frac{\Delta v^2}{2} + g\Delta z = -W_s - F$$

($\Delta p \to 0$, $\Delta v^2 \to 0$)

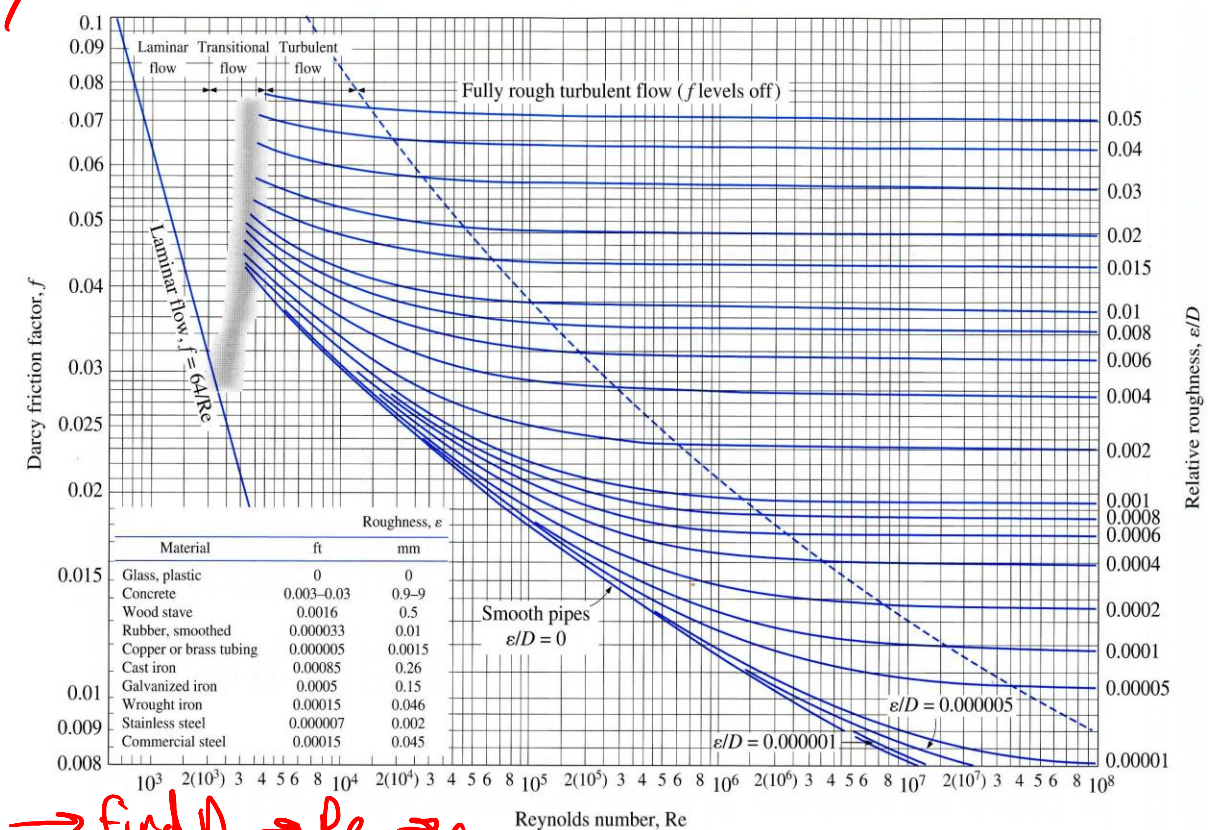
$$g(z_2 - z_1) = -W_s - f\frac{L}{D}\frac{v^2}{2} - K_{L\,tot}\frac{v^2}{2}$$

Guess a $D \to 0.2$ m

$Re = \frac{\rho v D}{\mu} = 2\times10^8$

$f \to \approx$ constant $= 0.023$

$\to$ find $D \to Re_2 \to f_2 \to D_3 \ldots$



Material	Roughness, ε ft	Roughness, ε mm
Glass, plastic	0	0
Concrete	0.003–0.03	0.9–9
Wood stave	0.0016	0.5
Rubber, smoothed	0.000033	0.01
Copper or brass tubing	0.000005	0.0015
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Wrought iron	0.00015	0.046
Stainless steel	0.000007	0.002
Commercial steel	0.00015	0.045

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 $\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$.