Bioprocess Engineering Lab: Flow Module

CONSERVATION OF ENERGY

Fluid systems: Mainly mechanical energy.

Kinetic and potential energy

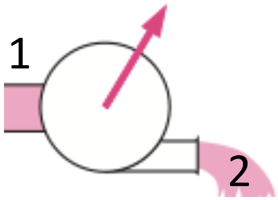
Not thermal, why?

$$e_{\text{mech}} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

Flow energy

Kinetic energy

Potential energy



$$\eta_{\text{pump}} = \frac{\Delta \dot{E}_{\text{mech, fluid}}}{\dot{W}_{\text{shaft, in}}}$$

Mechanical energy change of an incompressible fluid

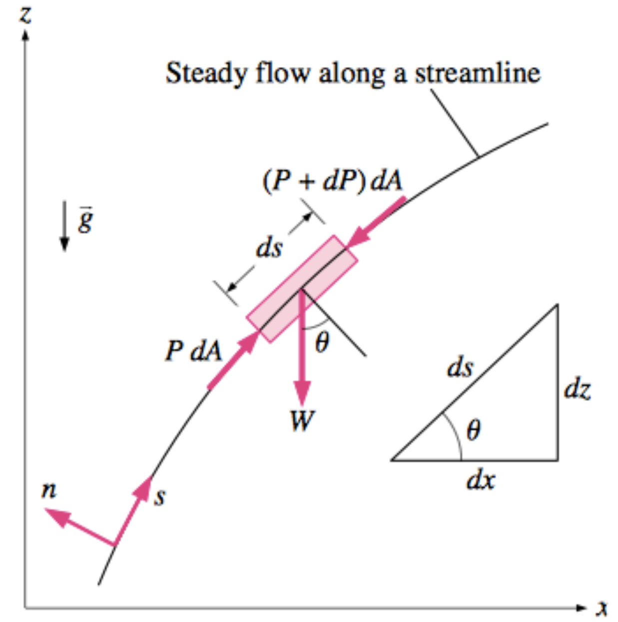
$$\Delta e_{\text{mech}} = \frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

BERNOULLI EQUATION

Is an <u>approximate relation</u> between pressure, velocity and elevation

When is the approximation valid?

- Regions of steady flow
- Incompressible flow
- No heat transfer



Steady, incompressible flow: $\dfrac{P}{\rho} + \dfrac{V^2}{2} + gz = \text{constant}$

Steady, incompressible flow: $\dfrac{P_1}{\rho} + \dfrac{V_1^2}{2} + gz_1 = \dfrac{P_2}{\rho} + \dfrac{V_2^2}{2} + gz_2$

USE OF HEIGHTS ("HEADS")

Bernoulli /g

$$\frac{P}{\rho} + \frac{V^2}{2} + gz = \text{constant}$$

Each term has LENGTH dimensions and represent different "heads":

$$\frac{P}{\rho g} + \frac{V^2}{2g} + z = H = \text{constant}$$

Pressure head

Velocity head

Elevation energy

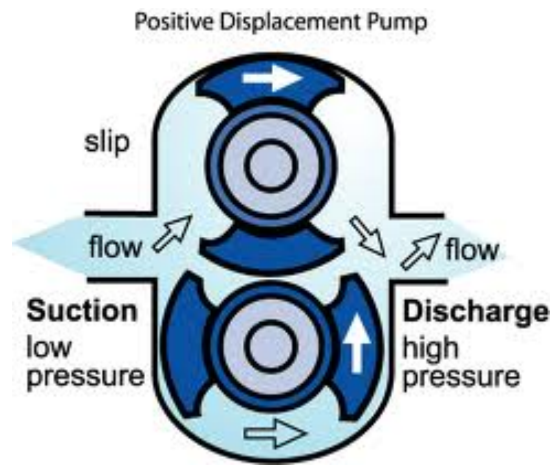
Pumps and Friction

- Types of pumps and operation
- Friction factor
  - Importance and calculations
- Friction losses

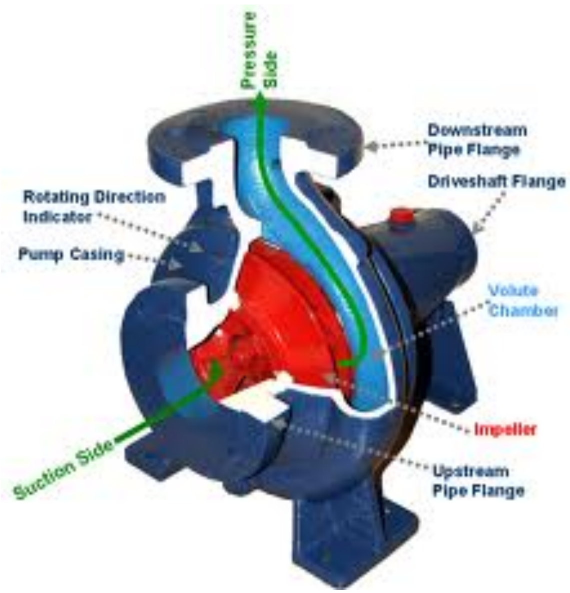
Types of Pumps

Types of Pumps

- Positive Displacement

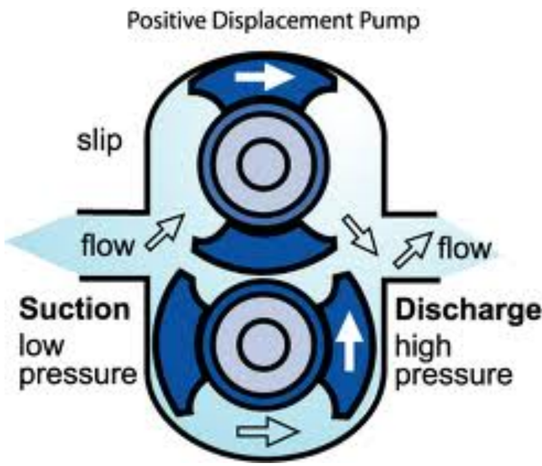


- Centrifugal



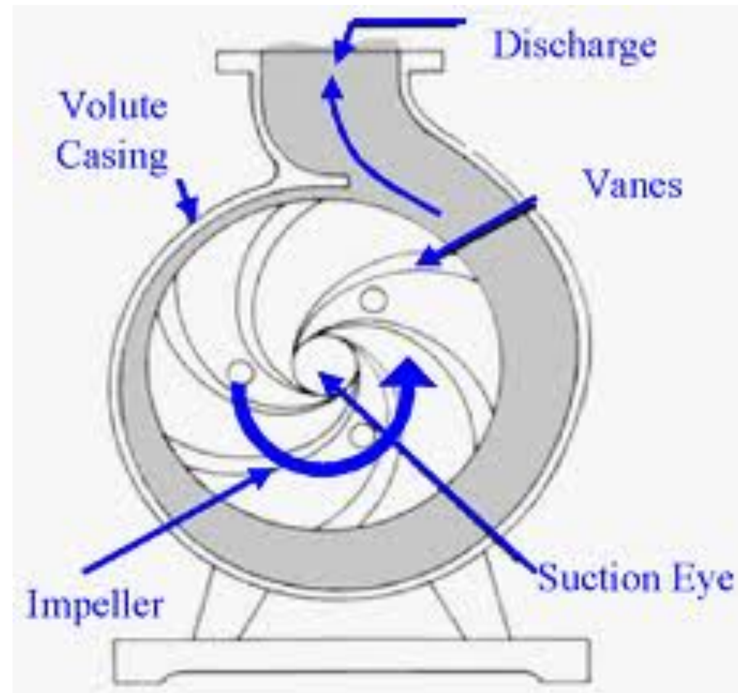
Positive Displacement Pump

- Apply pressure directly to a liquid by a reciprocating piston
- Fixed volume of liquid is trapped in a chamber and is alternately filled from the inlet and then discharged at higher pressure
  - Reciprocating Pump
    - Chamber is stationary and a piston moves to push the liquid
  - Rotary Pump
    - The chamber moves the liquid from the inlet to the outlet

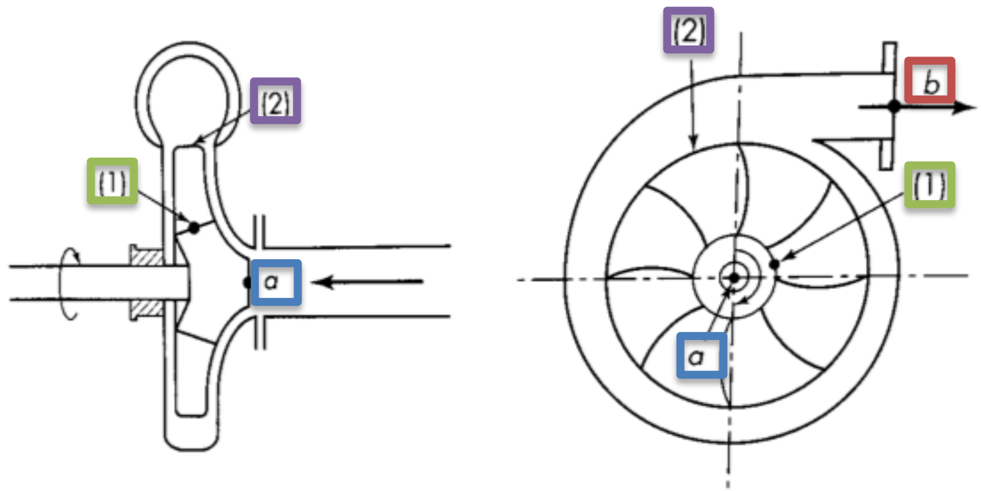


Centrifugal Pump

- Mechanical energy of the liquid is increased with centrifugal action of the pump
- Liquid enters in the center and is cast outwards with vanes
- The liquid collects in the outer casing as volute and is discharged at a higher pressure



Centrifugal Pump



1. Liquid enters at the suction connection a
2. Liquid is spread out radially by the impeller and enters the channels 1
3. Liquid flows through the impeller and is collected in the volute 2
4. Discharges from the pump b

Centrifugal Pump

- Pressure increase across a centrifugal pump

$$\Delta p = a - bQ^2$$

Where Δp is the pressure drop ≣ psi
Q is the volumetric flow rate ≣ gpm
a and b are constants of the pump ≣ psi and psi/gpm^2

- Can also be in terms of head increase

$$\Delta h = a - bQ^2$$

Centrifugal Pump

- Pump configuration
- How would $\Delta h = a - bQ^2$ change for multiple pumps?

  – Series

  – Parallel

Centrifugal Pump

- Pump configuration
- How would $\Delta h = a - bQ^2$ change for multiple pumps?
  - Series – flow is additive

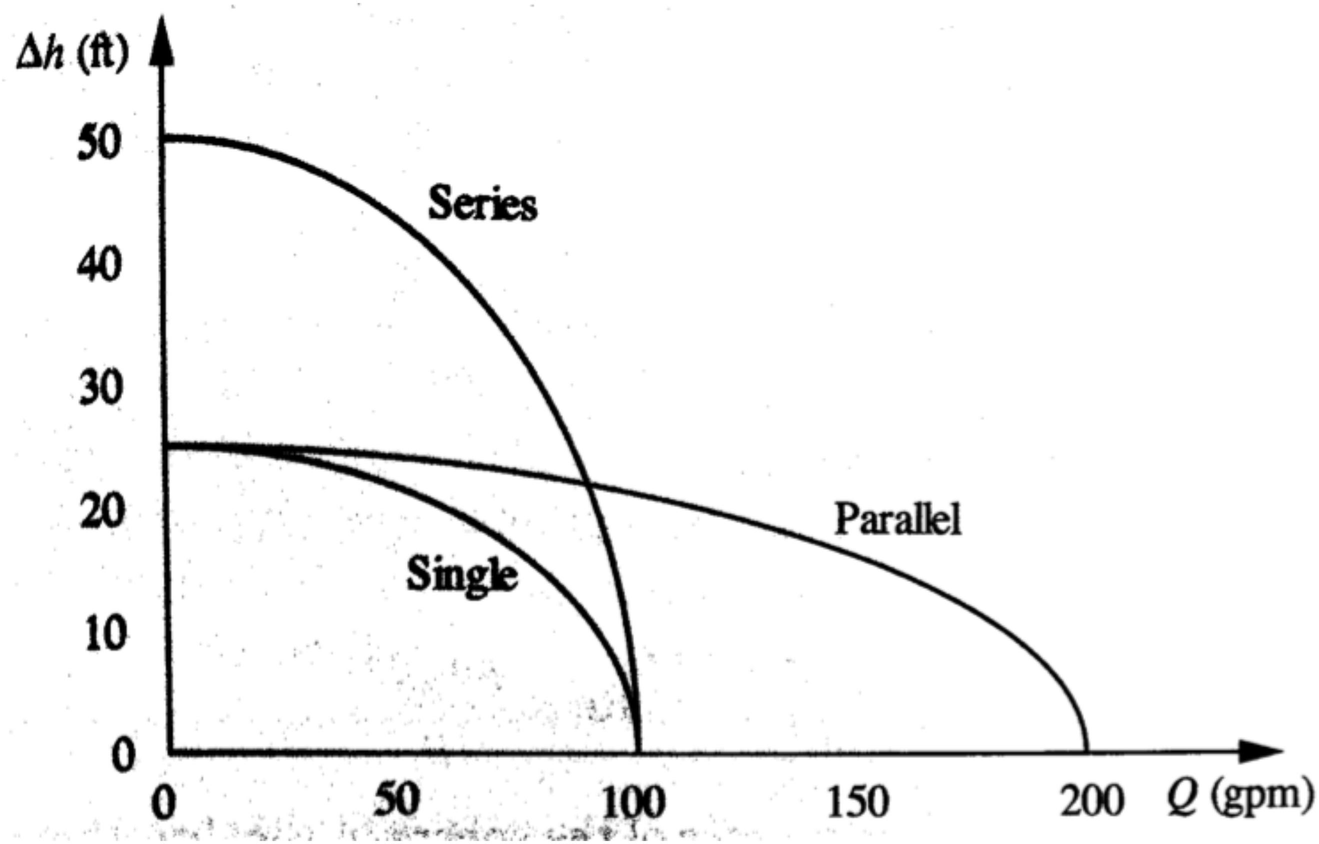
$$\Delta h = 2\left(a - bQ^2\right)$$

  - Parallel – flow through each pump is only Q/2

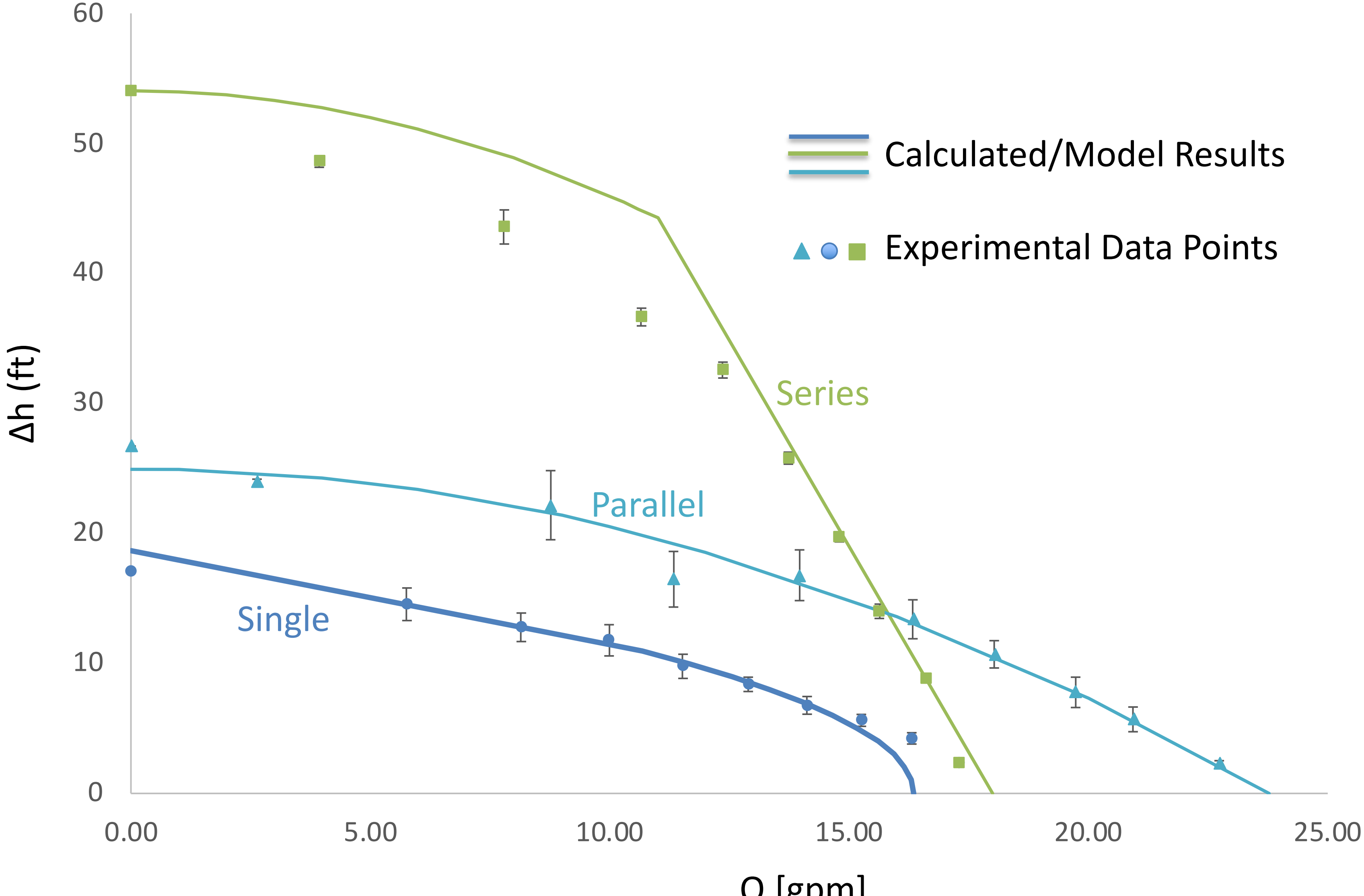
$$\Delta h = a - b\left(\frac{Q}{2}\right)^2$$

Centrifugal Pump Performance Curves

$$\Delta h = a - bQ^2$$



Pump Performance Curves



Friction Factor

- Why is friction important
  - Calculate how your fluid flow will decrease
  - Resistance to flow
- Fanning friction factor
  - Ratio of the wall shear stress to the product of the density and velocity head

Laminar Flow in a Round Tube

$$f = \frac{16}{\mathrm{Re}}$$

Geankoplis, Eq. 2.10-7

Turbulent Flow

$$f = \frac{\tau_s}{0.5\rho v^2}$$

Geankoplis, Eq. 2.10-4

Friction Correlation with Re

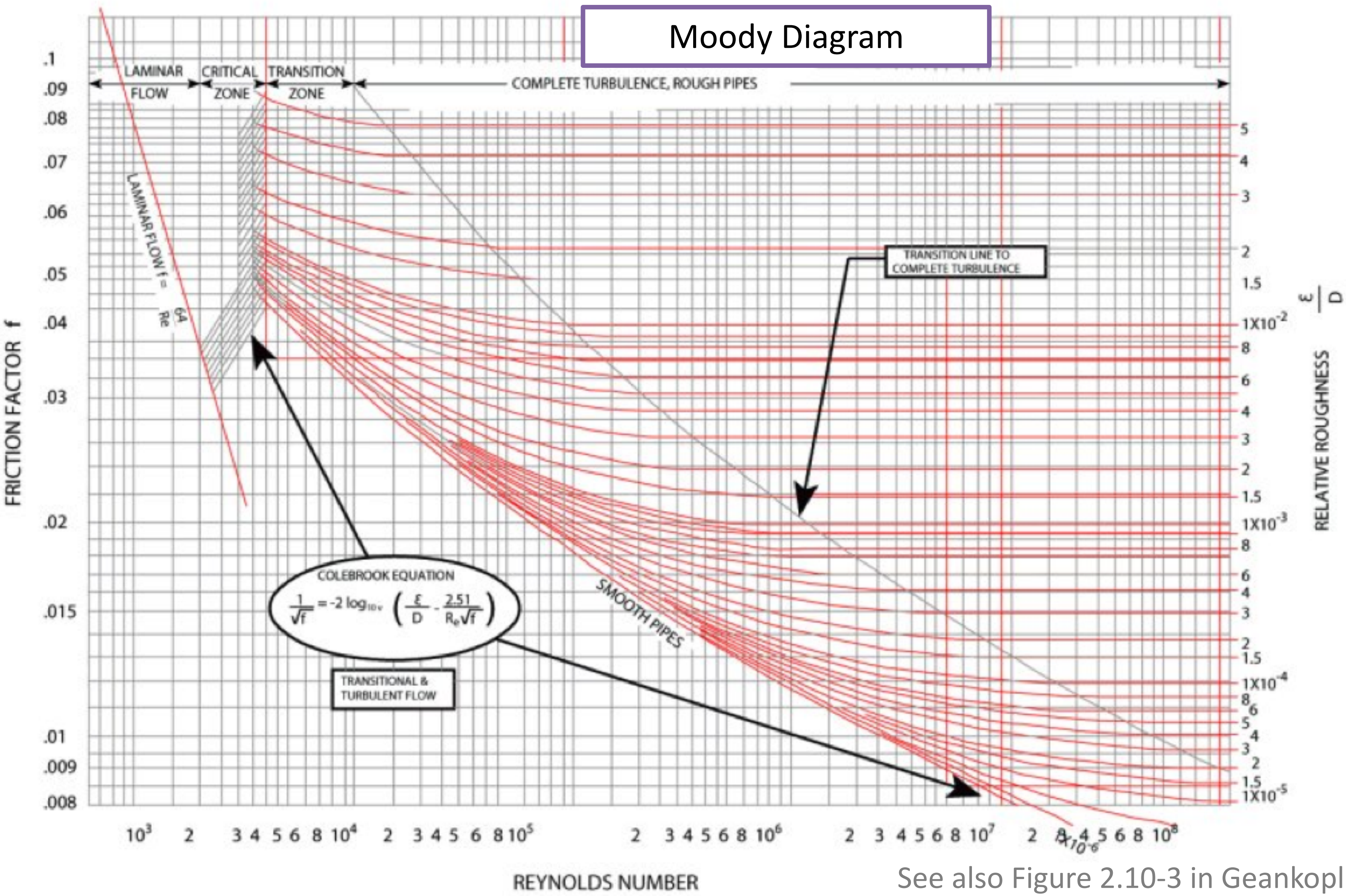
- In a smooth pipe, friction can be related to the pressure drop per unit length

$$f = \frac{D\Delta p}{2\rho u_m^2 L}$$

- Can also relate the the velocity to the Reynolds number

$$\mathrm{Re} = \frac{D u_m \rho}{\mu}$$

Friction Correlation with Re



See also Figure 2.10-3 in Geankoplis

Where else does friction occur?

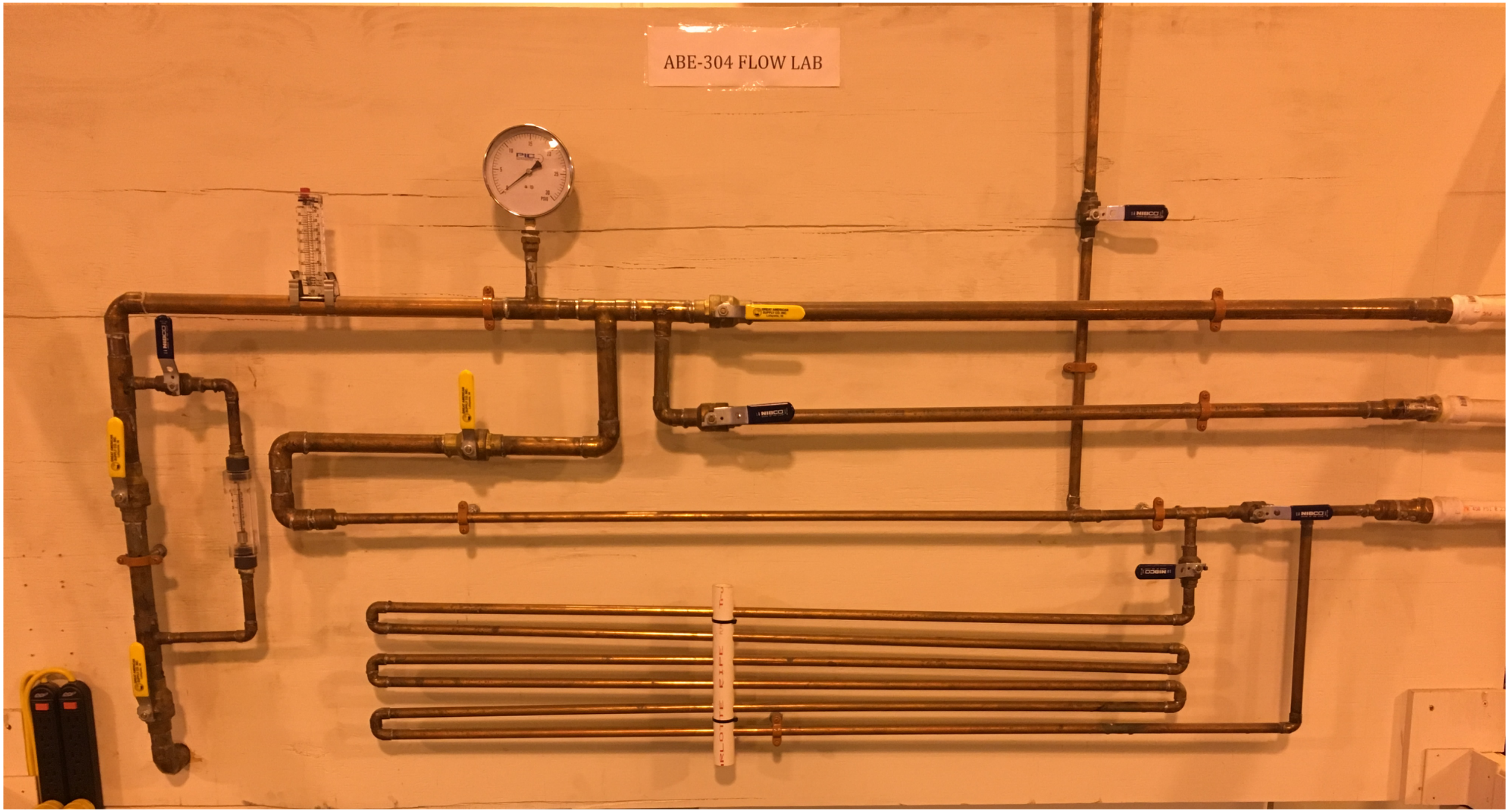
- Elbows

- Fittings

- Valves

Friction in your Lab?

- Where might friction occur in your apparatus?



Friction in your lab?

- Fittings & Elbows 180° and 90°
- Valves
  - Ball valves have minimal friction

Friction Correlation

TABLE 6-4 Additional Frictional Loss for Turbulent Flow through Fittings and Valves[a]

Type of fitting or valve	Additional friction loss, equivalent no. of velocity heads, K
45° ell, standard[b,c,d,e,f]	0.35
45° ell, long radius[c]	0.2
90° ell, standard[b,c,e,f,g,h]	0.75
Long radius[b,c,d,e]	0.45
Square or miter[h]	1.3
180° bend, close return[b,c,e]	1.5
Tee, standard, along run, branch blanked off[e]	0.4
Used as ell, entering run[g,i]	1.0
Used as ell, entering branch[c,g,i]	1.0
Branching flow[i,j,k]	1[l]
Coupling[c,e]	0.04
Union[e]	0.04
Gate valve,[b,e,m] open	0.17
¾ open	0.9
½ open	4.5
¼ open	24.0
Diaphragm valve, open	2.3
¾ open	2.6
½ open	4.3
¼ open	21.0
Globe valve,[e,m]	
Bevel seat, open	6.0
½ open	9.5
Composition seat, open	6.0
½ open	8.5
Plug disk, open	9.0
¾ open	13.0
½ open	36.0
¼ open	112.0
Angle valve,[b,e] open	2.0
Y or blowoff valve,[b,m] open	3.0
Plug cock	
$\theta = 5°$	0.05
$\theta = 10°$	0.29
$\theta = 20°$	1.56
$\theta = 40°$	17.3
$\theta = 60°$	206.0
Butterfly valve	
$\theta = 5°$	0.24
$\theta = 10°$	0.52
$\theta = 20°$	1.54
$\theta = 40°$	10.8
$\theta = 60°$	118.0
Check valve,[b,e,m] swing	2.0
Disk	10.0
Ball	70.0
Foot valve[e]	15.0
Water meter,[h] disk	7.0
Piston	15.0
Rotary (star-shaped disk)	10.0
Turbine-wheel	6.0

TABLE 6-5 Additional Frictional Loss for Laminar Flow through Fittings and Valves

Type of fitting or valve	Additional frictional loss expressed as K			
	Re = 1,000	500	100	50
90° ell, short radius	0.9	1.0	7.5	16
Gate valve	1.2	1.7	9.9	24
Globe valve, composition disk	11	12	20	30
Plug	12	14	19	27
Angle valve	8	8.5	11	19
Check valve, swing	4	4.5	17	55

Friction is additive

Depending on where you obtain the friction loss, you may use it differently

See also Table 2.10-1 in Geankoplis

Cited from *Perry's Chemical Engineers Handbook*, 8th Ed.
Available on-line through Purdue Elibrary

Causes of Pressure Drop

- Relationship between friction and pressure drop

In terms of velocity

$$\Delta p = \underbrace{2 f \rho u_m^2 \frac{L}{D}}_{\text{Friction}} + \underbrace{\rho g \Delta z}_{\text{Gravity}}$$

In terms of volumetric flow

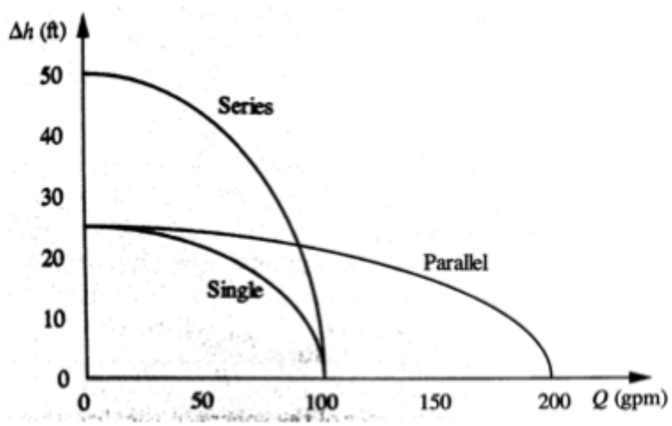
$$\Delta p = \underbrace{\frac{32 f \rho Q^2 L}{\pi^2 D^5}}_{\text{Friction}} + \underbrace{\rho g \Delta z}_{\text{Gravity}}$$

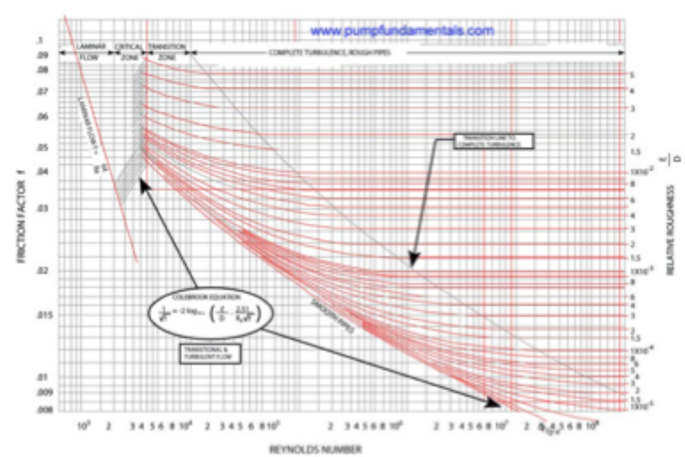
Where to find more?

- Perry’s Chemical Engineers Handbook
  - ebook through Purdue Library
- Transport Processes and Unit Operations
  - C. Geankoplis
- Unit Operations of Chemical Engineering
  - McCabe, Smith, and Harriott
    - On reserve at Library

In the lab…

- Measure flow and pressure drop in 3 pump configurations (single, series, parallel) and generate pump characteristic curves
  - Compare model results with experimental points
- Determine friction losses in different pipes
- Generate a Moody diagram





Prelab Assignment

- Due on Blackboard by Sunday at 5:00pm
  - Report addressing pump operation, friction losses, equations necessary for data analysis

- Prepare your notebook before coming to lab:
  - Preliminary procedure and experimentation summary
  - Charts/tables for recording the data
  - Write in black pen only

Flow Lab Schedule

The flow lab is set up in **<u>ABE 106</u>**. Report the following dates and times to complete your lab.

Week of Jan 22	Week of Jan 29
Groups 1, 2	Groups 3, 4
Prelab due Sun 1/21 by 5:00pm on Blackboard	Prelab due Sun 1/28 by 5:00pm on Blackboard