Chemical Engineering 374

Fluid Mechanics

Pump Scaling

Spiritual Thought

"How the Atonement was wrought, we do not know. No mortal watched as evil turned away and hid in shame before the light of that pure being.

All wickedness could not quench that light. When what was done was done, the ransom had been paid. Both death and hell forsook their claim on all who would repent. Men at last were free. Then every soul who ever lived could choose to touch that light and be redeemed.

By this infinite sacrifice, through this atonement of Christ, all mankind may be saved by obedience to the laws and ordinances of the gospel."

Elder Boyd K. Packer

OEP 9 (Clip)

OEP 9

Open Ended Problem #9

The Prince of Persia

GROUP WORK OKAY, Due 11/18/16 at beginning of class

(Don't be afraid to "Google" good assumptions!)

Unable to stop a pebble from hitting the sand trap, Dastan falls along with the coursing sand towards a chasm by way of a slanted stone wall. At the end, right before plummeting into the bottomless crevice with the sand, he is able to stop himself and grab onto a stone column. In reality, how fast would Dastan have been moving, and could he have stopped on that narrow column? (HINT – think 1-D Navier-Stokes, here!)

OEP 9, Part 7

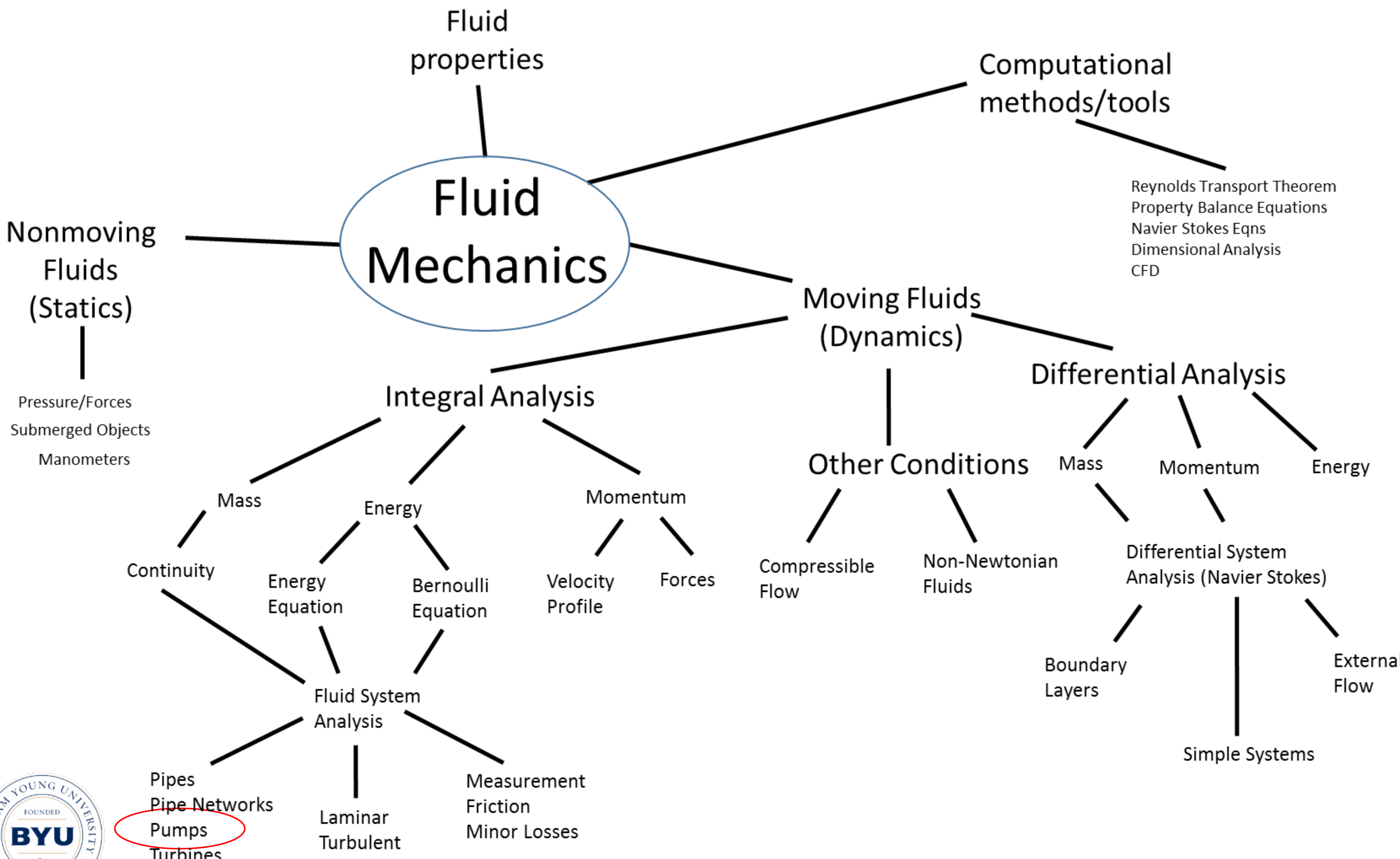
7) Verify your answer... Does it look reasonable? Anything odd about the calculation?

a) In reality, the stone blocks are falling all around Dastan as he slides down the slanted stone wall. How would these impacts affect the process you used to calculate the result?

b) Aside from what you listed in part a, is this method (simplifying of Navier-Stokes) reasonable? What about the sand makes this solution method questionable?

c) Based on your answer to part 1, generate an expression for the volumetric flow rate as a function of the sand properties and the sand flow thickness (i.e. between Dastan and the stone slab). Based on the estimated amount of sand initially resting at room's floor, is this flow rate reasonable?

Fluids Roadmap

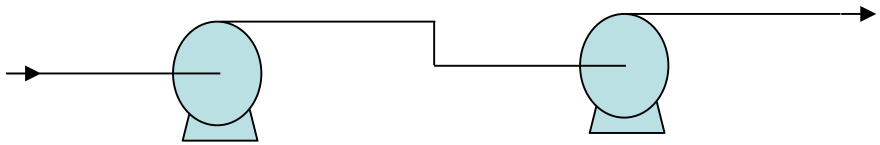


Overview

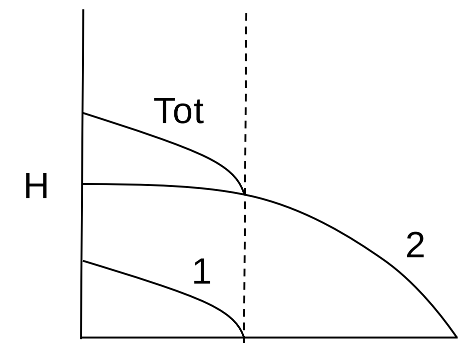
- Pumps/Turbines
  - Chp 14.1-14.2 (Monday), 14.2-14.3 (Today) 14.4-14-5 (Friday)
- Pumps
  - Combining to operate system in:
    - Series
    - Parallel
- Scaling of Pumps
  - Different operation
  - Different Fluid
  - Scaling Laws
- Pump Selection
- Example 14-60

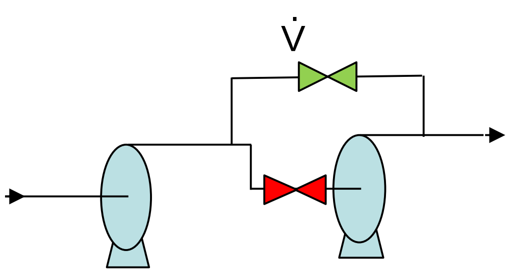
Pump Combination (Series)

- Goal: Provide Greater Head for Same Flow Rate



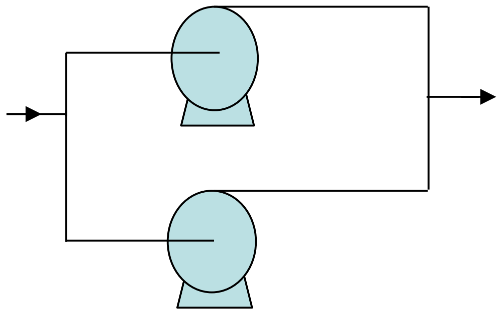
- $H_{tot} = H_1 + H_2$
- Pump Performance Curve is the **<u>VERTICAL</u>** sum
- $Bhp_{tot} = bhp_1 + bhp_2$ at operating point
- Issues: If pumps are not the same capacity, then smaller pump may operate beyond free delivery point (when H drops to 0) Become loss, not gain Cause Damage (shut off & bypass)

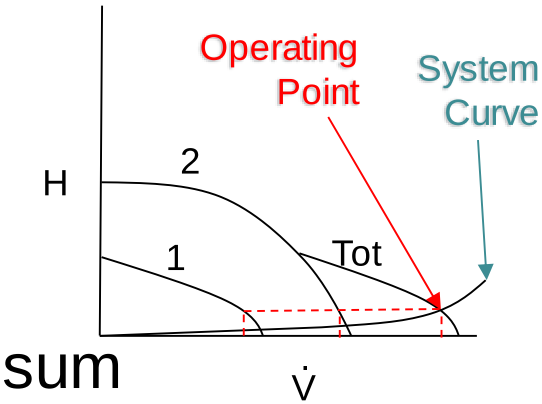




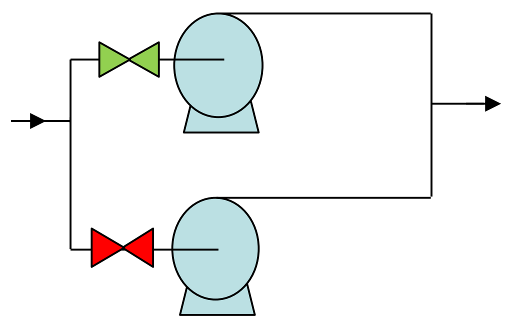
Pump Combination (Parallel)

- Goal: Provide Greater Flow Rate for Same Head
- $H_{tot} = H_1 = H_2$
- $\dot{V}_{tot} = \dot{V}_1 + \dot{V}_2$





- Pump Perf. Curve is the **<u>HORIZONTAL</u>** sum
- $Bhp_{tot} = bhp_1 + bhp_2$ at operating point
- $\dot{W}_{whp} = \rho g \dot{v} H_{tot}$, $\eta = \rho g \dot{v} H_{tot} / bhp_{tot}$
- Issues: If system head is greater than the shutoff head of the smaller pump, then flow may reverse through small pump
  - Cause Damage
  - shut off valve



Pump Scaling

- Often with a pump, you want to
  - Change operation
  - Change fluids
  - Design for different conditions
- In this case, use pump scaling laws
- Developed using dimensional analysis
  - Pump parameters:
  - D, $\dot{V}$, ω, ρ, μ, ε
  - Parameters? Dimensions?

Pump Scaling II

- 3 PI groups
  - $C_Q = \dot{V}/\omega D^3$
  - $Re = \rho\omega D^2/\mu = \rho D(\omega D)/\mu$
  - ε/D
- Pump Properties of Interest:
  - Head (H)
  - Power (bhp)
  - Efficiency (η)
  - Net positive suction head (NPSH)
- Non-dimensionalize these using Pump Parameters

Pump Scaling III

- Pump Properties:
  - Head ⟶ $H/[\omega^2(D^2/g)] = C_H = f(C_Q, Re, \varepsilon/D)$
  - Power ⟶ $bhp/[\rho\omega^3 D^5] = C_P = f(C_Q, Re, \varepsilon/D)$
  - Effic. ⟶ $\rho g\dot{V}H/bhp = \eta = f(C_Q, Re, \varepsilon/D)$
- For high Re, the impact decreases (as with f in pipe flow)
- ε/D differences are small
- Effectively only a function of C_Q
- See affinity laws in book, pg 829
- To scale pumps, match the groups

Pump Affinity (scaling) Laws

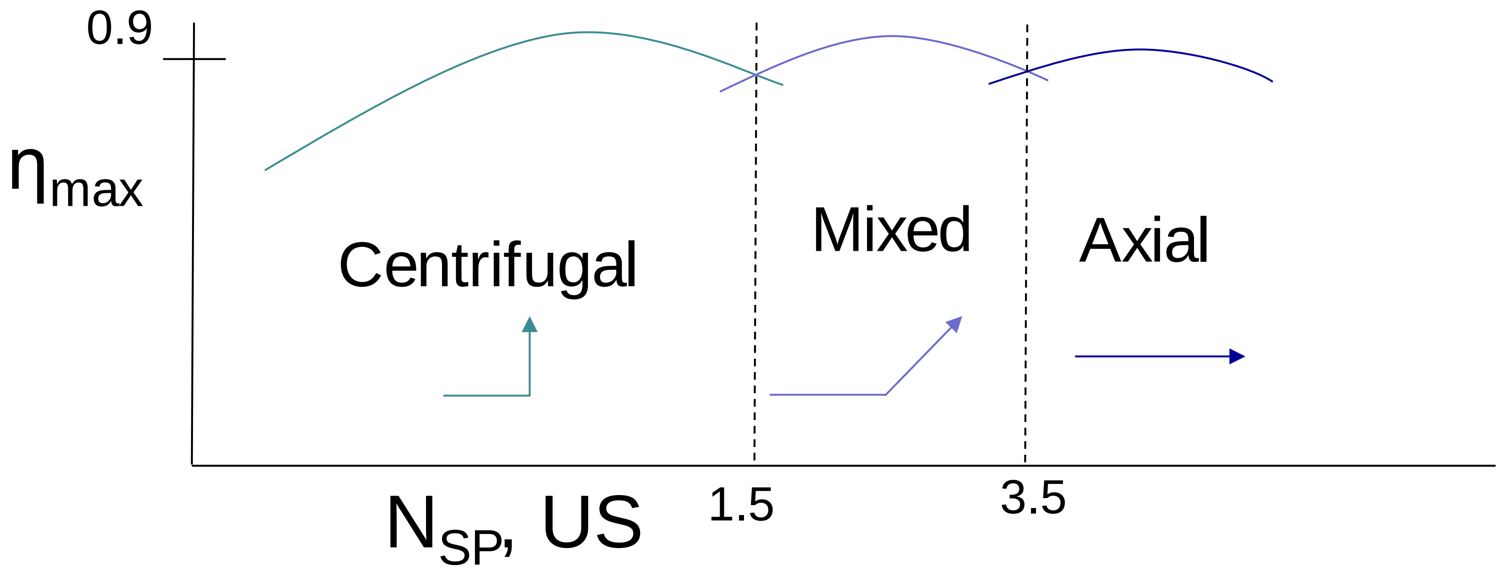
- Valid only for dynamically and geometrically similar pumps
- $\frac{\dot{V}_B}{\dot{V}_A} = \frac{\omega_B}{\omega_A}\left(\frac{D_B}{D_A}\right)^3$
- $\frac{H_B}{H_A} = \left(\frac{\omega_B}{\omega_A}\right)^2 \left(\frac{D_B}{D_A}\right)^2$
- $\frac{bhp_B}{bhp_A} = \frac{\rho_B}{\rho_A}\left(\frac{\omega_B}{\omega_A}\right)^3 \left(\frac{D_B}{D_A}\right)^5$

Example

- For a given C_Q, pump RPM (w) doubles
- What is new $\dot{V}$, head, power?
  - $C_Q = \dot{V}/\omega D^3$; $2\omega \longrightarrow 2\dot{V}$
  - $C_H = H_1/H_2$; $2\omega \longrightarrow 4H$
  - $C_P = bhp_1/bhp_2$; $2\omega \longrightarrow 8bhp$

Pump Selection

- Pump Specific Speed (N_{SP}) used to select pumps
- $N_{SP} = C_Q^{1/2}/C_H^{3/4}$
- Plot η_{max} vs N_{SP} for several different pump type (CAREFUL OF UNTS):



Example

- You need a pump to push 7,375 gpm of isopropyl alcohol through a system with total loses of 150 ft. What speed should the pump operate at if you want a Centrifugal pump with maximum efficiency?
- $N_{SP} = C_Q^{1/2}/C_H^{3/4}$ (pg. 829)
- $N_{SP} = \frac{\omega {V_p}^{1/2}}{\left(gH_p\right)^{3/4}}$
- $\omega = \frac{N_{SP}\left(gH_p\right)^{3/4}}{{V_p}^{1/2}}$
- ω = 1200 rpm

Book Problem, 14-60

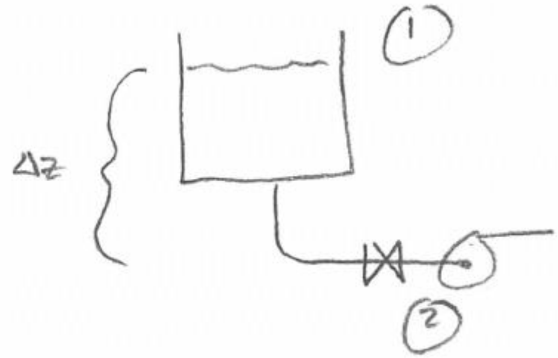
- Given diagram & parameters, find max volumetric flow rate that avoids cavitation.

Water @ 77°F

$D = 1.2$ in

$L = 12$ ft.

$K = 0.5 + 0.3 + 6$



$\rho = 62.244 \ lbm/ft^3$

$\mu = 6.0016 \times 10^{-4} \ lbm/ft \cdot s$

$\Delta z = 20$ ft.

$NPSH = 1 + 0.0054 \, Q^2$ ft w/ $Q (=) \frac{gal}{min}$

$P_{sat} = 0.46407 \ lbf/in^2$

Book Problem, 14-60 (cont)

$$\frac{P_2 - P_1}{\rho g} + \frac{V_2^2 - \cancel{V_1^2}}{2g} + \cancel{g}(z_2 - z_1) = -\frac{fLV^2}{2Dg} - \frac{KV^2}{2g}$$

$$NPSH = \frac{P_2}{\rho g} + \frac{V_2^2}{2} - \frac{P_{sat}}{\rho g}$$

$$\frac{P_2}{\rho g} + \frac{V_2^2}{2g} = z_1 - \frac{fLV^2}{2Dg} - \frac{KV^2}{2g} + \frac{P_1}{\rho g}$$

$$NPSH = z_1 - \frac{fLV^2}{2Dg} - \frac{KV^2}{2g} - \frac{P_{sat}}{\rho g} + \frac{P_1}{\rho g} = 1 + 0.0054\,Q^2$$

$$= 1 + 1087.8\,Q^2$$ (Q in ft^3/s)

$$Q = \frac{\pi}{4} D^2 V$$

$$\frac{1}{\sqrt{f}} = -2 \log\left(\frac{2.51}{Re\sqrt{f}}\right)$$

Solve w/ Mathcad → **56.6 gpm**