ChE 374–Lecture 31–Pump Scaling

- Series and parallel pumps:
  - Series
    - Goal: provide greater head for the same flow rate
    - $H_{tot} = H_1 + H_2$
    - Pump performance curve is the vertical sum of each individual pump
    - $bhp_{tot} = bkp_1 + bkp_2$ at the operating point
    - Issues: If the pumps are not the same capacity, then if the flow is too large, the smaller pump may operate beyond its free delivery flow rate (beyond where its H drops to zero). At that poiint, the pump acts as a loss, not a gain in head, and damage may result. In this case, shut off the pump and bypass it with a valve. This is not a problem for equal sized pumps.
  - Parallel
    - Goal: increase $\dot{V}$ for the same head
    - Pump performance curve is the horizontal sum of each individual pump
    - $H_1 = H_2$
    - $\dot{V}_{tot} = \dot{V}_1 + \dot{V}_2$
    - $bhp_{tot} = bkp_1 + bkp_2$ at the operating point
    - $\dot{W}_{whp} = \rho g \dot{V} H_{tot}$
    - $\eta = \rho g \dot{V} H_{tot}/bhp_{tot}$
    - Issues: Different sized pumps: if head is greater than the shutoff head of the smaller pump, then the flow may actually reverse through the pump, resulting in damage. In that case, bypass the pump with a valve. This is not a problem for equal sized pumps.
- Pump Scaling
  - Often have a pump and want to change the operation, or run with different fluids, or design for different conditions.
  - Know the scaling laws
  - Use dimensional analysis
    - Pump parameters: D, $\dot{V}$, ω, ρ, μ, ϵ.
      - 6 parameter - 3 dimensions = 3 Π's
      - $C_Q = \dot{V}/\omega D^3$, $Re = \rho\omega D^2/\mu$, ϵ/D.
    - Pump properties (depend on the params): Head (H), Power (bhp), Efficiency (η), NPSH.
      - Nondimensionalize thess too, using the pump parameters
        Head, $gH/\omega^2 D^2 = C_H = f(C_Q, Re, \epsilon/D)$
        Power, $bhp/\rho\omega^3 D^5 = C_P = f(C_Q, Re, \epsilon/D)$
        Efficiency, $\rho g \dot{V} H/bhp = \eta = f(C_Q, Re, \epsilon/D)$.
  - The effect of Re is small at high Re, like it is for pipes.
  - Small effect of ϵ/D, so the main dependency is on C_Q.
  - See the affinity laws on page 803.
- Pump selection
  - Pump specific speed (N_{sp}) is used to select pumps.
    - $N_{sp} = C_Q^{1/2}/C_H^{3/4}$
      - Careful of units, its often defined with inconsistent sets of units.
  - Plot η_{max} versus N_{sp} for several pump types.
    - Choose centrifugal for $N_{sp} < 1.5$, mixed for $1.5 < N_{sp} < 3.5$, and axial for $N_{sp} > 3.5$.
      - Here, N_{sp} is the U.S. version.

Class 31 - Pumps (2)

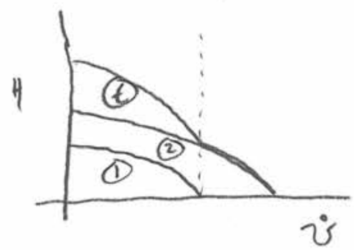
Example from last class : NPSH : 14-60 (see attached)

Pumps in Series and parallel

Series

Goal: provide greater head for same flow rate

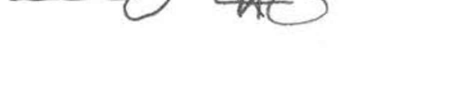
- $H_{tot} = H_1 + H_2$
- Pump performance curve is the <u>vertical</u> sum of each
- $bhp_{tot} = bhp_1 + bhp_2$ at operating point.



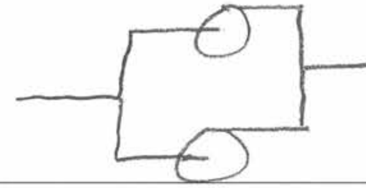
Issues : If pumps are not same capacity, then if flow is too large, the smaller pump may operate <u>beyond</u> its free delivery flow rate (beyond where its H drops to zero). At that point, pump acts as a <u>loss</u> not a gain, may damage

⟶ Shut it off and bypass.

(not a problem for 2 equal pumps)

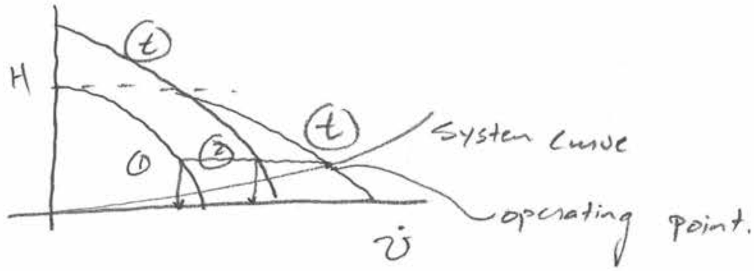


Parallel



- Goal: increase $\dot{V}$ for same head.

  - $H_1 = H_2$
  - $\dot{V}_t = \dot{V}_1 + \dot{V}_2$
  - Pump perf. curve is the <u>horizontal</u> sum of each pump.



  - $bhp_t = bhp_1 + bhp_2$
  - $\dot{W}_{WHP} = \rho g \dot{V} H_{tot}$
  - $\eta = \dfrac{\rho g \dot{V}_{tot} H_t}{bhp_{tot}}$
  - <u>Issues</u>: Different size pumps.
    - if head is greater than the shutoff head of the smaller pump, then the flow may actually <u>reverse</u> through the pump → Damage
    - In that case, bypass the pump with a valve.
    - Not a problem for equal pumps.

Pump Scaling

- Often Have a pump, want to change operation,
  or run Different fluids
  or Design for Different Conditions.

  ⟶ Know Scaling Laws.

- Use Dimensional Analysis.
  - Pump parameters : $D, \dot{V}, \omega, \rho, \mu, \epsilon$

    6 params − 3 Dims = 3 Π's

  - Pump properties (Depend on Pump Params) : Head, Power, efficiency, NPSH

    H, bhp, η, NPSH

    ⟶ Non-Dim These too, using Pump params.

- Pump Params ⟶ $C_Q = \dfrac{\dot{V}}{\omega D^3}$

  $Re = \dfrac{\rho \omega D^2}{\mu} = \dfrac{\rho D(\omega D)}{\mu}$

  ϵ / D

- Pump properties

  Head ⟶ $\dfrac{H}{\omega^2 D^2/g} = C_H = f\left(C_Q, Re, \dfrac{\epsilon}{D}\right)$

  Power ⟶ $\dfrac{bhp}{\rho \omega^3 D^5} = C_P = f\left(C_Q, Re, \dfrac{\epsilon}{D}\right)$

  efficiency ⟶ $\dfrac{\rho g \dot{V} H}{bhp} = \eta = f\left(C_Q, Re, \dfrac{\epsilon}{D}\right)$

- High Re ⟶ Small effect (as for pipes)
- ϵ/D ⟶ Small effect.
- See Affinity Laws on p 803.

- to Scale pumps, match the Groups.

Example

- A pump's rpm Doubles : $\omega \rightarrow 2\omega$
- what happens to its Head, Power if C_Q is Const ?

$$C_Q = \frac{\dot{\forall}}{\omega D^3} \quad ; \quad 2\omega \longrightarrow 2\dot{\forall}$$

$$C_H \longrightarrow \frac{H_1}{H_2} = \left(\frac{\omega_1}{\omega_2}\right)^2 \longrightarrow 2\omega \longrightarrow 4H$$

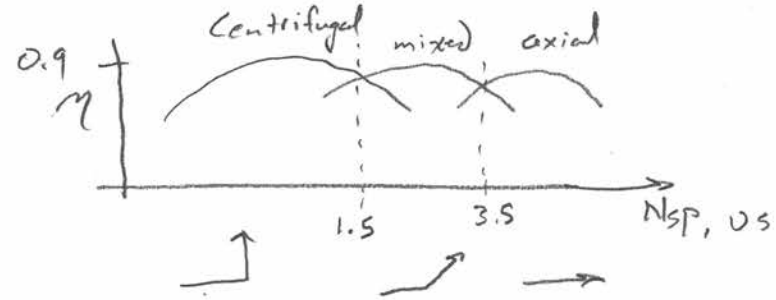
$$C_P \longrightarrow \frac{bhp_1}{bhp_2} = \left(\frac{\omega_1}{\omega_2}\right)^3 \longrightarrow 2\omega \longrightarrow 8\,bhp.$$

Pump Selection

Pump Specific Speed used to Select pumps.

$$N_{sp} = C_Q^{1/2} / C_H^{3/4}$$

Plot η_{max} vs N_{sp} for several pump types :



- Careful of Units, See Tbook.

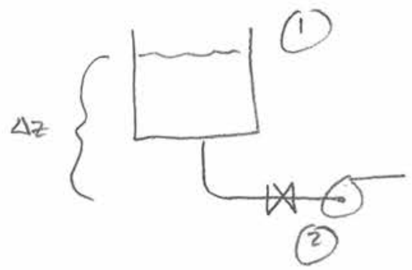
14-60

Water @ 77°F

$D = 1.2$ in

$L = 12$ ft.

$K: 0.5 + 0.3 + 6$



$\rho = 62.244$ lbm/ft³

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

$\Delta z = 20$ ft.

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

$P_{sat} = 0.46407$ lbf/in²

Max flow w/o cavitation.

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

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

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

$$NPSH = z_1 - \frac{fLV^2}{2Dg} - \frac{KV^2}{2g} - \frac{P_{sat}}{\rho g} + \frac{P_1}{\rho g} = 1 + 0.0054\, Q^2 = 1 + 1087.8\, Q^2$$

(Q → ft³/s)

$z = 20$ ft

$L = 12$ ft

$D = 0.1$ ft

$g = 32.17$ ft/s²

$P_{sat} = 2149.8$ lbm/ft·s²

$P_1 = 68078.7$ lbm/ft·s²

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

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

Solve w/ Mathcad → **56.6 gpm**