Chemical Engineering 374

Fluid Mechanics

Pumps

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Overview

- Pumps/Turbines
  - Chp 14.1-14.2 (today), 14.2-14.3 (Wed.) 14.4-14-5 (Friday)
- Pumps
  - Add energy to fluid (increase pressure, not speed)
- Liquids → pumps
- Gases
  - Fans: Low ΔP, High Flow, < ~ 1 psi
  - Blowers: Med ΔP, Med Flow, < ~ 40 psi
  - Compressors: High ΔP, Low Flow, >~ 40 psi
- Pumps
  - Positive displacement
  - Dynamic

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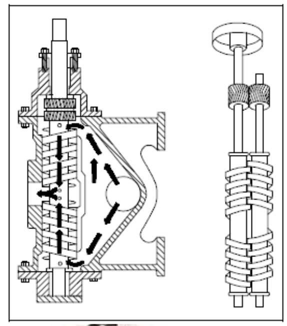
Positive Displacement Pumps

- Displace fluid by moving parts with low clearance
  - Piston/cylinder
  - Turning gears
  - Screws
- Lower flow rates
  - < 1000 gpm
- Self priming
- High pressures (> 500 psi)
  - Need safety devices
- High viscosity fluids
  - Oil, foods
- Pulsating flow, hard to control flow rate



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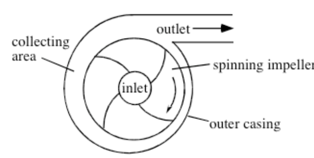
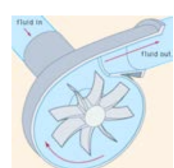
Centrifugal Pumps

- Centripetal forces accelerate fluid and increase pressure.
- Flow enters axially and is accelerated to the outside where pressure rises.
- High flow rates (> 300,000 gpm)
- Large gaps
- Lower pressures (relative) ~100 psi
- Not self priming
- The industry standard for moving gases and liquids.
  - If it's a pump, its probably a centrifugal pump



inlet view of a centrifugal pump


side view of impeller



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Centrifugal Pumps

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Performance Parameters

- Brake Horsepower
  - Shaft work
  - Work supplied to the pump
  - Some is lost → inefficiency
- Water Horsepower
  - mgH is the work imparted to fluid across the pump
- Efficiency
- Inefficiency
  - Leakage of fluid between spaces
  - Fluid friction in pump
  - Mechanical friction in pump
  - Does not include the motor

$$H = \left(\frac{P}{\rho g} + \frac{v^2}{2g} + z\right)_{out} - \left(\frac{P}{\rho g} + \frac{v^2}{2g} + z\right)_{in}$$

$$H = \frac{\Delta P}{\rho g}$$

$$\eta = \frac{\dot{W}_{water\,HP}}{\dot{W}_{shaft}} = \frac{\dot{W}_{water\,HP}}{bhp} = \frac{\rho g Q H}{bhp}$$

Pump Performance

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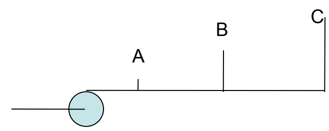
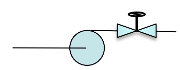
- Key parameters are $\mathcal{V}$ and **H**
- Most pumps are ***on*** or ***off***
- Consider pump to three elevations A, B, C
- Pump head lifts fluid
- Ignore any pipe losses
- **A:** Pump just "throws" fluid, but H=0
  - **W = ρ*g*H***$\mathcal{V}$
- **B:** Start elevating, flow rate drops and head increases
- **C:** At some point flow stops and head is maximum



	$\mathcal{V}$	H	W	eff
A	High	0	0	0
B	Med	Med	Med	High
C	0	High	0	0

- Note, head increases over the pump, then drops over the load.
- Load can be KE or elevation, or loss or pressure.
- Could think of this as



Pump Curve Schematic

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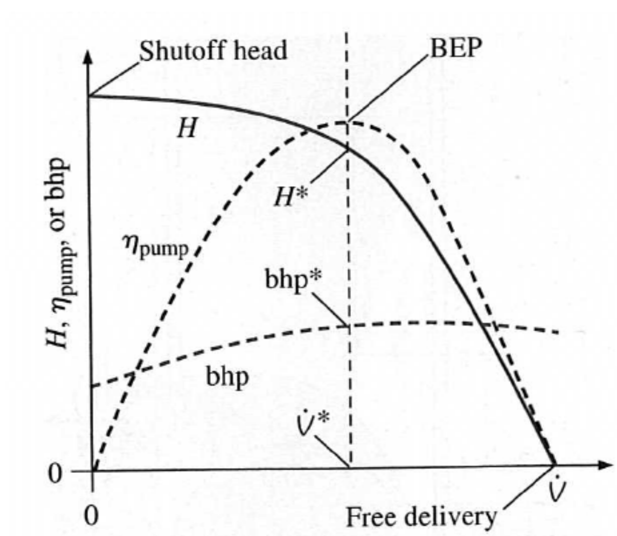
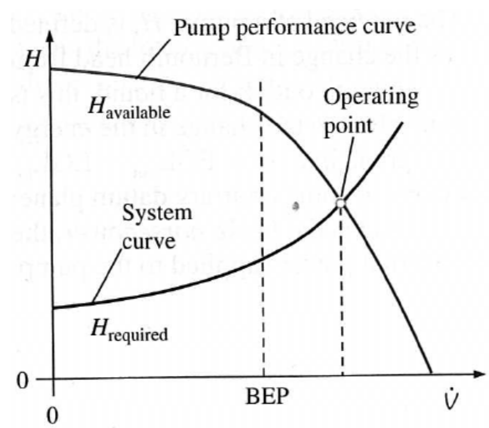


Pump Operation Curves

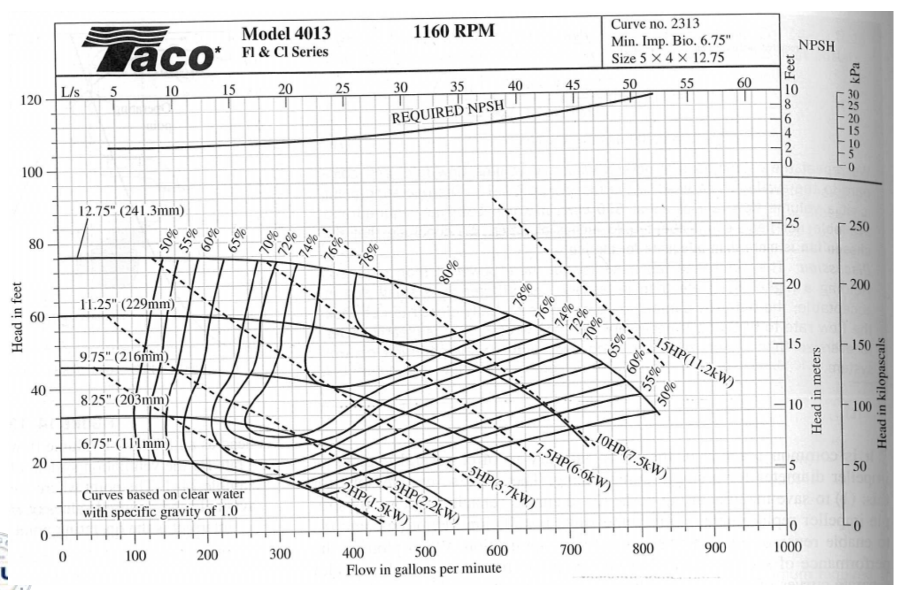
- Piping system requires a given $\mathcal{V}$ and a given H.

$$H_{req} = \frac{P_2 - P_1}{\rho g} + \frac{v_2^2 - v_1^2}{2g} + (z_2 - z_1) + H_{loss}$$

  - H_{loss} is friction and minor losses, etc.
- Pump has a corresponding $\mathcal{V}$ and H.
- These **must match**, forming the operating point.
  - This may not be the best efficiency.
- Select a pump so that the best efficiency point (BEP) occurs at the operating point.
- Generally oversize the pump a bit
  - higher flow for given H_{req}
  - or Higher H_{avail} for given flow
  - Add a valve after pump → raises H_{req} to match H_{avail} for given flow
  - Somewhat wasteful, but offers control.
  - Also may increase efficieny. (But higher efficieny may not compensate for extra work wasted in the valve (see example 14.2)

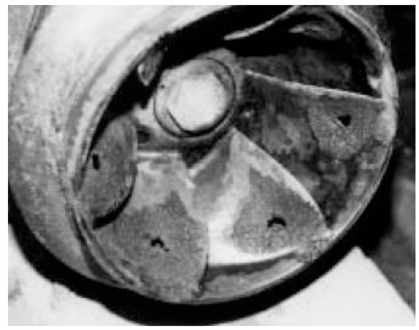


Pump Performance Curves



Cavitation

- Pressures inside pumps can decrease locally in some spots (like the low pressure side of a blade)
- Recall flow separation and wakes
- Cavitation causes local boiling, bubble collapse.
  - Think of th pinging you hear when water bubble start to form on the stove.
  - Causes erosion and pitting of blades.



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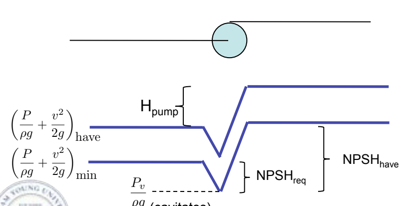
Net Positive Suction Head (NPSH)

$$\text{NPSH} = \left(\frac{P}{\rho g} + \frac{v^2}{2g}\right)_{\text{pump inlet}} - \frac{P_v}{\rho g}$$

- Think of NPSH as the pressure drop inside the pump.
  - If pump NPSH is 10, then you need $\left(\frac{P}{\rho g} + \frac{v^2}{2g}\right)_{\text{pump inlet}} - \frac{P_v}{\rho g}$ at the pump inlet to be more than 10.
- NPSH_{req} is specified for a given pump. Operate ABOVE it.
- NPSH_{req} increases with flow rate (higher flow, more cavitation tendency.
- NPSH of the operating system decreases with increasing flow.
  - Higher flow means more pressure drop means lower pressure at the pump inlet, means lower NPSH.



- Locate pumps down low (below tanks and columns. (To maximize P)
- Lower temperature is better (lower P_v)
- As increase T, and/or Flow rate, watch out for cavitation!

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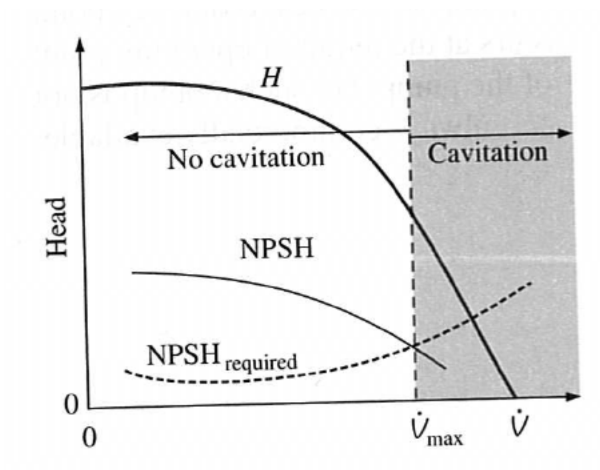
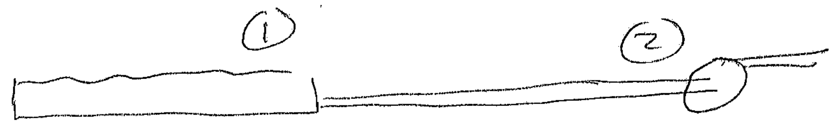
NPSH


H
No cavitation
Cavitation
Head
NPSH
NPSH required
0
0
$\dot{V}_{max}$
$\dot{V}$

NPSH Notes.

Example :



$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 - h_L = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

To get $(NPSH)_{have}$: at point (2)

$- \frac{P^v}{\rho g}$ from both sides

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 - h_L - \frac{P^v}{\rho g} = \underbrace{\frac{P_2}{\rho g} + \frac{V_2^2}{2g} - \frac{P^v}{\rho g}}_{(NPSH)_{have}} + z_2$$

That is, group terms in the energy eqn to get NPSH

$$\rightarrow (NPSH)_{have} : \quad \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 - z_2 - \frac{P^v}{\rho g} - h_L$$

If have a Pump Curve, Then can plot $(NPSH)_{have}$ vs $\dot{V}$ and operate where $(NPSH)_{have} > (NPSH)_{pump}$

If have a correlation for $(NPSH)_{pump}$ versus $\dot{V}$, Then

Set $(NPSH)_{have} = (NPSH)_{pump} \longrightarrow$ Solve for $\dot{V}$

Remember, NPSH is like a scaled inlet pressure: Higher P avoids cavitation. Operate so as to maximize NPSH.