Chemical Engineering 374

Fluid Mechanics

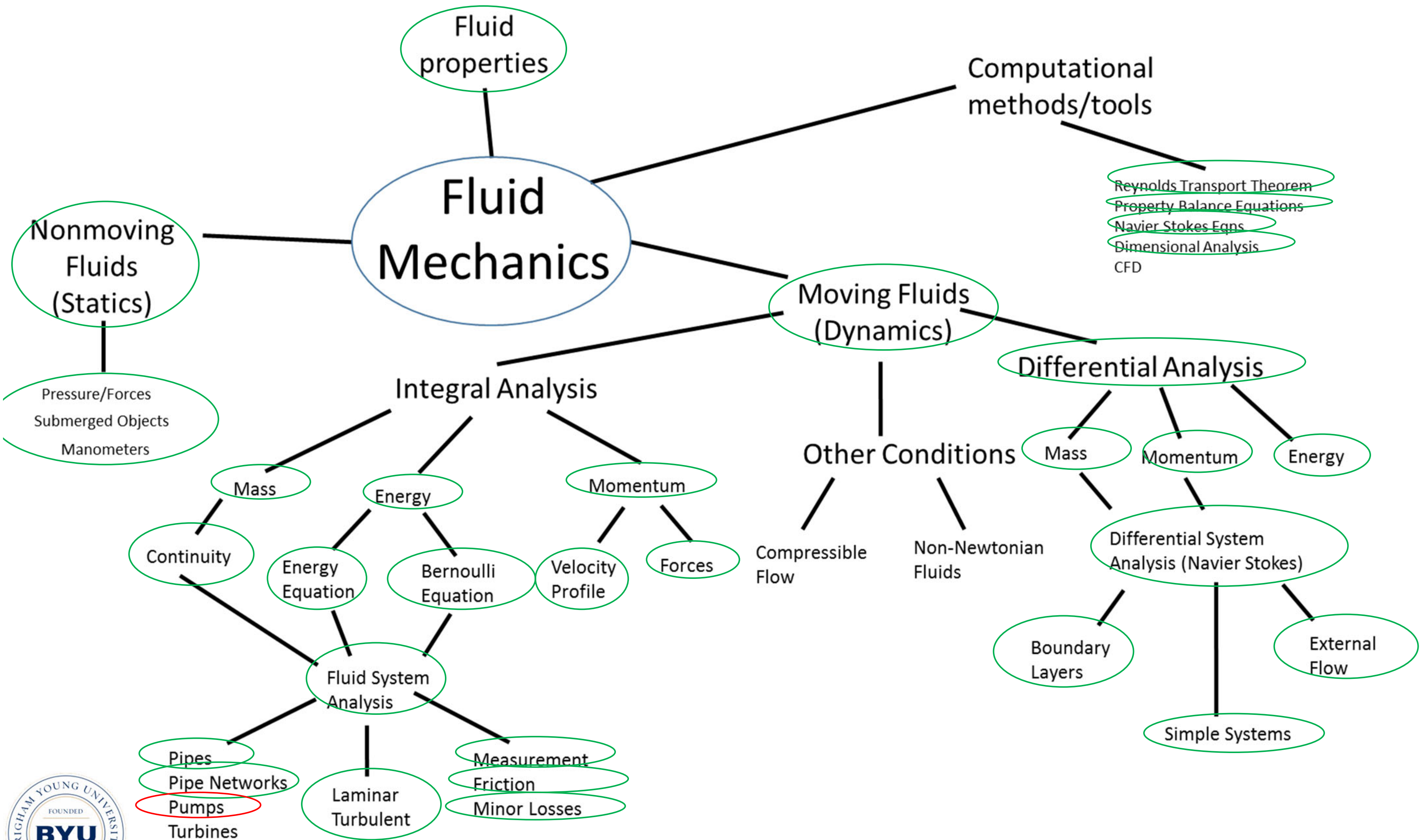
Pumps

Spiritual Thought

The Lord said to Abraham, “My name is Jehovah, and I know the end from the beginning; therefore my hand shall be over thee” (Abr. 2:8). My young friends, today I say to you that if you trust the Lord and obey Him, His hand shall be over you, He will help you achieve the great potential He sees in you, and He will help you to see the end from the beginning.

- Elder Dieter F. Uchtdorf

Fluids Roadmap

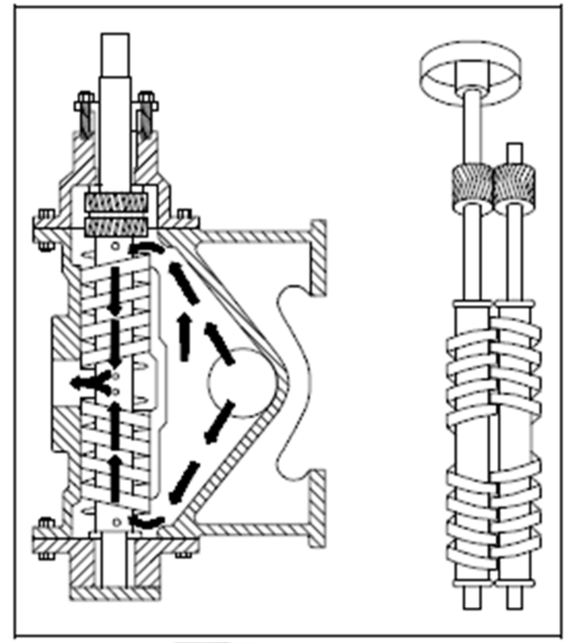


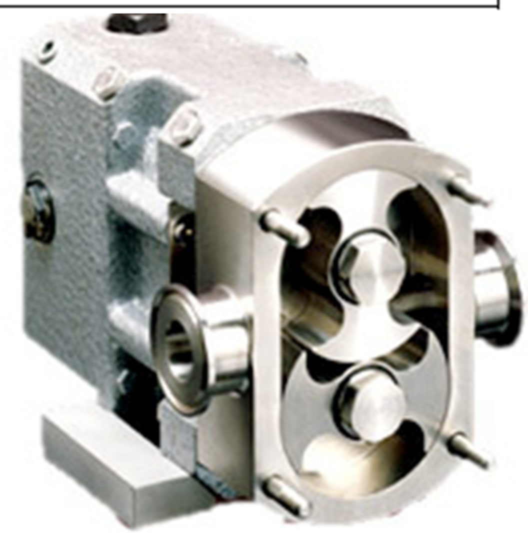
Key Points

- 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

Positive Displacement Pumps

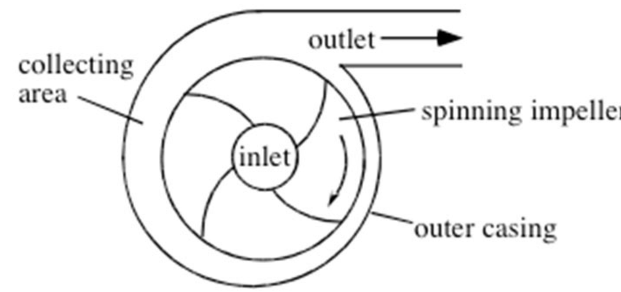
- Displace fluid by moving parts with low clearance
  - Piston/cylinder
  - Turning gears
  - Screws
- Lower flow rates
  - < 1000 gpm
- Self priming
- High pressures (> 500 psi)
  - Need safety devices
- High viscosity fluids
  - Oil, foods
- Pulsating flow, hard to control flow rate





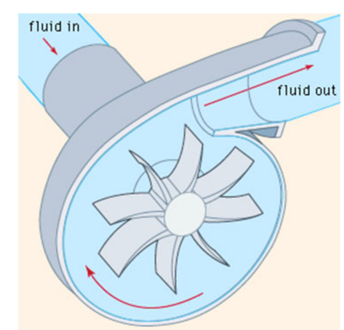
Centrifugal Pumps

- 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

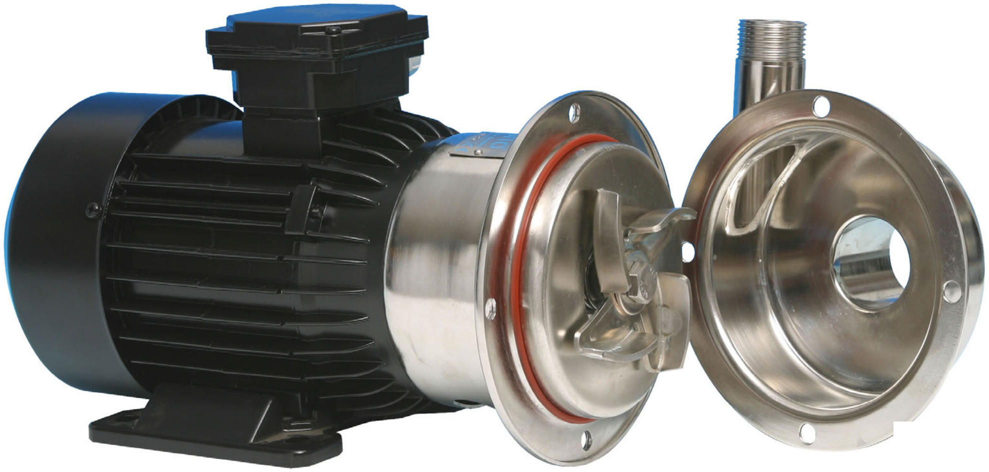


inlet view of a centrifugal pump


side view of impeller



Centrifugal Pumps



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

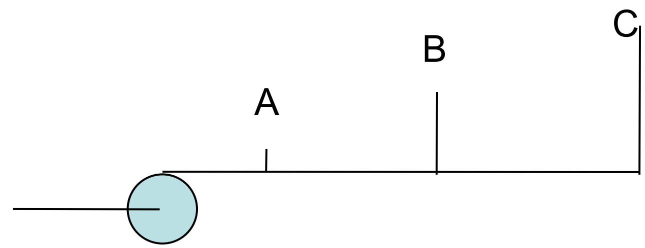
$$H = \left(\frac{P}{\rho g} + \frac{v^2}{2g} + z\right)_{out} - \left(\frac{P}{\rho g} + \frac{v^2}{2g} + z\right)_{in}$$

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

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

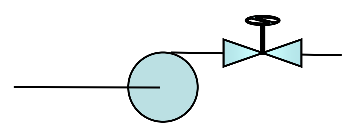
Pump Performance

- Key parameters are **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
  - $\mathbf{W} = \rho * \mathbf{g} * \mathbf{H} * \dot{V}$
- **B:** Start elevating, flow rate drops and head increases
- **C:** At some point flow stops and head is maximum

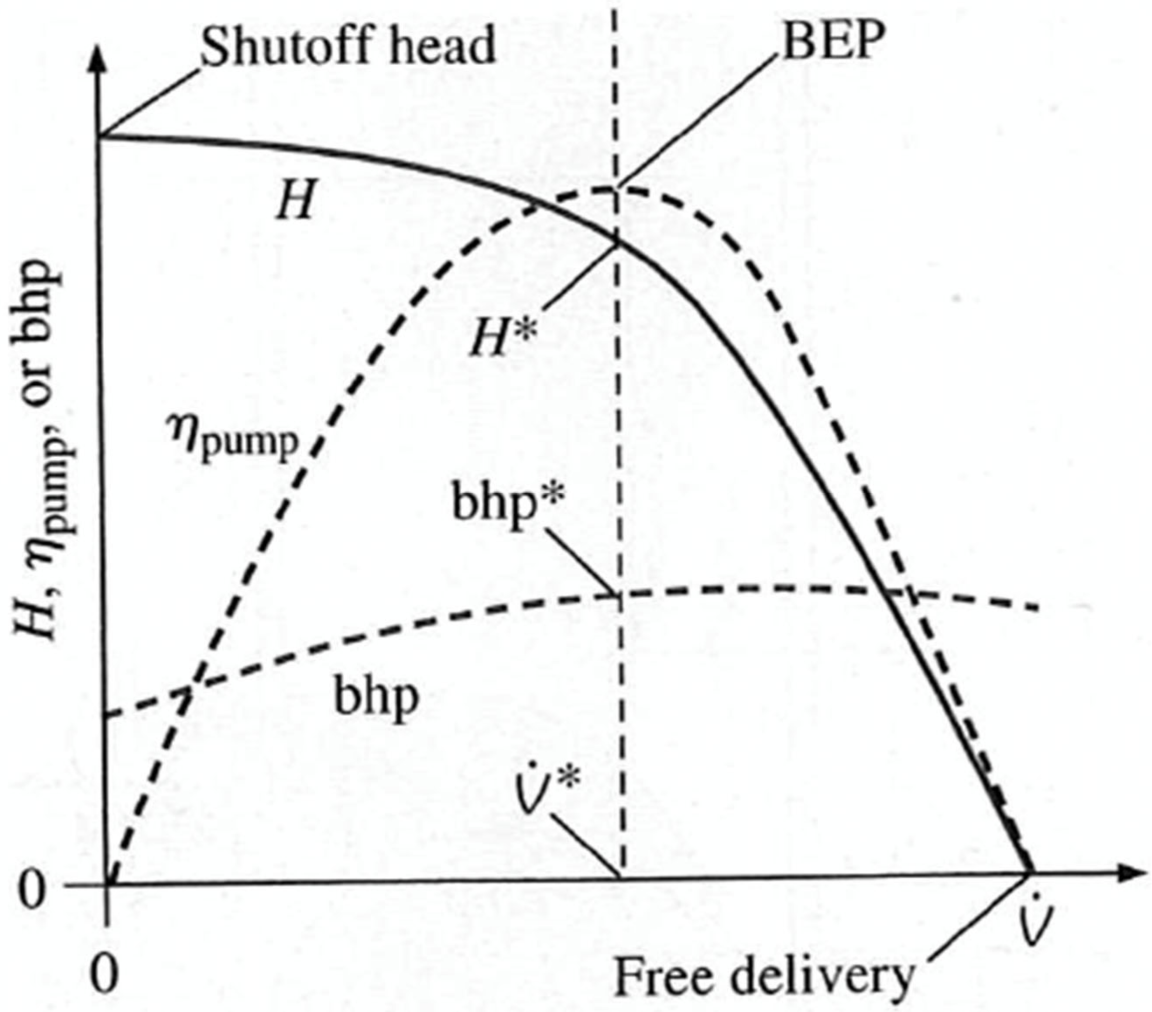


	V	**H**	**W**	**eff**
A	High	0	0	0
B	Med	Med	Med	High
C	0	High	0	0

- 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

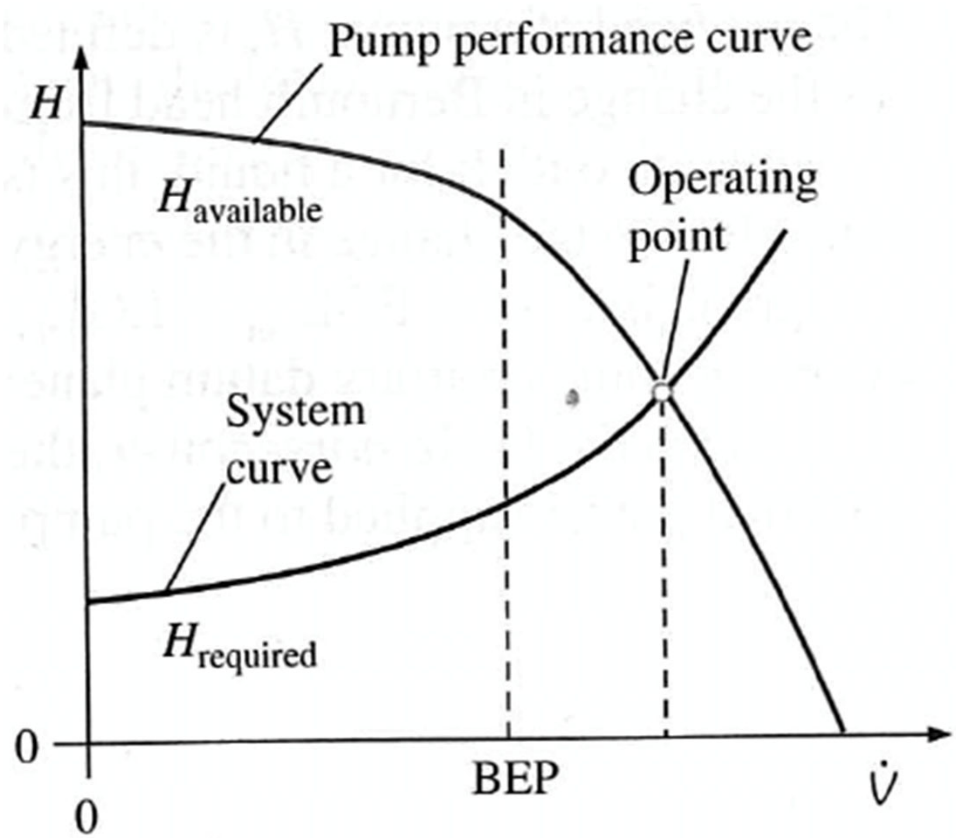


Pump Operation Curves

- Piping system requires a given **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 **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)

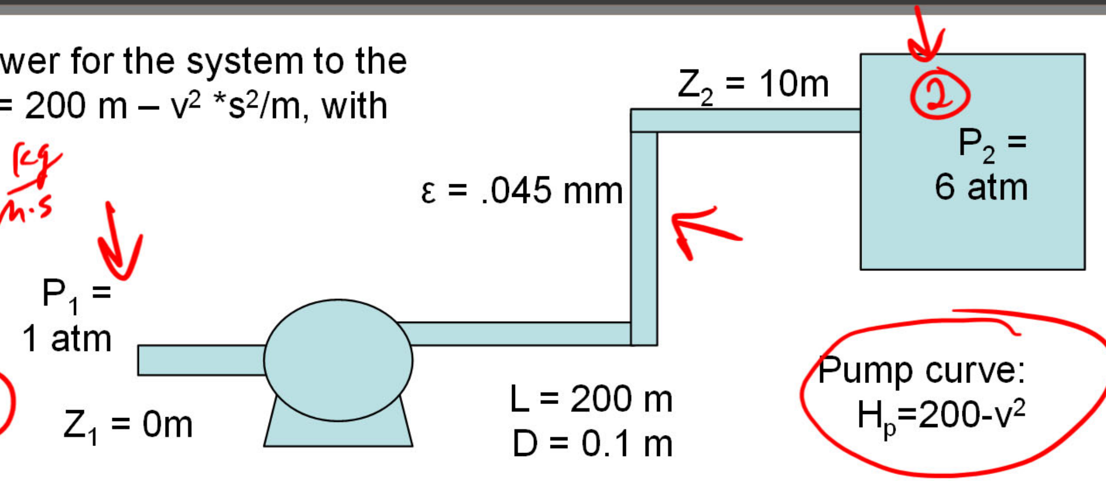


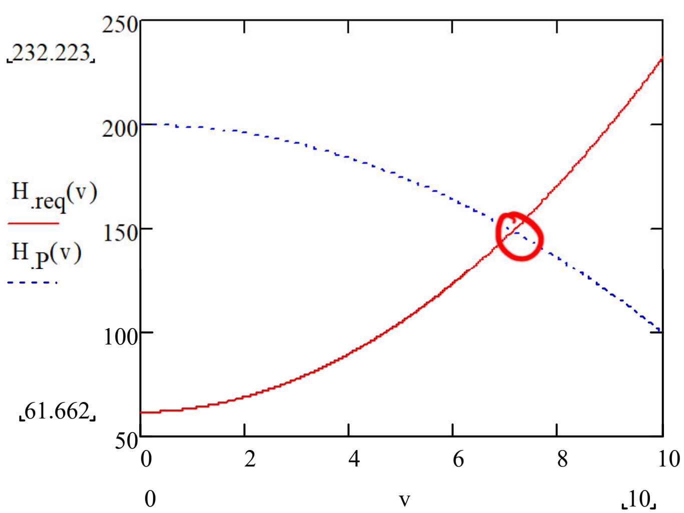
Example

Find the flow rate and required pumping power for the system to the right. The pumping curve is defined by H_p = 200 m – v^2 *s^2/m, with a pump efficiency of 90%.

$\rho = 1000\ kg/m^3 \quad \mu = .798 \times 10^{-3}\ \frac{kg}{m \cdot s}$

$H_{req} = \frac{\Delta P}{\rho g} + \Delta z + f \frac{L}{D} \frac{\rho v^2}{2}$





Operating Point is at intersection of two lines:

H_{op} = 149.149 m

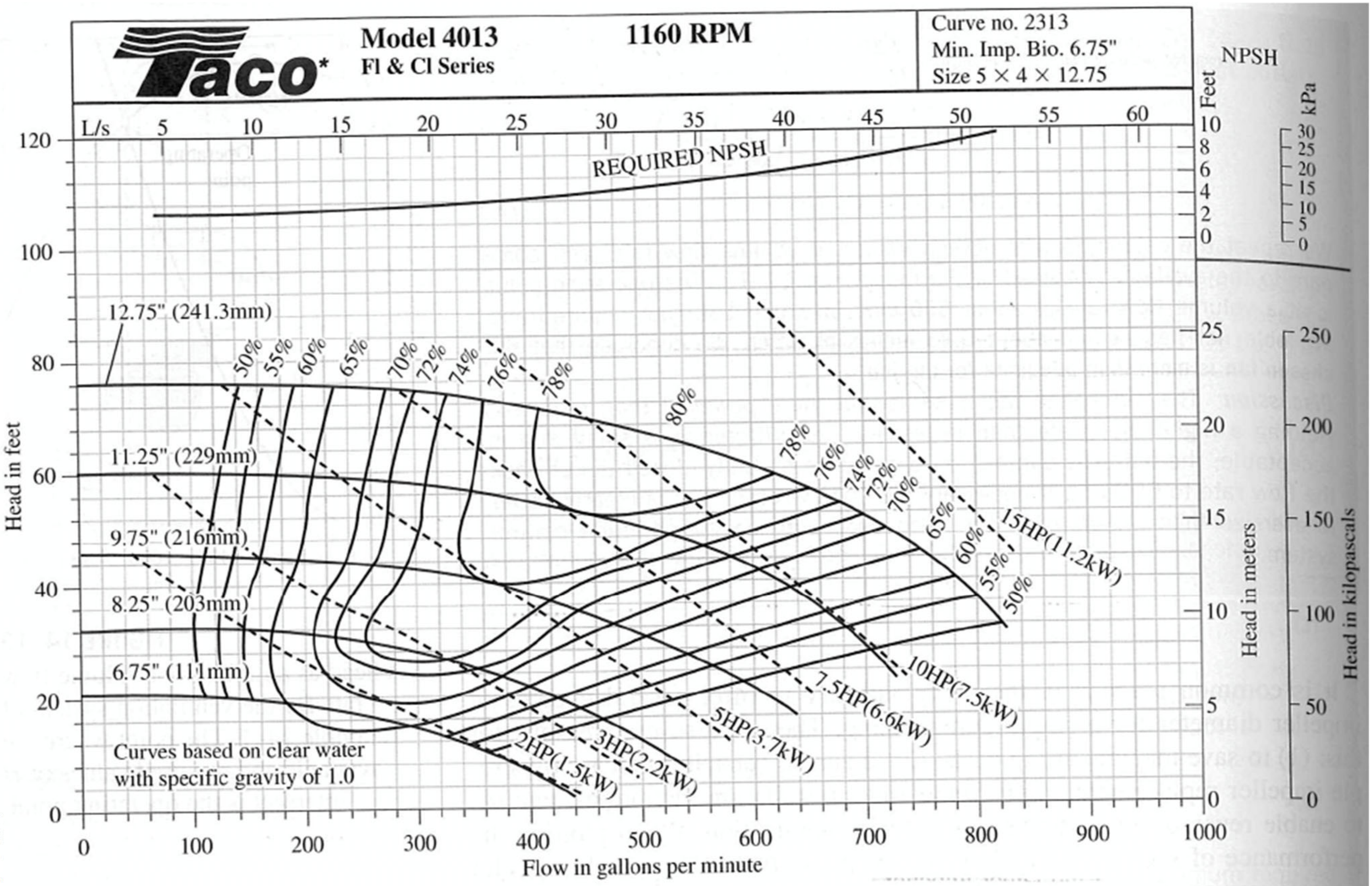
v_{op} = 7.131 m/s

$\dot{v}_{op}$ = 0.055 m^3/s

$$bhp = \frac{\rho g H \dot{V}}{\eta}$$

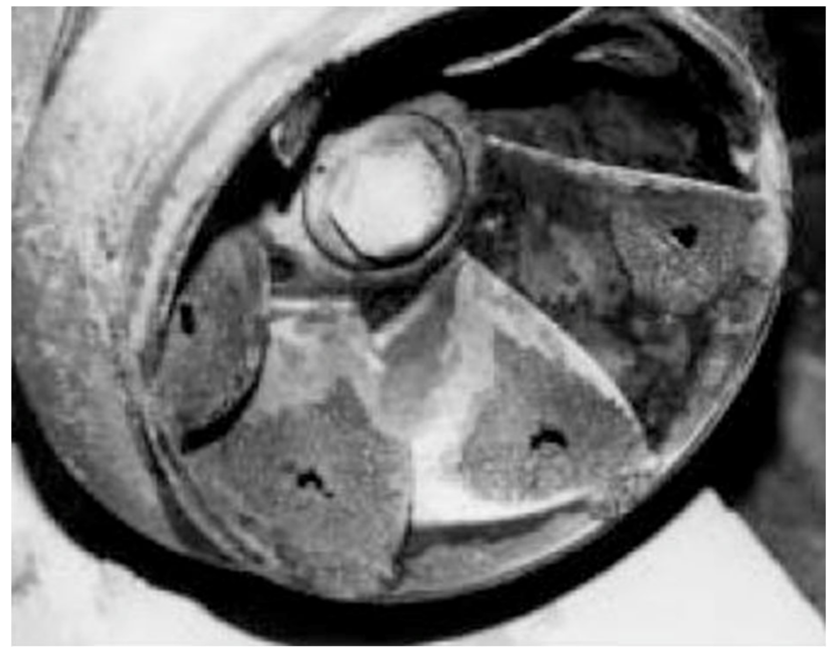
$$bhp = 89.35\ kW$$

Pump Performance Curves



Cavitation

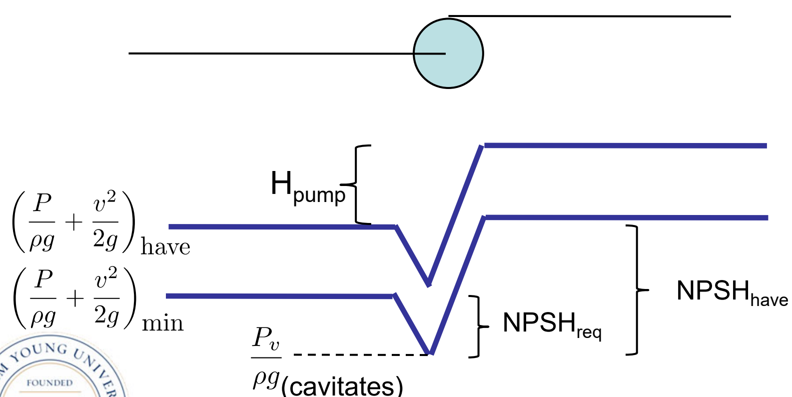
- Pressures inside pumps can decrease locally in some spots (like the low pressure side of a blade)
- Recall flow separation and wakes
- Cavitation causes local boiling, bubble collapse.
  - Think of th pinging you hear when water bubble start to form on the stove.
  - Causes erosion and pitting of blades.



Net Positive Suction Head (NPSH)

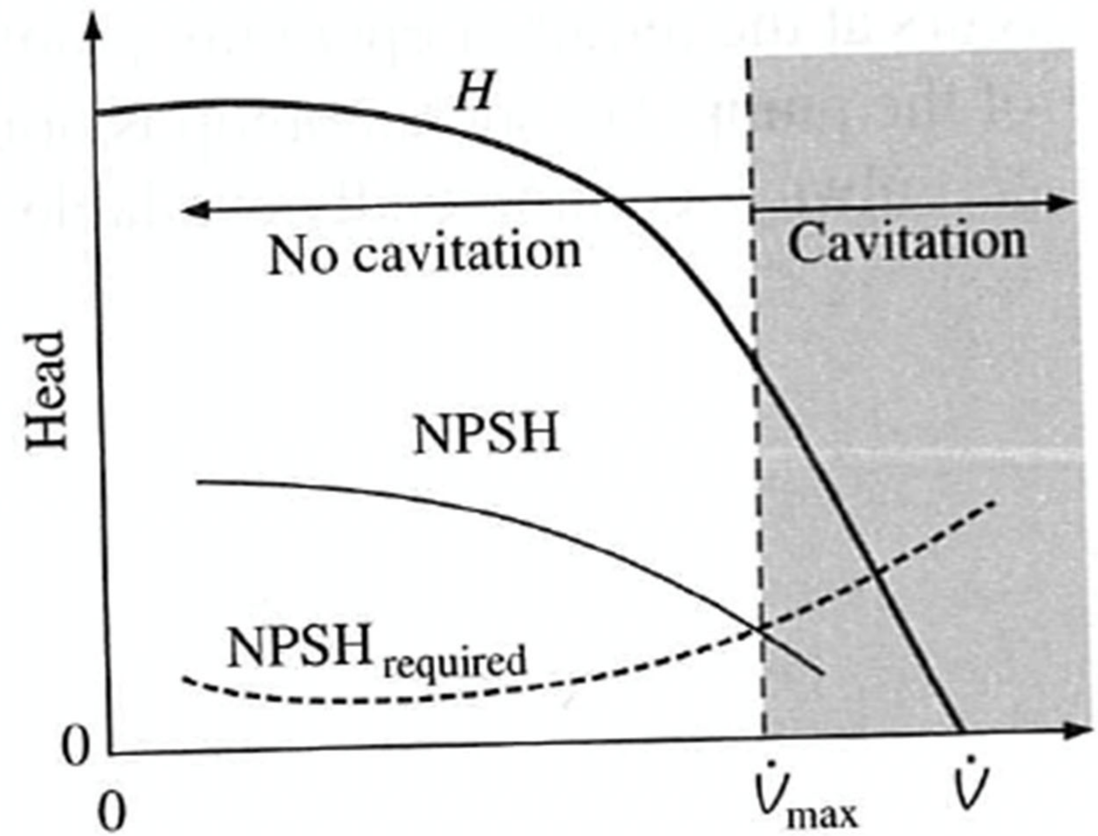
$$\text{NPSH} = \left(\frac{P}{\rho g} + \frac{v^2}{2g}\right)_{\text{pump inlet}} - \frac{P_v}{\rho g}$$

- 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!

NPSH


H
No cavitation
Cavitation
Head
NPSH
NPSH required
0
0
V̇max
V̇