Centrifugal Pumps

- Centrifugal force is used to fling fluid from the suction side to the discharge.
- Centrifugal pumps put out **neither** constant flow rate **nor** constant pressure.
- We must use the mechanical energy balance to figure out how a centrifugal pump will perform in a given situation.
Pumping Head Characteristic Curves are plots of what an existing pump can do under various loads (duties). We measure the pump characteristic curve by determining \( \Delta p = p_{\text{discharge}} - p_{\text{suction}} \) on the suction/discharge system.

How do you choose a centrifugal pump for a given duty?

- Calculate the flow-rate-dependent demands of a system = system head curve (this assignment).
- Compare the system-head curve (demands) to the available pumping-head curve (supply), and choose the right pump.

Pumping Head Lab (week 10)

- Pumping Head Characteristic Curves are plots of what an existing pump can do under various loads (duties).
- We measure the pump characteristic curve by determining \( \Delta p = p_{\text{discharge}} - p_{\text{suction}} \) on the suction/discharge system.
Krum Pump Company  
Kalamazoo, MI  
Model: Peerless pump  
Type: PE50B  
Performance Curve No: 4848278  
RPM: 3450

System Head - MEB written on total system, excluding pump

\[
\frac{\Delta P}{\rho g} + \frac{\Delta (v^2)}{2 g \alpha} + \Delta z + \frac{F_{\text{friction}}}{g} = H_{\text{system}}
\]

For example (this is NOT our system):

The pump is omitted from system calculations.
The pump must overcome pressure, velocity, elevation, and friction \textbf{both} when it pulls upstream fluid towards it \textbf{and} while it pushes downstream fluid away from it.

For example (this is NOT our system):

\begin{align*}
\text{System Head - MEB written on total system, excluding pump}

H_{system} & \equiv \frac{\Delta p}{\rho g} + \frac{\Delta \langle v \rangle^2}{2g \alpha} + \Delta z + \frac{F_{friction}}{g} \\
& = \frac{p_{finish} - p_{start}}{\rho g} + \frac{\langle v \rangle_{finish}^2 - \langle v \rangle_{start}^2}{2g \alpha} \\
& \quad + (z_{finish} - z_{start}) + \frac{F_{finish,start}}{g}
\end{align*}

For a system that is not yet built, how can we estimate these frictional loads on the pump?
MEB on Fittings and Straight Pipe

Straight pipe:

\[
\frac{\Delta p}{\rho g} + \frac{\Delta (v)^2}{2ga} + \Delta z + \frac{F_{\text{friction}}}{g} = \frac{W_{\text{on}}}{mg}
\]

valve:

\[
\frac{\Delta p}{\rho g} + \frac{\Delta (v)^2}{2ga} + \Delta z + \frac{F_{\text{friction}}}{g} = \frac{W_{\text{on}}}{mg}
\]

90° bend:

\[
\frac{\Delta p}{\rho g} + \frac{\Delta (v)^2}{2ga} + \Delta z + \frac{F_{\text{friction}}}{g} = \frac{W_{\text{on}}}{mg}
\]

etc.

Friction manifests as \(\frac{\Delta p}{\rho g}\) for each fitting or pipe, which can be added up.

\[
F_{\text{finish,start}} = \sum_{\text{fittings, straight pipe,}i} \left(\frac{\Delta p}{\rho g}\right)_i
\]

System Head - MEB written on total system, excluding pump

\[
H_{\text{system}} = \frac{\Delta p}{\rho g} + \frac{\Delta (v)^2}{2ga} + \Delta z + \frac{F_{\text{friction}}}{g}
\]

\[
H_{\text{system}} = \frac{p_{\text{finish}} - p_{\text{start}}}{\rho g} + \frac{(v)^2_{\text{finish}} - (v)^2_{\text{start}}}{2ga} + (z_{\text{finish}} - z_{\text{start}}) + \frac{F_{\text{finish,start}}}{g}
\]

\[
F_{\text{finish,start}} = \sum_{\text{fittings, straight pipe}} \left(\frac{\Delta p}{\rho g}\right)_i
\]
Friction in Fittings, Straight Pipe: Data Correlations from Literature

\[
\frac{F_{\text{finish, start}}}{g} = \sum_{\text{fittings, straight pipe}} \left( \frac{\Delta p}{\rho g} \right)_i
\]

These have been measured and correlated in the literature as a function of flow rate through Fanning friction factor \( f(\text{Re}) \) (straight pipes) and \( K_f \) (fittings).

\[
\frac{F_{\text{finish, start}}}{g} = \sum_{\text{fittings, straight pipe}} \left( \frac{\Delta p}{\rho g} \right)_i \quad \langle \nu \rangle = \frac{Q}{\pi R^2}
\]

\[
= \left( 4f \frac{L}{D} + \sum_{\text{i fittings}} K_f n_i \right) \langle \nu \rangle^2 2g
\]

Note: if diameter changes, \( \langle \nu \rangle \) changes; thus we need separate calculations for every \( \langle \nu \rangle \)

Data correlation for friction factor \( \Delta p \) versus \( \text{Re} \) (flow rate) in a pipe

![Moody Chart](Image)
Some terms go as $Q^2$

\[
H_{\text{system}} = \frac{p_{\text{finish}} - p_{\text{start}}}{\rho g} + \frac{\langle v \rangle_{\text{finish}}^2 - \langle v \rangle_{\text{start}}^2}{2g \alpha} + (z_{\text{finish}} - z_{\text{start}}) + \frac{F_{\text{finish,start}}}{g}
\]

\[
F_{\text{finish,start}} = \left(4f \frac{L}{D} + \sum_{i \text{ fittings}} K_f n_i \right) \frac{\langle v \rangle^2}{2}
\]

\[
\langle v \rangle = \frac{Q}{\pi R^2}
\]

(slight additional $Q$ dependence)
System Head - MEB written on total system, excluding pump

\[ H_{system} = \frac{p_{finish} - p_{start}}{\rho g} + \frac{(v)_{finish}^2 - (v)_{start}^2}{2 ga} + (z_{finish} - z_{start}) + \frac{F_{finish,start}}{g} \]

Some terms go as \( Q^0 \)

\[ (v) = \frac{Q}{\pi R^2} \]

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System Head - MEB written on total system, excluding pump

\[ H_{system} = \frac{p_{finish} - p_{start}}{\rho g} + \frac{(v)_{finish}^2 - (v)_{start}^2}{2 ga} + (z_{finish} - z_{start}) + \frac{F_{finish,start}}{g} \]

\[ F_{finish,start} = \left(4f \frac{L}{D} + \sum_{i \text{ fittings}} K_i n_i \right) \frac{(v)^2}{2} \]

\[ H_{system} = aQ^2 + b \]

\[ H_{system}(Q) \text{ is the system head curve} \]

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Calculating the System curve:

- Choose two points that enclose the entire system from start to finish.
- Write pressures, elevations, velocities at finish and start.
- Write velocities in terms of flow rate Q.
- Calculate the friction of all piping, fittings, devices between start and finish as a function of Q.
- Do not include a pump (we are calculating what expected load the as-yet-unchosen pump must overcome).
Assignment 5: Calculate and plot the system head curves for the assigned system.
(come into lab to get measurements you need)

CM3215 Assignment 5: System-head Curves for a Piping System
Under Conditions of Different Valve Positions

Complete all calculations described below; you may verbally consult with any of your classmates, but you must submit individual assignments. Deliver your submission with a memo of transmittal that clearly lists where to find your submitted answers to the five assigned objectives.

Overall objective: Determine the equations for the system-head curves for three different systems. Plot these curves.

1. Sketch the following system using Visio or by hand (make the sketch the size of an entire sheet of paper):

   The system:  All the pipes, fittings, and devices between the exit of the orifice meter (point A) and the pressure tap on the suction side of the centrifugal pump (point B). Include the sizes and locations of all valves, pressure taps, thermo wells,

What’s this good for?

(choosing pumps)
How do we use the system head curve to choose a pump?

Plot this versus $Q$

$$H_{\text{system}} = \frac{W_{s,\text{on}}}{mg} = H_{\text{pump}}$$

Obtain this versus $Q$ from the manufacturer.

All the contributions to load on the pump = $H_{\text{sys}}$

Pumping effort and friction are accounted for when the system curve intersects the pumping head curve $H_{\text{pump}}(Q)$.

Where the two intersect, that’s where the pump operates.

Sizing a Pump

Operating points, where $\text{SUPPLY} = \text{DEMAND}$

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Pumping Head Lab (week 10)

- Pumping Head Characteristic Curves are plots of what an existing pump can do under various loads (duties).
- We measure the pump characteristic curve by determining $\Delta p = p_{\text{discharge}} - p_{\text{suction}}$ on the suction/discharge system.
The CM3215 “Lossy” Pump

- Extends from the pump suction to the exit of the orifice meter.
- The system on which this pump operates thus is the piping and fittings between the exit of the orifice meter and the pump suction.