There are two sides to pump performance:

- **Demand**
- **Supply**
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 a pump's characteristic curve by determining \( \Delta p = p_{\text{discharge}} - p_{\text{suction}} \) on the suction/discharge system.

### System Curve Assignment (week 9)

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 12)

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

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Before a system is built, how can we choose an appropriate pump?

**Mechanical Energy Balance**

The pump must overcome pressure, velocity, elevation, and friction both when it pulls upstream fluid towards it and while it pushes downstream fluid away from it.

For example:

**Demand**

The pump is omitted from system calculations.
For a system that is not yet built, how can we estimate the frictional loads that must be overcome by the pump?
How does pressure vary as water travels through the flow loop?
How does pressure vary as water travels through the flow loop?

Each fitting, bend, device contributes pressure drop (friction loss) which together comprise the system demand on the pump.

Electrical analogy:

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

Apply MEB to Fittings, Straight Pipe

Straight pipe:

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

Valve:

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

90° bend:

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

etc.

Friction manifests as \( \Delta p/\rho g \) for each fitting or pipe, which can be added up.
**System Head $\equiv$ MEB written on total system, excluding pump**

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

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

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

**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 $f(Re)$ (straight pipes) and $K_f$ (fittings)

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

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

Note: if diameter changes, $\langle v \rangle$ changes; thus we need separate calculations for every $D$

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Apply MEB to Fittings, Straight Pipe

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

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

\[ \text{Re} = \frac{\rho u D}{\mu} \]

Moody Chart

(Geankoplis)
Some terms go as $Q^2$

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

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

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

Reference: Morrison, Faith A, An Introduction to Fluid Mechanics, Cambridge University Press, 2013, Figure 7.18, page 532.

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System Head - MEB written on total system, excluding pump

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

Some terms go as \( Q^0 \)

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

Demand

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

System Head - MEB written on total system, excluding pump

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

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

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

\( H_{system}(Q) \) is the system head curve; it's the amount of energy per unit weight the pump must supply when we install it.

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**System Head - MEB written on total system, excluding pump**

$H_{system}(Q)$ is the system head curve

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

**Demand**

<table>
<thead>
<tr>
<th>$Q$ (gpm)</th>
<th>$H_{system}$ (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.003</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
</tr>
<tr>
<td>3</td>
<td>10.8</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
</tr>
</tbody>
</table>

... ... ...

Two different system curves

**Calculating the System curve:**

- Choose two points that enclose the entire system from **start** to **finish** (there are lots of choices when it’s a flow loop, but you need to choose points that you know enough about)
- 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 $Q$ (choose convenient values)
- Do not include a pump (we are calculating the expected load that the as-yet-unchosen pump must overcome)
Assignment 6: Calculate and plot the system head curves for the assigned system.

(come into lab to get measurements you need)

**CM3215 Assignment 6:**
System-head Curves for a Proposed Piping System
Under Conditions of Different Needle-Valve Positions

Due: Friday 30 October 2015 10:00am in Homework Box A
This is an individual assignment. Note the due time.

Complete all calculations described below; you may verbally consult with any of your classmates, but you must submit individual assignments that represent your own work: you may not exchange papers or electronic files. Deliver your submission with a memo of transmittal that clearly lists where to find your submitted answers to the four assigned objectives. You must submit only your own work.

**Overall objective:** Determine the equations for the system-head curves for a flow loop under three different operating conditions (three different needle valve settings). The three different systems are described below. Plot these curves as instructed.

In a future laboratory, you will need to perform identical calculations.
How do we use the system head curve to choose a pump?

Plot this versus Q

\[ W_{s,\text{on}} \frac{mg}{m} = H_{pump} \]

Obtain this versus Q from the manufacturer

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

When you buy a pump, the manufacturer tells you what it is capable of.

Krum Pump Company
Kalamazoo, MI
Model: Peerless pump
Type: PE50B
Performance Curve No: 4848278
RPM: 3450
Sizing a Pump

**SUPPLY meets DEMAND**

- **Operating points, where**
  
  
  **SUPPLY**=**DEMAND**

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**This week**

**System Curve Assignment (week 9)**

**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

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**Assignment 6:**

Prepare to choose a pump for a system

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

We measure a pump’s 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.

Report 6: Characterize a laboratory pump

Take the role of the manufacturer