CM3215

Fundamentals of Chemical Engineering Laboratory

Pumping Performance: System Head and Pumping Head Analysis

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There are two sides to pump performance:

Demand

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Pumping System Curves

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Supply

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Analysis of a Centrifugal Pump: Pumping Head Curves

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Pumping System Curves

This week: Demand

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Reference: Morrison, *An Introduction to Fluid Mechanics*, Section 9.2.4.

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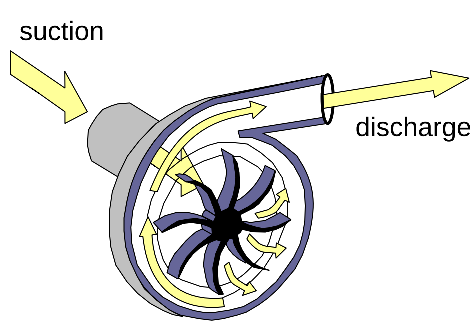
Centrifugal Pumps

- 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



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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 $\Delta p = p_{discharge} - p_{suction}$ on the suction/discharge system

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Discuss now

System Curve Assignment (week 9)

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

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Pumping Head Lab (week 12)

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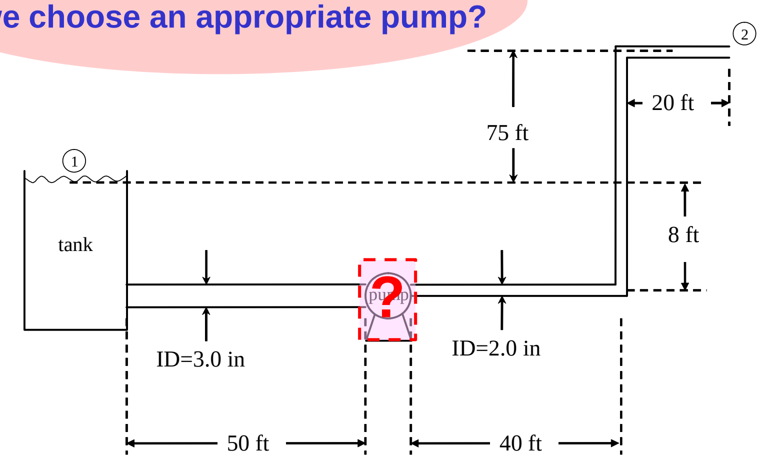
Before a system is built, how can we choose an appropriate pump?



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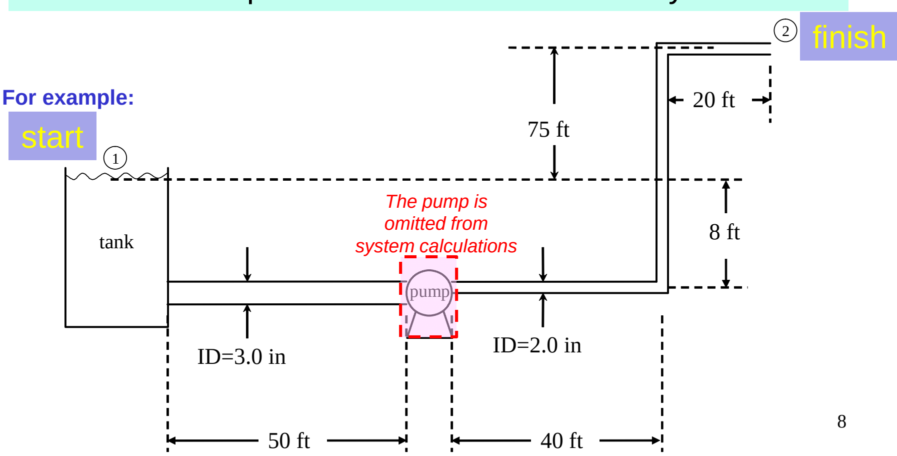
Mechanical Energy Balance

Demand

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:



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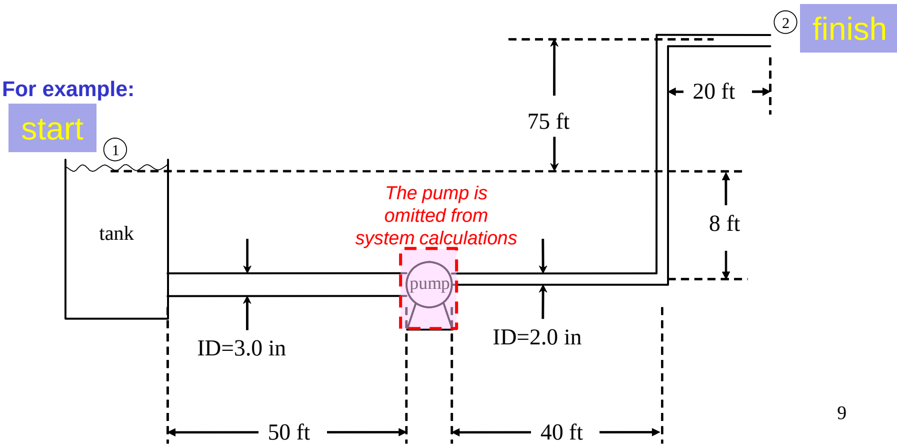
System Head - MEB written on total system, excluding pump

$$\underbrace{\frac{\Delta P}{\rho g}+\frac{\Delta\left(v^2\right)}{2g\alpha}+\Delta z+\frac{F_{friction}}{g}}_{\text{DEMAND}} = \underbrace{\frac{W_{s,on}}{\dot{m}g}}_{\text{SUPPLY}}$$

Demand

$$\frac{\Delta P}{\rho g}+\frac{\Delta\left(v^2\right)}{2g\alpha}+\Delta z+\frac{F_{friction}}{g}=H_{system}$$

For example:



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System Head ≡ MEB written on total system, excluding pump

Demand

$$H_{system} \equiv \frac{\Delta p}{\rho g}+\frac{\Delta\langle v\rangle^2}{2g\alpha}+\Delta z+\frac{F_{friction}}{g}$$

$$H_{system} \equiv \frac{p_{finish}-p_{start}}{\rho g}+\frac{\langle v\rangle^2_{finish}-\langle v\rangle^2_{start}}{2g\alpha}+\left(z_{finish}-z_{start}\right)+\frac{F_{finish,start}}{g}$$

For a system that is not yet built, how can we estimate the frictional loads that must be overcome by the pump?

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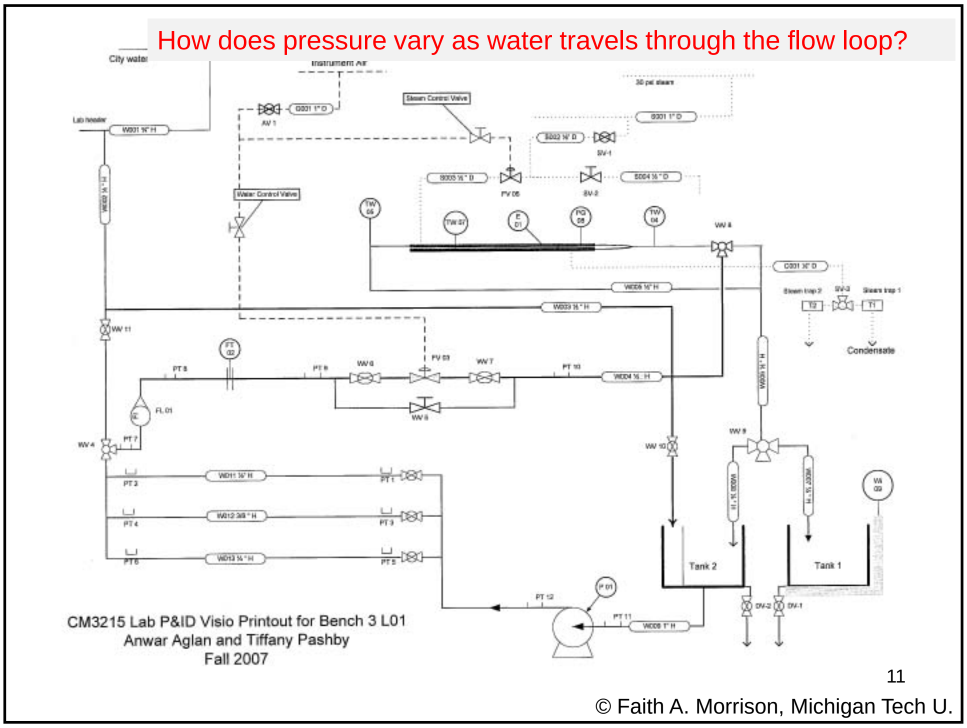
How does pressure vary as water travels through the flow loop?
City water
Tank 2
Tank 1
Condensate
CM3215 Lab P&ID Visio Printout for Bench 3 L01
Anwar Aglan and Tiffany Pashby
Fall 2007
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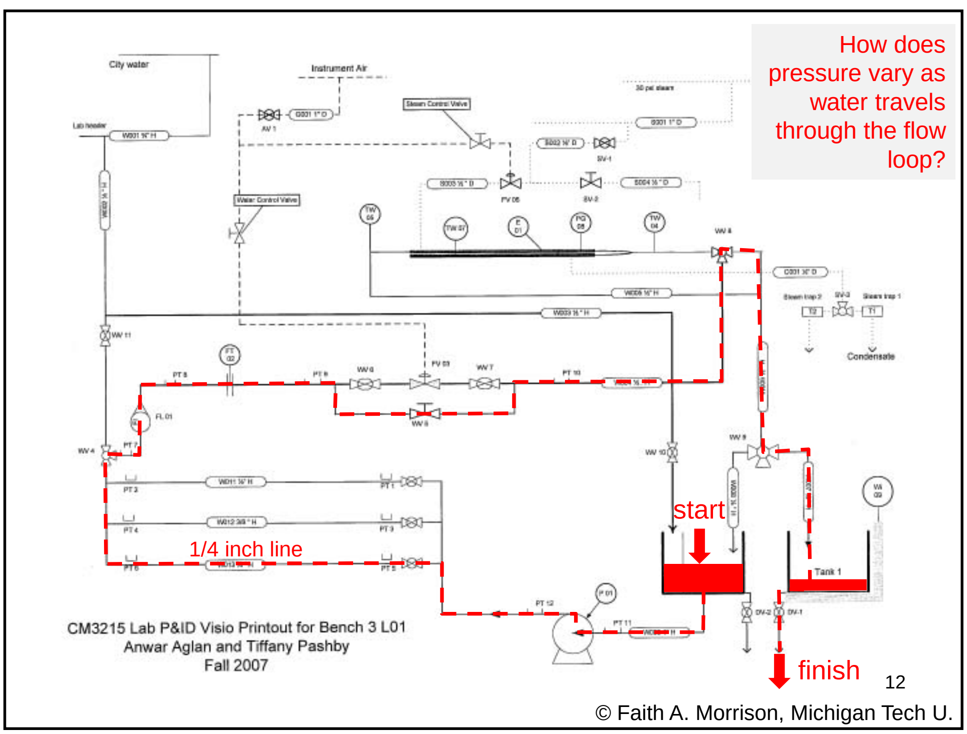
How does pressure vary as water travels through the flow loop?
City water
Instrument Air
start
1/4 inch line
Tank 1
Condensate
finish
CM3215 Lab P&ID Visio Printout for Bench 3 L01
Anwar Aglan and Tiffany Pashby
Fall 2007
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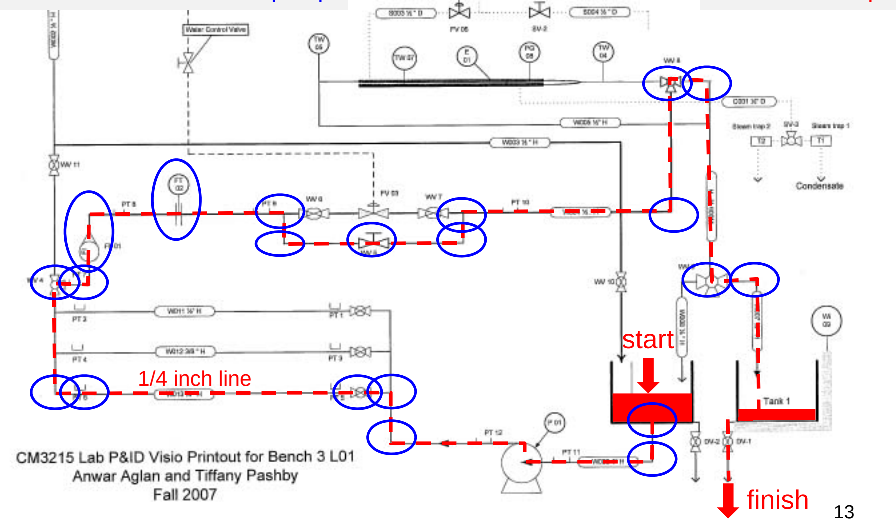
Each fitting, bend, device contributes pressure drop (friction loss) which together comprise the system demand on the pump.

How does pressure vary as water travels through the flow loop?



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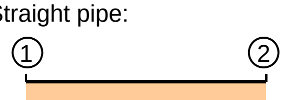
Apply MEB to Fittings, Straight Pipe

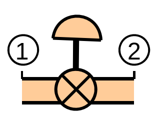
MEB on the "1"- "2" system

Straight pipe:



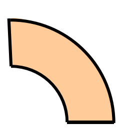
$$\frac{\Delta p}{\rho g} + \frac{\Delta\langle v\rangle^2}{2g\alpha} + \Delta z + \frac{F_{friction}}{g} = \frac{W_{s,on}}{\dot{m}g}$$

valve:



$$\frac{\Delta p}{\rho g} + \frac{\Delta\langle v\rangle^2}{2g\alpha} + \Delta z + \frac{F_{friction}}{g} = \frac{W_{s,on}}{\dot{m}g}$$

90^0 bend:



$$\frac{\Delta p}{\rho g} + \frac{\Delta\langle v\rangle^2}{2g\alpha} + \Delta z + \frac{F_{friction}}{g} = \frac{W_{s,on}}{\dot{m}g}$$

etc.

Friction manifests as $\Delta p/\rho g$ for each fitting or pipe, which can be added up

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

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System Head ≡ MEB written on total system, excluding pump

Demand

$$H_{system} \equiv \frac{\Delta p}{\rho g} + \frac{\Delta \langle v \rangle^2}{2g\alpha} + \Delta z + \frac{F_{friction}}{g}$$

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

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

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Friction in Fittings, Straight Pipe: Data Correlations from Literature

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

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

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

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

$$= \left(4f\frac{L}{D} + \sum_{i\ fittings} K_{f_i} n_i\right)\frac{\langle v \rangle^2}{2g}$$

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

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

Why Study Fluid Mechanics?

Table 1.4. Published friction-loss factors for turbulent flow through valves, fittings, expansions, and contractions

Fitting	Friction-loss factor, K_f
Standard elbow, 45°	0.35
Standard elbow, 90°	0.75
Tee used as ell	1.0
Tee, branch blanked off	0.4
Return bend	1.5
Coupling	0.04
Union	0.04
Gate valve, wide open	0.17
Gate valve, half open	4.5
Globe valve, bevel seat, wide open	6.0
Globe valve, bevel seat, half open	9.5
Check valve, ball	70.0
Check valve, swing	2.0
Water meter, disk	7.0
Expansion from A_1 to A_2	$\left(1-\frac{A_1}{A_2}\right)^2$
Contraction from A_1 to A_2	$0.55\left(1-\frac{A_2}{A_1}\right)$

Source: Perry's Handbook [132]

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Data correlation for friction factor Δp versus Re (flow rate) in a pipe

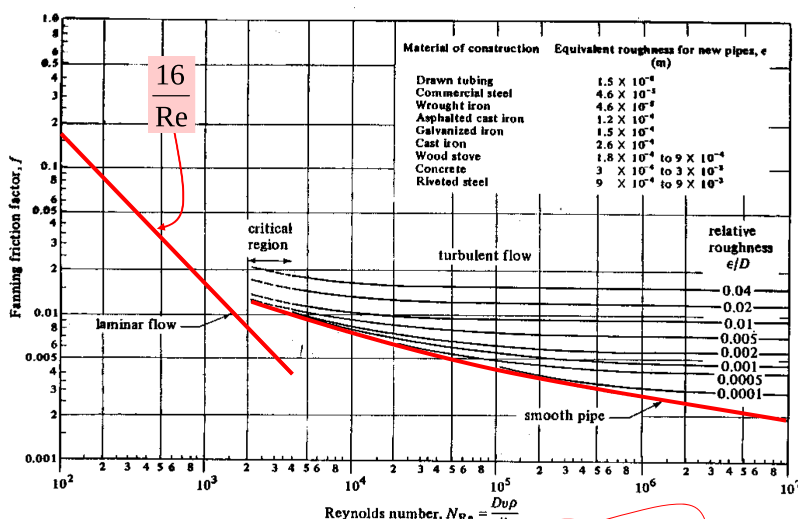

FIGURE 2.10-3. *Friction factors for fluids inside pipes.* [Based on L. F. Moody, *Trans. A.S.M.E.*, **66**, 671, (1944); *Mech. Eng.* **69**, 1005 (1947). With permission.]

Moody Chart

(Geankoplis)

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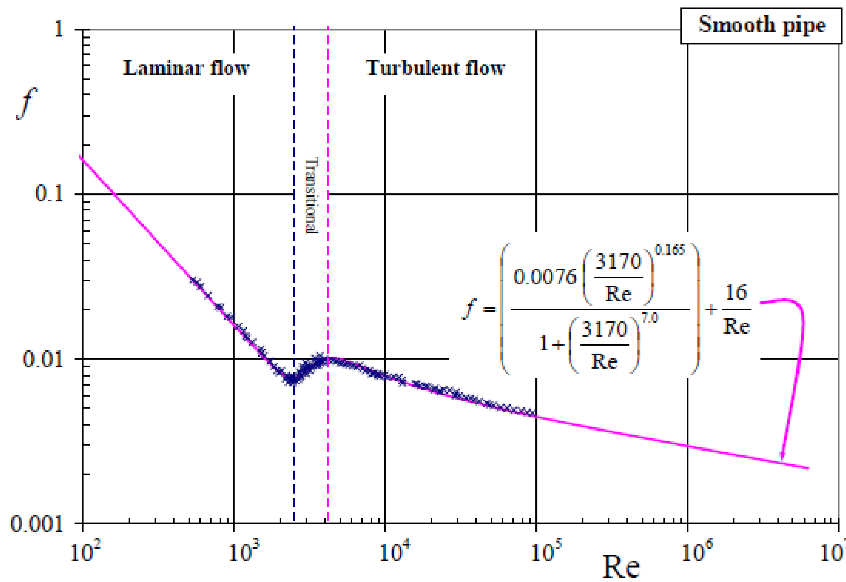

Reference: *Morrison, Faith A, An Introduction to Fluid Mechanics, Cambridge University Press, 2013, Figure 7.18, page 532.*

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System Head - MEB written on total system, excluding pump

Demand

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

Some terms go as Q^2

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

(slight additional Q dependence)

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

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System Head - MEB written on total system, excluding pump

Demand

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

Some terms go as Q^0

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

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

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System Head - MEB written on total system, excluding pump

Demand

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

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

$$H_{system} = aQ^2 + b$$

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

$H_{system}(Q)$ 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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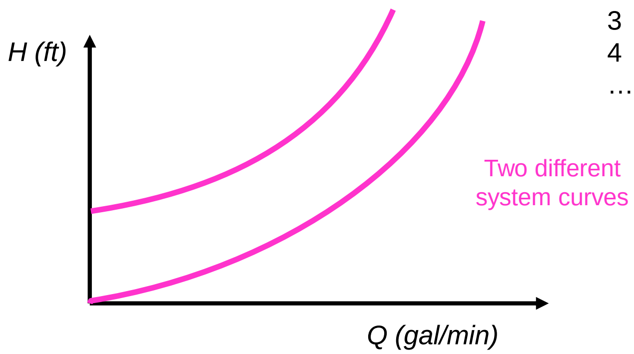
System Head - MEB written on total system, excluding pump

Demand

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

$$H_{system} = aQ^2 + b$$

$Q(gpm)$	$H_{system}(ft)$
1	0.003
2	4.5
3	10.8
4	39
…	…



DEMAND

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

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)

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Demand

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 10:05am** 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 predict the performance of a particular

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What's this good for?

(choosing pumps)

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How do we use the system head curve to choose a pump?

Plot this versus Q

$$H_{system} = \frac{W_{s,on}}{\dot{m}g} \equiv H_{pump}$$

Obtain this versus Q from the manufacturer

$$\underbrace{\frac{\Delta P}{\rho g} + \frac{\Delta(v^2)}{2g\alpha} + \Delta z + \frac{F_{friction}}{g}}_{} = \frac{W_{s,on}}{\dot{m}g}$$

All the contributions to load on the pump = H_{sys}, system head

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

DEMAND | **SUPPLY**

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

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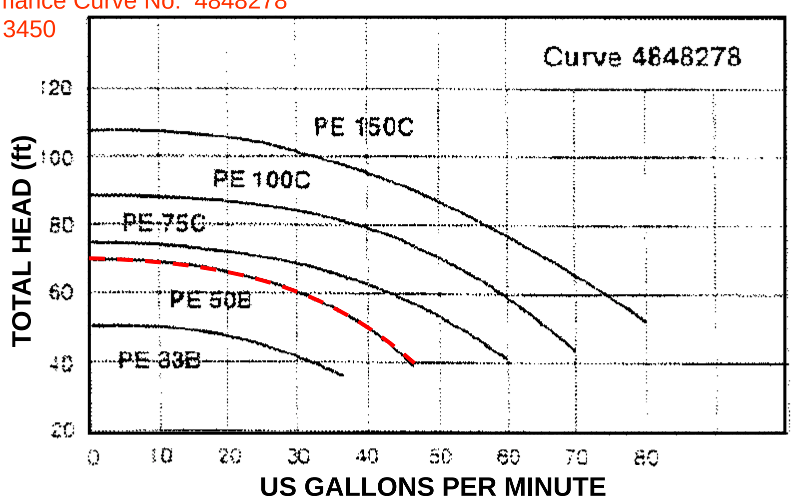
Krum Pump Company
Kalamazoo, MI
Model: Peerless pump
Type: PE50B
Performance Curve No: 4848278
RPM: 3450

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



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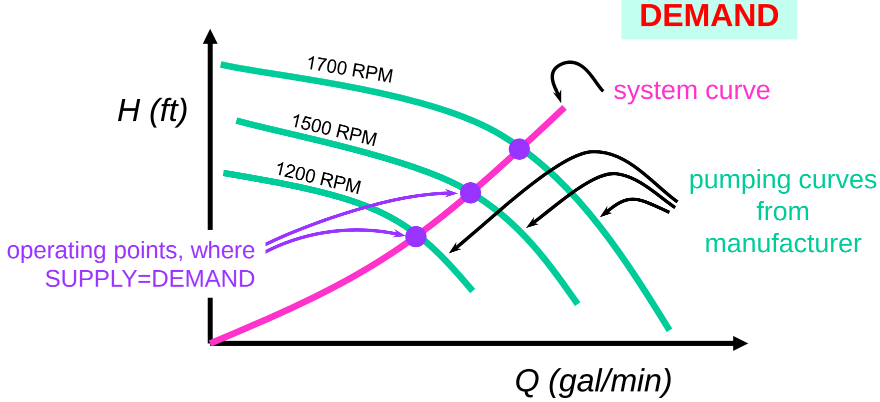
Sizing a Pump

SUPPLY meets 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

Take the role of the user

Pumping Head Lab (week 12)

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

Assignment 6: Prepare to choose a pump for a system

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System Curve Assignment (week 9; due Monday after break)

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

Take the role of the manufacturer

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 $\Delta p = p_{discharge} - p_{suction}$ on the suction/discharge system

WEEK 12

Report 6: Characterize a laboratory pump

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