CM3215

Fundamentals of Chemical Engineering Laboratory

MichiganTech

Pumping System Curves

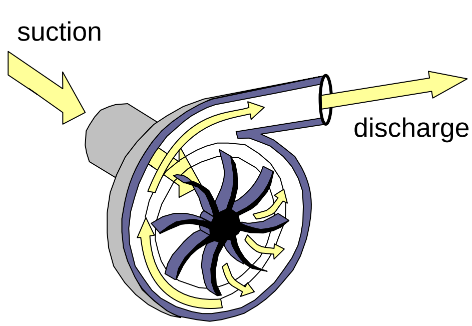
Professor Faith Morrison

Department of Chemical Engineering
Michigan Technological University

1

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



2

CM3215 Fundamentals of Chemical Engineering Laboratory

System Curve Assignment (week 9; due Wed 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

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

3

CM3215 Fundamentals of Chemical Engineering Laboratory

Discuss now

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

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

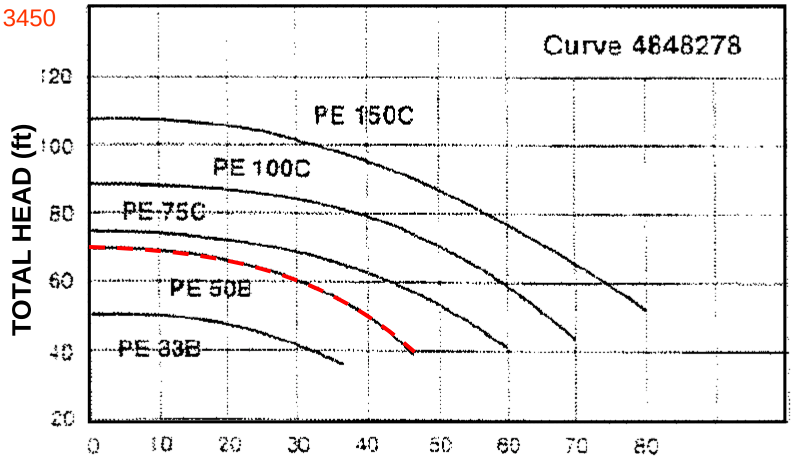
- Calculate the flow-rate-dependent **demands** of a system = **system head curve** (this assignment)
- Compare the system-head curve (demands) to the available pumping-head curve (**supply**), and choose the right pump

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

4

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



5

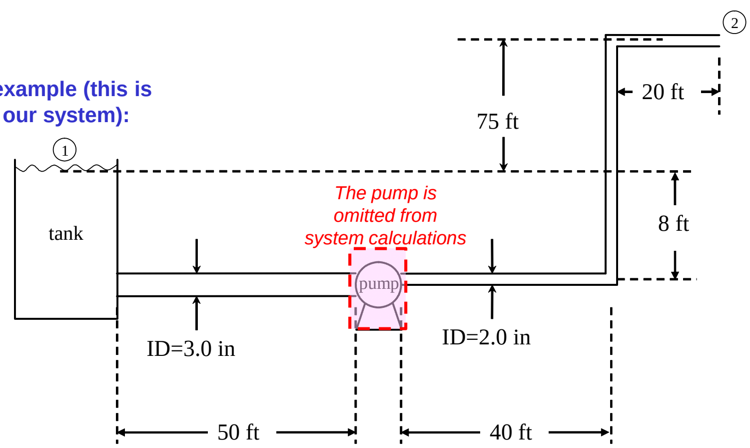
System Head - MEB written on total system, excluding pump

DEMAND

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

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

For example (this is NOT our system):

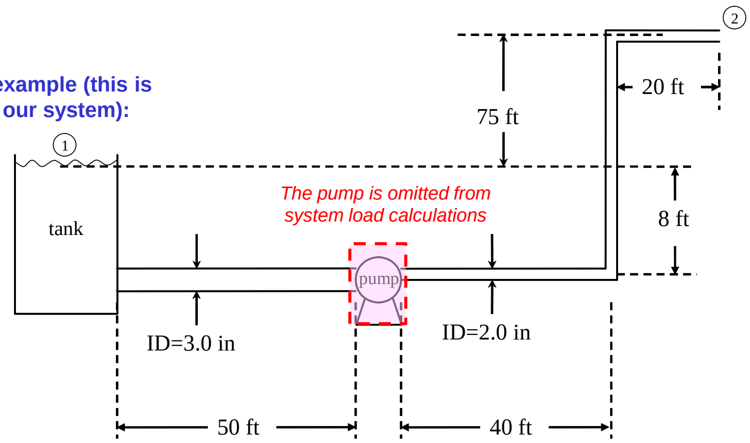


6

System Head - MEB written on total system, excluding pump

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 (this is NOT our system):



7

System Head - MEB written on total system, excluding pump

DEMAND

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

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

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

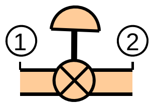
8

MEB on Fittings and Straight Pipe

Straight pipe:

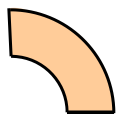
$$\frac{\Delta p}{\rho g}+\frac{\Delta\langle v\rangle^2}{2g\alpha}+\Delta z+\frac{F_{friction}}{g}=\frac{W_{s,on}}{\dot{m}g}$$

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.

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

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

9

System Head - MEB written on total system, excluding pump

DEMAND

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

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

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

10

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 $\langle v \rangle$

11

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

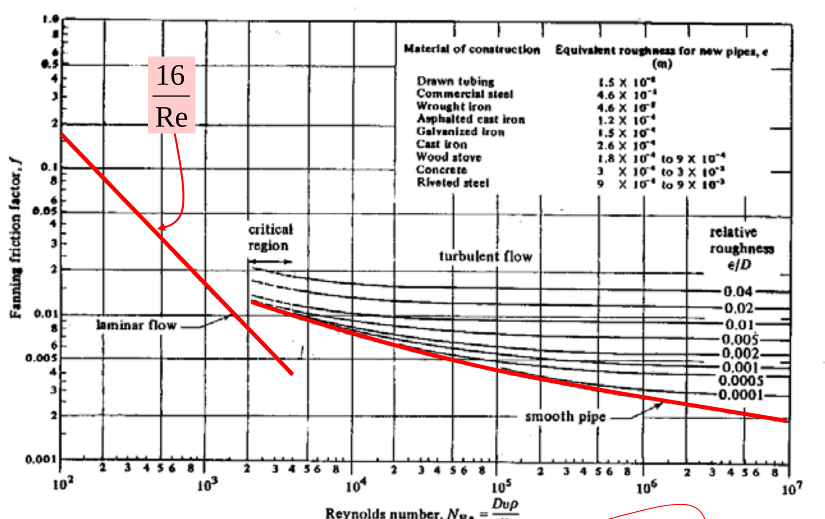
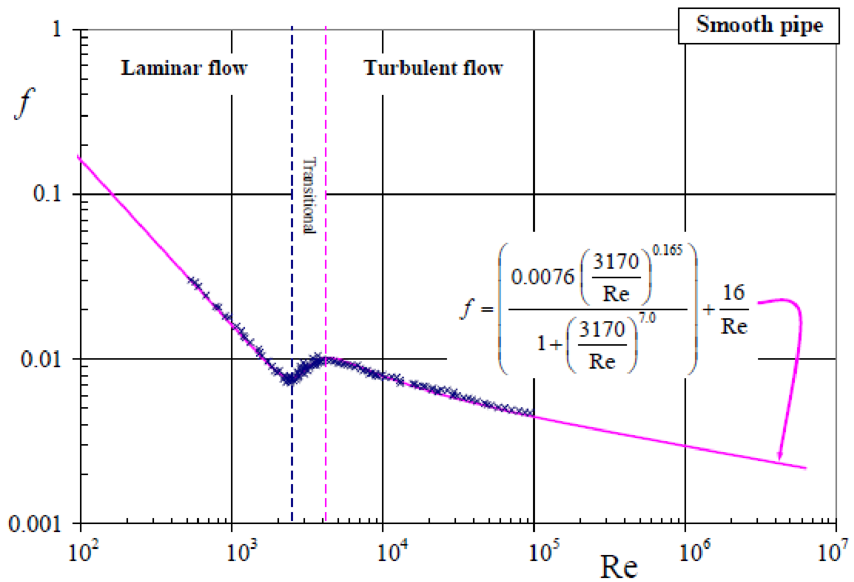


FIGURE 2.10-3. *Friction factors for fluids inside pipes. [Based on L. F. Moody, Trans. A.S.M.E., 66, 671, (1944); Mech. Eng. 69, 1005 (1947). With permission.]*

Moody Chart

(Geankoplis)

12



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

13

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)

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

14

System Head - MEB written on total system, excluding pump

DEMAND

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

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

Some terms go as Q^0

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

15

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

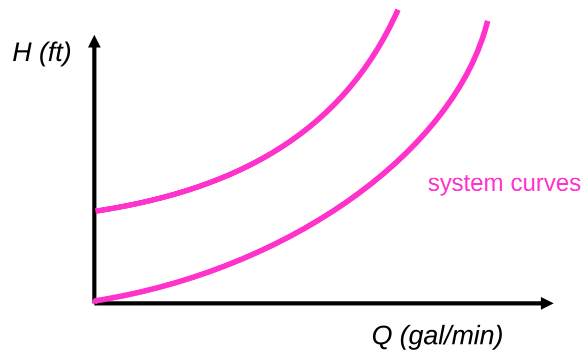
16

System Head - MEB written on total system, excluding pump

DEMAND

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

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



17

DEMAND

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

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)

18

CM3215 Fundamentals of Chemical Engineering Laboratory

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 Krum centrifugal pump (point B). Include the sizes and locations of all valves, pressure taps, thermo wells,

CM3215 Fundamentals of Chemical Engineering Laboratory

What's this good for?

(choosing pumps)

20

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

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

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**

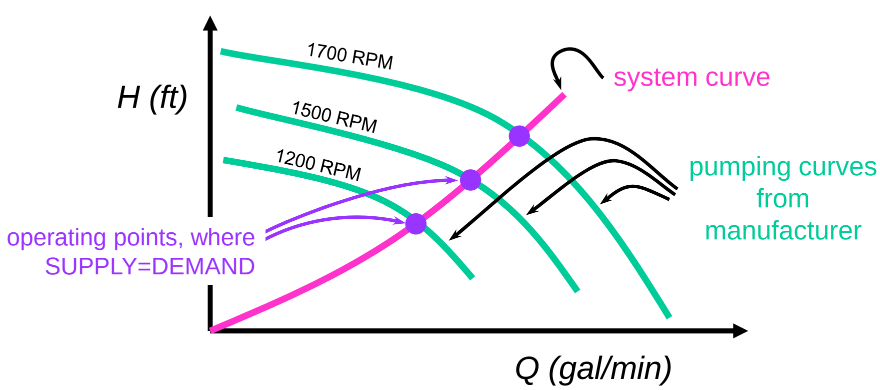
Where the two intersect, that's where the pump operates.

21

CM3215 Fundamentals of Chemical Engineering Laboratory

Sizing a Pump

SUPPLY



22

CM3215 Fundamentals of Chemical Engineering Laboratory

THIS WEEK

System Curve Assignment (week 9; due Wed 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

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

23

CM3215 Fundamentals of Chemical Engineering Laboratory

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

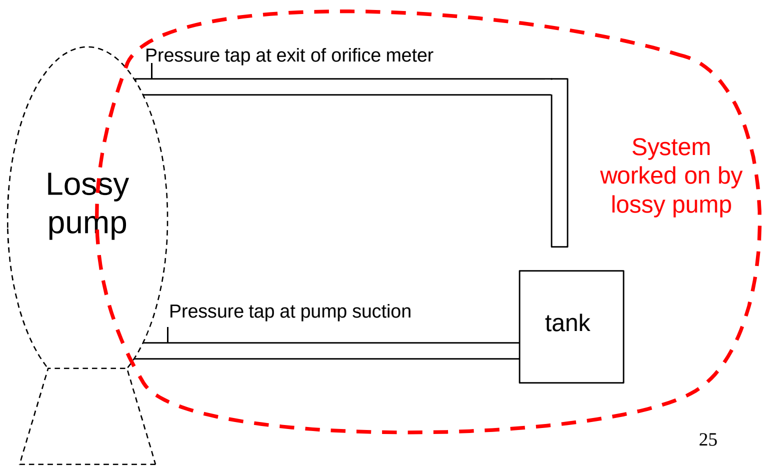
WEEK 10

24

CM3215 Fundamentals of Chemical Engineering Laboratory

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



25