

CAE 464/517 HVAC Systems Design

Spring 2023

April 13, 2023

Hydronic systems: system characteristics and pump selection

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ANNOUNCEMENTS

Announcements

- Assignment 5 is posted (optional)
- A new measurement activity will be posted (optional)
- Anyone opposed to change the exam time?

Announcements

33rd Street Productions
presents

Book by MARKSHALL BRICKMAN and RICK ELICE
Music and Lyrics by ANDREW LIPPA
Orchestrations by LARRY HOCHMAN
Based on Characters Created
by CHARLES ADDAMS



The Addams Family

A NEW MUSICAL
COMEDY

Thursday, April 13th,
7:00 pm

and

Saturday, April 15th,
2:00 pm and 7:00 pm

in the Hermann Hall Auditorium

THE ADDAMS FAMILY A NEW MUSICAL is presented through special arrangement with
and all authorized performance materials are supplied by Theatrical Rights Worldwide.
1180 Avenue of the Americas, Suite 640, New York, NY 11036. www.theatricalrights.com

SAF FUNDED
Free Admission!

RECAP

Recap

- We also sometimes define equivalent length:

$$\text{Head loss in a pipe} = f \frac{L}{D} \frac{V^2}{2g}$$

$$K = f \frac{L}{D}$$

$$\text{Head loss in a fitting} = K \frac{V^2}{2g}$$

- $\frac{L}{D}$ is the equivalent length in pipe diameters of straight pipe that will cause the same pressure drop as the valve or fitting under the same flow conditions

Recap

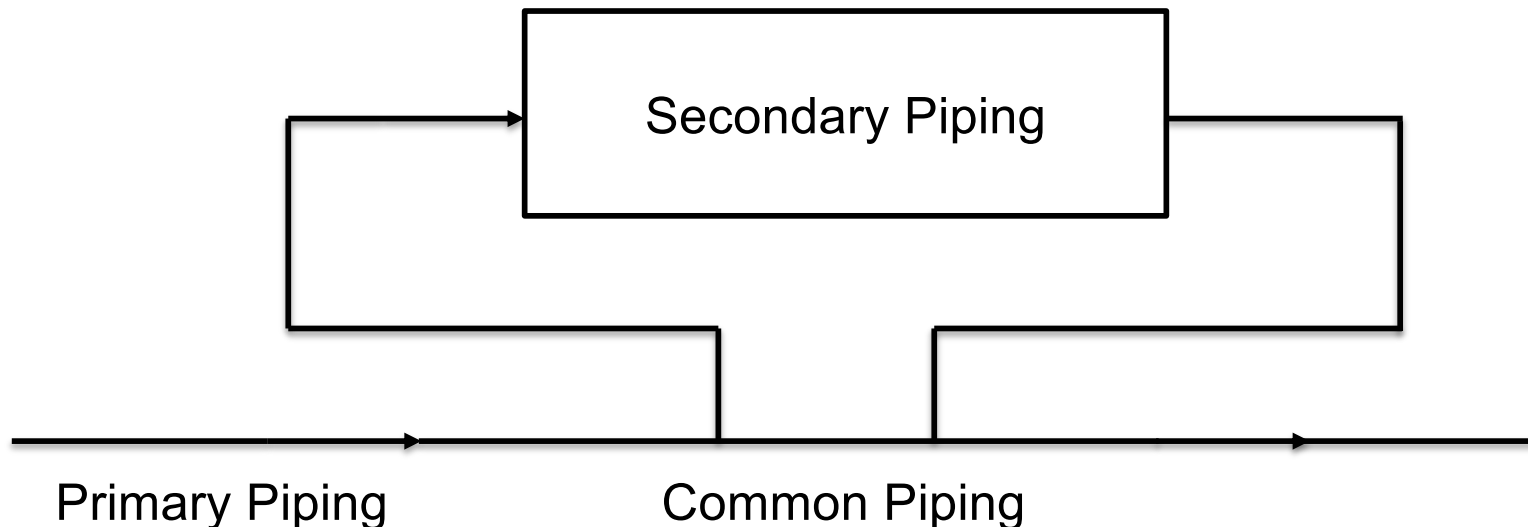
PRIMARY – SECONDARY PUMPING

Primary Secondary Pumping

- Was developed by Bell & Gossett in 1954 as a method to increase system temperature drops, decrease total pump power requirements and increase system controllability
- Systems utilizing low or medium temperatures were allowed due to Primary – Secondary pumping
- Most modern systems utilize some variation of Primary - Secondary pumps

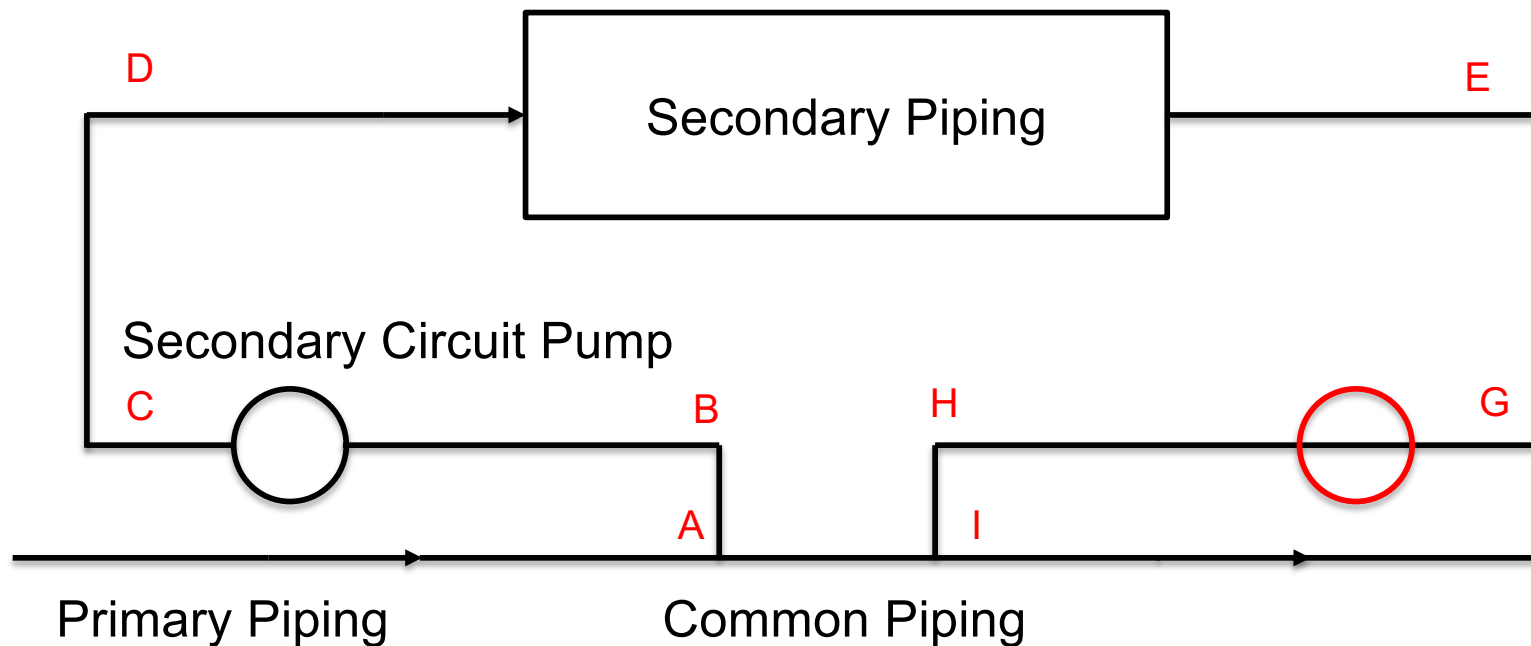
Primary Secondary Pumping

- Common Piping:
 - Interconnects the primary to the secondary circuit
 - Should have minimal to no pressure drop
- Hydraulically disconnects the two piping loops
- Flow in one loop will not cause flow in the other loop



Primary Secondary Pumping

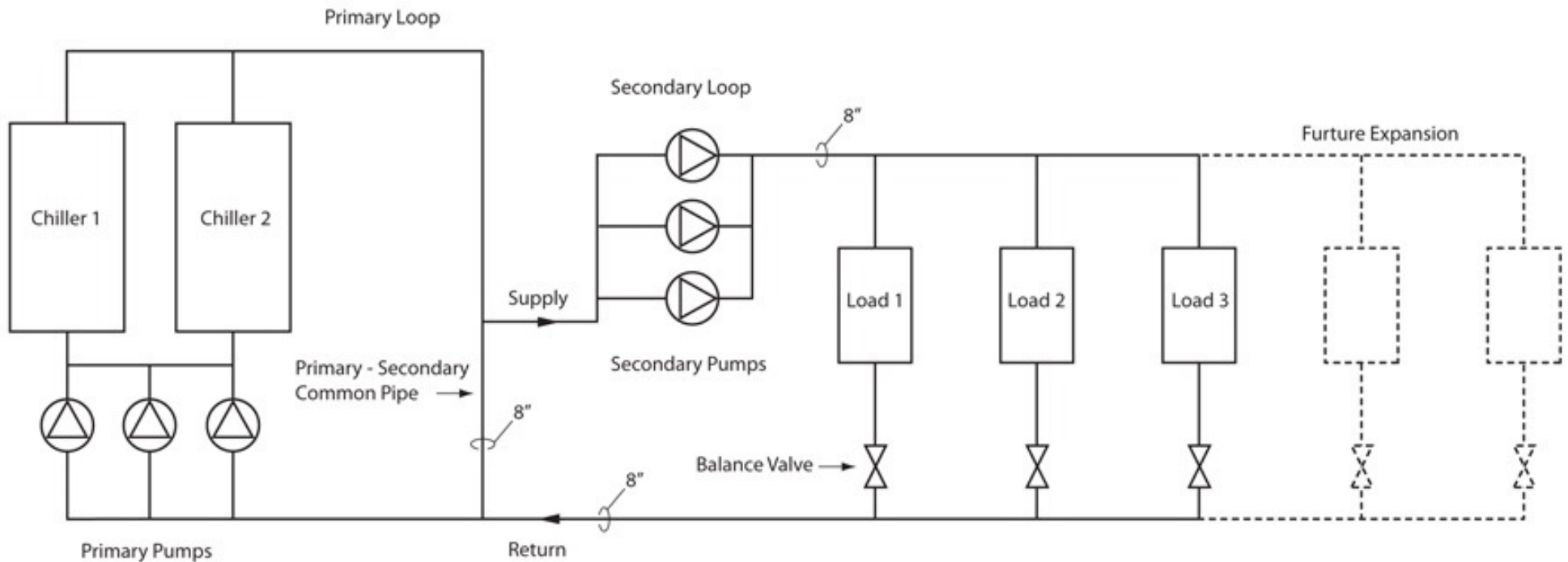
- Secondary pipe pump sized for pressure drops A-B, B-C, C-D, D-E, E-G, G-H, H-I
- I-A should have no pressure drop



Why do not we put the secondary pump at the end of the secondary circuit?

Primary Secondary Pumping

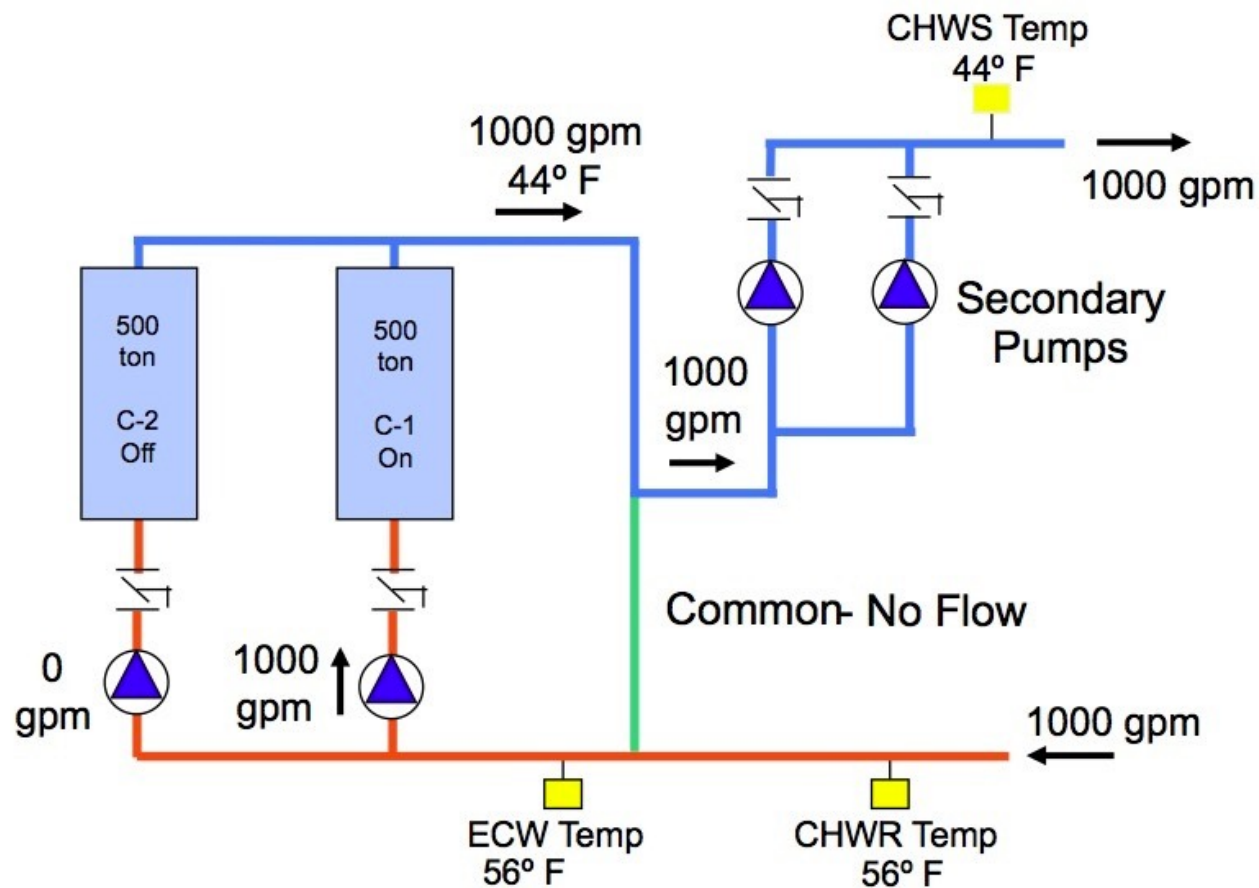
- In hydronic systems, we use this strategy:



Primary Secondary Pumping

- In hydronic systems, we use this strategy:

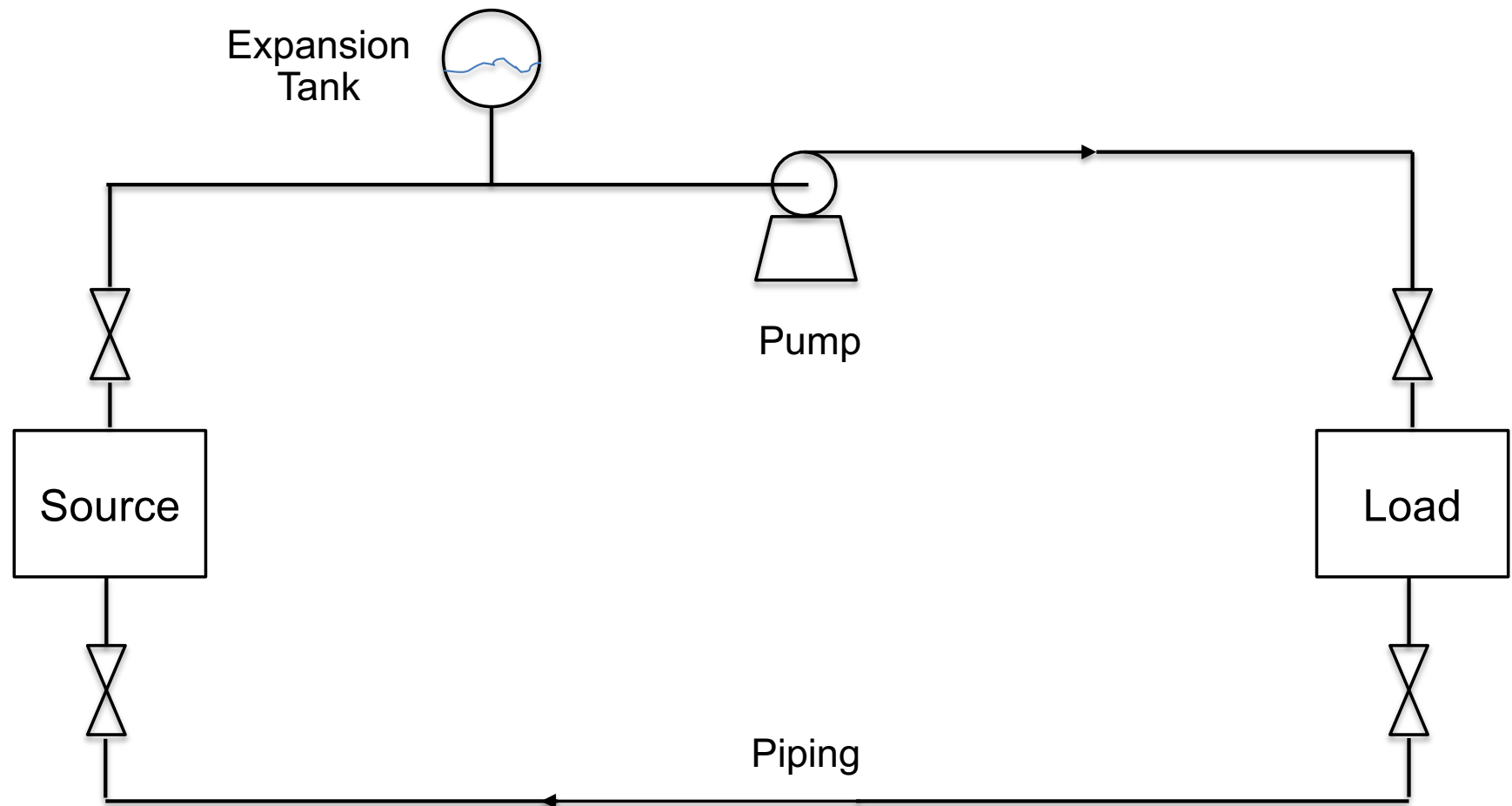
Primary flow equal to secondary flow



PUMPS

Intro to Pumps

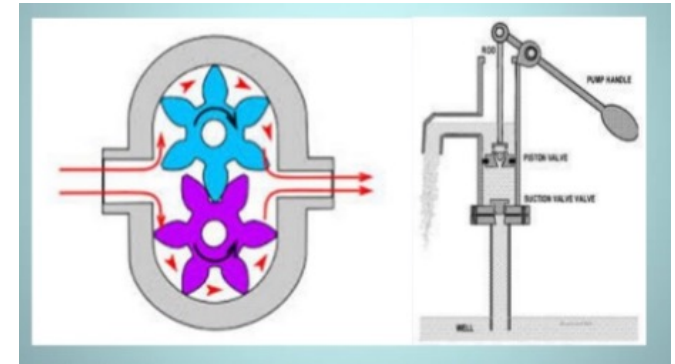
- Pumps provide differential pressure by converting electrical energy to move water



Intro to Pumps

- Positive displacement pumps

- Rotary-type pumps
- Reciprocating-type pump



- Rotodynamic pumps

- Centrifugal pump
 - Radial flow pump
 - Axial flow pump
 - Mixed flow pump

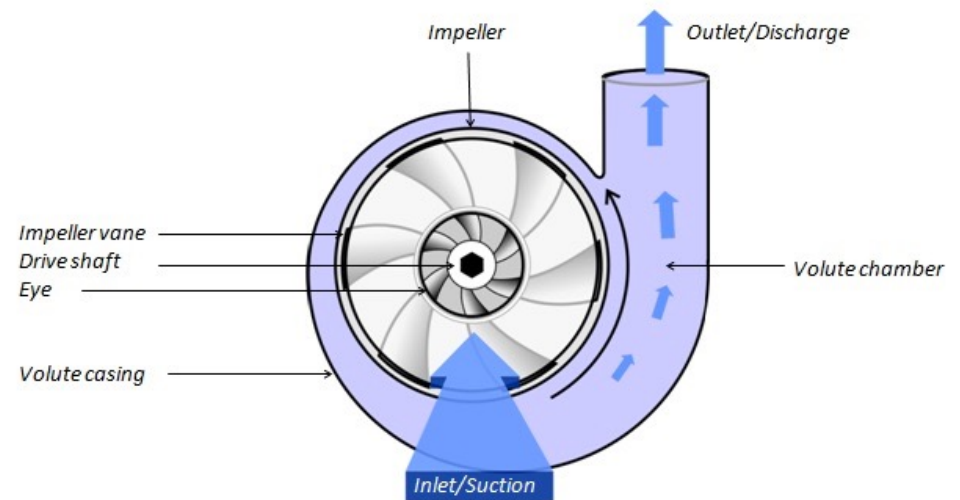
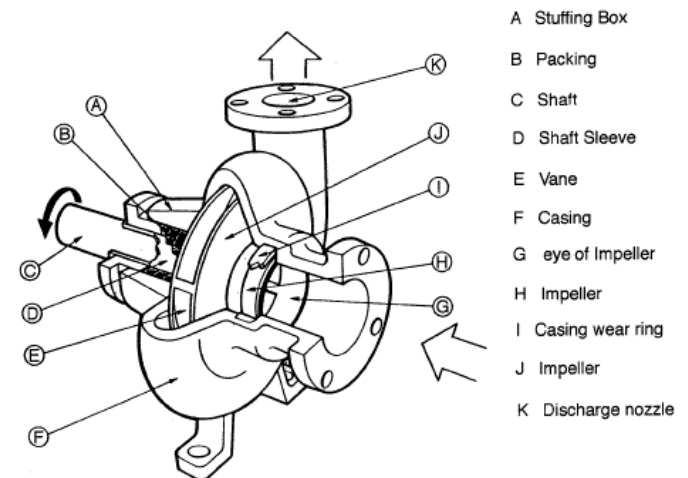
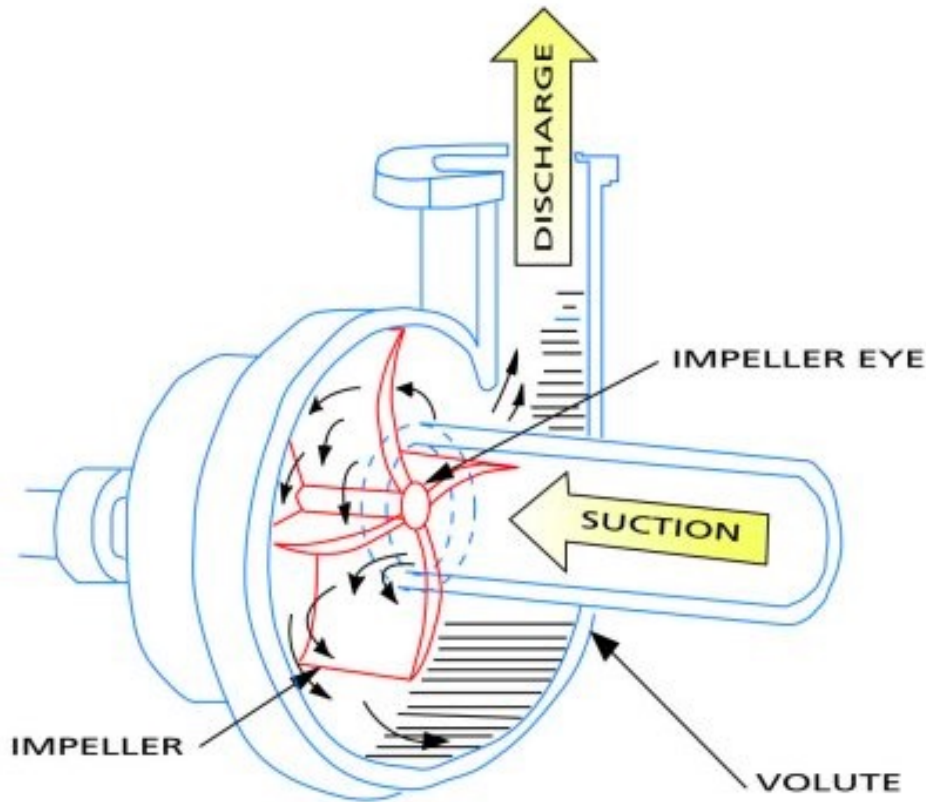


Figure 2. Volute case design

Centrifugal Pumps



Centrifugal Pumps

- Most common use in HVAC industry
 - ❑ Chilled water
 - ❑ Cooling tower

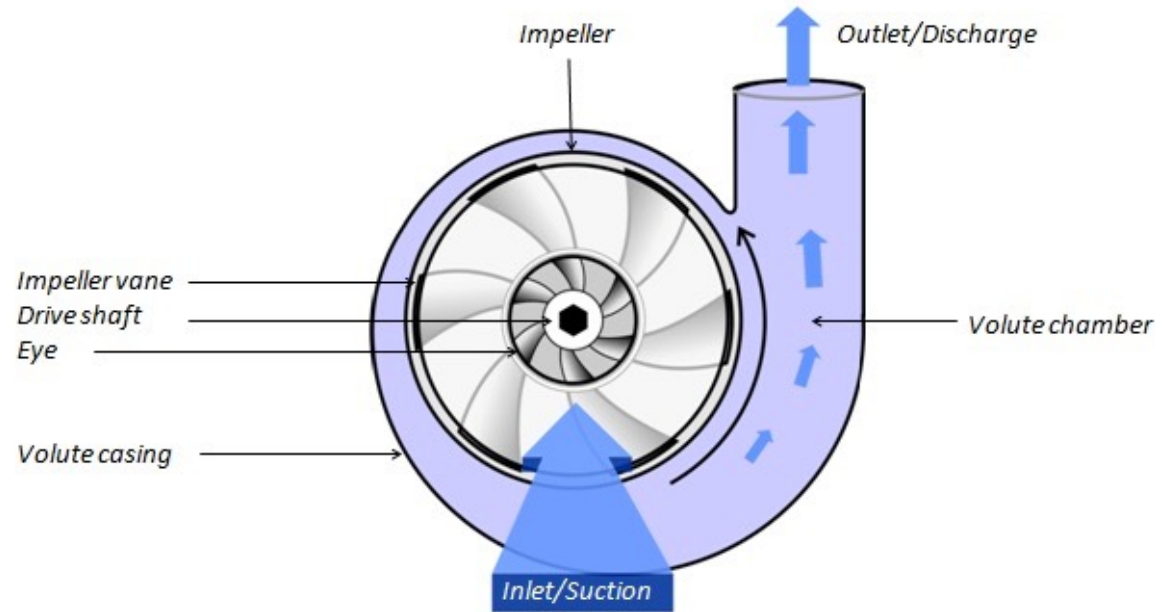


Figure 2. Volute case design

- Basic Principle
 - ❑ Water enters impeller at low velocity & pressure
 - ❑ Water thrown outward by centrifugal force
 - ❑ Water leaves at high velocity & pressure

Centrifugal Pumps

- Impeller types



Figure 1. Impeller Types (l to r): Open, Semi-Enclosed (or Semi-Open), Enclosed.

Centrifugal Pumps

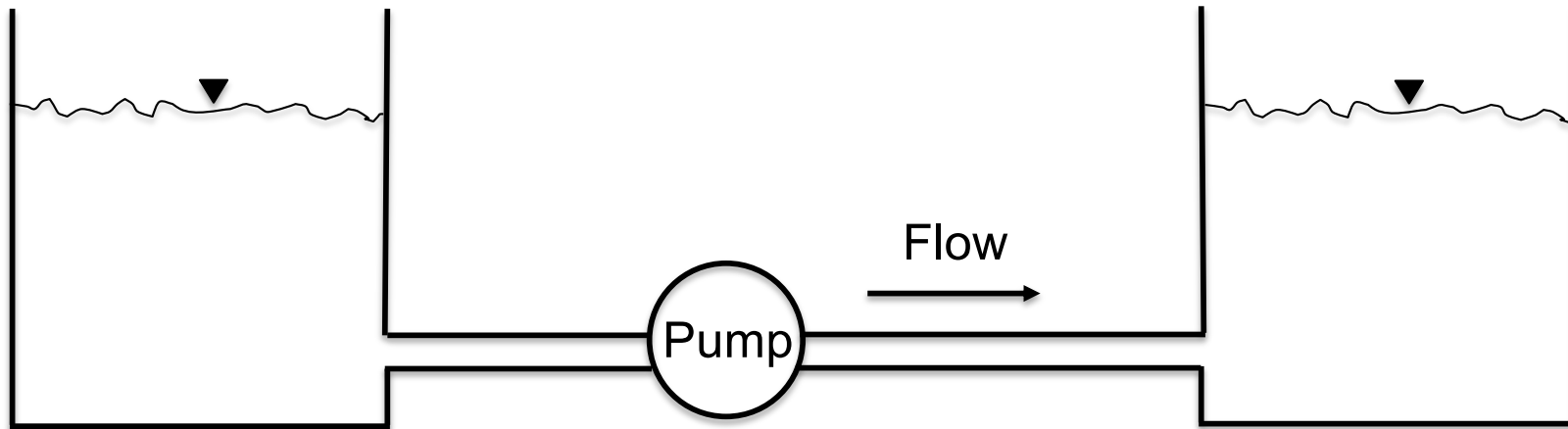
- It needs to be base mounted:



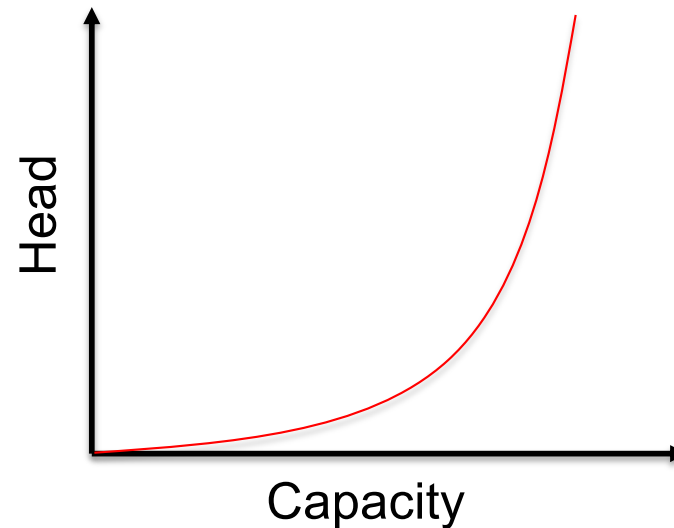
SYSTEM CURVE

System Curve

- Assume there is only friction and no change in elevation (no static lift)

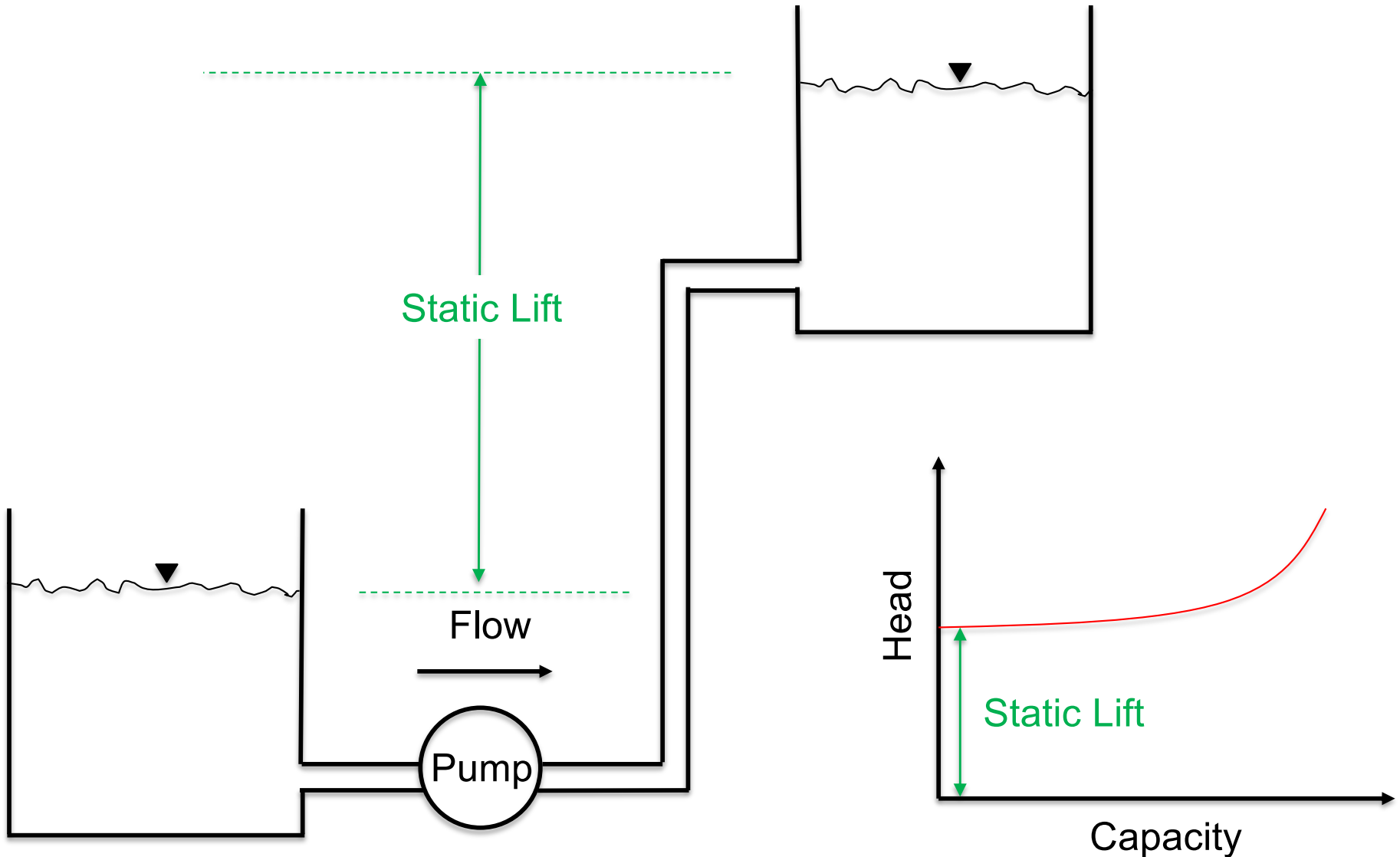


- How is the system curve?



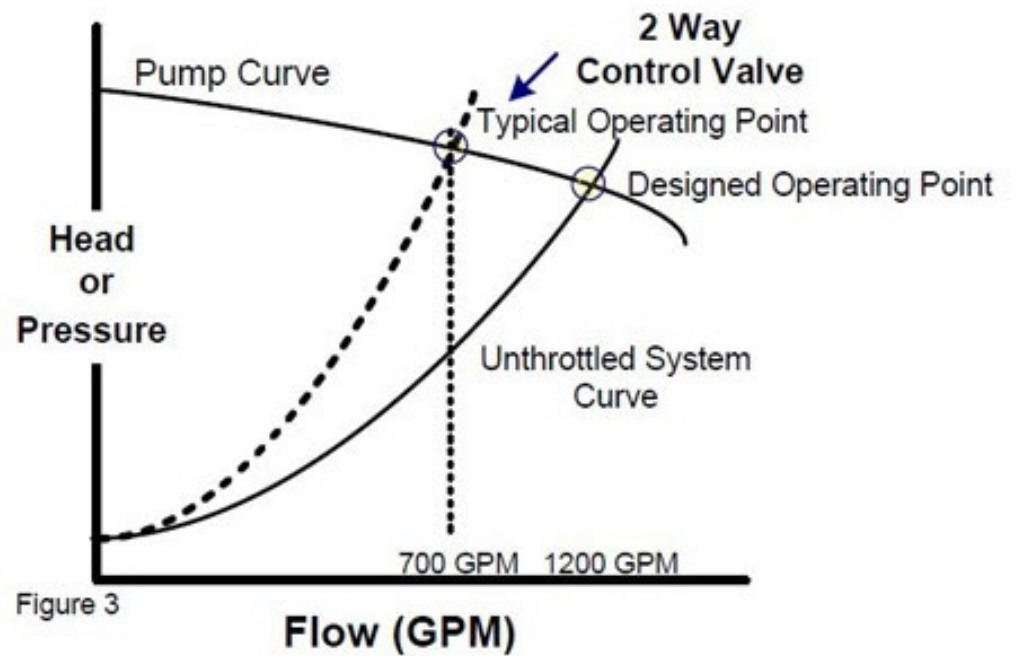
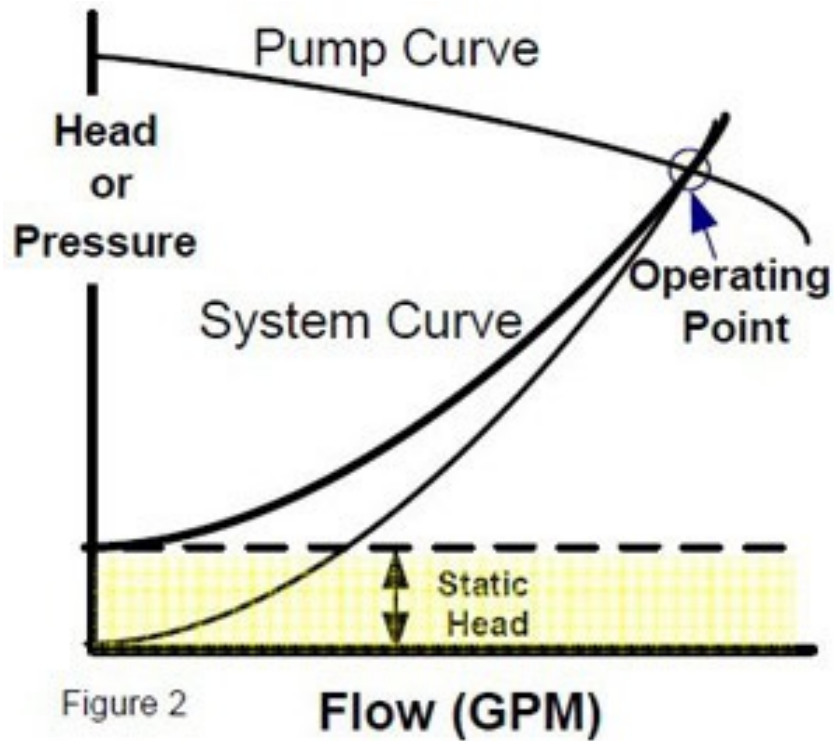
System Curve

- How is the system curve for this one?



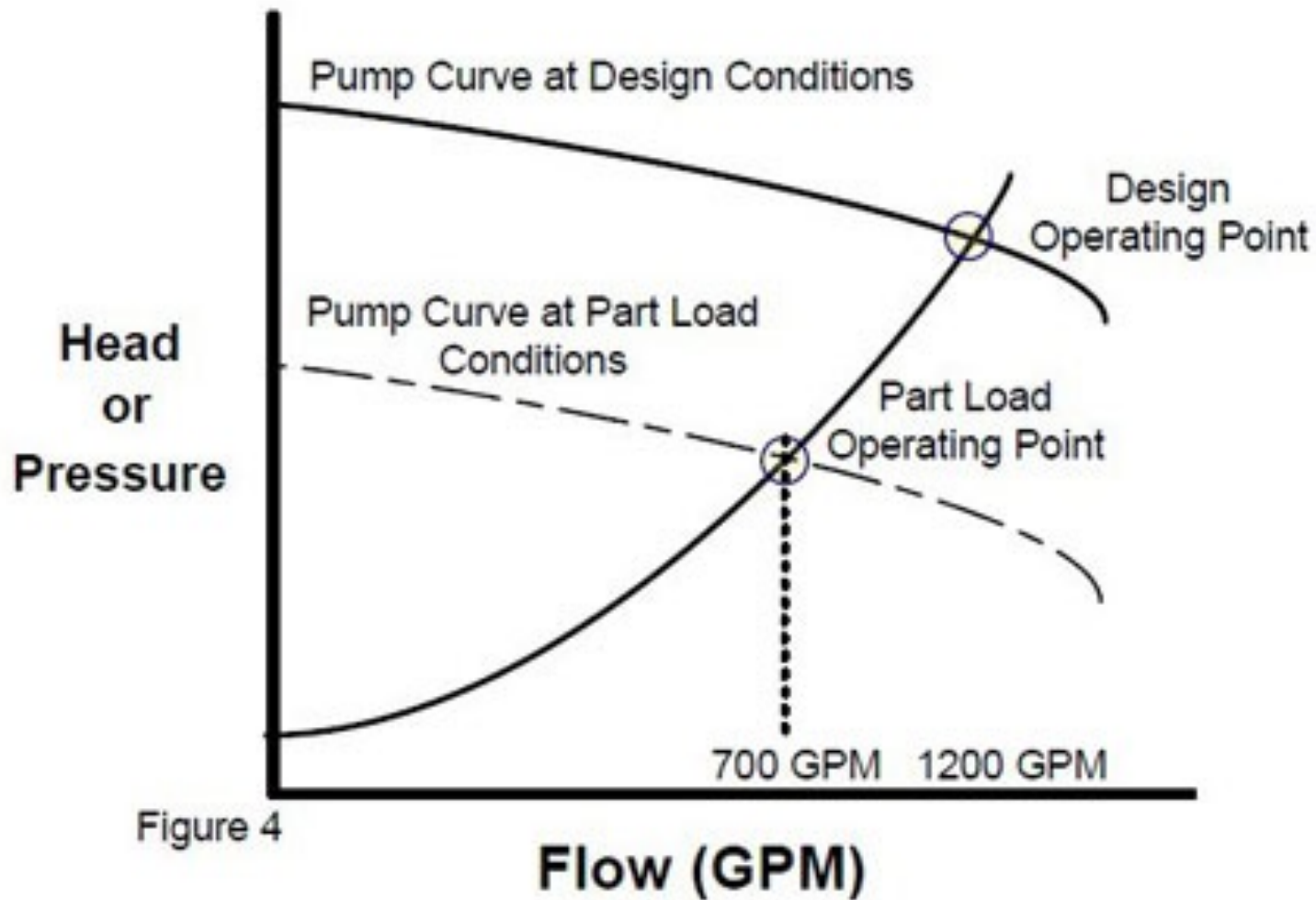
System Curve

- System curve can change over time



System Curve

- System curve can change over time



PUMP SELECTION

Pump Selection

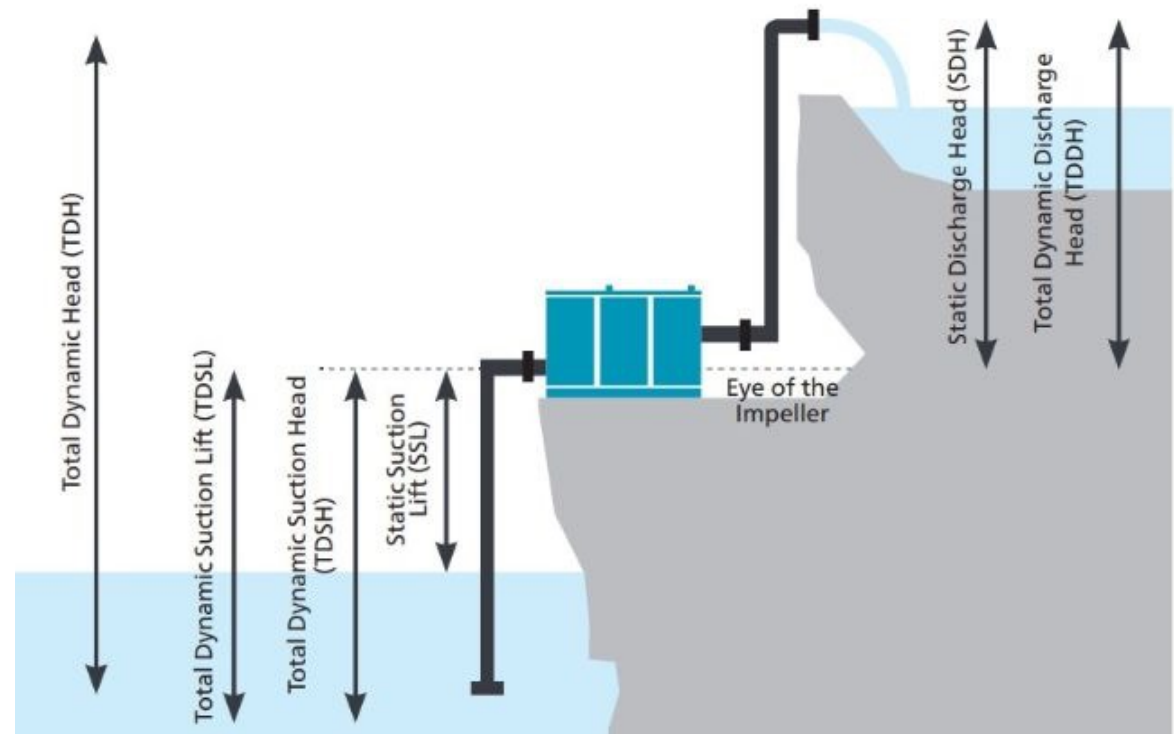
- Capacity
 - ❑ The amount of fluid the pump will move is determined mainly by the width of the impeller and the shaft speed
 - ❑ Capacity is normally measured in gallons per minute

Pump Selection

- Total Dynamic Head (TDH)
 - ❑ The difference in total head between the suction side and the discharge side of the pump
 - ❑ Head is normally measured in feet of fluid flowing (ft.)
 - ❑ Feet of head is a unit of length

$$\begin{aligned} \text{TDSL} &= \text{SSL} + \text{Friction Loss} \\ \text{TDDH} &= \text{SDH} + \text{Friction Loss} \\ \text{TDH} &= \text{TDSL} + \text{TDDH} \end{aligned}$$

$$\text{Head} = \frac{2.3 \times P(\text{in Psi})}{\text{Specific gravity}}$$

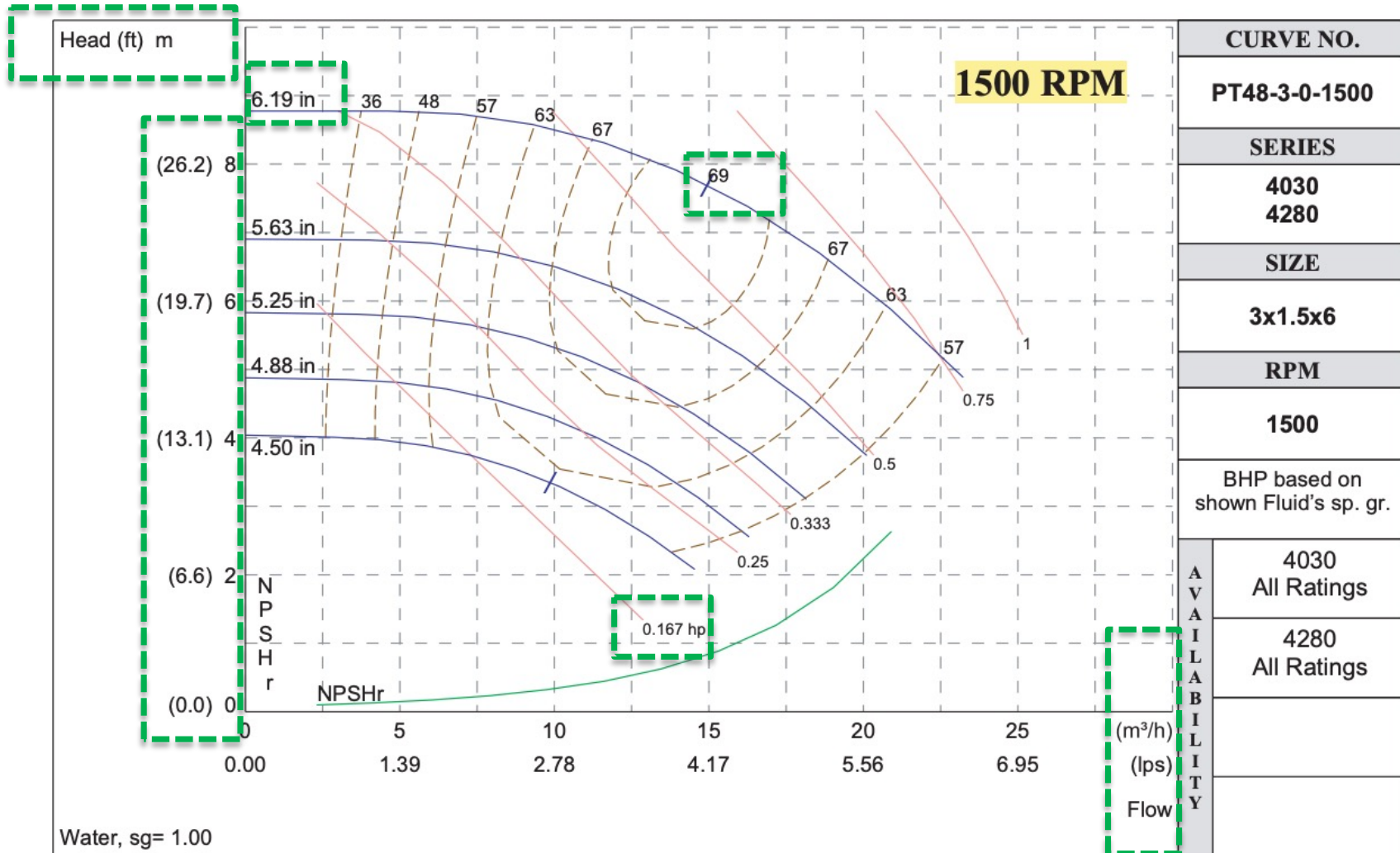


Pump Selection

- Rules:
 - Velocity + Pressure = Constant
 - Velocity \times Area = constant
 - Pressure \times Area = Force

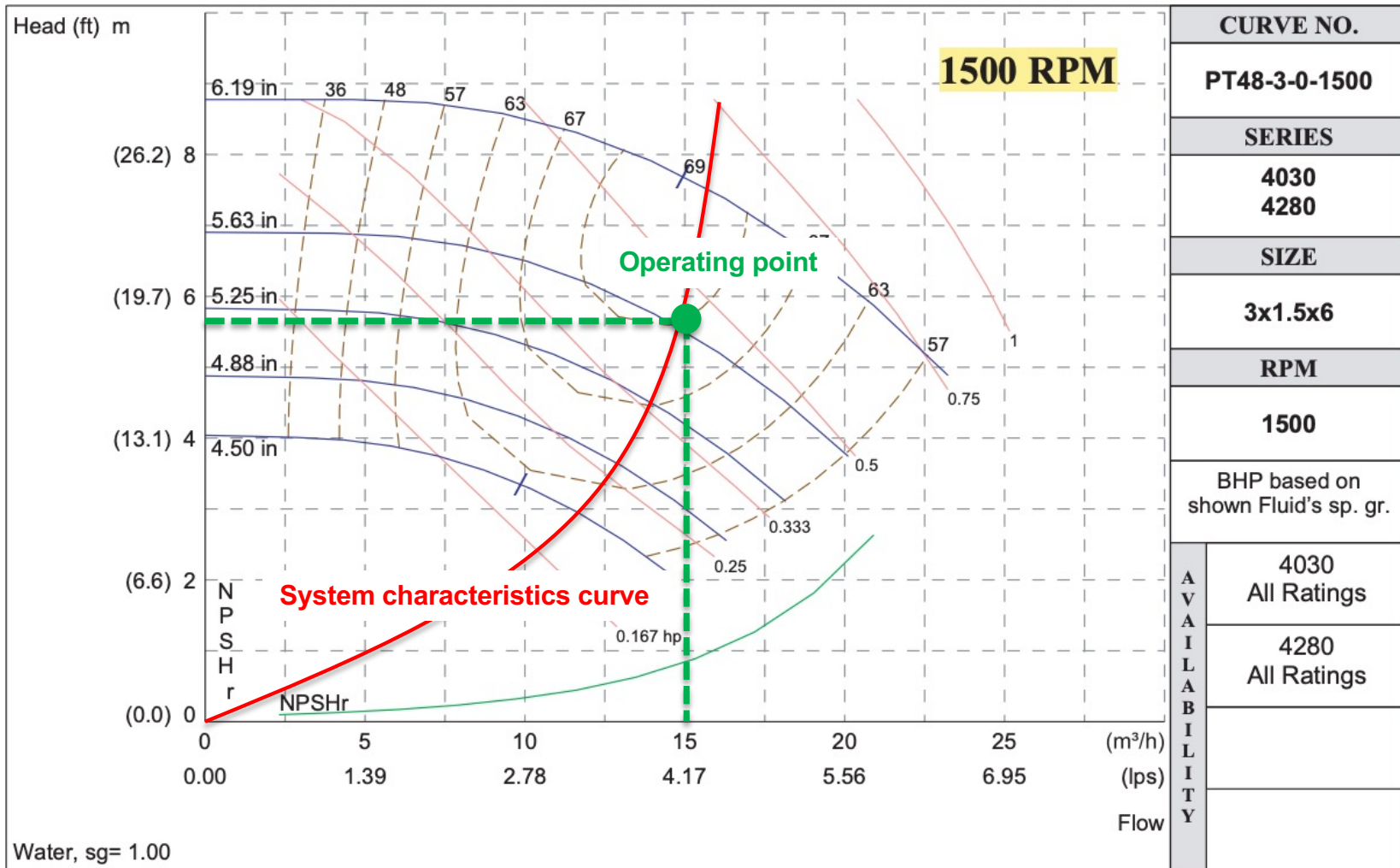
Pump Selection

- Familiarize yourself with the pump curve



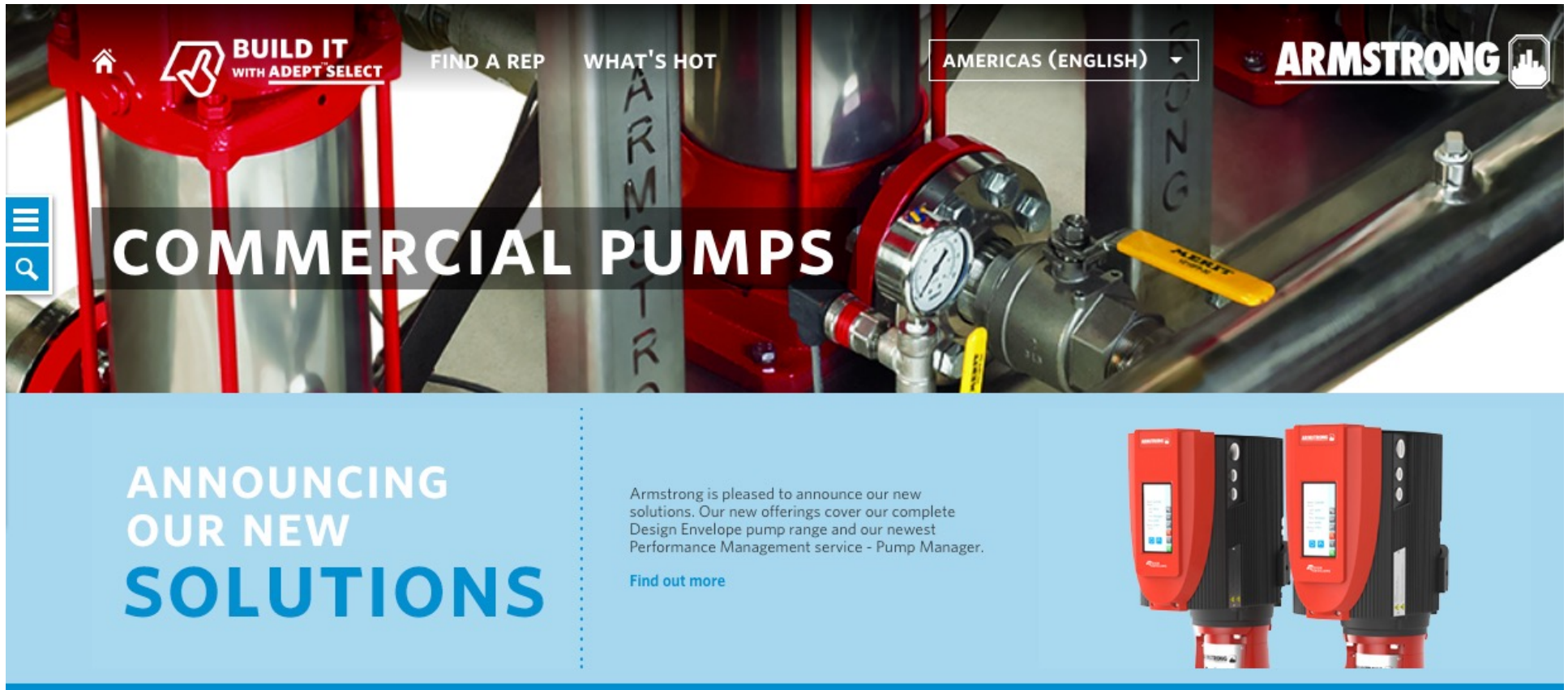
Pump Selection

- Intersect the system characteristics with the fan curve



Pump Selection

- Manufacture 1:



The image is a screenshot of the Armstrong Commercial Pumps website banner. The top section features a navigation bar with a home icon, the text "BUILD IT WITH ADEPT SELECT", "FIND A REP", "WHAT'S HOT", "AMERICAS (ENGLISH)", and the "ARMSTRONG" logo. The main headline reads "COMMERCIAL PUMPS". Below this, the text "ANNOUNCING OUR NEW SOLUTIONS" is displayed in large, bold letters. To the right, a paragraph of text states: "Armstrong is pleased to announce our new solutions. Our new offerings cover our complete Design Envelope pump range and our newest Performance Management service - Pump Manager." Below this text is a link that says "Find out more". On the right side of the banner, two red and black Armstrong pumps are shown. The background of the banner is a close-up photograph of a red and silver commercial pump system with various pipes and valves.

Pump Selection

- Manufacture 1:

ADEPT™ SELECT | FOR YOUR PROJECT SELECTION NEEDS

ADEPT™ Select is an online product selection tool that makes it easy to size and configure Armstrong solutions. With intuitive new screen designs, ADEPT Select is easy for anyone to use on a pc, laptop, tablet or other smart devices and is compatible with all the most popular browsers.

<https://adept.armstrongfluidtechnology.com/armstrongcpq#/Adept/ProductSelection>

Pump Selection

- Manufacture 1:

4280 Motor Mounted Pumps



ARMSTRONG

Benefits & Features

Design & Submittals

Warranty

Installation, Maintenance & Parts

Best-in-class design

- ANSI style centerline discharge casing eliminates casing vapor lock
- Sintered silicon carbide mechanical seal seat for longer life
- Confined casing gasket eliminates blow-outs
- Pre-lubricated and sealed ball bearings for convenient installation (simply pipe, align, wire and start)
- Motor feet mounting only needed with over-hung casing
- Compact design

Learn More

(PDFs)

4280 Motor Mounted Pumps - brochure

[English](#)

[English \(India\)](#)

[English \(United Kingdom\)](#)

[español \(Estados Unidos\)](#)

[português \(Portugal\)](#)

[中文\(中华人民共和国\)](#)

Pump Selection

- Manufacture 1:

4280 Motor Mounted Pumps

Benefits & Features	Design & Submittals	Warranty	
---------------------	--------------------------------	----------	--

Submittals & Forms | **Curves & Diagrams** | Other

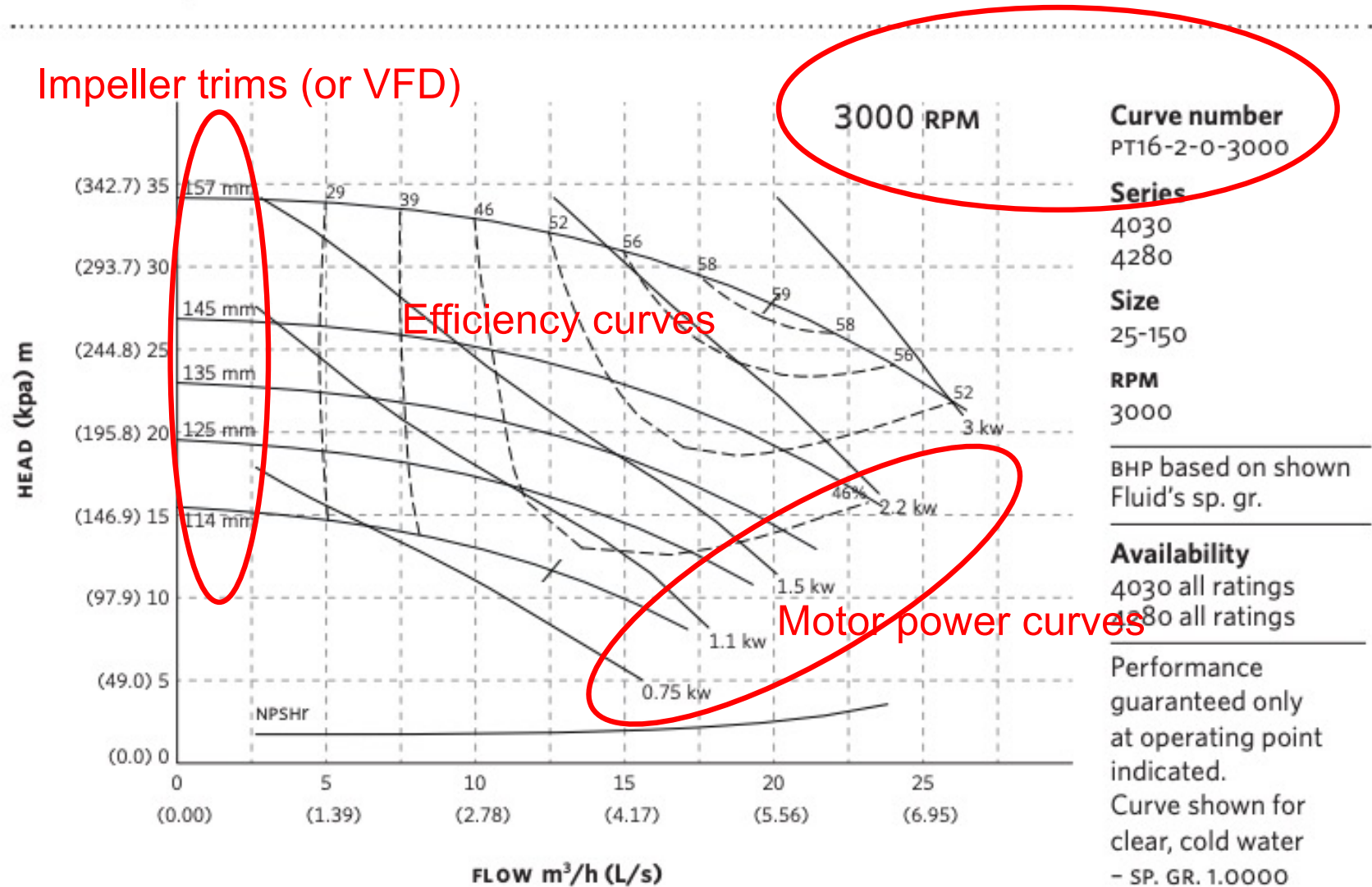
Submittals (50Hz)
(PDF)

- 4280 motor mounted pump, 1.5 x 1 x 6 - 50Hz submittal
- 4280 motor mounted pump, 2 x 1.5 x 6 - 50Hz submittal
- 4280 motor mounted pump, 3 x 2 x 6 - 50Hz submittal
- 4280 motor mounted pump, 3 x 2.5 x 6 - 50Hz submittal
- 4280 motor mounted pump, 4 x 3 x 6 - 50Hz submittal
- 4280 motor mounted pump, 1.5 x 1 x 8 - 50Hz submittal
- 4280 motor mounted pump, 2 x 1.5 x 8 - 50Hz submittal
- 4280 motor mounted pump, 3 x 2 x 8 - 50Hz submittal
- 4280 motor mounted pump, 3 x 2.5 x 8 - 50Hz submittal
- 4280 motor mounted pump, 4 x 3 x 8 - 50Hz submittal
- 4280 motor mounted pump, 5 x 4 x 8 - 50Hz submittal
- 4280 motor mounted pump, 5 x 4 x 8 - 50Hz submittal
- 4280 motor mounted pump, 1.5 x 1 x 10 - 50Hz submittal
- 4280 motor mounted pump, 2 x 1.5 x 10 - 50Hz submittal

Pump Selection

- Manufacture 1:

SERIES 4280 PERFORMANCE CURVES

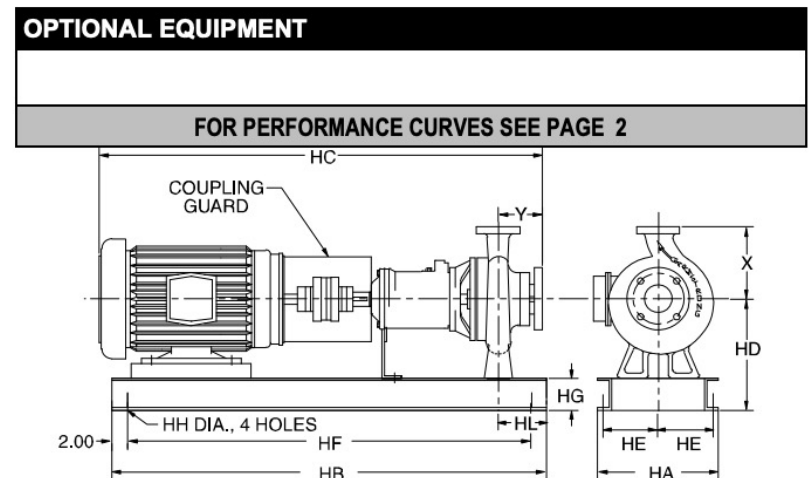


Pump Selection

- Manufacture 1:

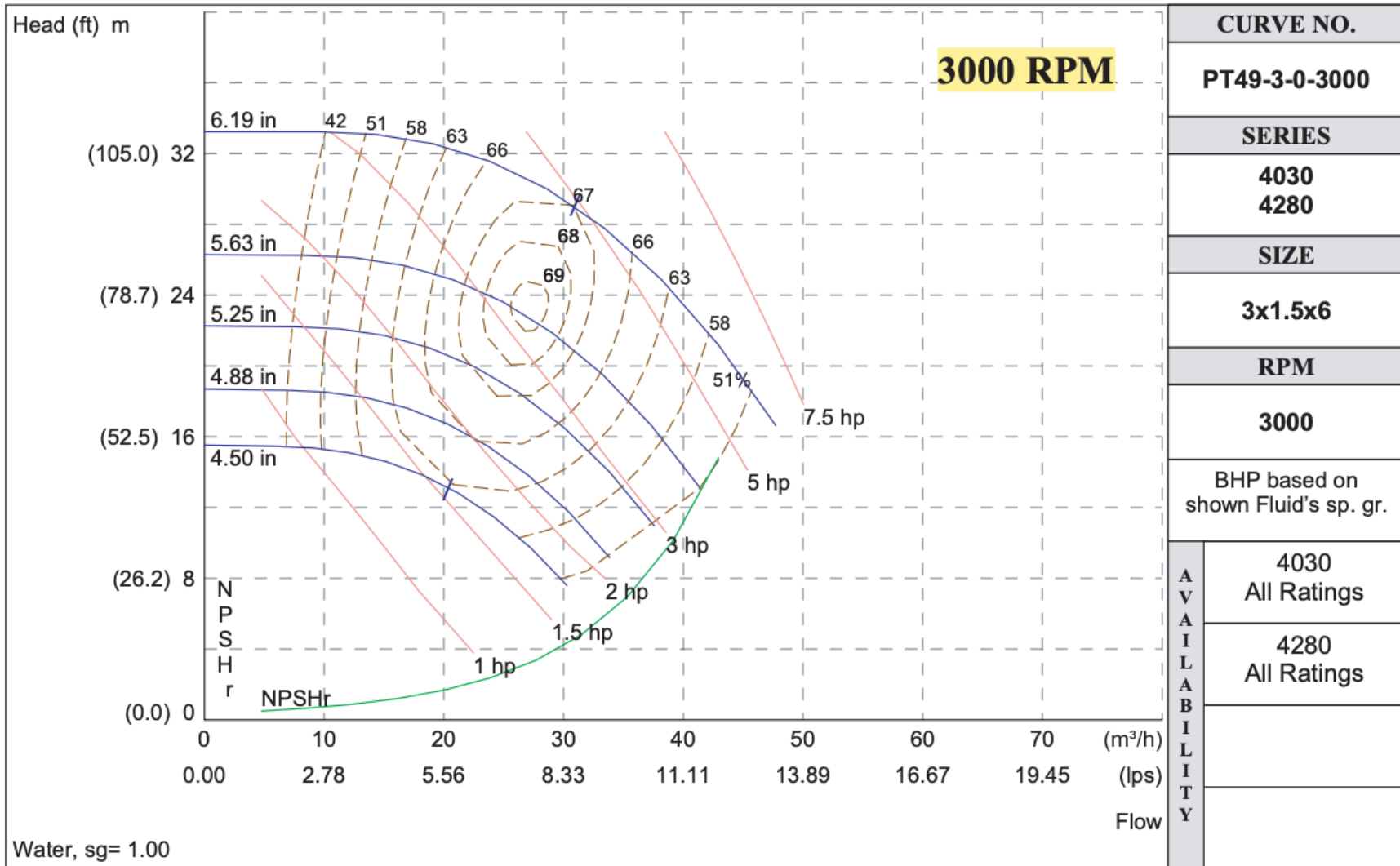
MOTOR HORSEPOWER				MAX. DIMENSIONS mm (inches)												MAX. ASSEMBLY WEIGHT*	
ODP		TEFC		FRAME	ODP / TEFC												kg (lbs.)
3000	1500	3000	1500		HA	HB	HC	HD	HE	HF	HG	HH	HL	X	Y		
---	0.33-0.75	---	0.33-0.75	56	356 (14.00)	762 (30.00)	670 (26.38)	210 (8.25)	162 (6.38)	660 (26.00)	76 (3.00)	19 (0.75)	114 (4.50)	165 (6.50)	102 (4.00)	49.5 (109)	
1.5	---	1.5	---	143T	356 (14.00)	762 (30.00)	712 (28.03)	210 (8.25)	162 (6.38)	660 (26.00)	76 (3.00)	19 (0.75)	114 (4.50)	165 (6.50)	102 (4.00)	53.1 (117)	
2 & 3	---	2	---	145T	356 (14.00)	762 (30.00)	712 (28.03)	210 (8.25)	162 (6.38)	660 (26.00)	76 (3.00)	19 (0.75)	114 (4.50)	165 (6.50)	102 (4.00)	53.1 (117)	
5	---	3	---	182T	356 (14.00)	762 (30.00)	781 (30.73)	210 (8.25)	162 (6.38)	660 (26.00)	76 (3.00)	19 (0.75)	114 (4.50)	165 (6.50)	102 (4.00)	64.5 (142)	
7.5	---	5	---	184T	356 (14.00)	762 (30.00)	781 (30.73)	210 (8.25)	162 (6.38)	660 (26.00)	76 (3.00)	19 (0.75)	114 (4.50)	165 (6.50)	102 (4.00)	69.0 (152)	
---	---	7.5	---	213T	356 (14.00)	838 (33.00)	874 (34.40)	210 (8.25)	162 (6.38)	737 (29.00)	76 (3.00)	19 (0.75)	114 (4.50)	165 (6.50)	102 (4.00)	84.9 (187)	

*Assembly weight combines pump and motor.



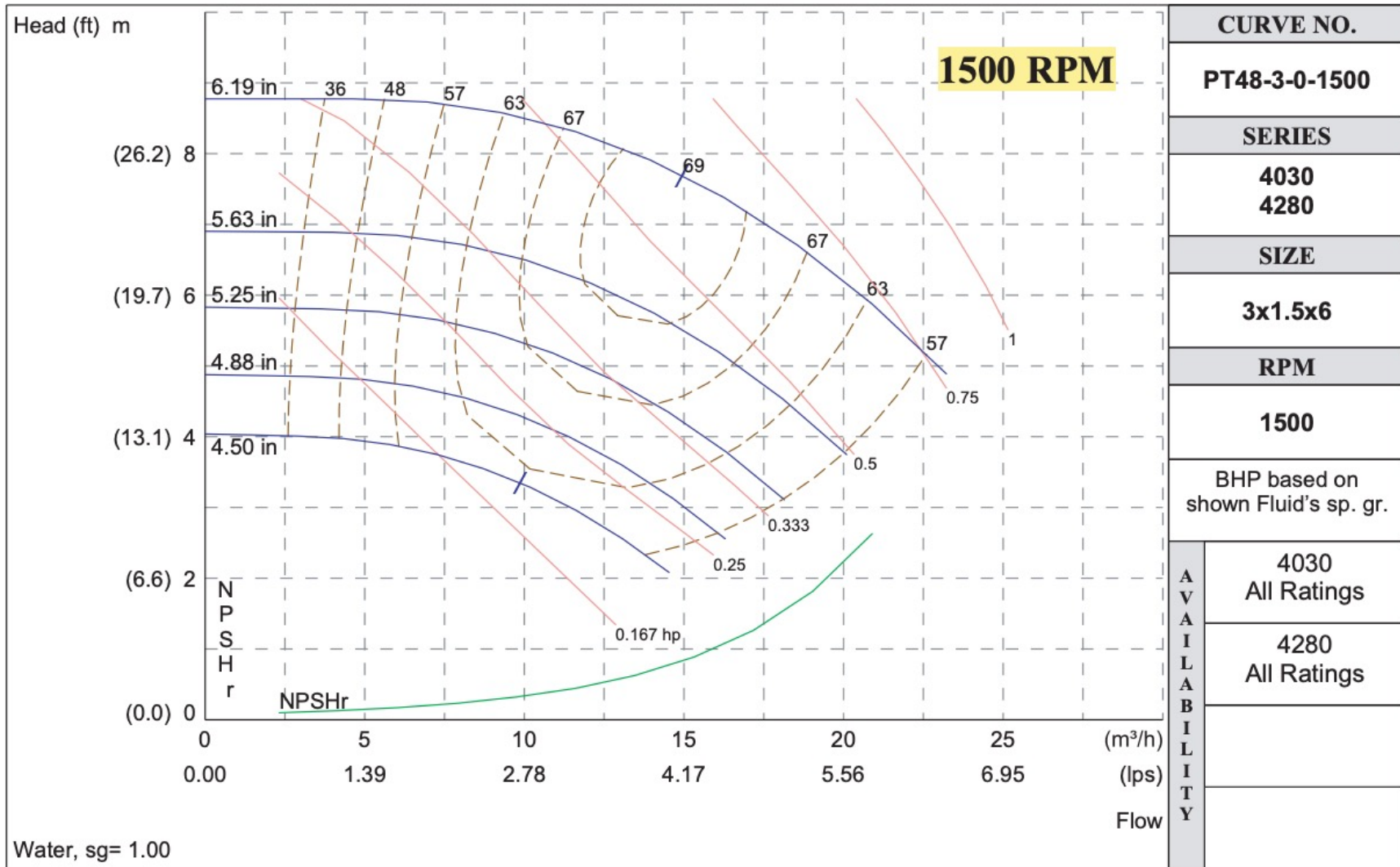
Pump Selection

- Manufacture 1:



Pump Selection

- Manufacture 1:



Pump Selection

- Manufacture 2:

<https://product-selection.grundfos.com/>

Pump Selection

- Manufacture 2:

Size your product

Find the right pump for your installation requirements.

1 2 3

Select criteria Set Flow and Head Size product

Size by Application <input type="button" value="v"/>	Select application ... Commercial bu <input type="button" value="v"/>	Select application Commercial he <input type="button" value="v"/>	Flow (Q) 50 <input type="button" value="v"/>	Head (H) 30 <input type="button" value="v"/> ft <input type="button" value="v"/>	<input type="button" value=">"/>
--	---	---	--	--	-------------------------------------

Pump Selection

- Manufacture 2:

Select parameters

Select type of installation ▼

Flow (Q)* ▼

[Calculate](#)

Head (H)* ▼

[Calculate](#)

BMS connectivity

Evaluation criterion ▼





Prefer fast delivery

SPECIFY MORE

START SIZING

Pump Selection

- Manufacture 2:

Curve	Product No	/15 years]	Pump orient.	Phases	U [V]	P2 [kW]	IE efficiency	Con size outlet	Max. operating [bar]	Q [US GPM]	Q-dev [%]	H [ft]	H-dev
<input type="checkbox"/> 	97924270	-	-	1	230	-	-	DN 40	10	47.4	-5.1	29.4	-2.0
<input type="checkbox"/> 	96503184 +..	-	Vertical	3	380 - 440	0.75	NEMA Premium / IE3 60Hz	1 1/2	16	50	0.0	30	0.0
<input type="checkbox"/> 	99088786 +..	-	-	3	380 - 415	0.64	-	1 1/2	10	50	0.0	30	0.0
<input type="checkbox"/> 	96935806 +..	-	-	3	380 - 415	0.74	-	1 1/2	10	50	0.0	30	0.0
<input type="checkbox"/> 	96503208 +..	-	Vertical	3	380 - 440	0.75	NEMA Premium / IE3 60Hz	DN 50	16	50	0.0	30	0.0
<input type="checkbox"/> 	96503222 +..	-	Vertical	3	380 - 440	0.75	NEMA Premium / IE3 60Hz	DN 50	16	50	0.0	30	0.0
<input type="checkbox"/> 	97924271	-	-	1	230	-	-	DN 40	10	50	0.0	30	0.0
<input type="checkbox"/> 	96806944 +..	-	-	3	380 - 415	0.6	IE2	1 1/2	10	50	0.0	30	0.0

Pump Selection

- Manufacture 3:

The screenshot displays the ESP Systemwize Pump Selection web application. At the top, the ESP Systemwize logo is on the left, and navigation links for Xylem Brands, News & Events, Careers, and Xylem Inc. are on the right. A 'FIND YOUR LOCAL REP' button is also present. Below the navigation is a red banner with the text 'RAPID SYSTEM DESIGN AT YOUR FINGERTIPS' and the ESP Systemwize logo. The main interface is divided into several sections:

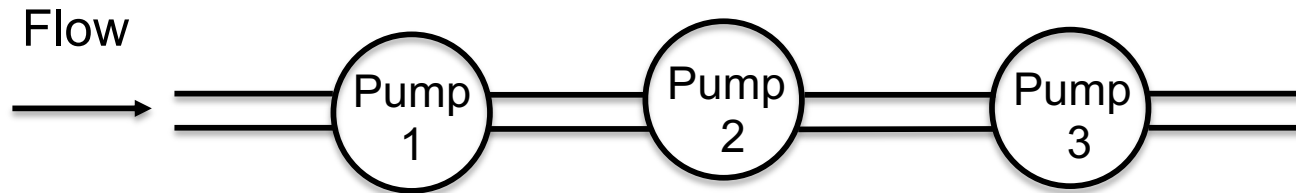
- Selection Options:** Includes dropdowns for Selection Mode (Variable speed), Controller Options (Sensored), Frequency (60Hz), and Unit of Measurement (Imperial/US).
- Product Family:** A grid of pump models categorized into End-Suction, In-Line, Double Suction, and Multi-Stage. Each model has a checkbox and an information icon. An 'Express Select' button is located in the top right of this section.
- Duty Point:** Includes input fields for Total System Flow (0 US gpm), Total Head (0 ft), and Control Head (0 ft). It also features dropdowns for the number of pumps (1) and their configuration (Parallel).

A sidebar on the left contains a 'Clear Inputs' button and a list of product categories such as Pumps, System Designer, Suction Diffuser Plus, Triple Duty Valves, Air & Dirt Separators, Expansion Tanks, PIC Valve, Drives & Controls, Wastewater & Stormwater, Replacement Parts, Schedule, Projects, REVIT FILE, Log In, and Knowledge Center.

MULTIPLE PUMPS

Multiple Pumps

- Pumps in series:
 - Operate with the same flow rate
 - Allow increase the total head



$$Q = Q_1 = Q_2 = Q_3$$

$$H = H_1 + H_2 + H_3$$

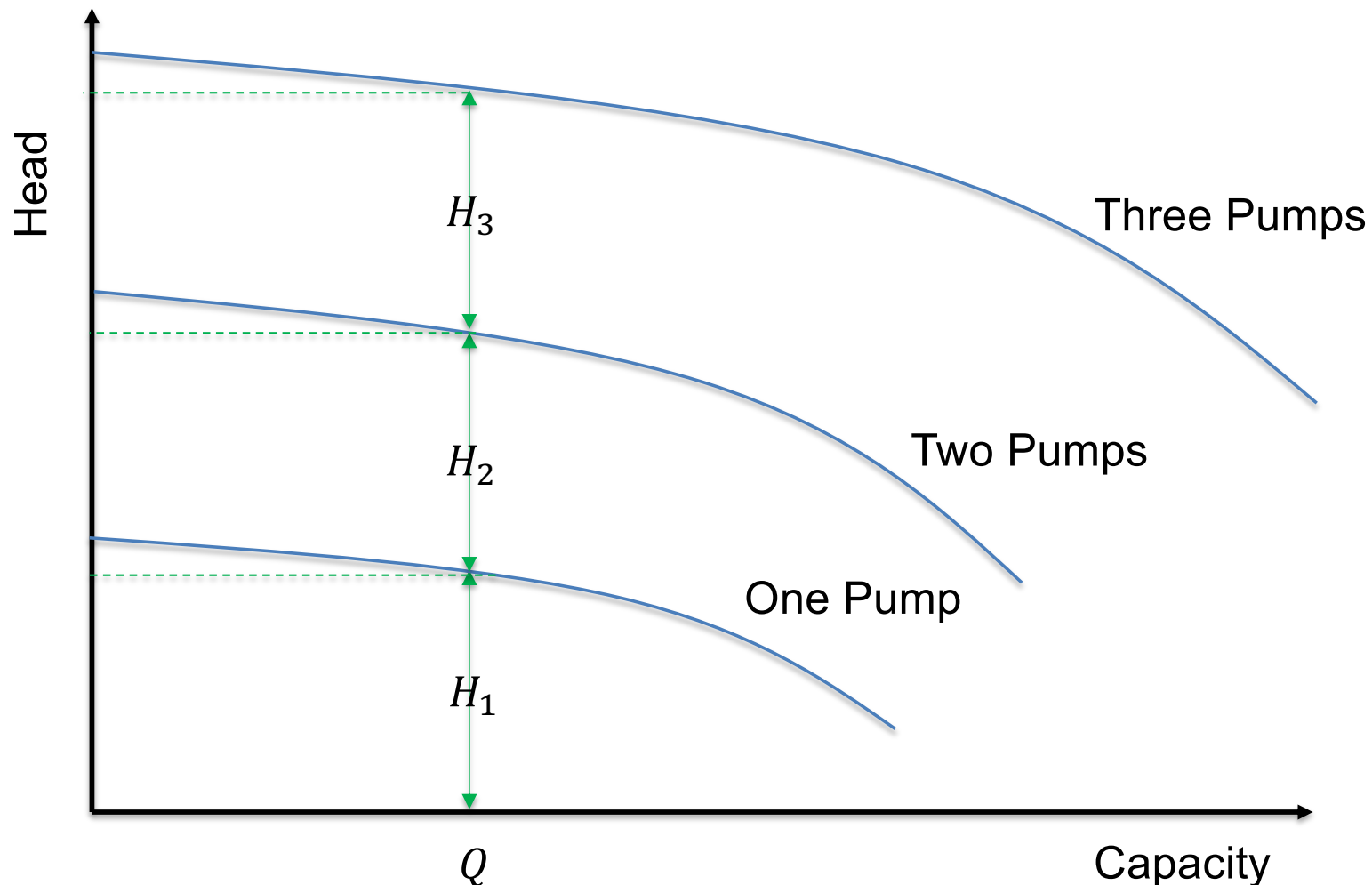
Multiple Pumps

- Pumps in series:

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- Allow increase the total head

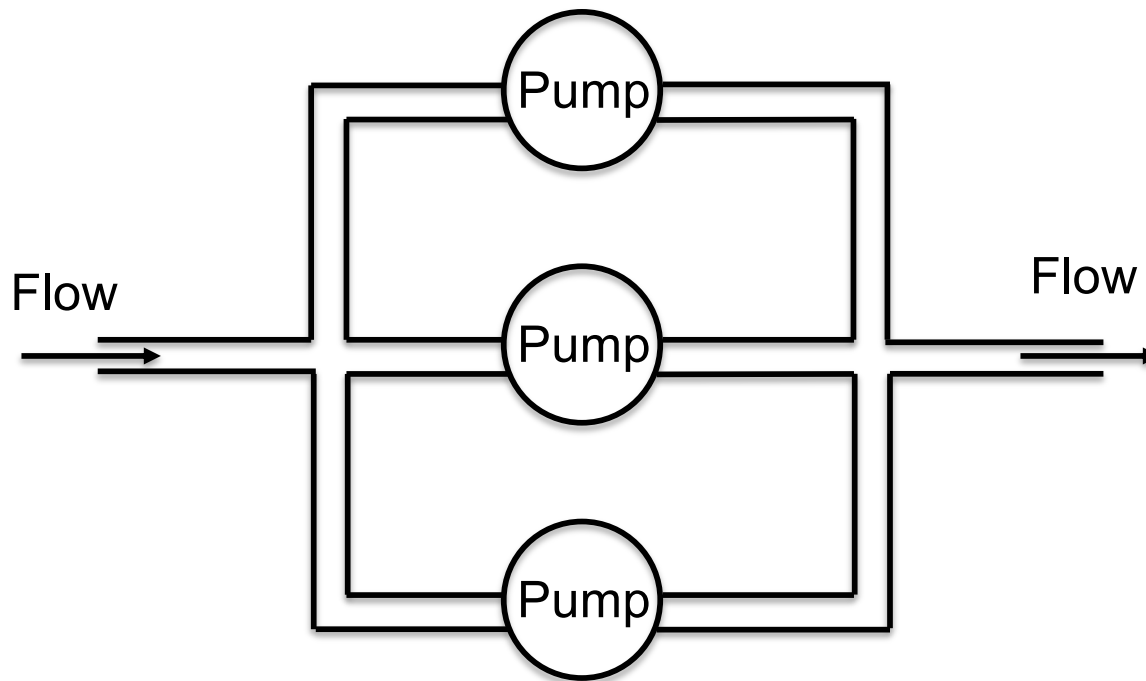
$$H = H_1 + H_2 + H_3$$

$$Q = Q_1 = Q_2 = Q_3$$



Multiple Pumps

- Pumps in parallel:
 - ❑ Operate at the same head
 - ❑ The total flow rate in the system is the sum of each pump flow rate

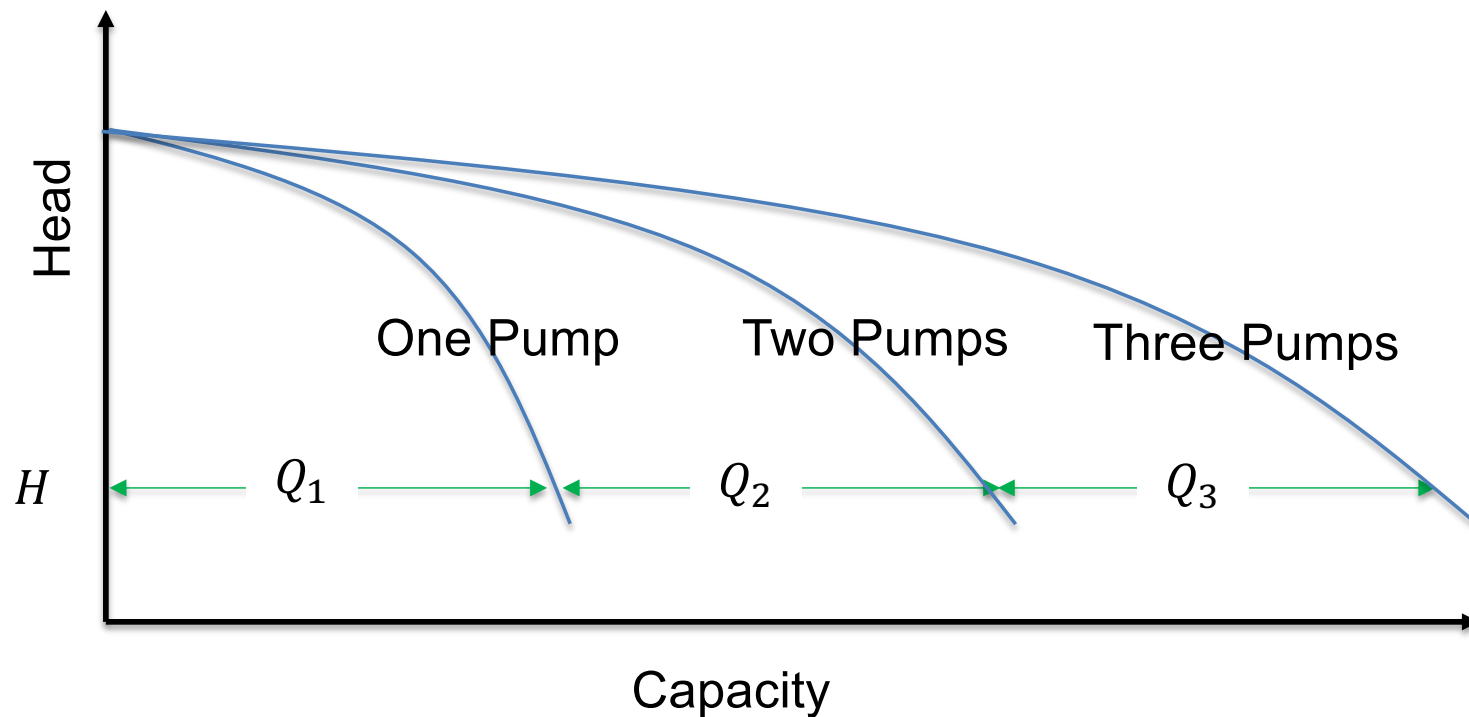


$$H = H_1 = H_2 = H_3$$

$$Q_{total} = Q_1 + Q_2 + Q_3$$

Multiple Pumps

- Pumps in parallel:
 - Operate at the same head
 - The total flow rate in the system is the sum of each pump flow rate



$$H = H_1 = H_2 = H_3$$

$$Q_{total} = Q_1 + Q_2 + Q_3$$

AFFINITY LAWS

Affinity Laws

- For a fixed impeller diameter

Flow Rate:

$$Q_n = Q_o \left(\frac{rpm_n}{rpm_o} \right)$$

Head:

$$H_n = H_o \left(\frac{rpm_n}{rpm_o} \right)^2$$

$$H_n = H_o \left(\frac{Q_n}{Q_o} \right)^2$$

Shaft Power:

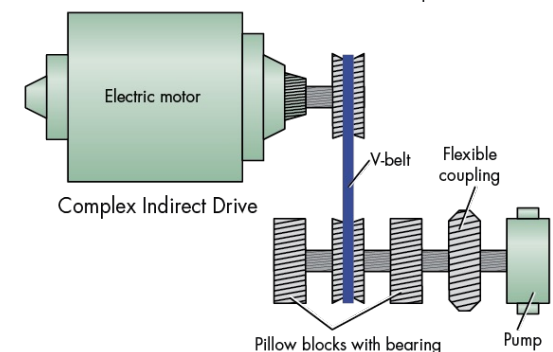
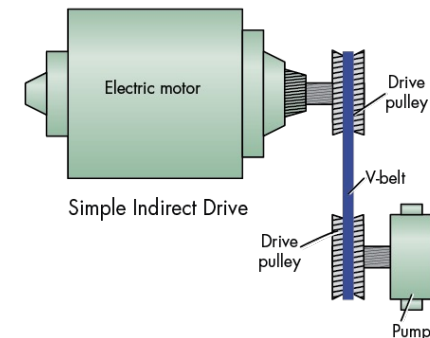
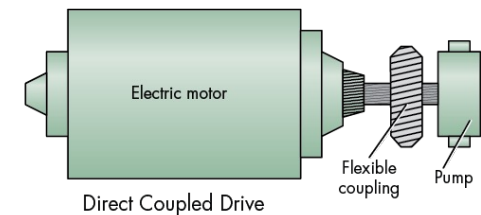
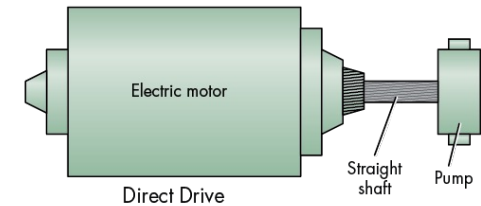
$$W_n = W_o \left(\frac{rpm_n}{rpm_o} \right)^3$$

Affinity Laws

- Water horsepower (whp) is equal to:

$$whp = \frac{Q \times H \times SG}{3960}$$

- Q : Flow rate (gpm)
- H : head (ft)
- SG : Specific gravity



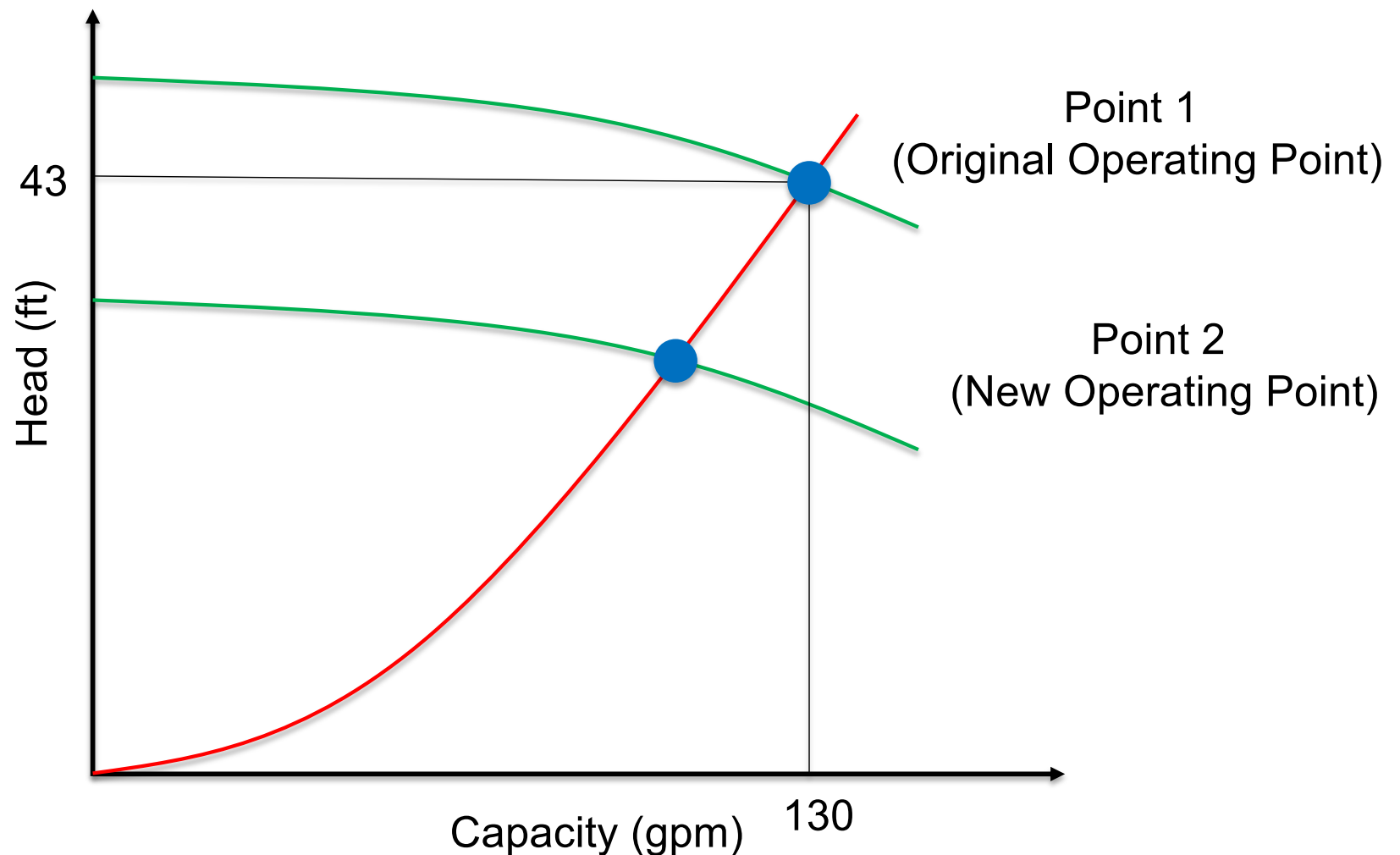
CLASS ACTIVITY (AFFINITY LAWS)

Class Activity

- **Problem:** We have a 1750 rpm pump with a 7 in. impeller. The the best operating point for the pump occurs when the total head is 43 ft and the capacity is 130 gallons per minute. It is desired to reduce the pump speed until the flow rate is 100 GPM. Assume the static head is 0 ft. Find
 - New pump head
 - New shaft power (assuming the original shaft power is 2.1 hp)
 - New efficiency

Class Activity

- Solution:
 - Add the schematic of the system curve and identify the operating point:



Class Activity

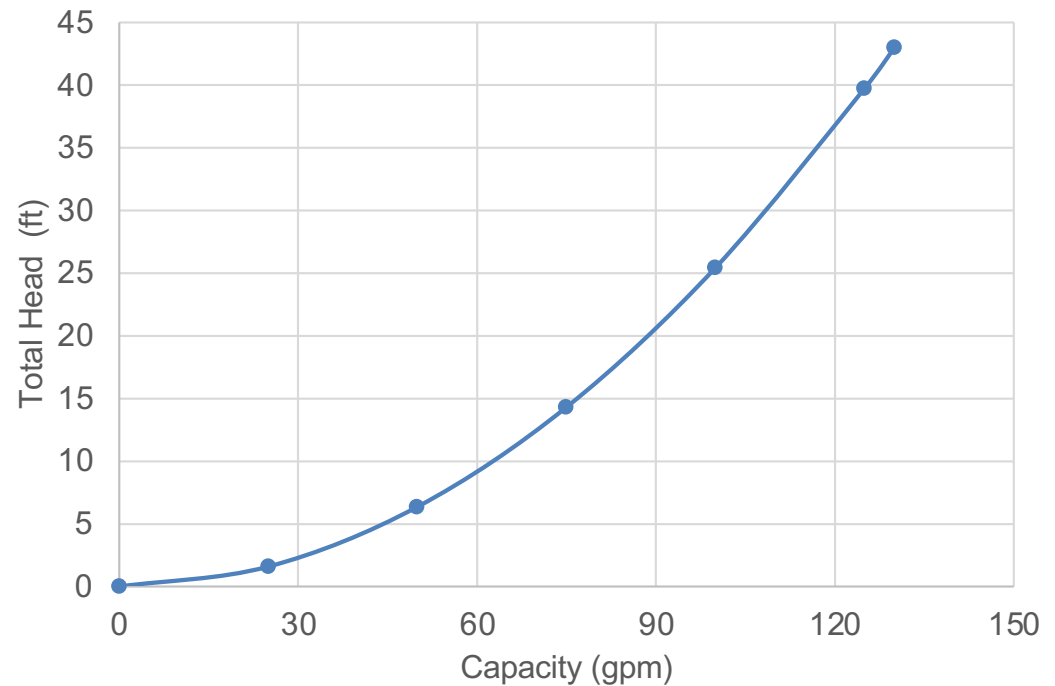
- **Solution:**

- Establish the system curve

$$H = a + bQ^2$$

$$43 = 0 + b(130)^2 \quad \rightarrow \quad b = 0.00254438$$

Flow Rate (GPM)	Head (ft)
130	43
100	25
75	14
50	6.4
25	1.6



Class Activity

- **Solution:**

- Use the affinity laws

- $rpm_o = 1750$

- $Q_o = 130 \text{ gpm}$

- $Q_n = 100 \text{ gpm}$

- New speed is equal to:

- $rpm_n = rpm_o \left(\frac{Q_n}{Q_o} \right)$

- $rpm_n = 1750 \left(\frac{100}{130} \right)$

- $rpm_n = 1346$

Class Activity

- **Solution:**

- New shaft power is:

$$W_n = W_o \left(\frac{rpm_n}{rpm_o} \right)^3$$

$$W_n = 2.1 \left(\frac{1346}{1750} \right)^3$$

$$W_n = 0.96 \text{ hp}$$

Class Activity

- **Solution:**

- New efficiency is:

$$\frac{\eta_n}{\eta_o} = \frac{Q_n H_n}{W_n} / \left(\frac{Q_o H_o}{W_o} \right)$$

$$\frac{\eta_n}{\eta_o} = \frac{100(25)}{0.096} / \left(\frac{130(43)}{2.1} \right) = 0.978$$

$$\eta_n = (69.2)(0.978) = 67.7\%$$

NET POSITIVE SUCTION HEAD (NPSH)

Net Positive Suction Head (NPSH)

- Head required at the suction of a pump to prevent cavitation
- Cavitation is the formation of bubbles due to low pressure area and the subsequent collapse upon migration to a high-pressure area
- Cavitation causes noise and damage



Net Positive Suction head (NPSH)

- The amount of pressure in excess of the vapor pressure required to prevent cavitation in the pump is known as required net positive suction head ($NPSH_R$)

$$NPSH_A = \frac{(P_s - P_v)}{\gamma} + (H_z - h_l) + \frac{V_s^2}{2g}$$

$$NPSH_A > NPSH_R$$

- P_s : Static head at the pump inlet
- P_v : Static vapor pressure head of the liquid
- h_l : Friction loss
- H_z : Minimum fluid level above pump or (negative if below pump)
- V_s : Pump inlet velocity

Be careful of the units

Net Positive Suction head (NPSH)

- For a given system, a higher the water temperature yields a lower $NPSH_A$

$$P_v(100\text{ }^\circ\text{F}) = 0.95044\text{ psi}$$

$$P_v(200\text{ }^\circ\text{F}) = 11.5376\text{ psi}$$

Net Positive Suction head (NPSH)

- Notice the $NPSH_r$ line

