CAE 464/517 HVAC Systems Design

Spring 2023

April 13, 2023

Hydronic systems: system characteristics and pump selection

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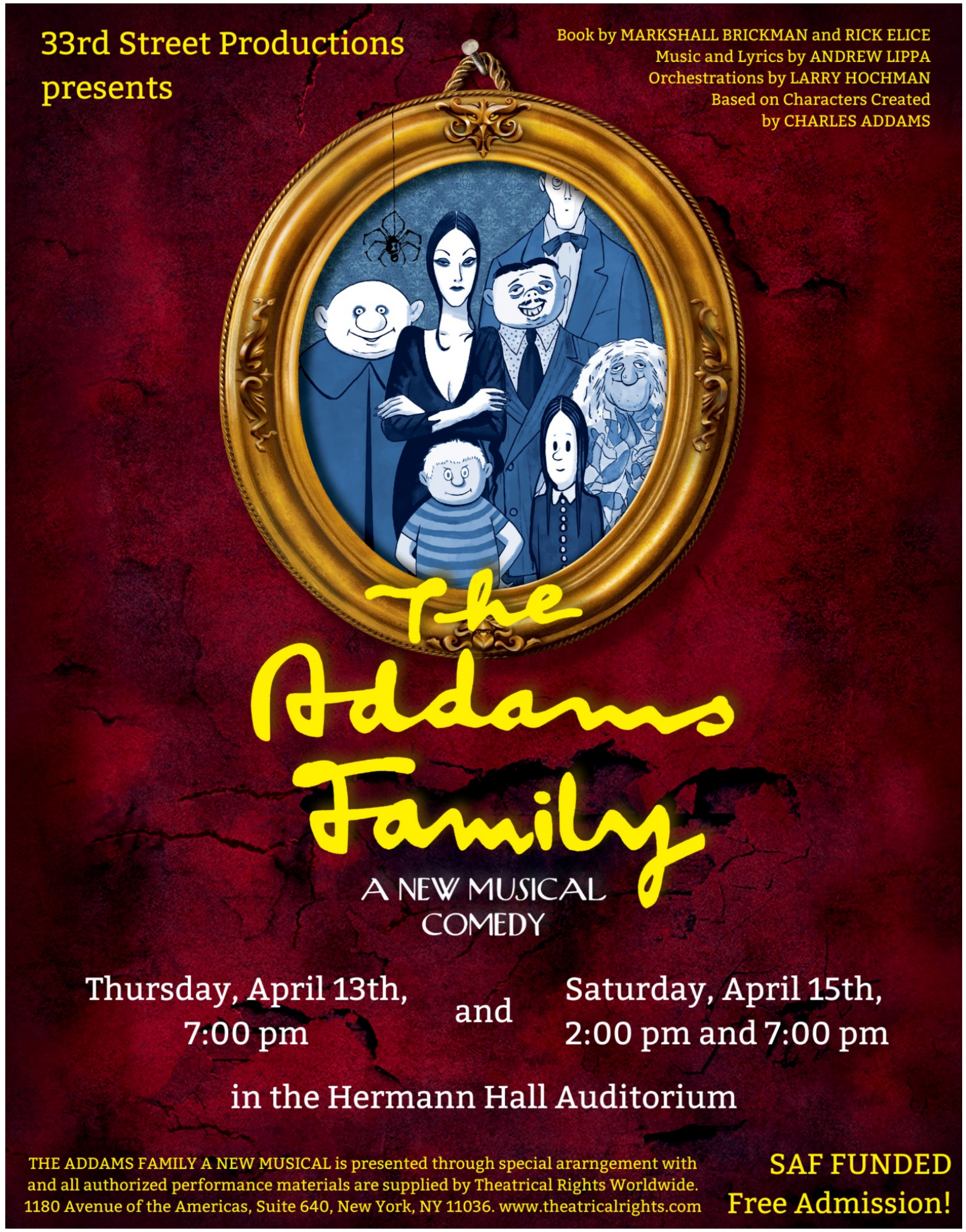
ANNOUNCEMENTS

Announcements

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

Announcements



RECAP

Recap

- We also sometimes define equivalent length:

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

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

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

- $\frac{L}{D}$ 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

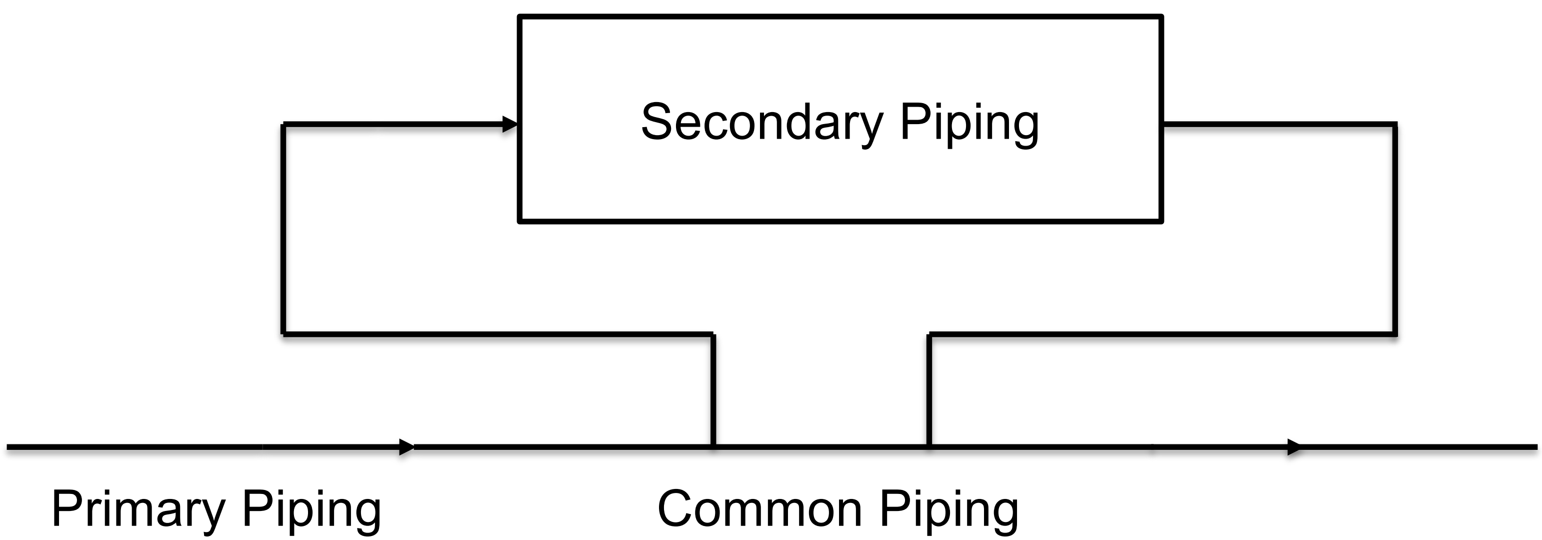
PRIMARY – SECONDARY PUMPING

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

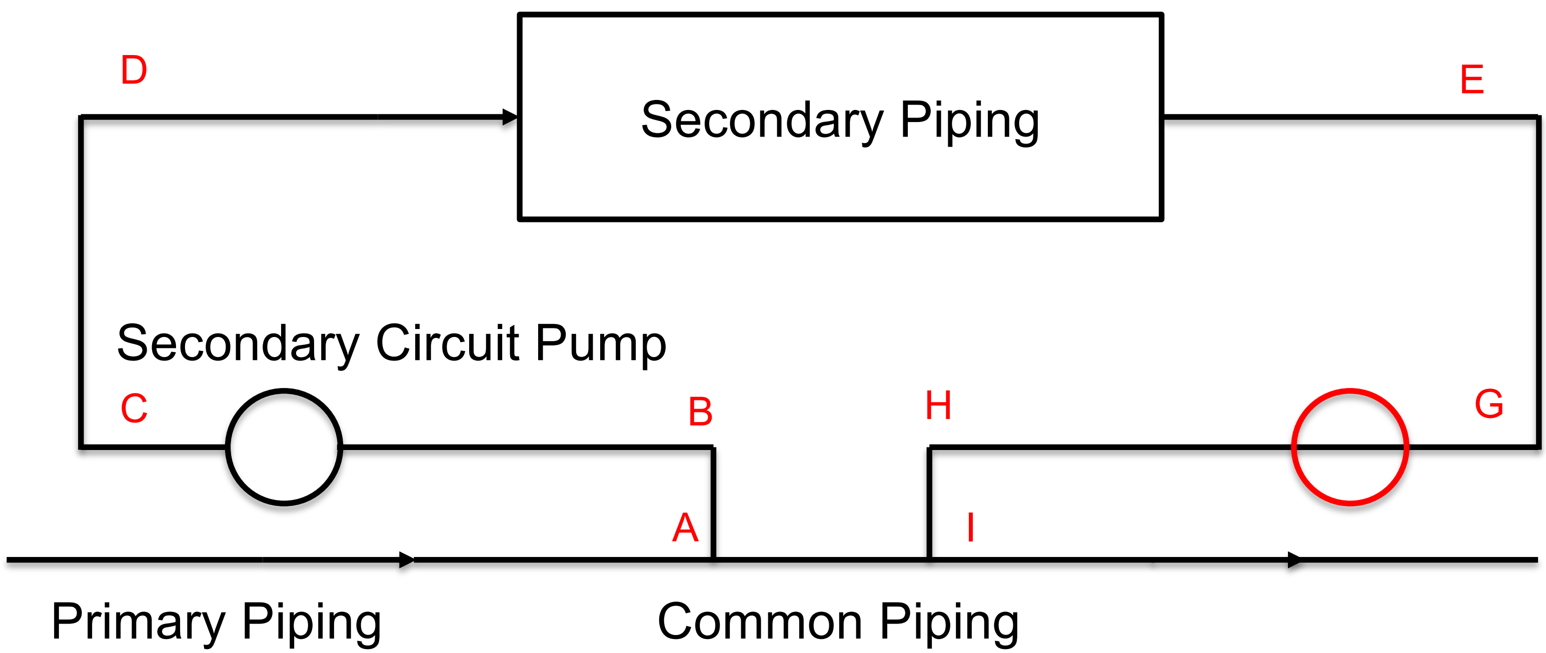
Primary Secondary Pumping

- 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

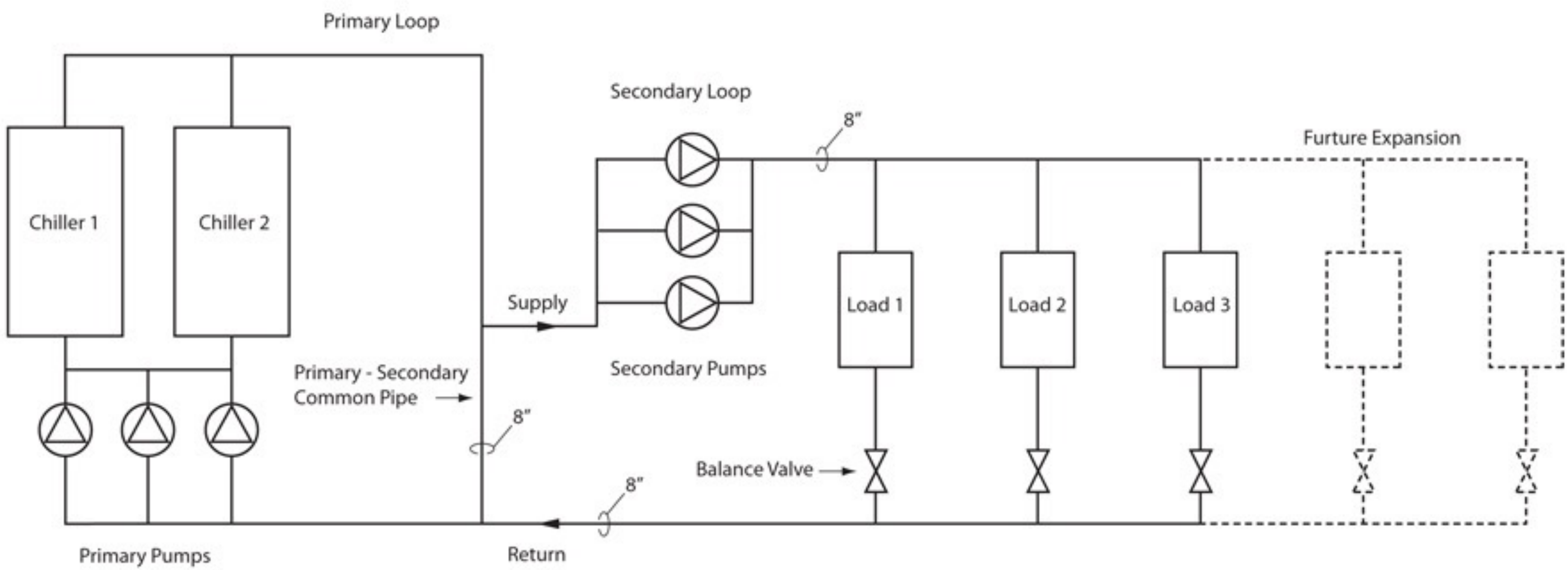
- Secondary pipe pump sized for pressure drops A-B, B-C, C-D, D-E, E-G, G-H, H-I
- I-A should have no pressure drop



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

Primary Secondary Pumping

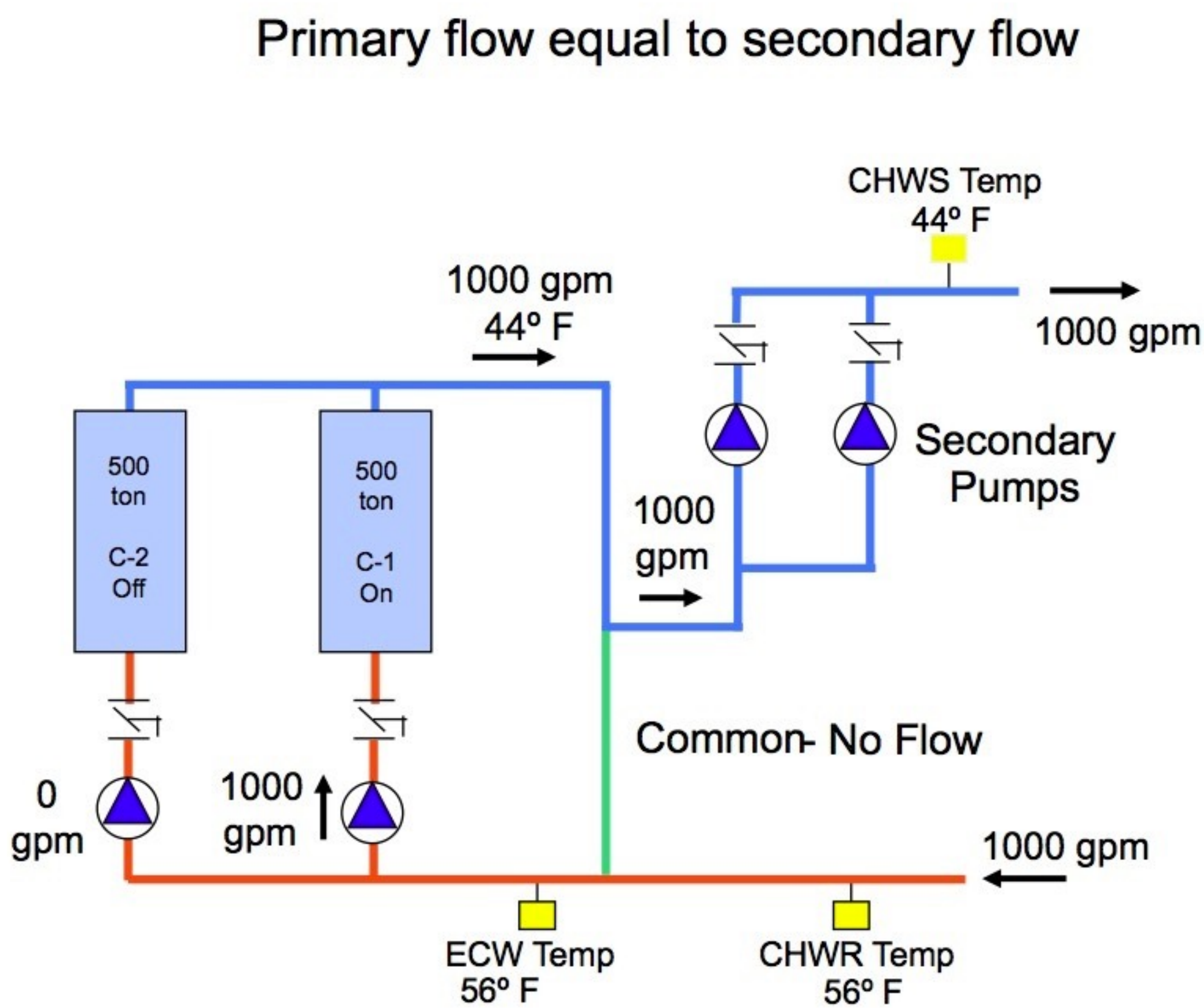
- In hydronic systems, we use this strategy:



https://www.advantageengineering.com/fyi/286/advantageFYI286.php

Primary Secondary Pumping

- In hydronic systems, we use this strategy:

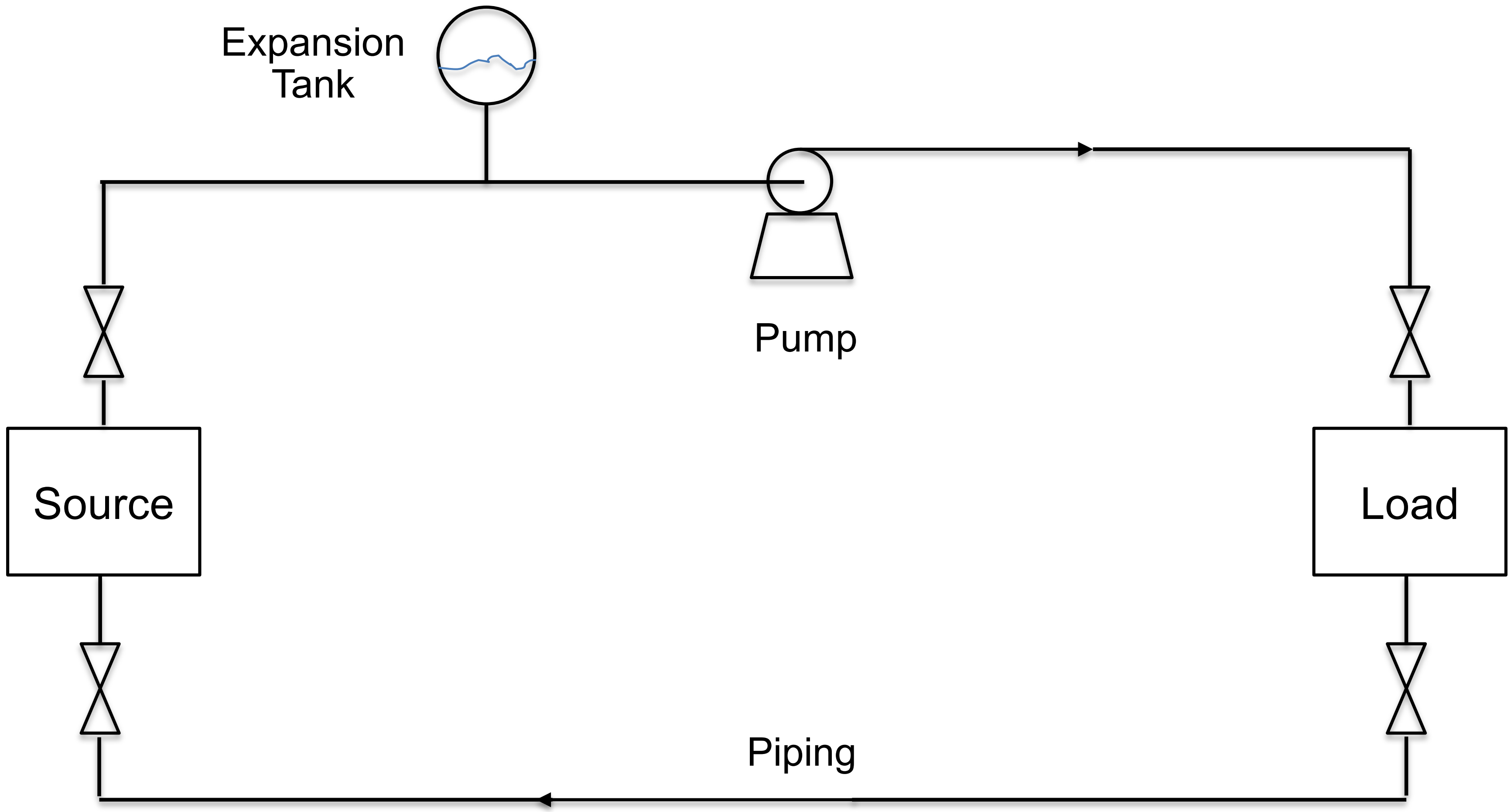


http://jmpcoblog.com/hvac-blog/understanding-primary-secondary-pumping-part-4-what-happens-when

PUMPS

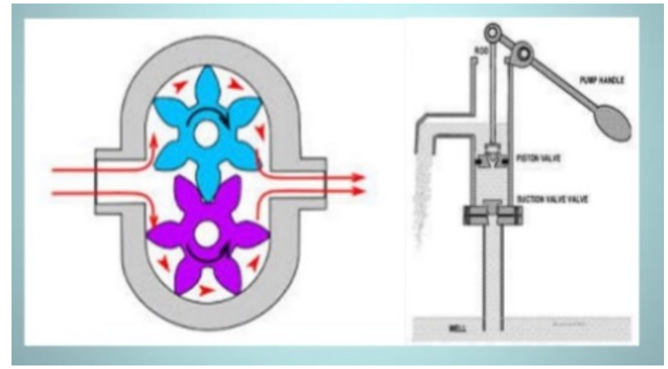
Intro to Pumps

- 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

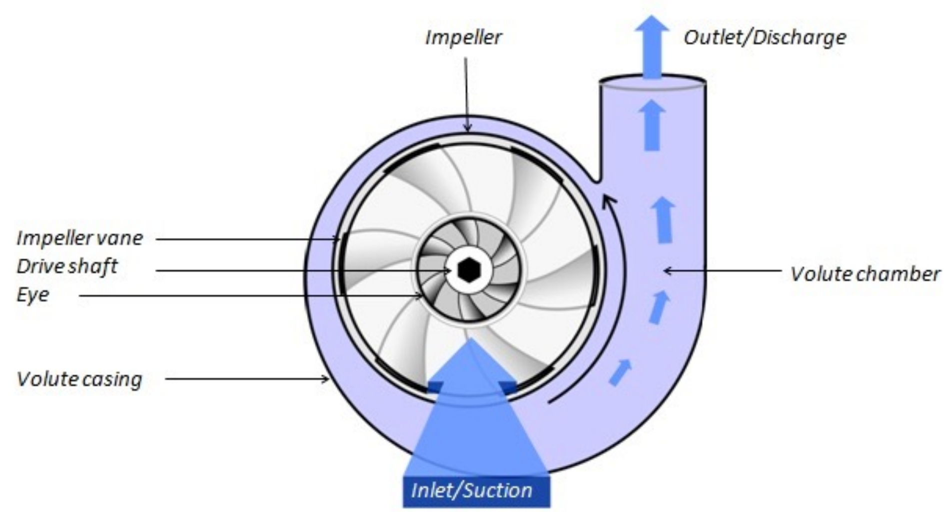
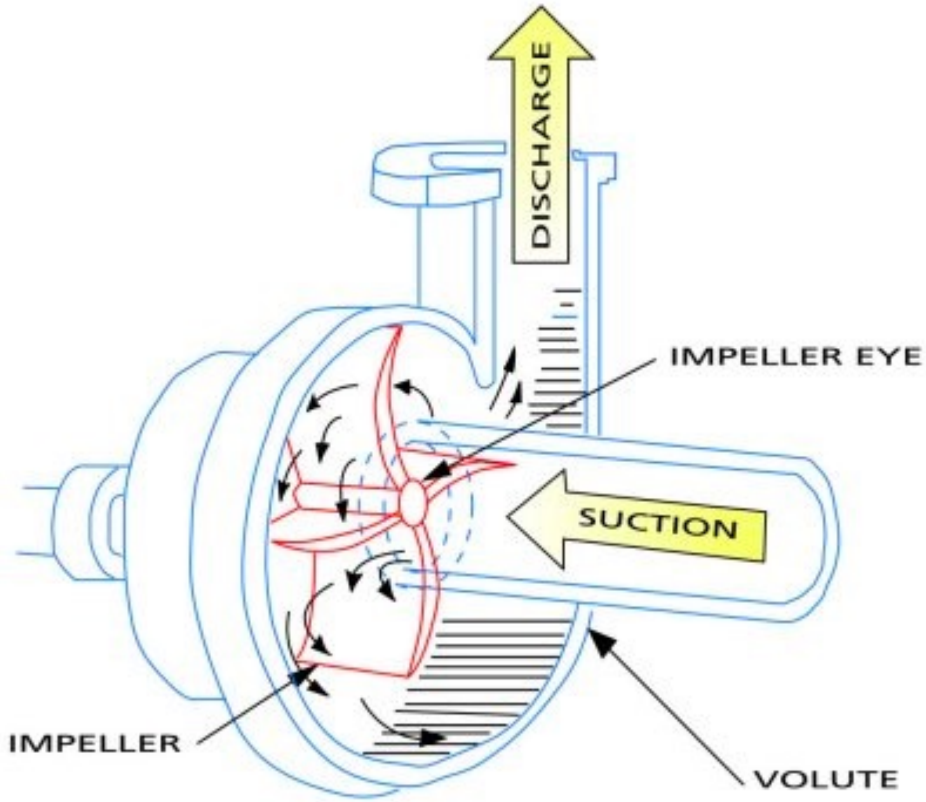
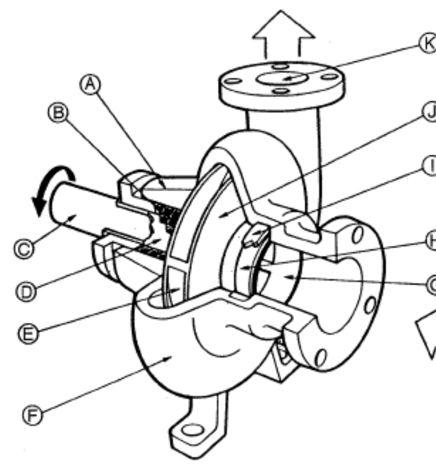


Figure 2. Volute case design

https://www.slideshare.net/MohammudHanifDewan/positive-displacement-pumps-46499848 & https://www.michael-smith-engineers.co.uk/resources/useful-info/centrifugal-pumps

Centrifugal Pumps





https://www.pumpfundamentals.com/tutorial2.htm

Centrifugal Pumps

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

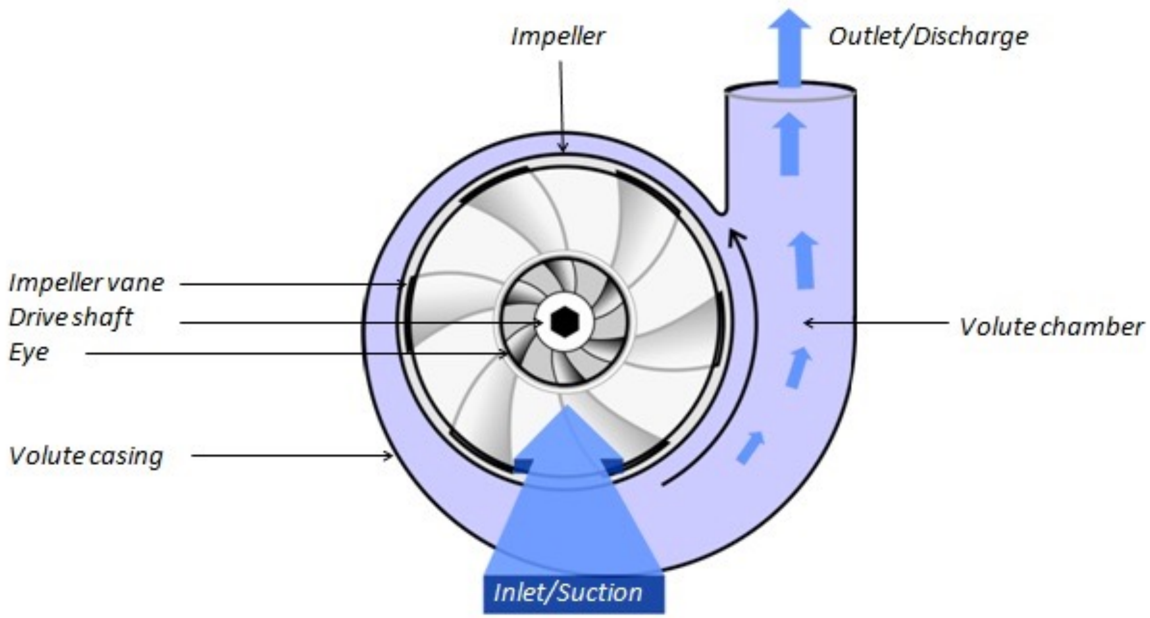


Figure 2. Volute case design

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

https://www.michael-smith-engineers.co.uk/resources/useful-info/centrifugal-pumps

Centrifugal Pumps

- Impeller types

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

https://www.michael-smith-engineers.co.uk/resources/useful-info/centrifugal-pumps

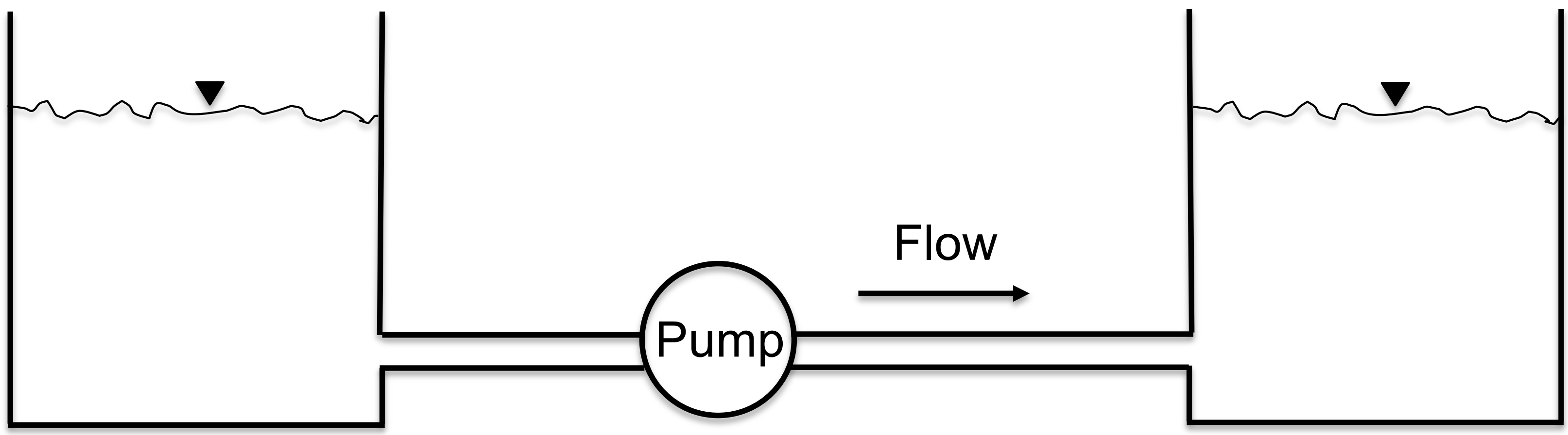
Centrifugal Pumps

- It needs to be base mounted:

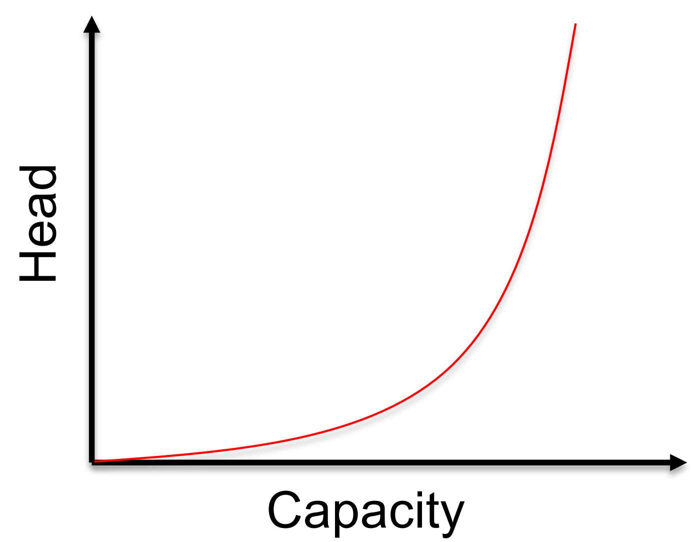
SYSTEM CURVE

System Curve

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

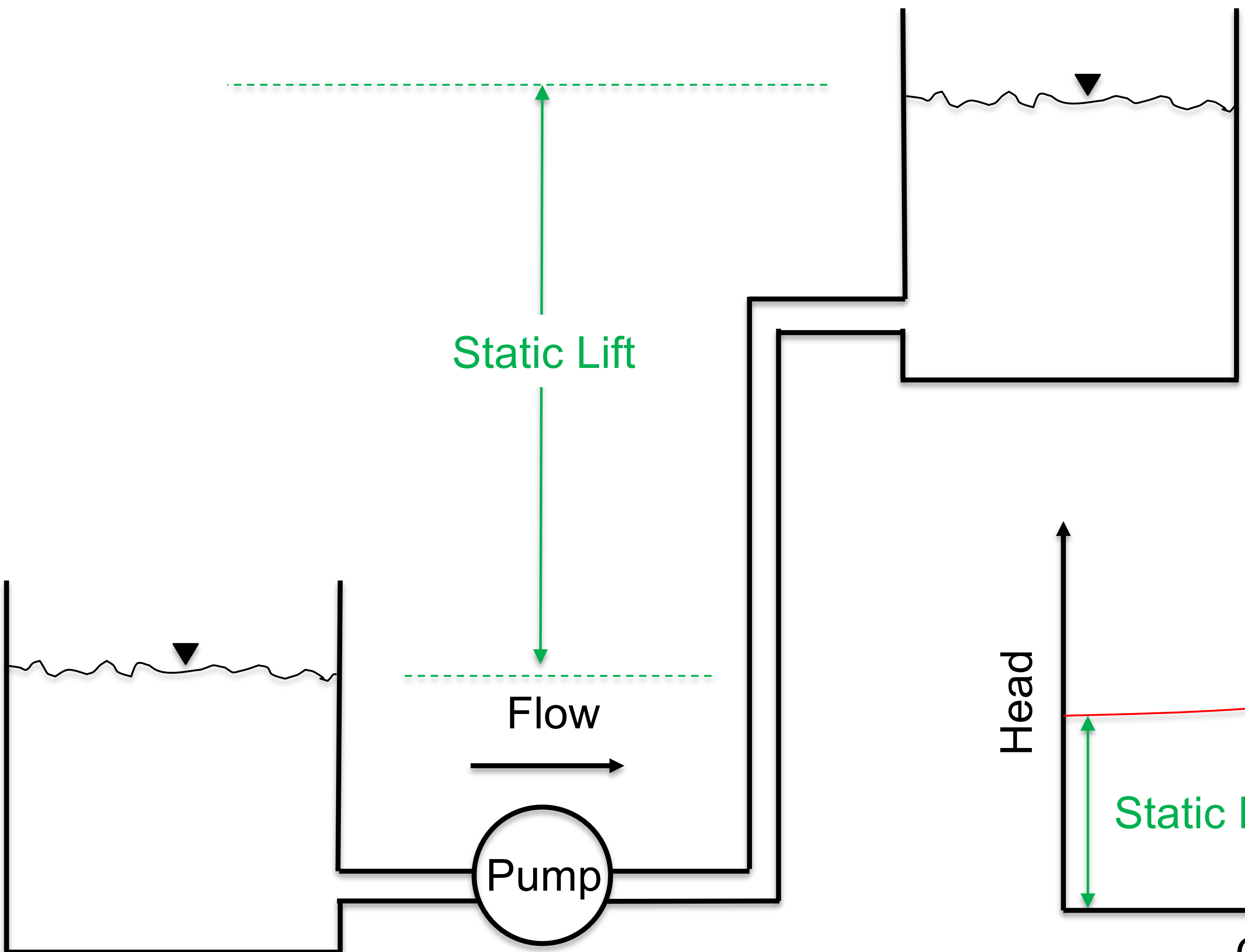


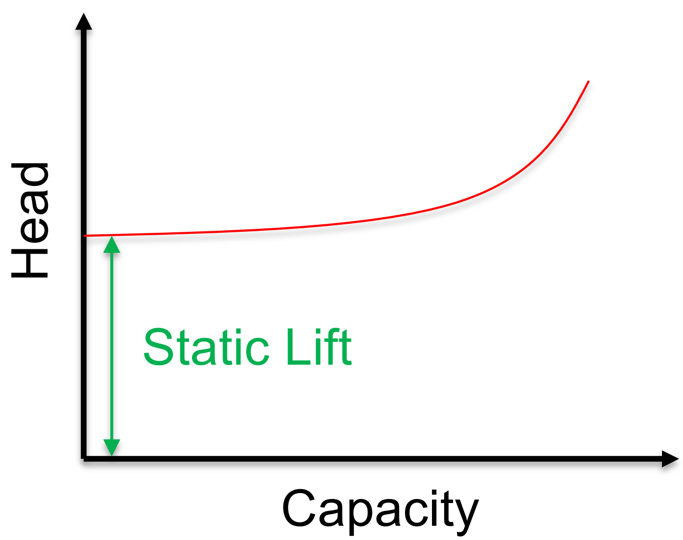
- How is the system curve?



System Curve

- How is the system curve for this one?





System Curve

- System curve can change over time

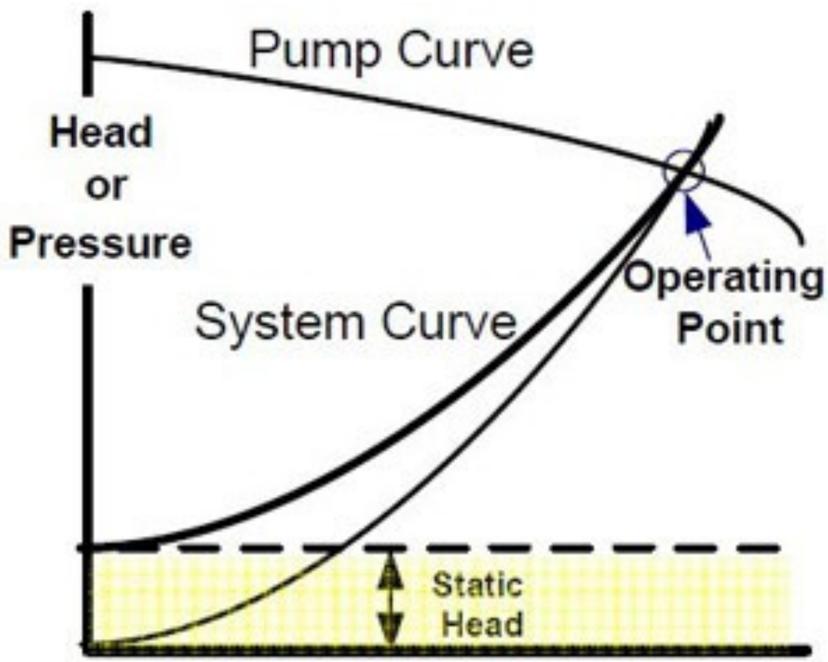


Figure 2

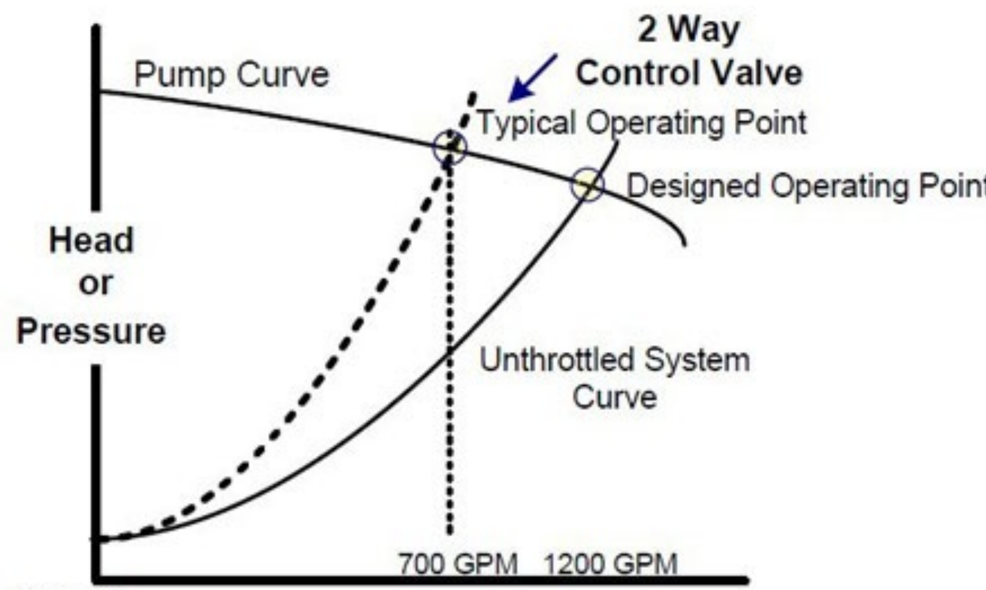
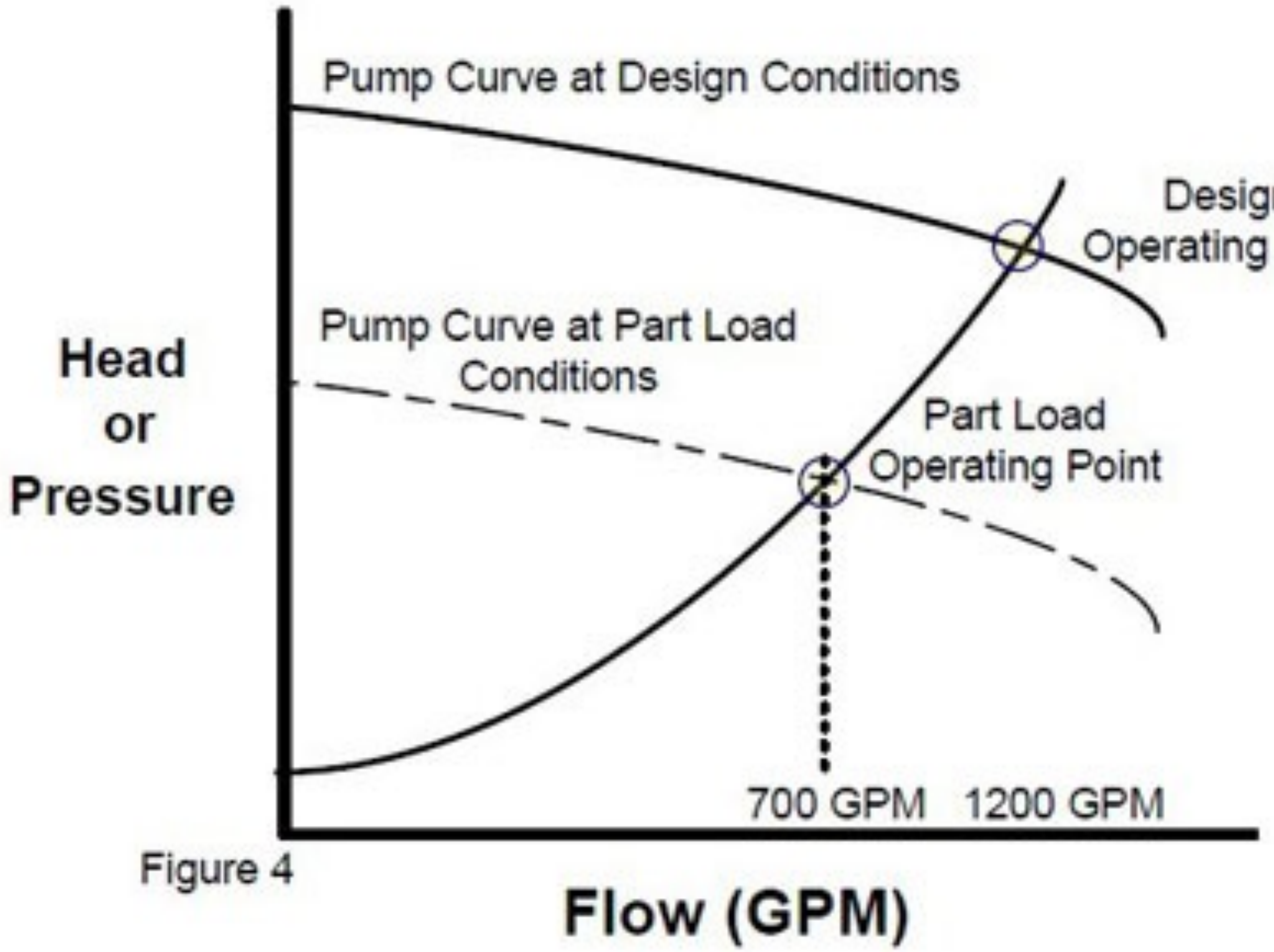


Figure 3

http://www.frequencyinverters.org/frequency-converter-for-pumps-278604.html

System Curve

- System curve can change over time



http://www.frequencyinverters.org/frequency-converter-for-pumps-278604.html

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

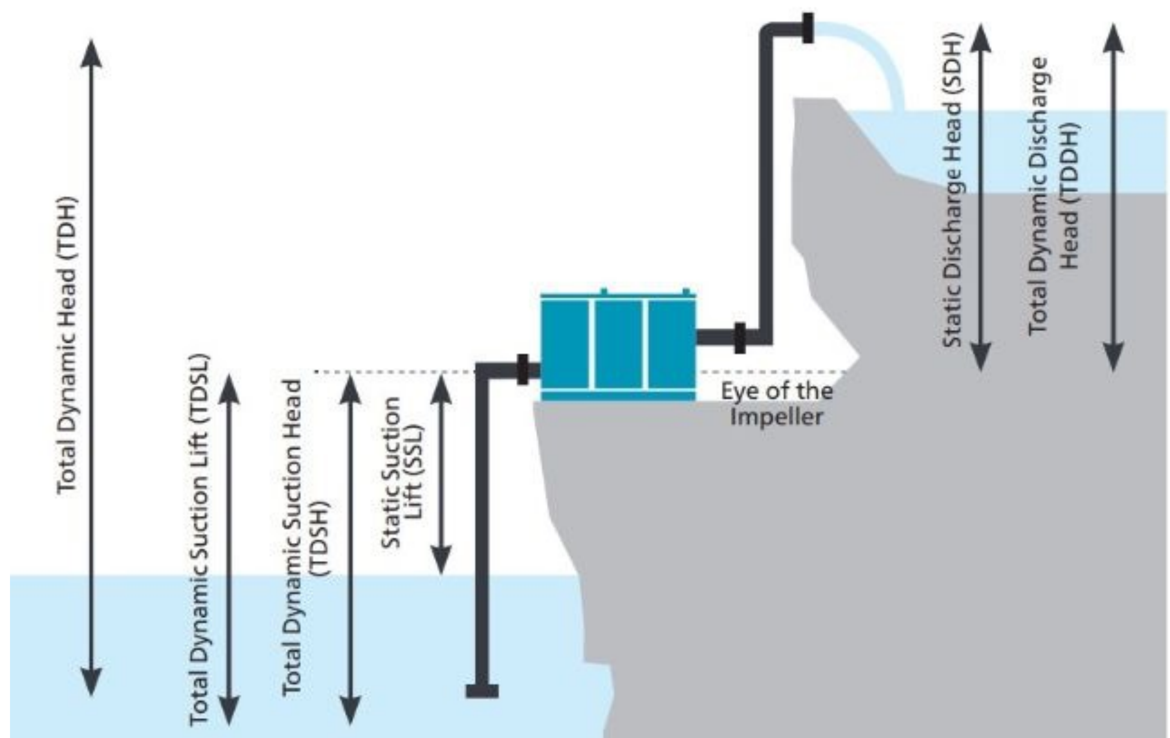
- Total Dynamic Head (TDH)
  - ❑ The difference in total head between the suction side and the discharge side of the pump
  - ❑ Head is normally measured in feet of fluid flowing (ft.)
  - ❑ Feet of head is a unit of length

TDSL = SSL + Friction Loss

TDDH = SDH + Friction Loss

TDH = TDSL + TDDH

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



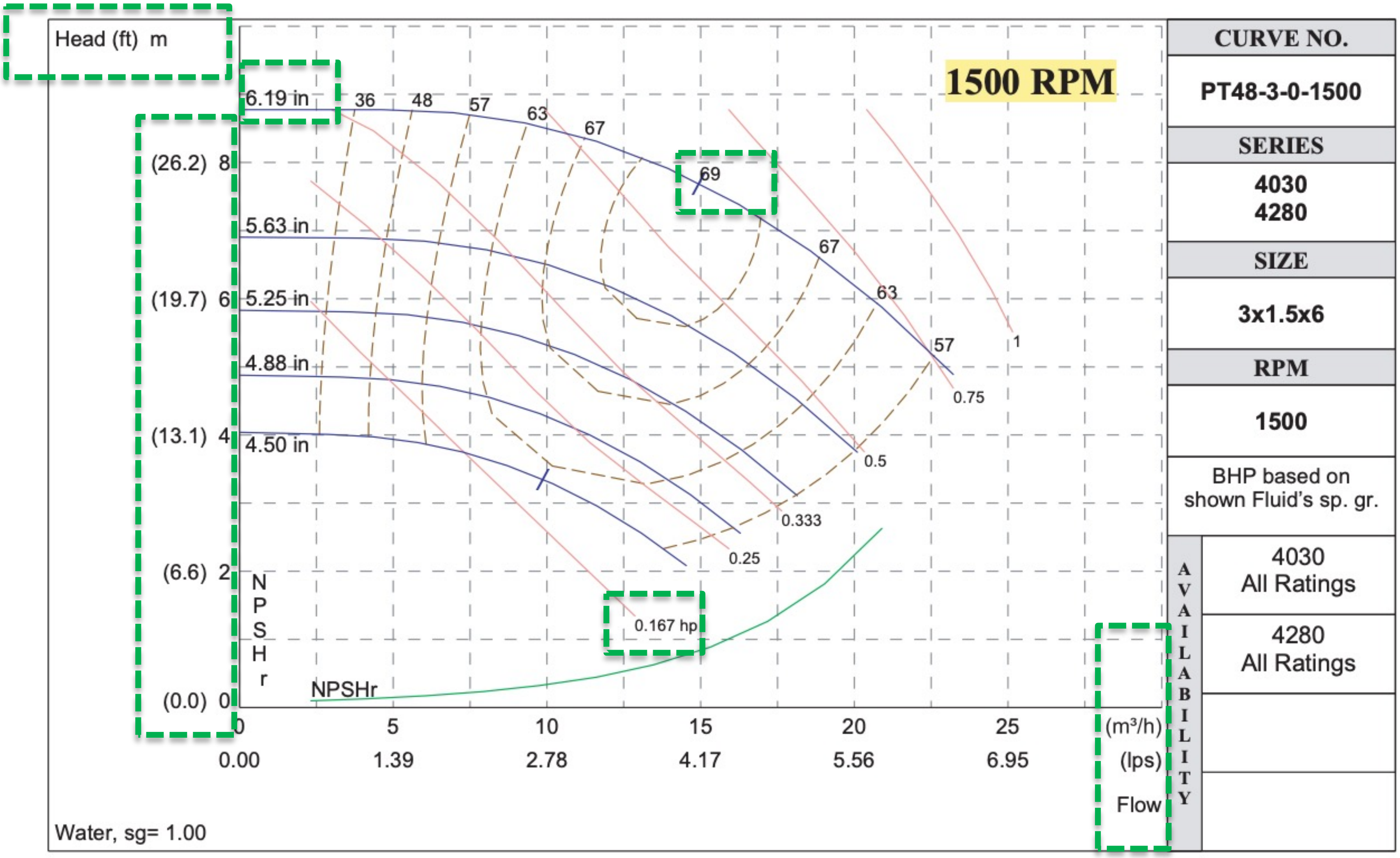
https://www.atlascopco.com/en-us/construction-equipment/resources/dewatering-pumps-guide/pump-head

Pump Selection

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

Pump Selection

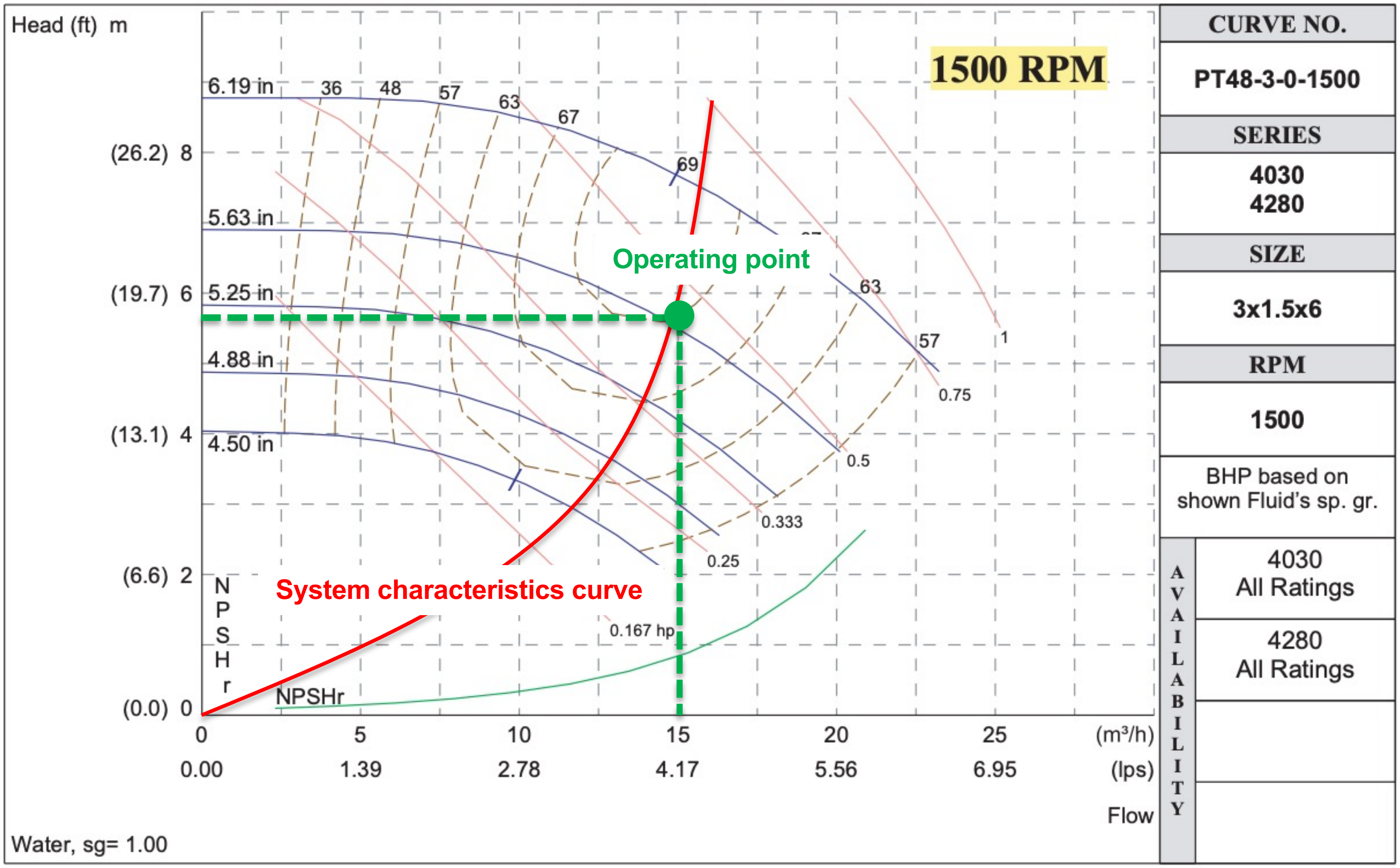
- Familiarize yourself with the pump curve



https://armstrongfluidtechnology.com/~/media/documents/specifications/submittal-data/4030-base-mounted-pumps/4030-50hz/40-51l_4030_3x1-5x6.pdf?la=en&display=1

Pump Selection

- Intersect the system characteristics with the fan curve



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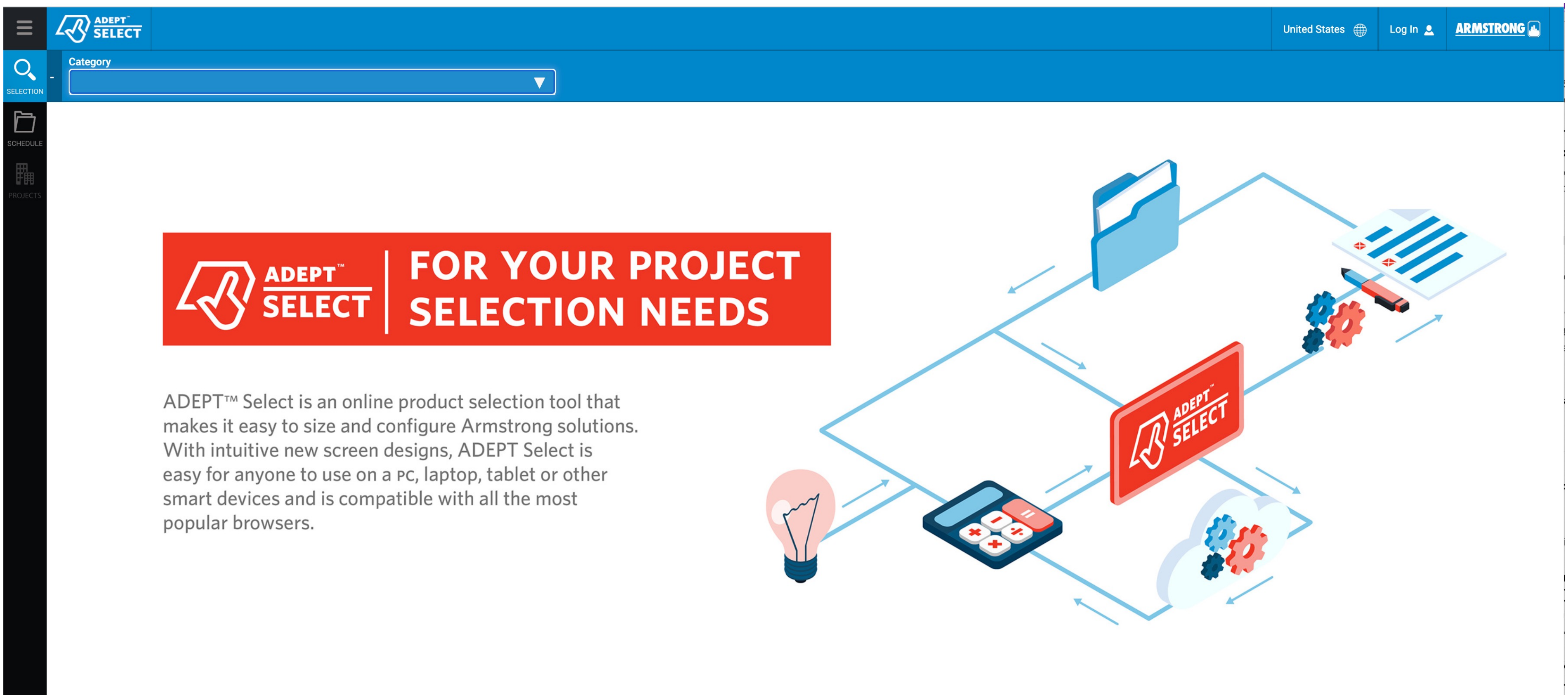
Pump Selection

- Manufacture 1:

https://armstrongfluidtechnology.com/en/products-and-services/plumbing-and-water-supply/commercial-pumps

Pump Selection

- Manufacture 1:



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)

https://armstrongfluidtechnology.com/en/products/4280-motor-mounted-pumps

Pump Selection

- Manufacture 1:

4280 Motor Mounted Pumps

Benefits & Features | Design & Submittals | Warranty

Submittals & Forms | Curves & Diagrams | Other

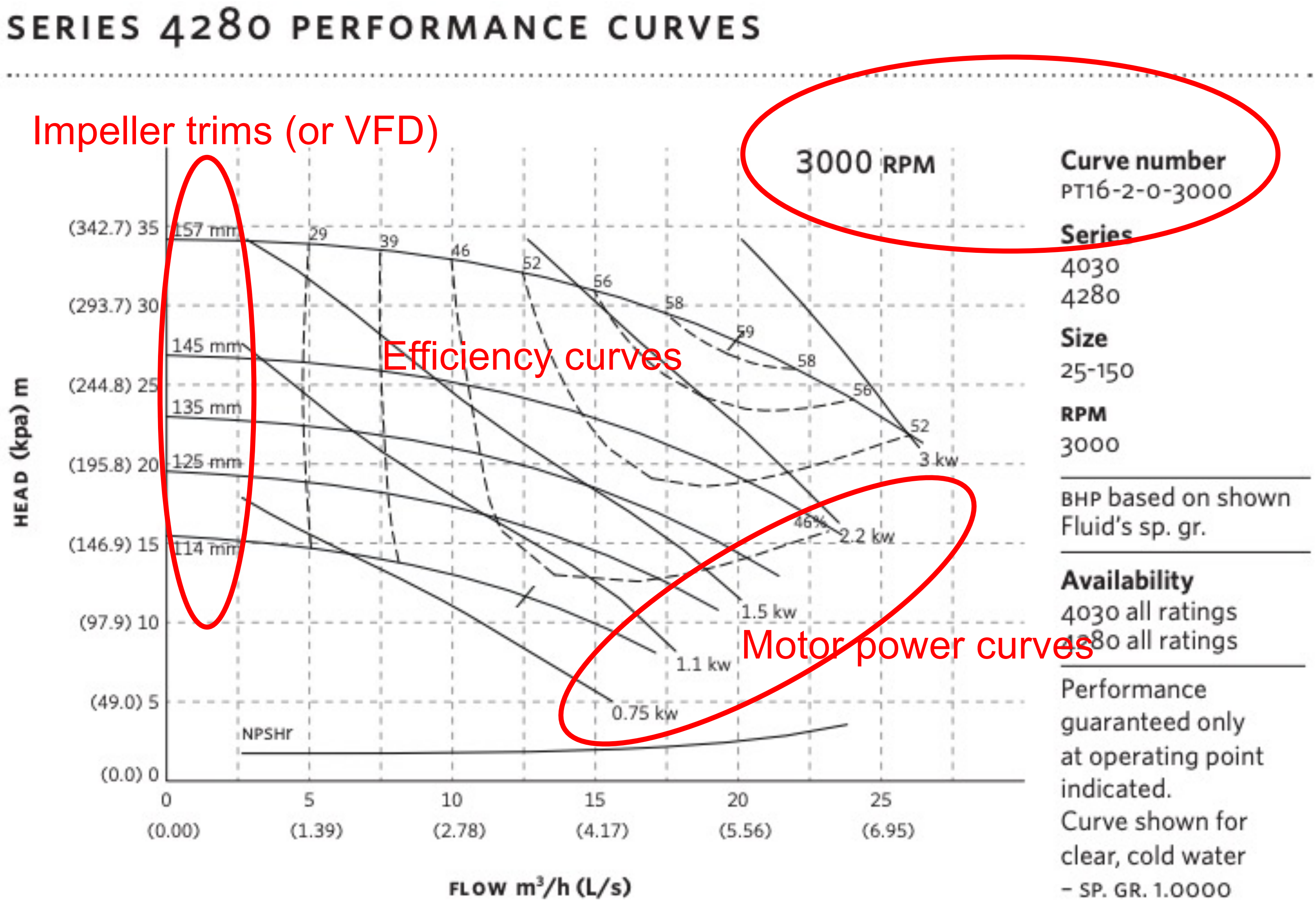
Submittals (50Hz)
(PDF)

- 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

https://armstrongfluidtechnology.com/en/products/4280-motor-mounted-pumps

Pump Selection

- Manufacture 1:



https://armstrongfluidtechnology.com/en/products/4280-motor-mounted-pumps

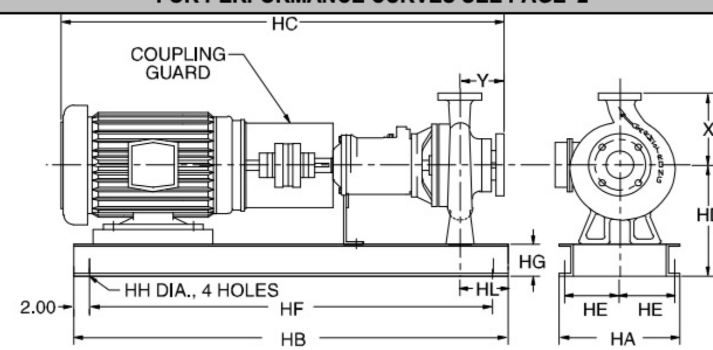
Pump Selection

- 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.

OPTIONAL EQUIPMENT
FOR PERFORMANCE CURVES SEE PAGE 2



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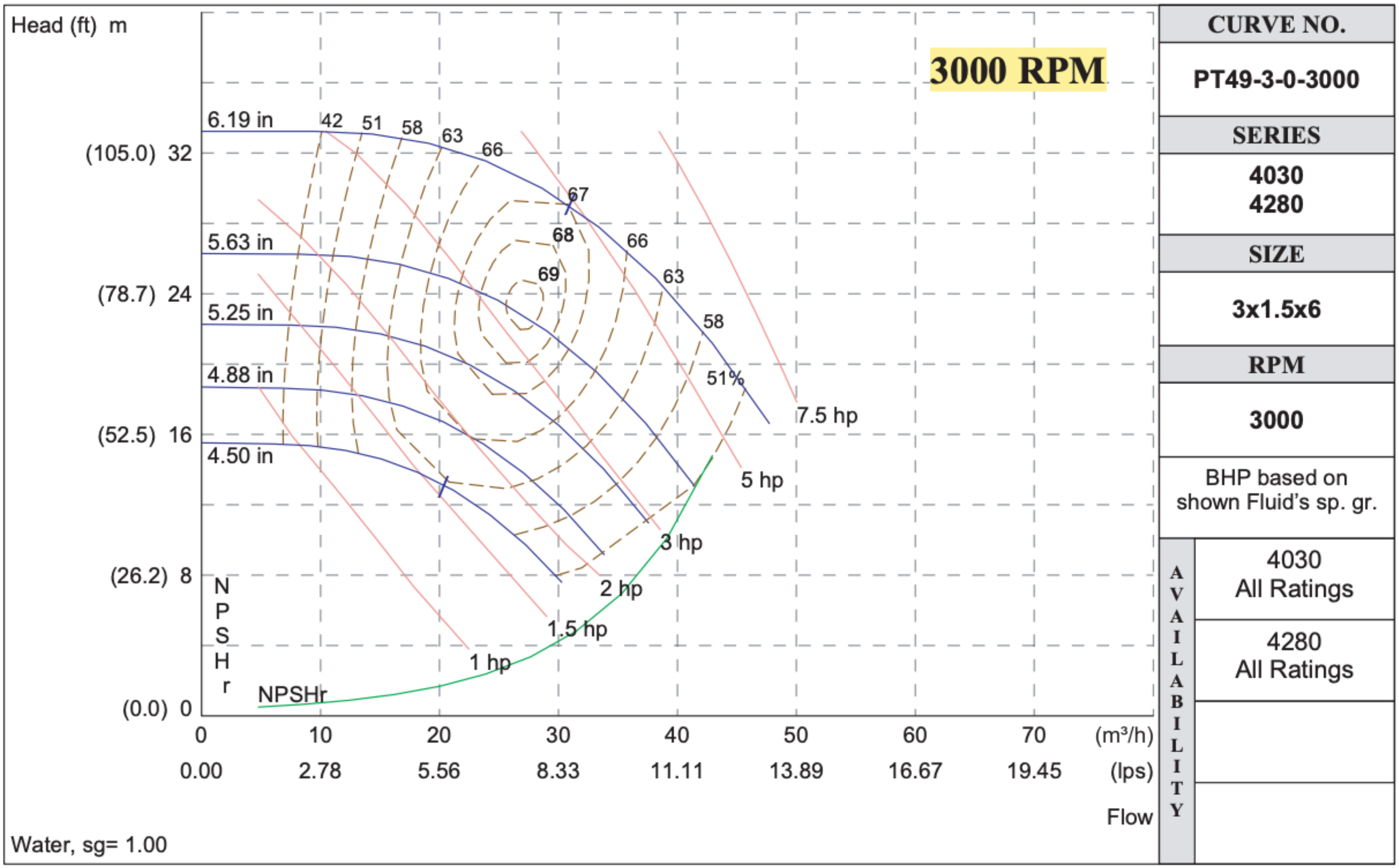
Pump Selection

- Manufacture 1:



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Pump Selection

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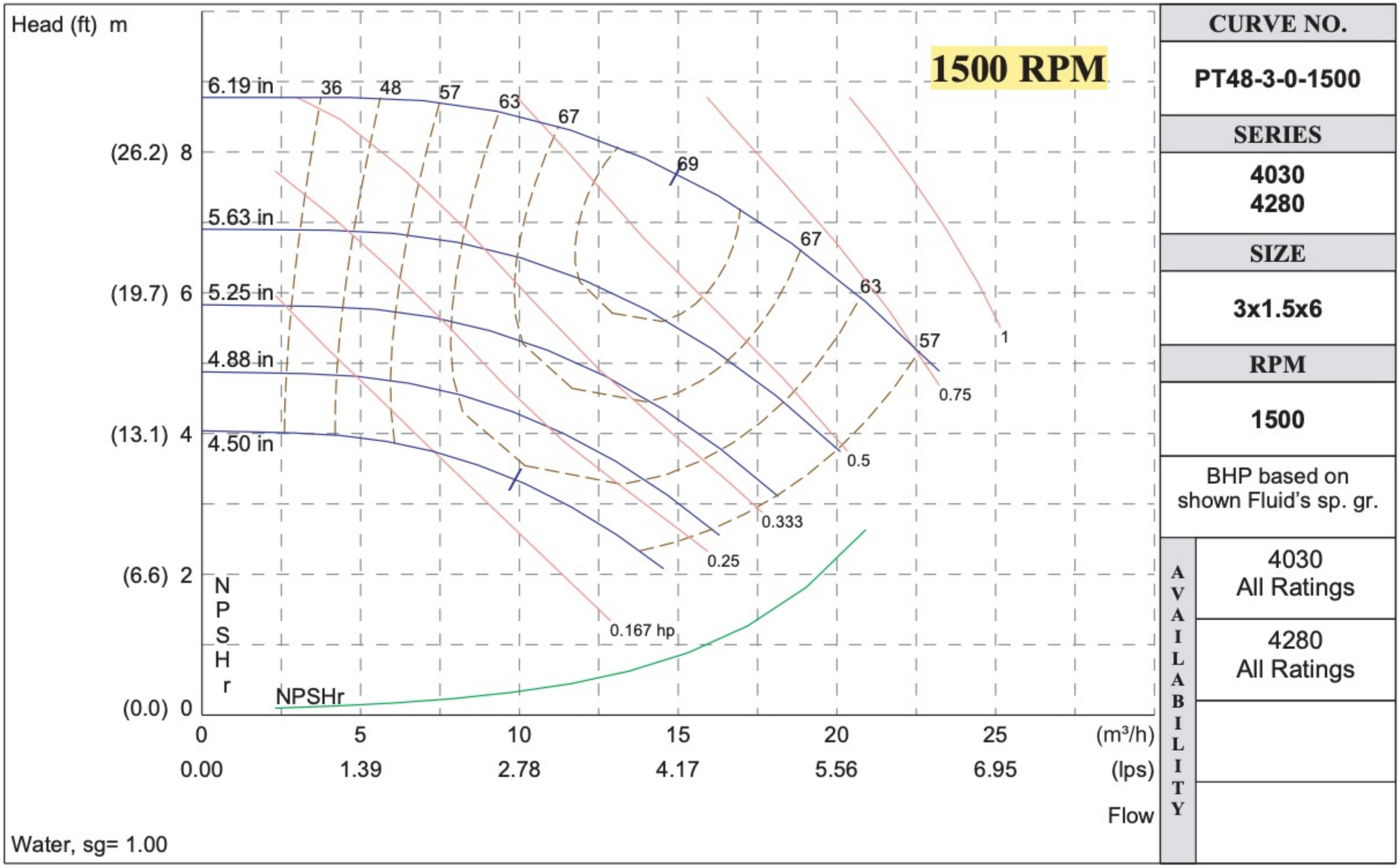

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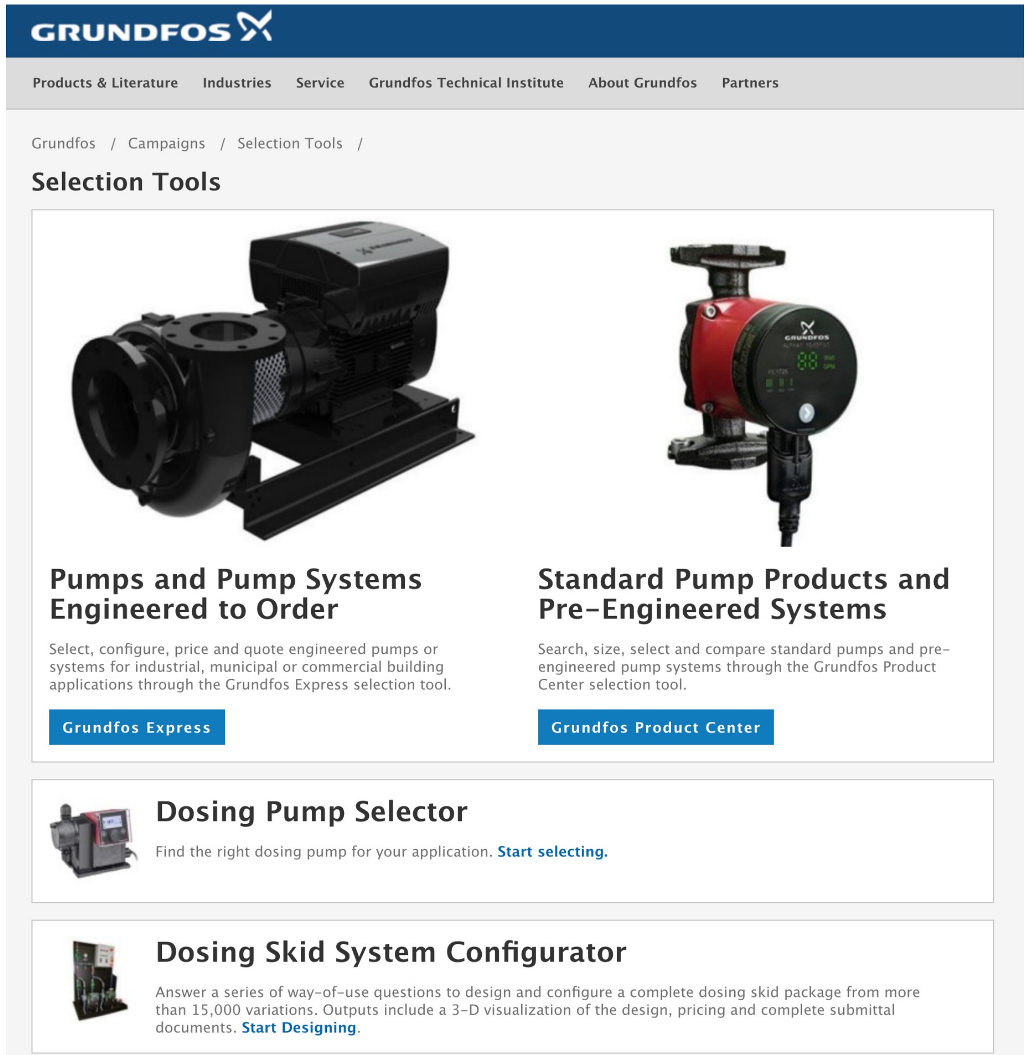
Pump Selection

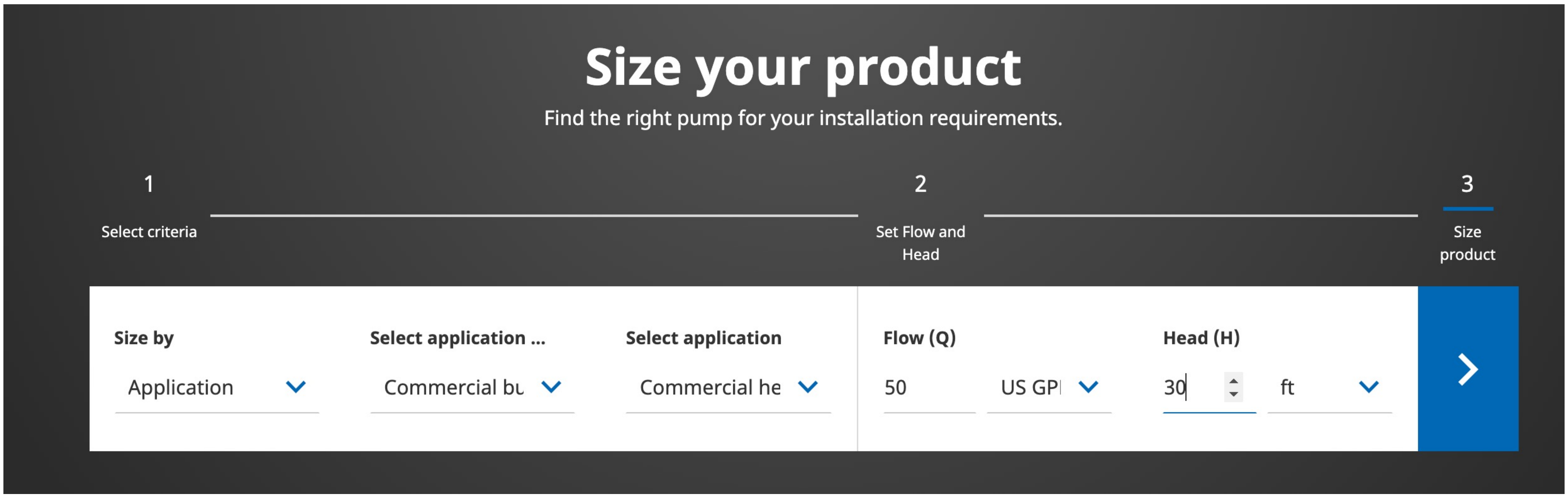
- Manufacture 2:



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

Pump Selection

- Manufacture 2:



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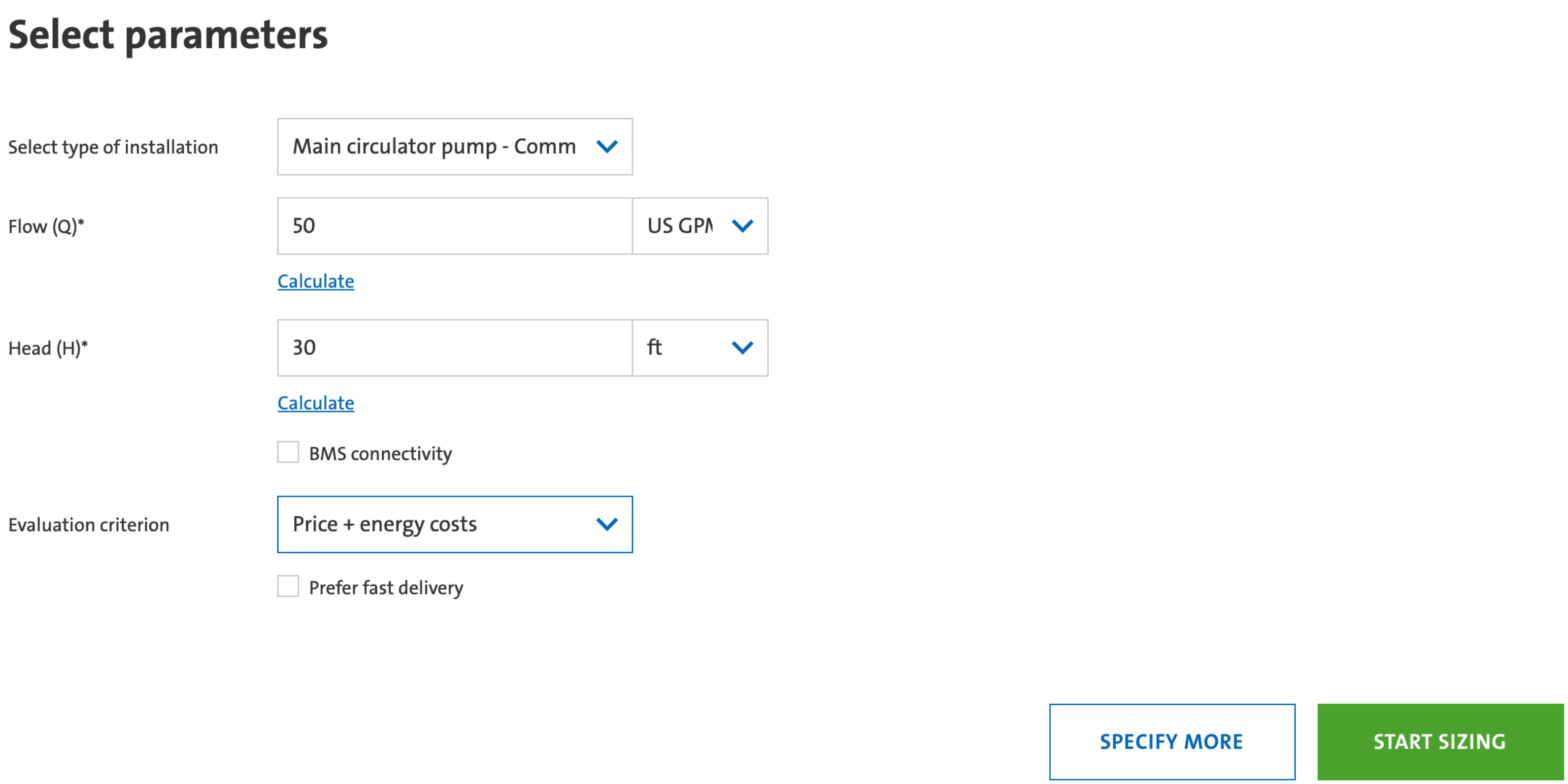
Pump Selection

- Manufacture 2:



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

Pump Selection

- Manufacture 2:

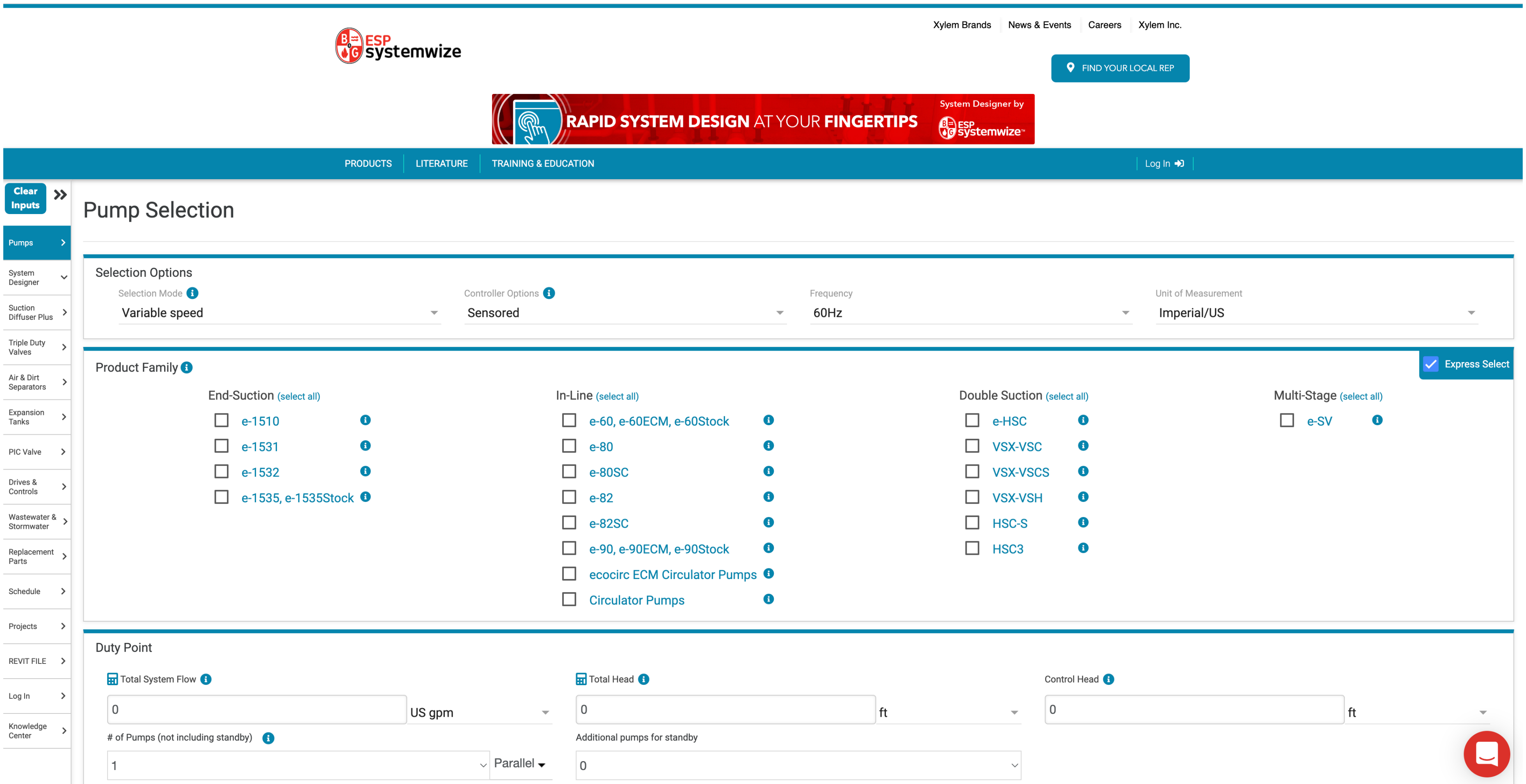
Curve	Product No	/15 years]	Pump orient.	Phases	U [V]	P2 [kW]	IE efficiency	Con size outlet	Max. operating [bar]	Q [US GPM]	Q-dev [%]	H [ft]	H-de
	97924270		-	1	230	-	-	DN 40	10	47.4	-5.1	29.4	-2.0
	96503184 + ..		Vertical	3	380 - 440	0.75	NEMA Premium / IE3 60Hz	1 1/2	16	50	0.0	30	
	99088786 + ..		-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

GMA 50Hz

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

Pump Selection

- Manufacture 3:

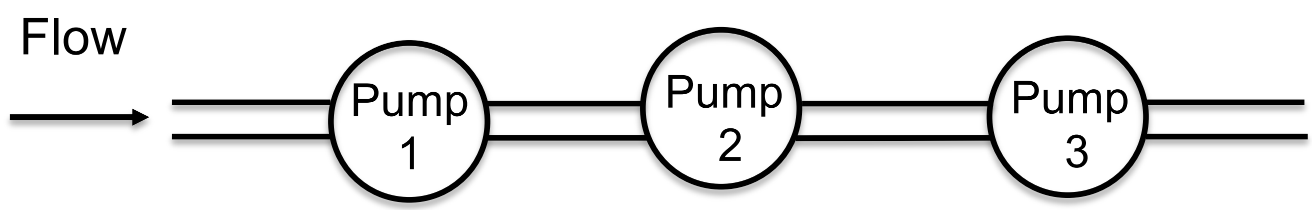


https://www.esp-systemwize.com/

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

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  - ❑ Operate with the same flow rate
  - ❑ Allow increase the total head

$$H = H_1 + H_2 + H_3$$

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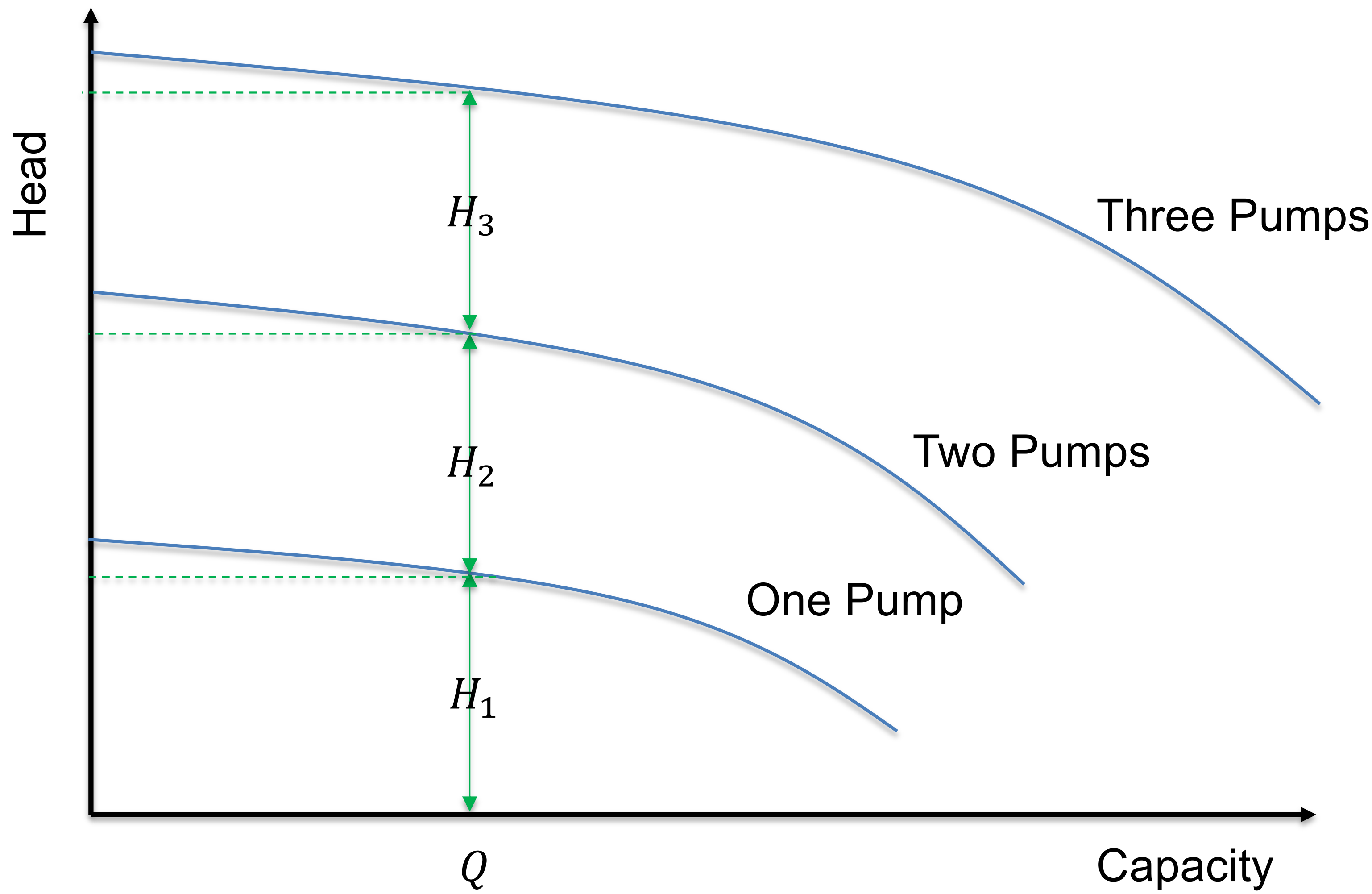
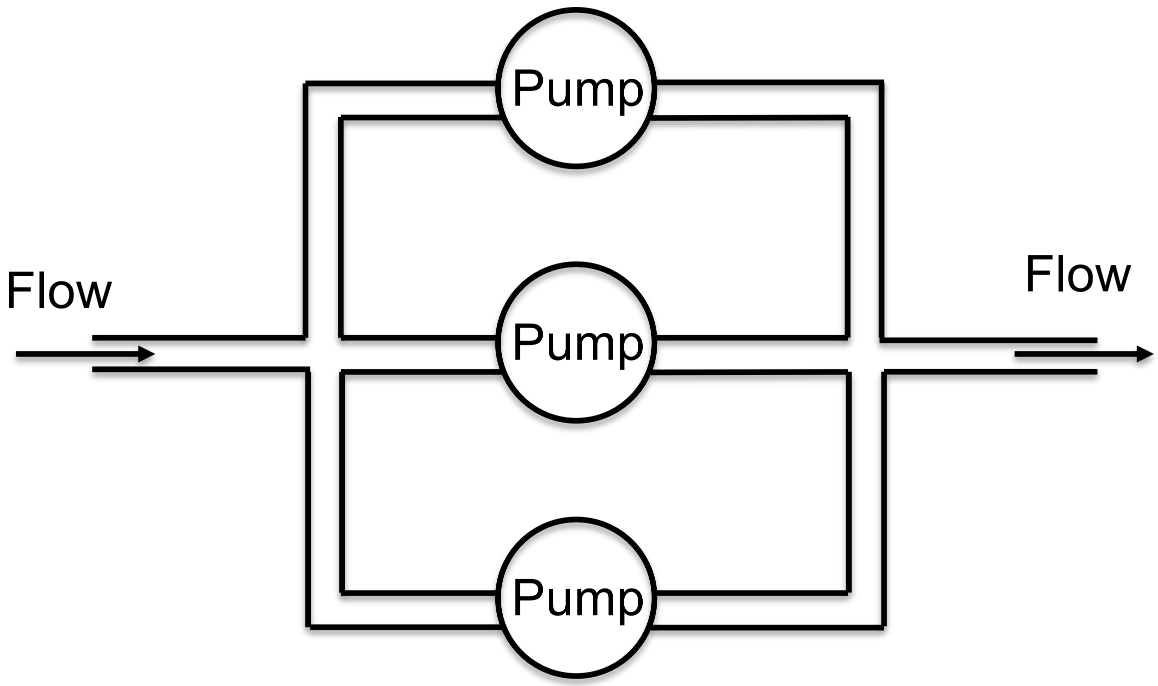


Multiple Pumps

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

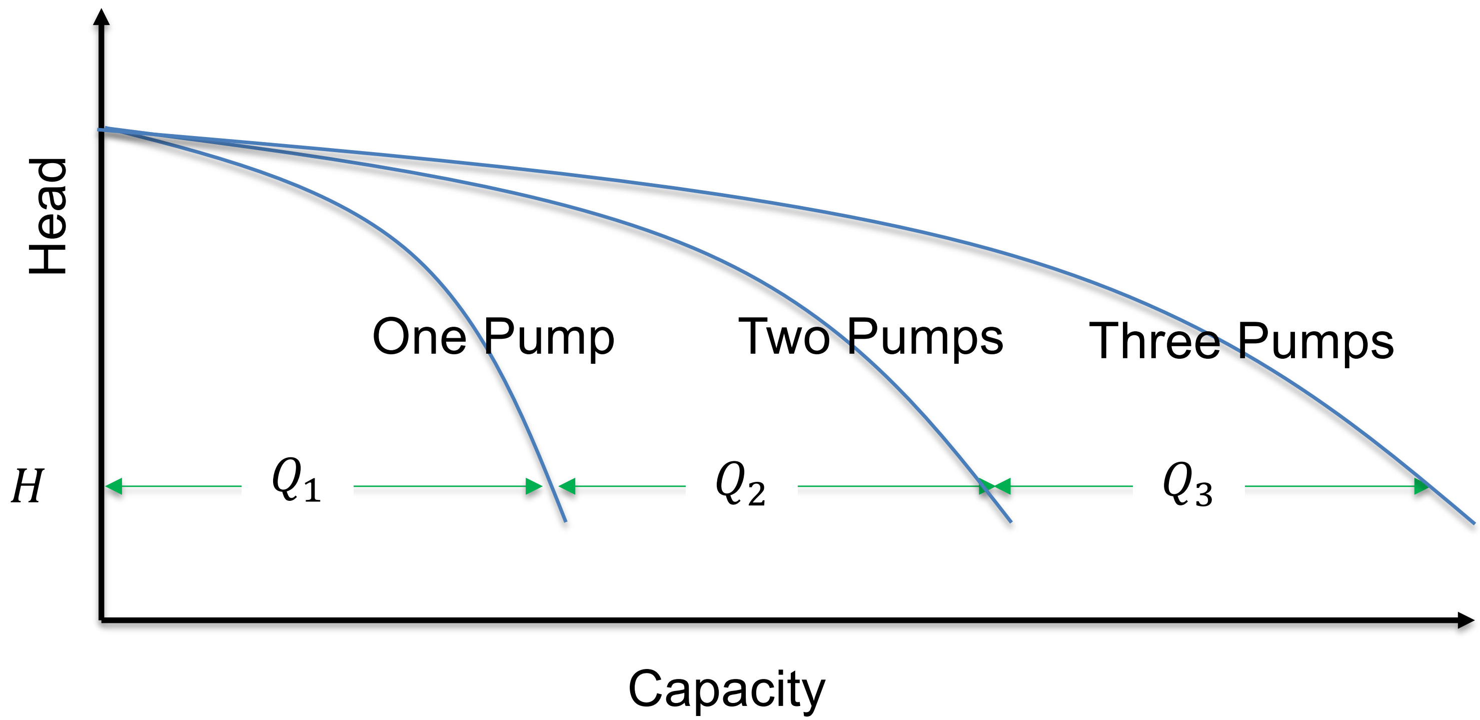


$$H = H_1 = H_2 = H_3$$

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

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:

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

Shaft Power:

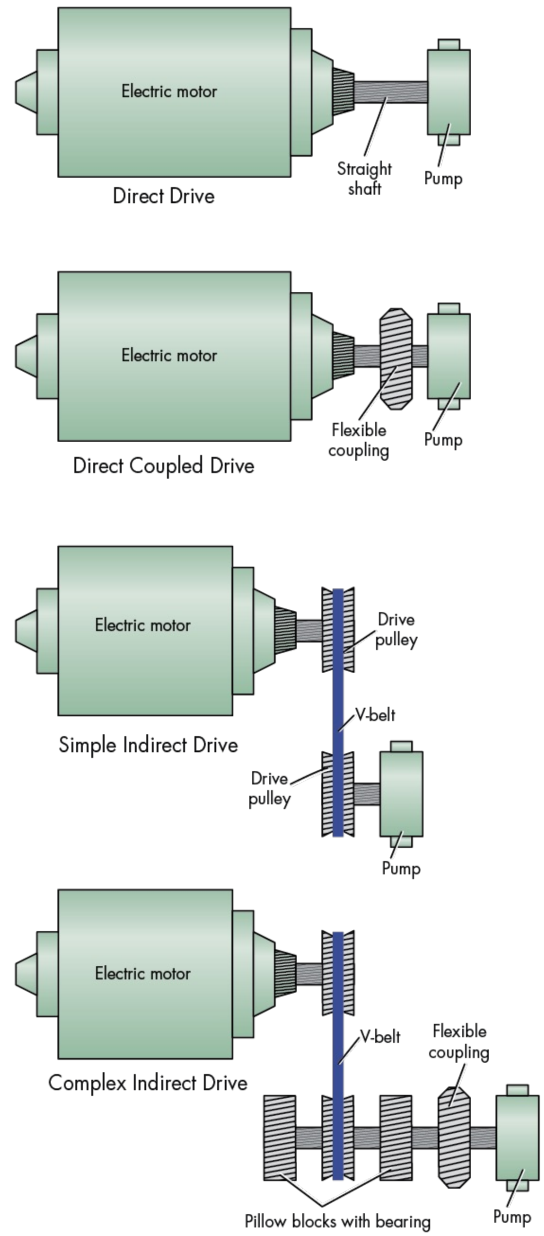
$$W_n = W_o\left(\frac{rpm_n}{rpm_o}\right)^3$$

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



https://www.indiamart.com/proddetail/motor-pump-couplings-6451712691.html

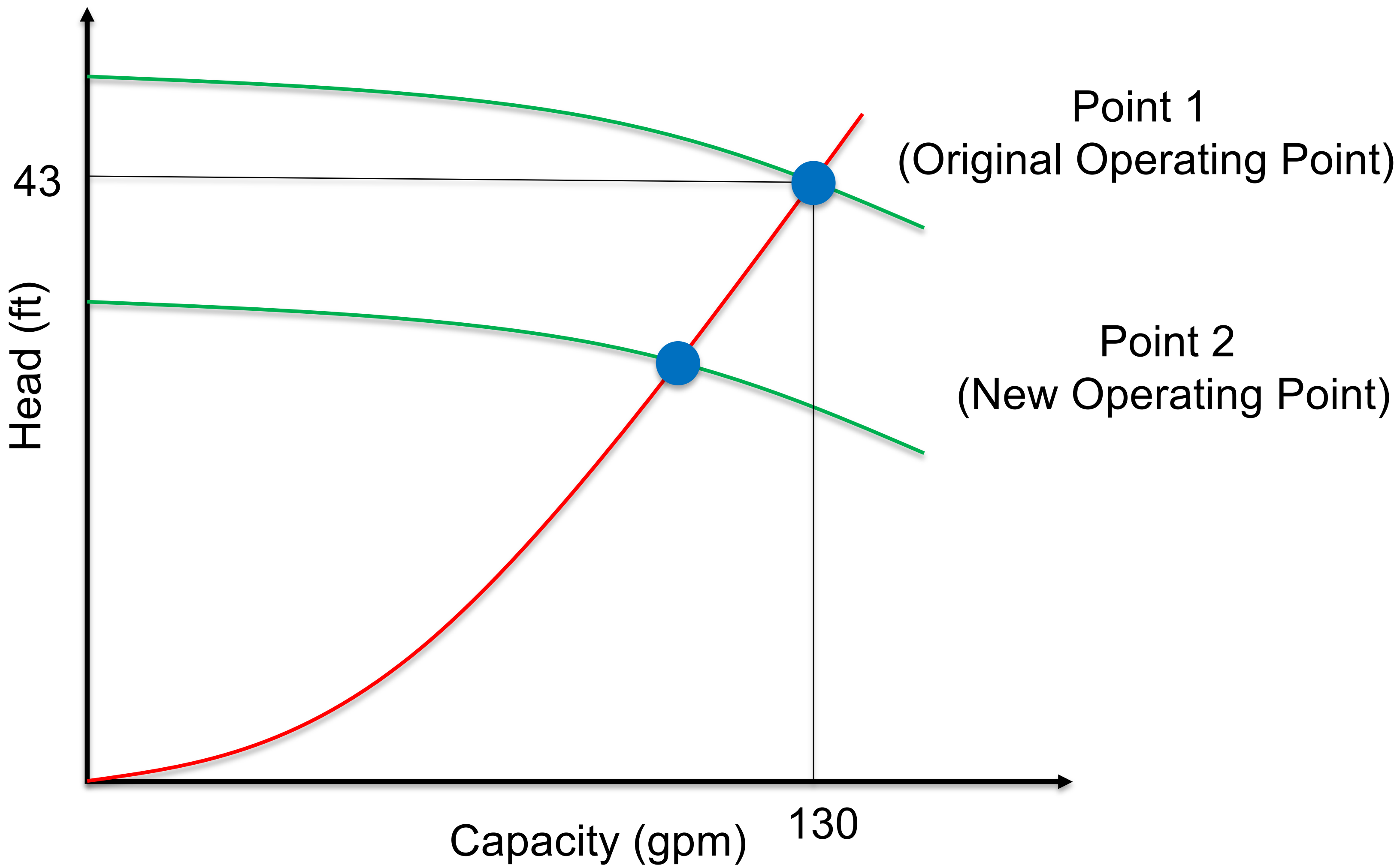
CLASS ACTIVITY (AFFINITY LAWS)

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:



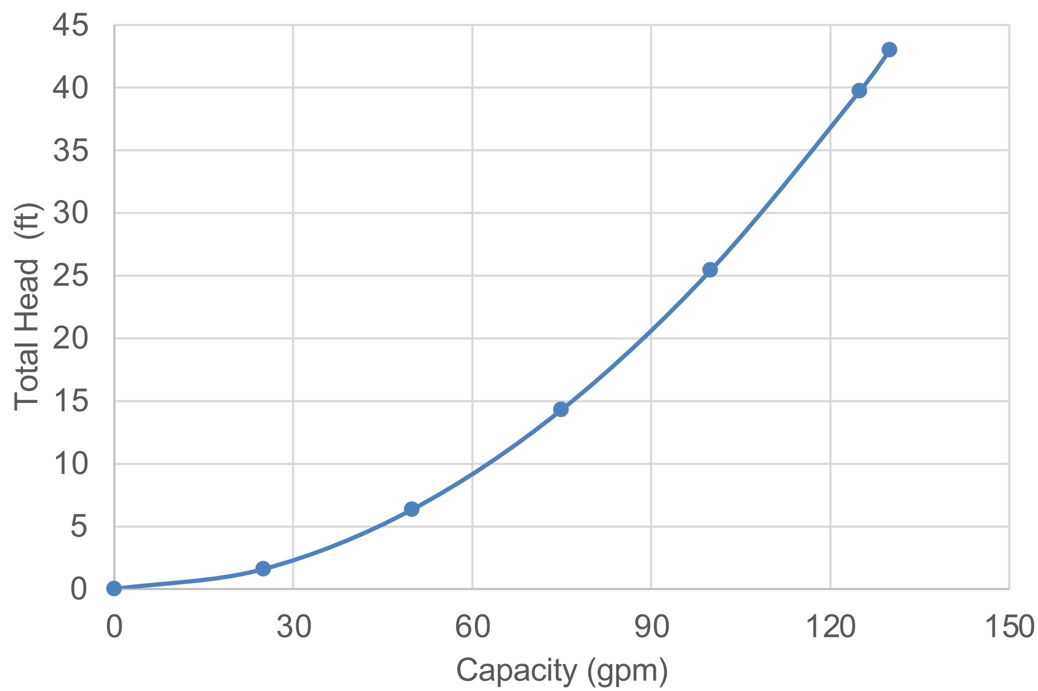
Class Activity

- **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
  - ❑ $rpm_o = 1750$
  - ❑ $Q_o = 130\ gpm$
  - ❑ $Q_n = 100\ gpm$
  - ❑ 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:

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

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

$$W_n = 0.96\ hp$$

Class Activity

- **Solution:**
  - New efficiency is:

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

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

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

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

https://www.britannica.com/science/cavitation

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)

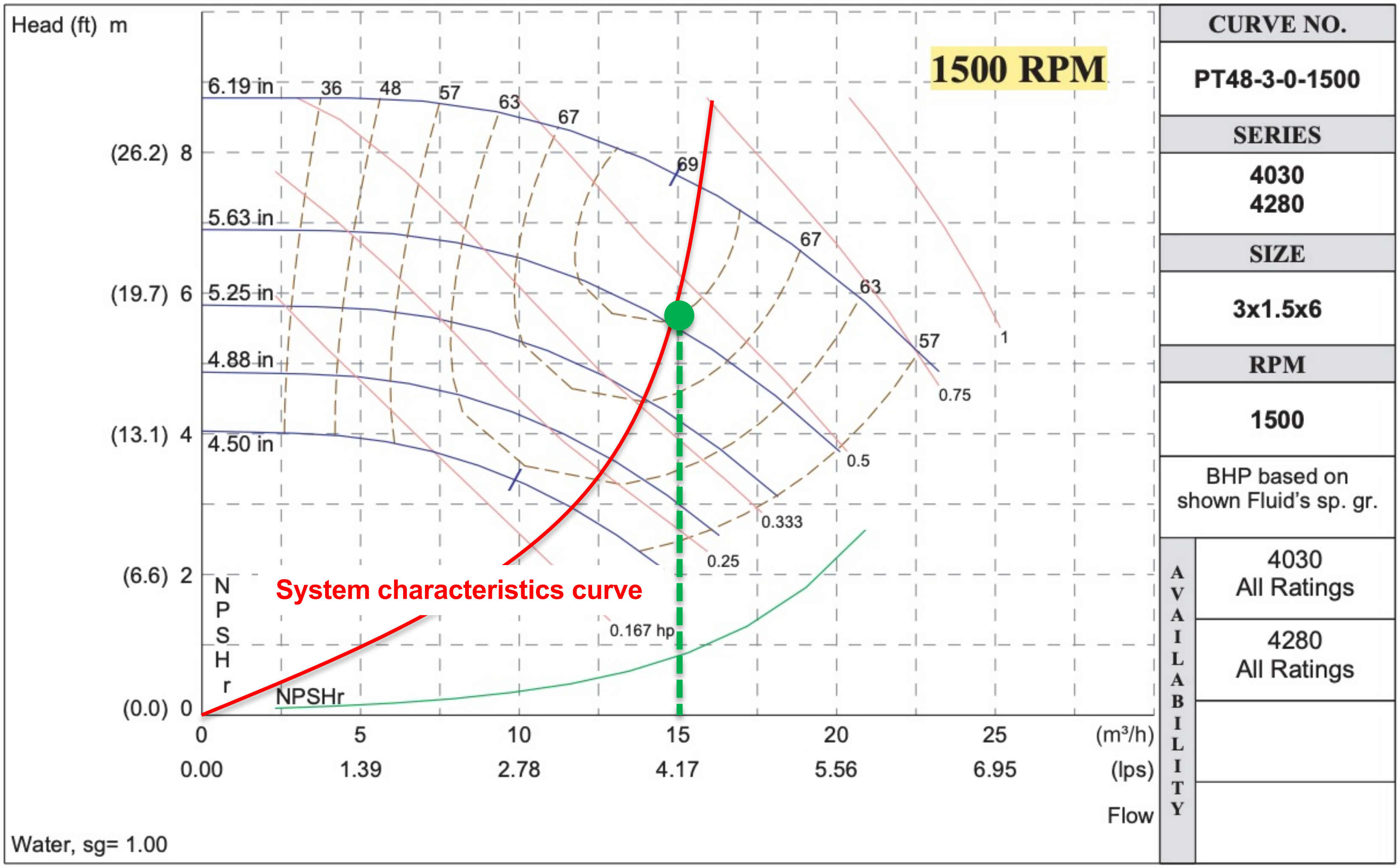
- For a given system, a higher the water temperature yields a lower $NPSH_A$

$$\mathrm{P_v}(100\ \mathrm{°F}) = 0.95044\ \mathrm{psi}$$

$$\mathrm{P_v}(200\ \mathrm{°F}) = 11.5376\ \mathrm{psi}$$

Net Positive Suction head (NPSH)

- Notice the $NPSH_r$ line”



https://armstrongfluidtechnology.com/~/media/documents/specifications/submittal-data/4030-base-mounted-pumps/4030-50hz/40-51l_4030_3x1-5x6.pdf?la=en&display=1