Florida International University, Department of Civil and Environmental Engineering

CWR 3201 Fluid Mechanics, Fall 2018

Hydraulic Pumps

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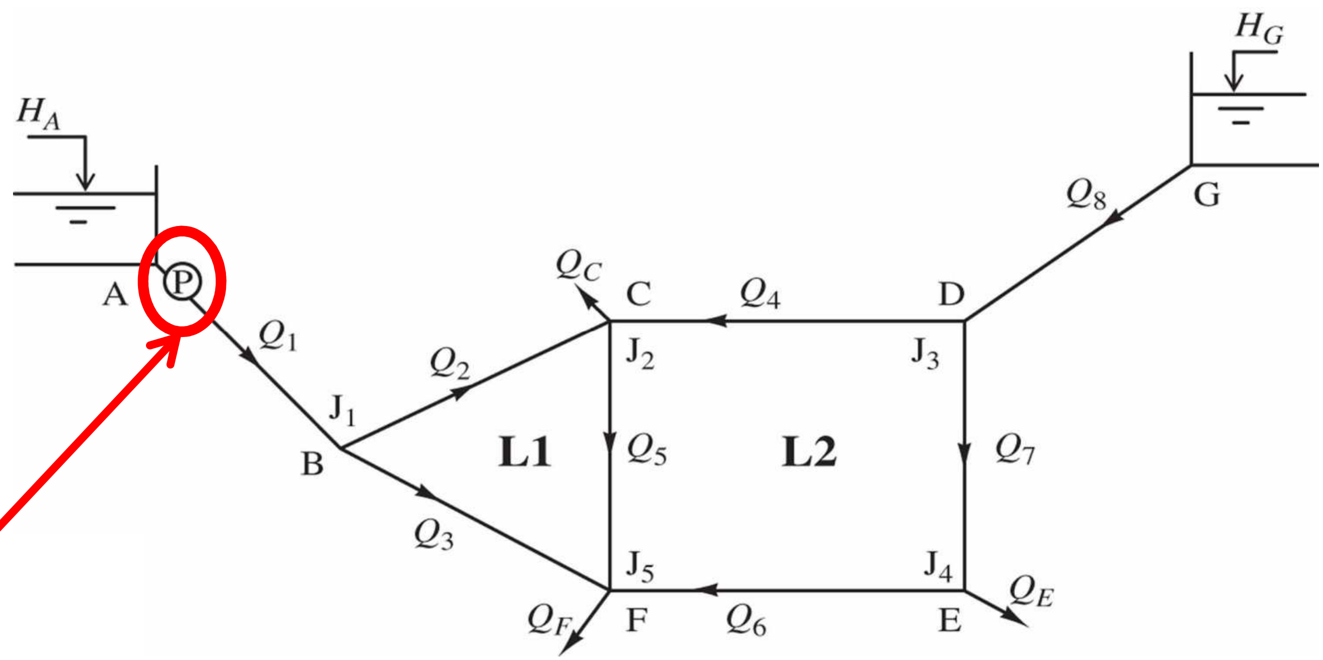
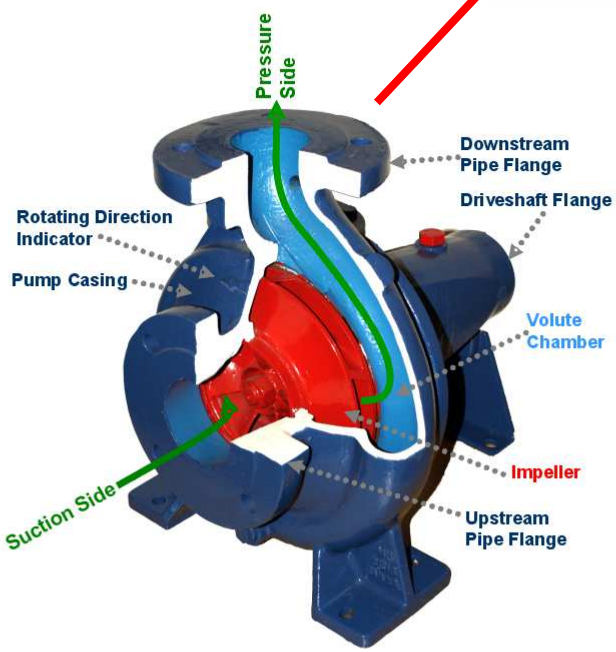
Hydraulic Pump Videos:

Centrifugal pump **[Most used pump]**
https://www.youtube.com/watch?v=BaEHVpKc-1Q

RAM pump **[No external energy is required]**
https://www.youtube.com/watch?v=aUTjVovpKvA

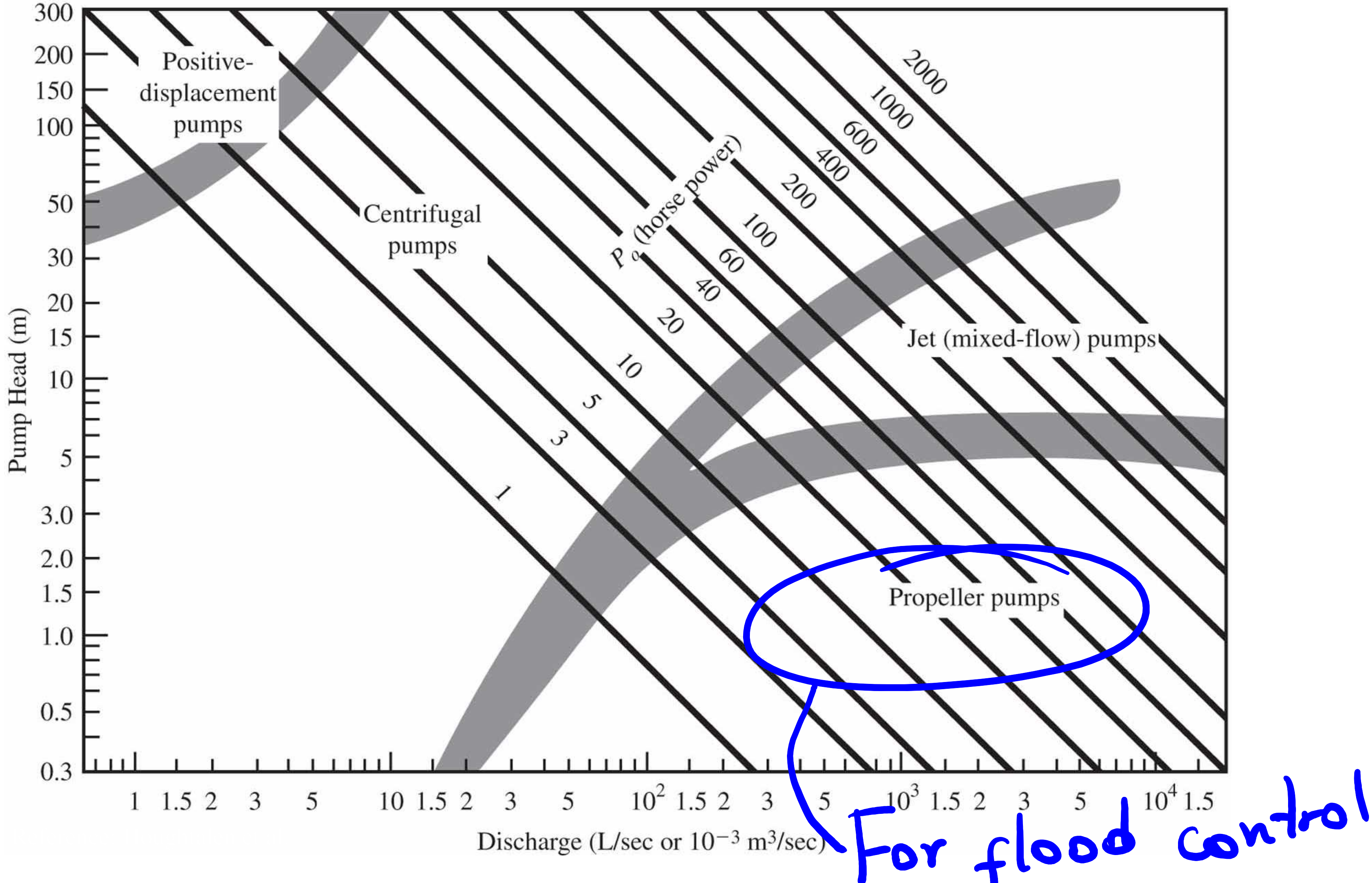
Pipe Network with Hydraulic pumps





A hydraulic pump adds energy to a system, with the result that the pressure is increased.

Typical discharge, head, and power requirements for different types of pumps

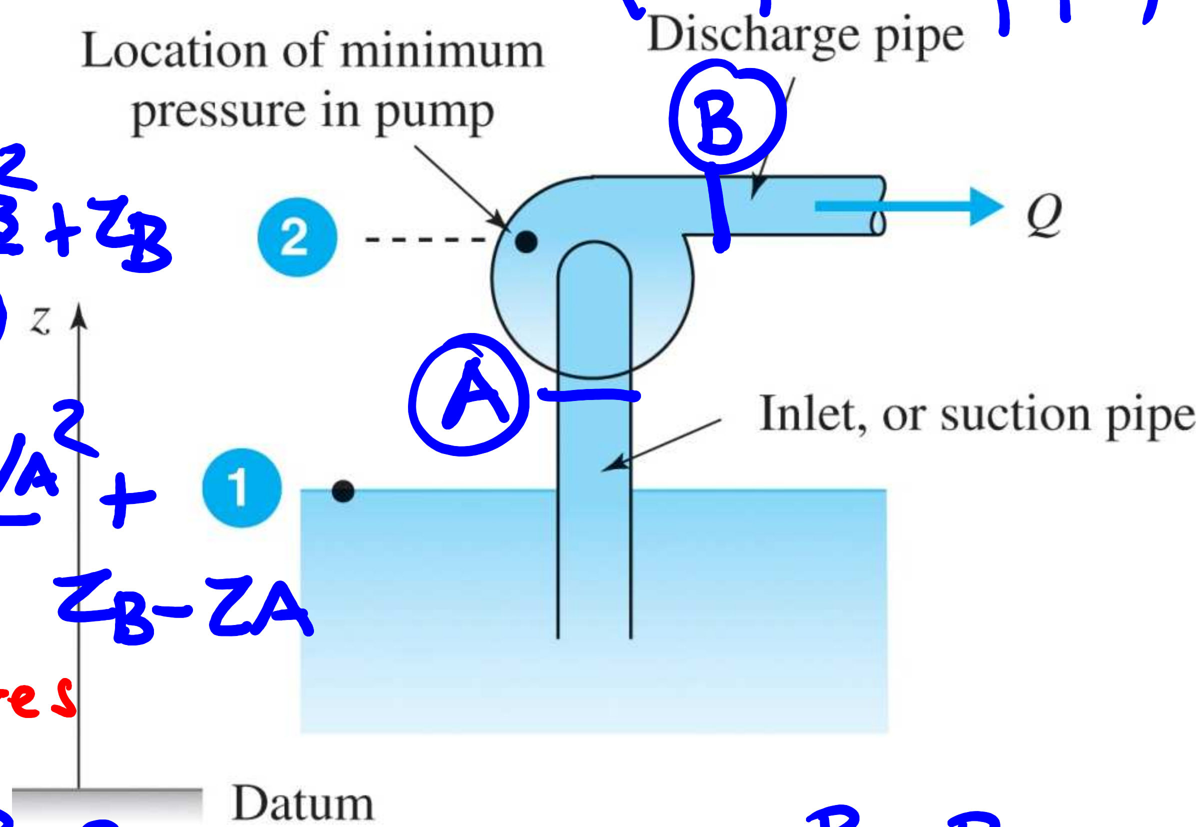


Pump Performance Characteristics

$E_A = E_B$ + H_p

$$\frac{P_A}{\gamma} + \frac{V_A^2}{2g} + z_A = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + z_B$$

(Impulsion pipe)



$$H_p = \frac{P_B - P_A}{\gamma} + \frac{V_B^2 - V_A^2}{2g} + z_B - z_A$$

* For large pressures

$$\frac{V_B^2 - V_A^2}{2g} << \frac{P_B - P_A}{\gamma}, \quad z_B - z_A << \frac{P_B - P_A}{\gamma}$$

$$\boxed{H_p \approx \frac{P_B - P_A}{\gamma}}$$

H_p = actual head gained by the fluid from the pump theoretical power

Pump Performance Characteristics (Cont.)

$$\boxed{P = \frac{\gamma Q H_p}{550}}$$

P: power in HP

HP: Horsepower

H_p: Increase of head due to pump

bhp: brake horse power

$$\eta = \frac{\text{power gained by the fluid}}{\text{shaft power driving the pump (bhp)}}$$

$$\boxed{\eta = \frac{\gamma Q H_p}{550\,(bhp)}}$$

Where: γ in lb/ft^3, Q in ft^3/s and H_p in ft

$\boldsymbol{\eta}$ = overall efficiency

Pump Performance Characteristics (Cont.)

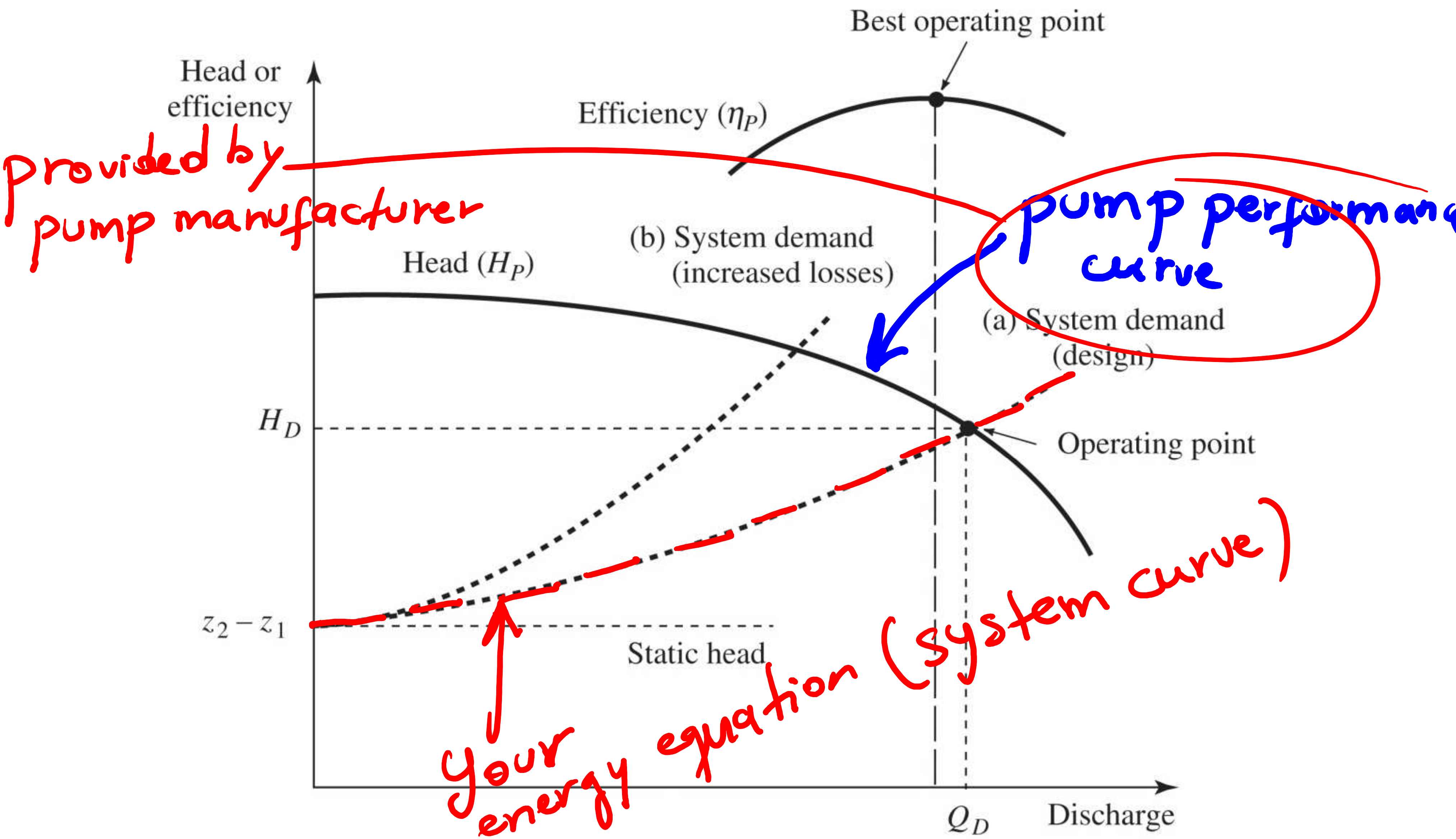
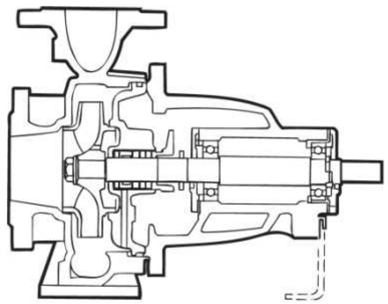


Fig. 12.16 Pump characteristic curve and system demand curve.



Pump Performance Characteristics (Cont.)

Performance curves for four different impellers for a radial-flow pump (2900 RPM)

$Q = 190\ m^3/h$

$H_p = 48\ m$

$\eta = 72\%$

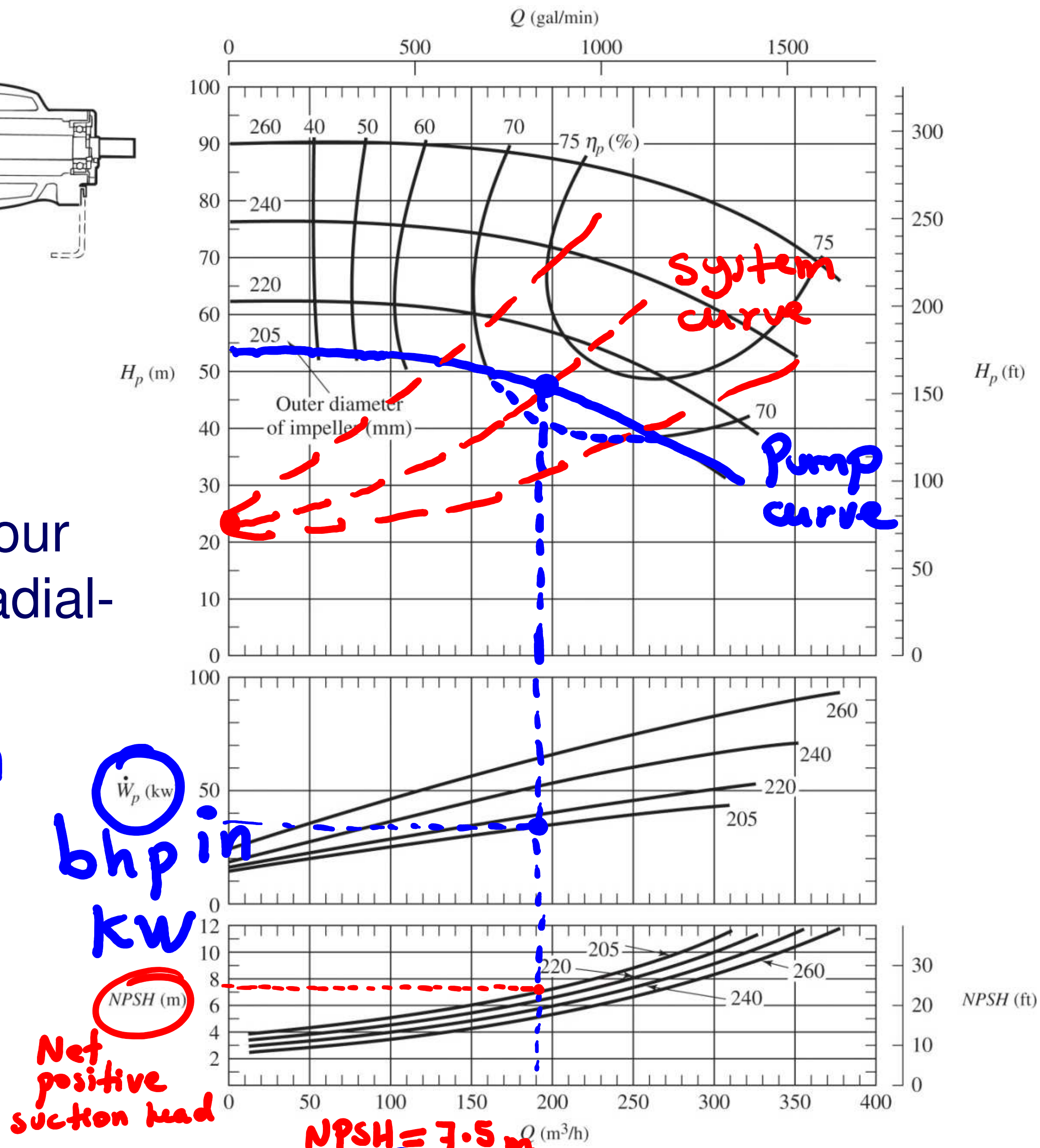


Fig. 12.6 Radial-flow pump and performance curves for four different impellers with $N = 2900$ rpm ($\omega = 304$ rad/s). Water at 20°C is the pumped liquid. (Courtesy of Sulzer Pumps Ltd.)

Net Positive Suction Head

(NPSH)

Net Positive Suction Head (NPSH)

- On the suction side of a pump, low pressures are very common. Check for cavitation (Vapor pressure).
- Cavitation occurs when the liquid pressure at a given location is reduced to the vapor pressure of the liquid.
- How to characterize the potential for cavitation…

NPSH

Pv: Vapor pressure

Energy Equation between 1 and 2 (using absolute pressure)

$E_1 = E_2$

$$\frac{P_{atm}}{\gamma} + \overset{0}{\frac{V_1^2}{2g}} + z_1 = \overset{\frac{P_v}{\gamma}}{\frac{P_2}{\gamma}} + \frac{V_2^2}{2g} + z_2 + \Sigma h_L$$

$$\underbrace{\frac{P_{atm}}{\gamma} - \frac{P_v}{\gamma} - \Delta z - \Sigma h_L}_{NPSH_A} = \frac{V_2^2}{2g}$$

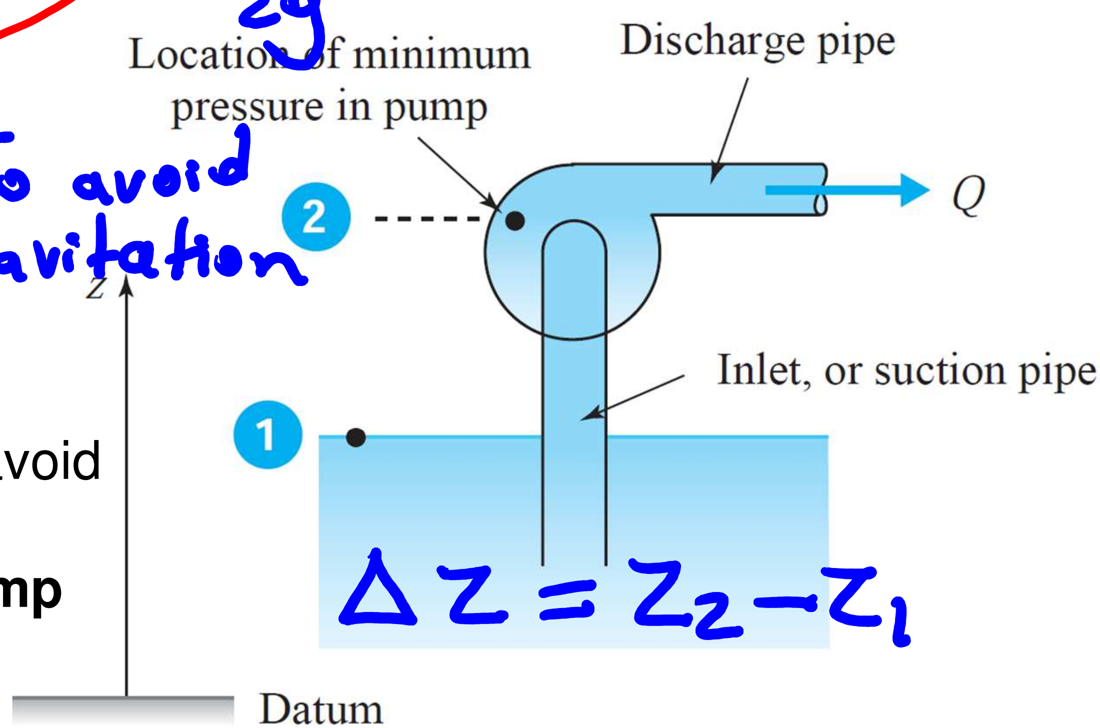
To avoid cavitation

$$\boxed{NPSH_R < NPSH_A}$$

$NPSH_A$ = Theoretical NPSH to avoid cavitation

$NPSH_R$ = NPSH provided by pump manufacturer

p_v = vapour pressure



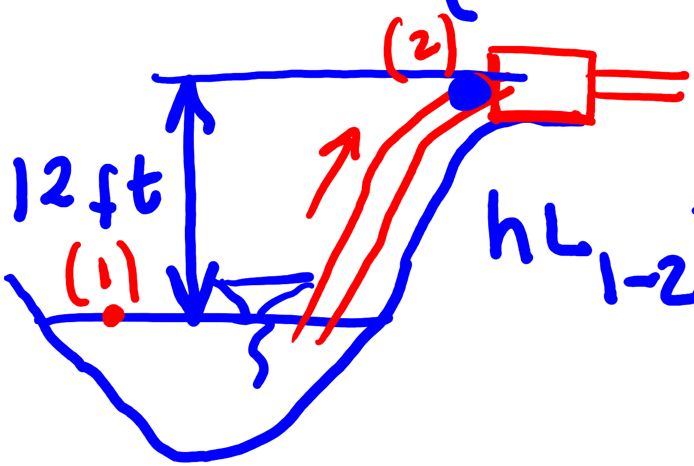
$\Delta Z = Z_2 - Z_1$

Fig. 12.11 Cavitation setting for a pump.

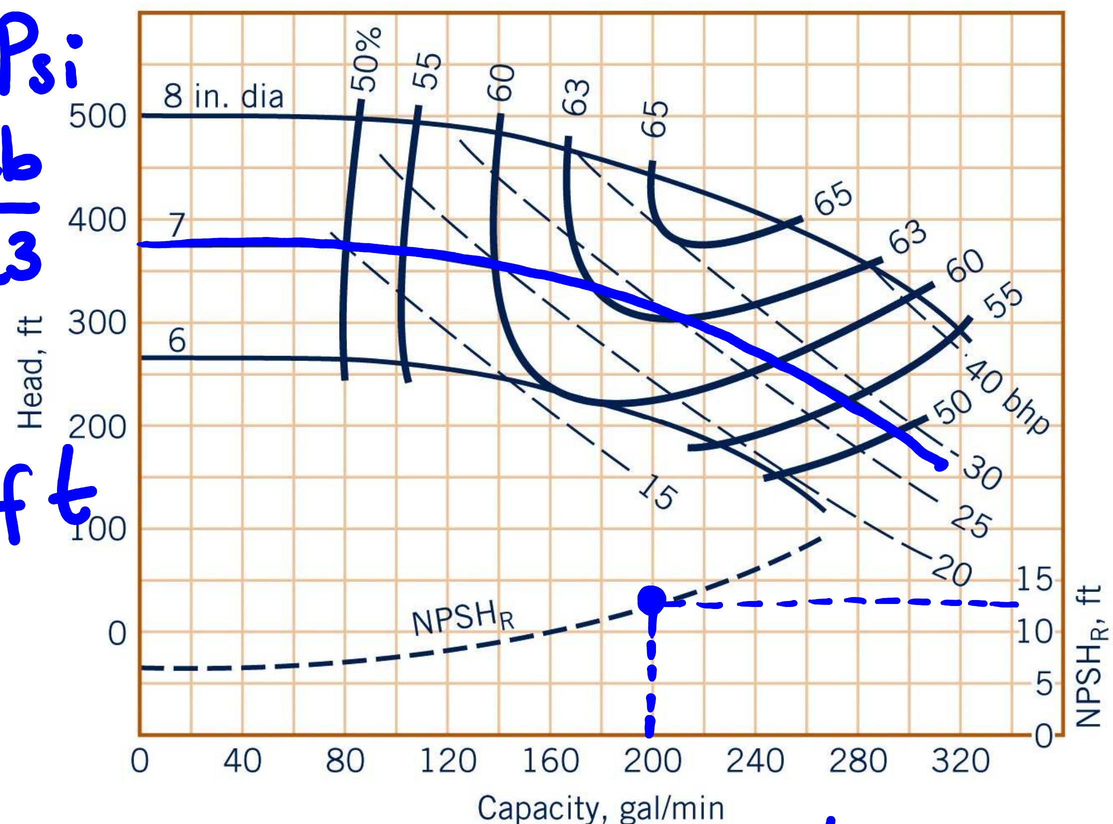
Example of application (P12.21):

A centrifugal pump with a 7-in diameter impeller has the performance characteristics shown below. The pump is used to pump water at 100° F, and the pump inlet is located 12ft above the open water surface. When the flow rate is 200 gpm, the head loss between the water surface and the pump inlet is 6 ft of water. Would you expect cavitation in the pump to be a problem? Assume standard atmospheric pressure.

$T_{water} = 100°F \; \begin{cases} P_v = 0.949 \text{ Psi} \\ \gamma = 62.1 \dfrac{lb}{ft^3} \end{cases}$



$h_{L_{1-2}} = 6 \text{ ft}$



$NPSH_R = 12.5 \text{ ft}$

$$NPSH_A = \frac{P_{atm} - P_v}{\gamma} - \Delta z - \Sigma h_L$$

$$\boxed{P_{atm} = 14.7 \text{ Psi}}$$

$$NPSH_A = \frac{14.7 \frac{\cancel{lb}}{\cancel{in^2}} \frac{144 \cancel{in^2}}{ft^2} - 0.949 \times 144}{62.1 \frac{\cancel{lb}}{ft^3}}$$

$$- 12 ft - 6 ft$$

$$NPSH_A = 13.9 ft$$

* To avoid cavitation

$$NPSH_R < NPSH_A$$

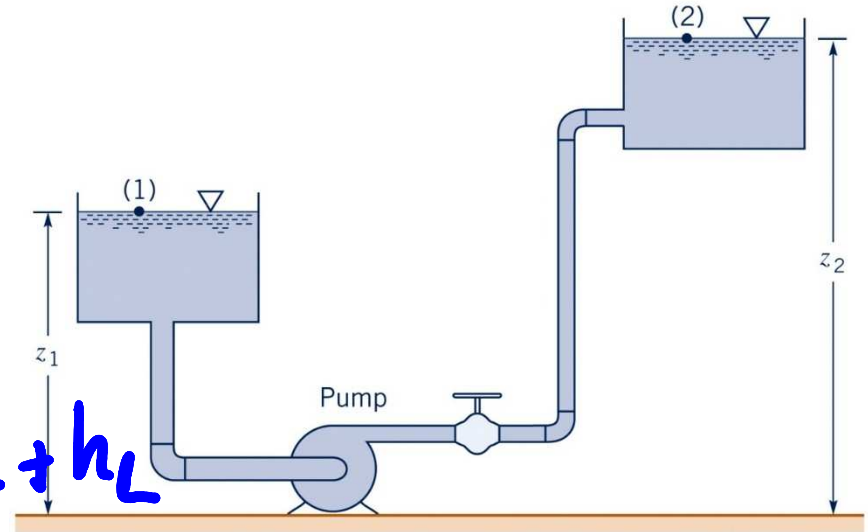
Is $\boxed{12.5_{ft} < 13.9 ft}$ Yes

No cavitation

System Characteristics and Pump Selection

System Characteristics and Pump Selection

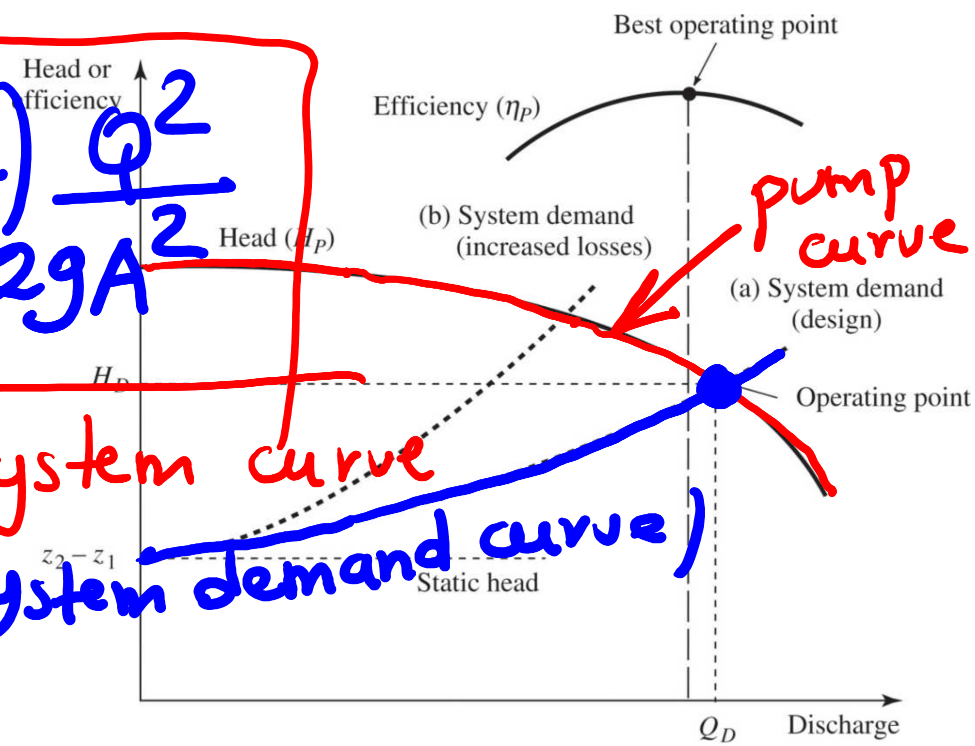
The energy equation between points (1) and (2) gives



$$E_1 = E_2$$

$$\cancel{\frac{P_1}{\gamma}} + \cancel{\frac{V_1^2}{2g}} + z_1 + H_p = \cancel{\frac{P_2}{\gamma}} + \cancel{\frac{V_2^2}{2g}} + z_2 + h_L$$

$$\boxed{H_p = z_2 - z_1 + \left(f\frac{L}{D} + \Sigma k\right)\frac{Q^2}{2gA^2}}$$



System demand curve:

H_p = actual head gained by the fluid from the pump

System Characteristics and Pump Selection

- To select a pump, it is necessary to utilize both the **system curve** (**determined by the system equation**), and the **pump performance curve**.
- The intersection of both curves represents the **operating point for the system**.
- The operating point should be near the best efficiency point.

Pumps in Parallel

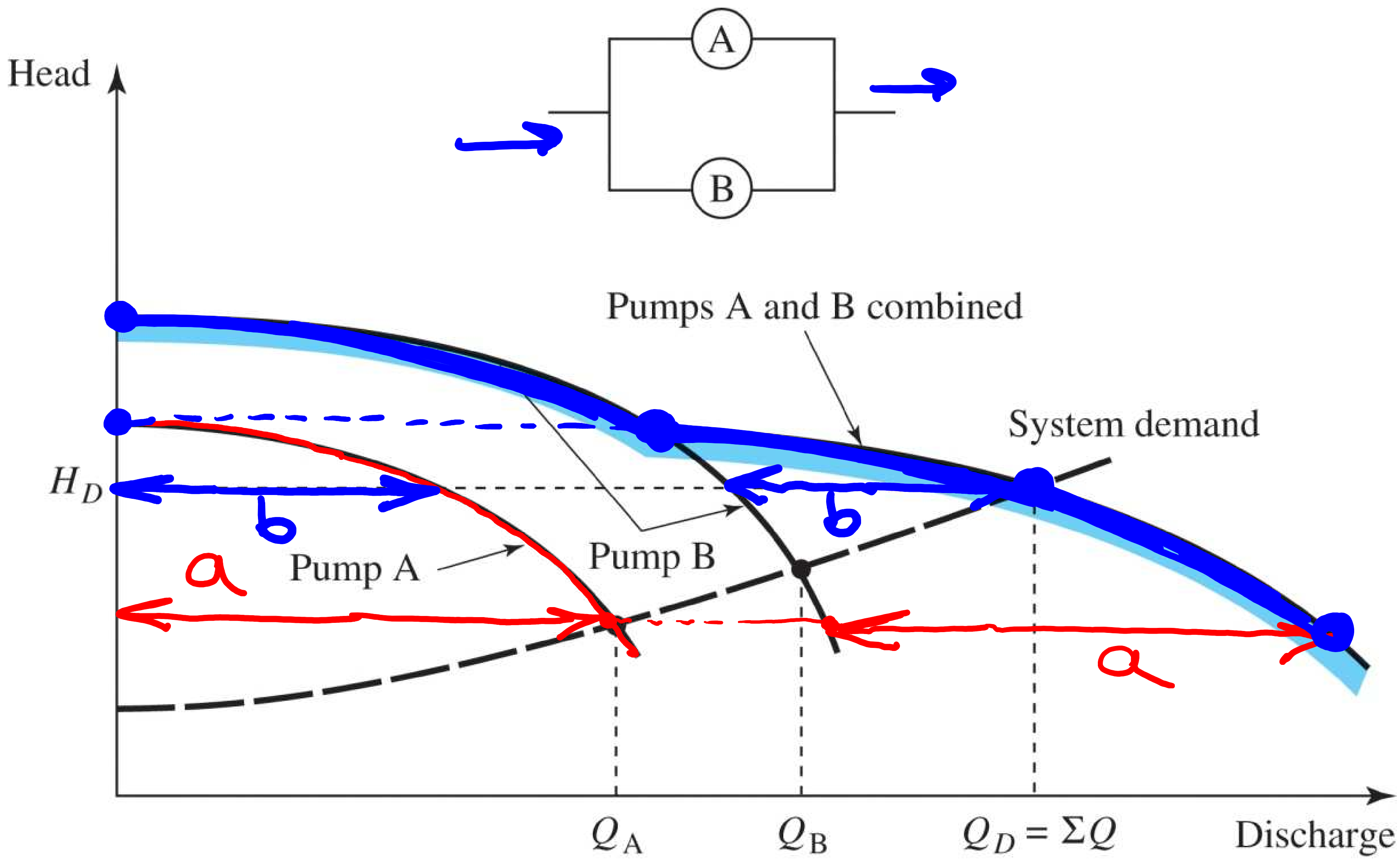


Fig. 12.17 Characteristic curves for pumps operating in parallel.

Pumps in Series

Q with only pump A = 0

Q with pump B = Q_B

Q with pumps A and B = Q_D

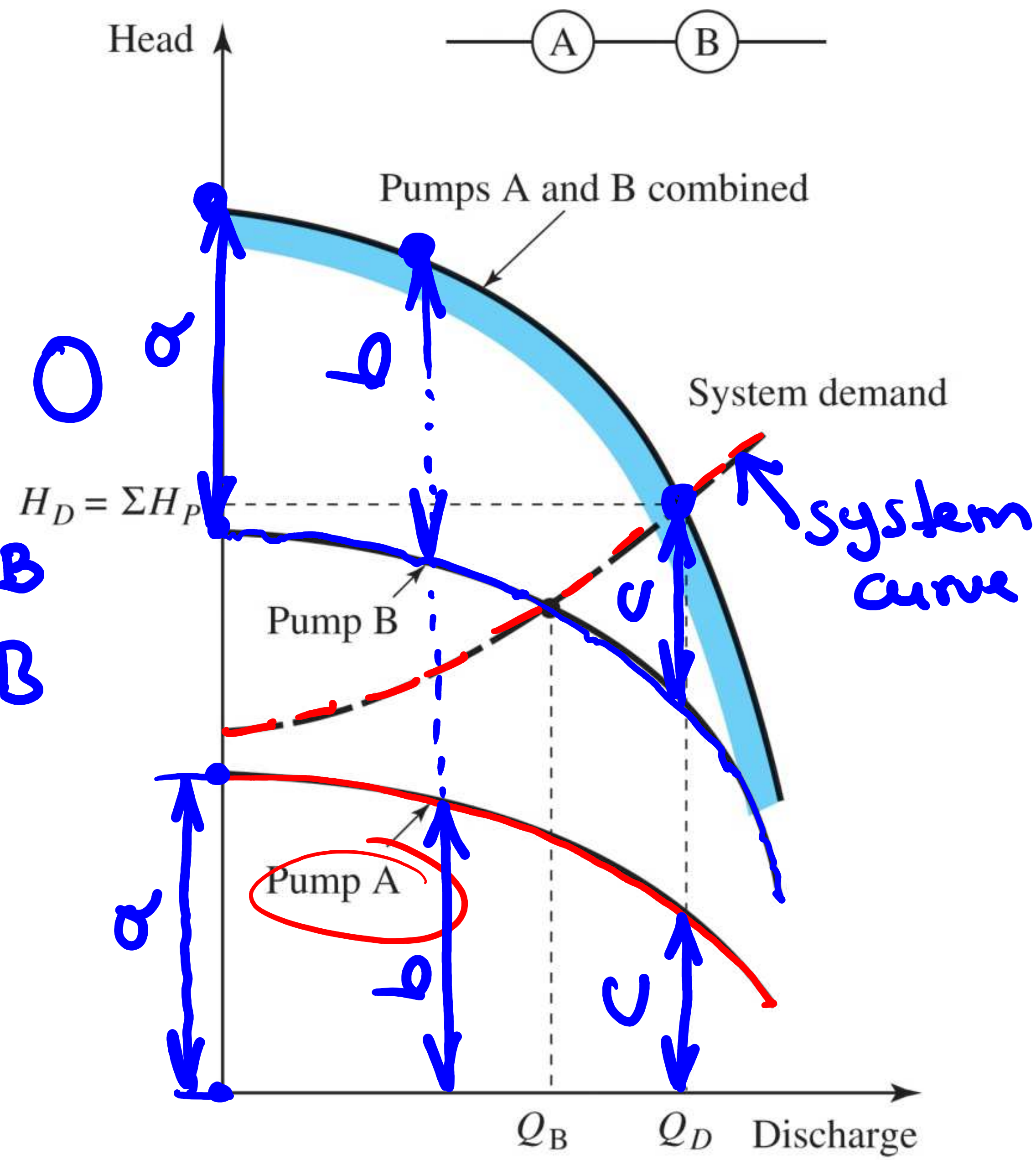


Fig. 12.18 Characteristic curves for pumps operating in series.

Example 12.7. Water is pumped between two reservoirs in a pipeline with the following characteristics:
$D = 300$ mm, $L = 70$ m, $f = 0.025$, $\Sigma K = 2.5$. The radial-flow pump characteristic curve is approximated by the formula

$$\boxed{H_P = 22.9 + 10.7Q - 111Q^2}$$

pump curve

where H_P is in meters and Q is in m^3/s. Determine the discharge Q_D and pump head H_D for the following situations:
(a) $z_2 - z_1 = 15$ m, one pump placed in operation; (b) $z_2 - z_1 = 15$ m, with two identical pumps operating in parallel; and (c) the pump layout, discharge, and head for $z_2 - z_1 = 25$ m.

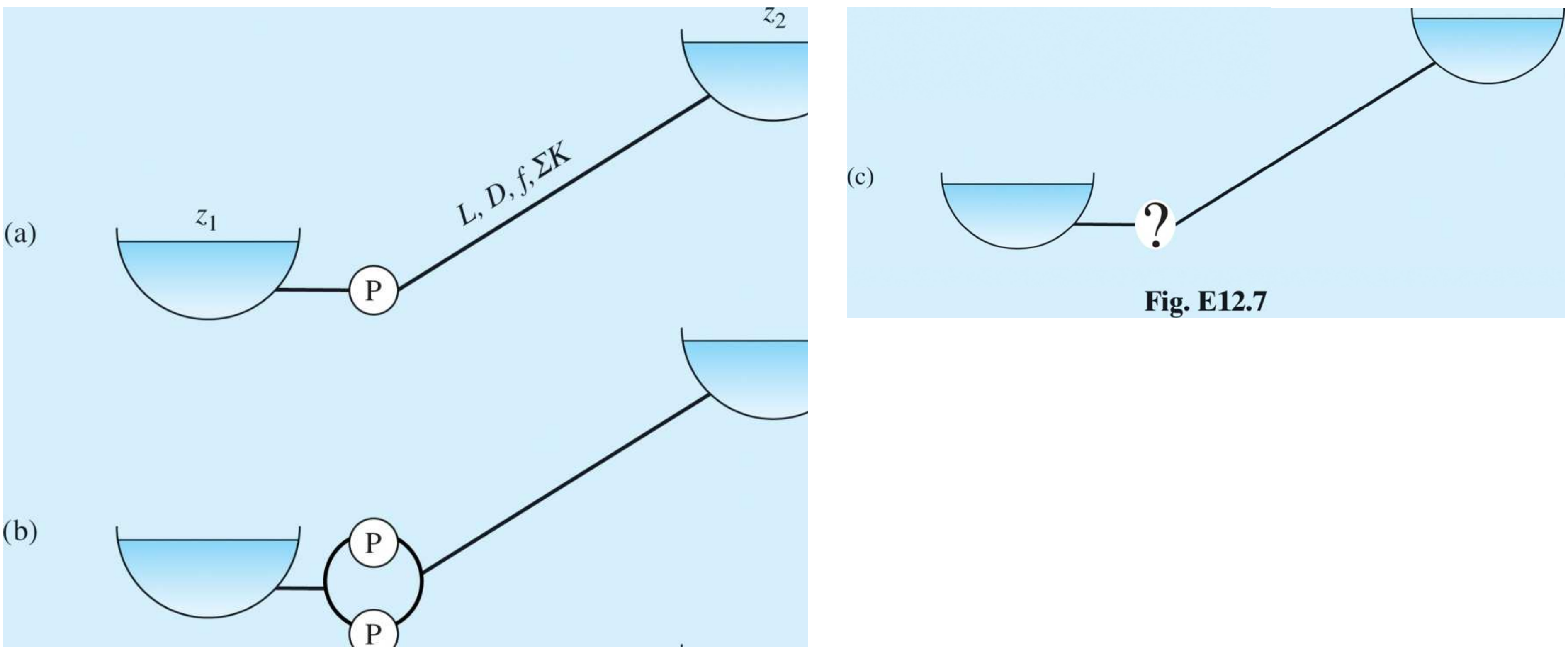
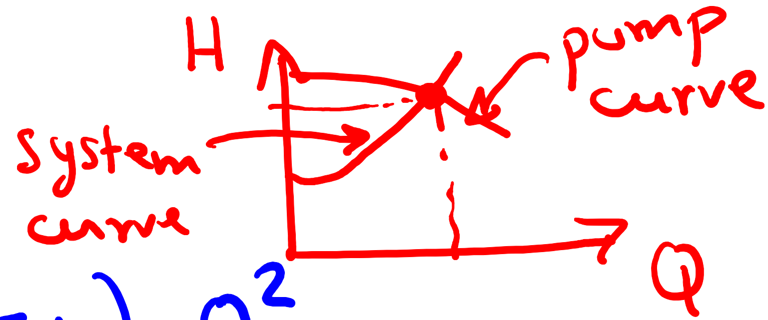


Fig. E12.7

a) One pump, $z_2 - z_1 = 15\,m$



system curve

$$H_p = z_2 - z_1 + \left(\frac{fL}{D} + \Sigma K\right)\frac{Q^2}{2gA^2}$$

$$H_p = 15 + \left(\frac{0.025 \times 70}{0.3} + 2.5\right)\frac{Q^2}{2 \times 9.8 \times \left(\frac{\pi \times 0.3^2}{4}\right)^2}$$

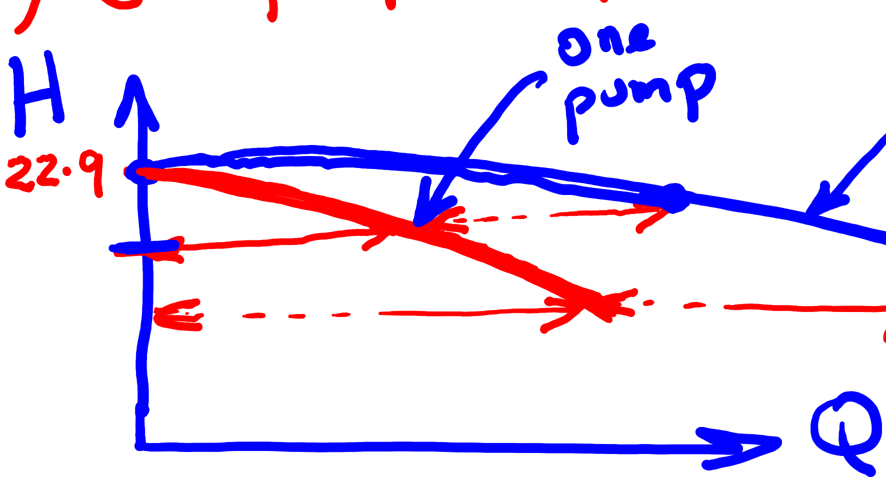
$$\boxed{H_p = 15 + 85.09\,Q^2}$$ ← system curve

$$15 + 85.09\,Q^2 = 22.9 + 10.7\,Q - 111\,Q^2$$

$$Q = 0.23\,m^3/s$$

$$H_p = 15 + 85.09\,(0.23^2) = \underline{19.50\,m}$$

b) two pumps in parallel $(z_2 - z_1 = 15\,m)$



for two pumps in parallel

$$H_p = 22.9 + 10.7\left(\frac{Q}{2}\right) -$$

$111\left(\frac{Q}{2}\right)^2$

* for "N" pumps in parallel

$$\boxed{H_p = 22.9 + 10.7\left(\frac{Q}{N}\right) - 111\left(\frac{Q}{N}\right)^2}$$

$$22.9 + 10.7\left(\frac{Q}{2}\right) - 111\left(\frac{Q}{2}\right)^2 = 15 + 85.09Q^2$$

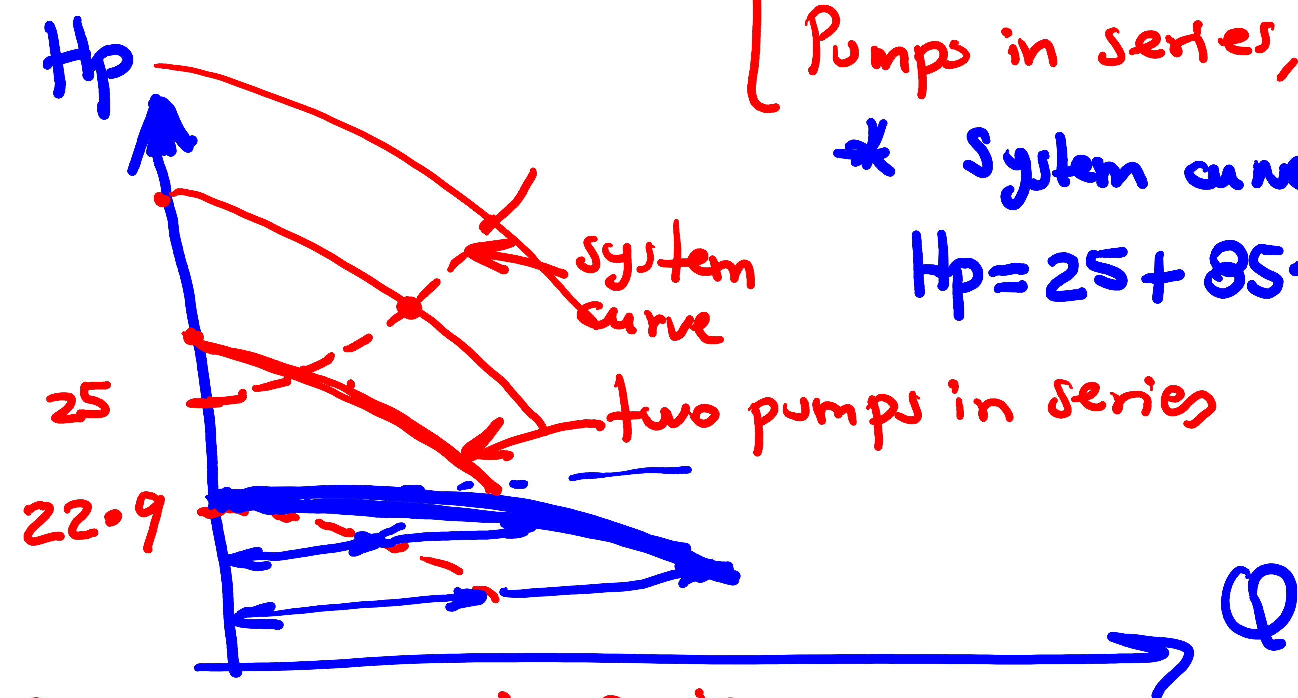
$$\boxed{\begin{array}{l} Q = 0.29\ m^3/s \\ H_p = 22.2\,m \end{array}}$$

c) $Z_2 - Z_1 = 25\,m$

How many pumps?
Pumps in series, parallel

* System curve

$H_p = 25 + 85.09\,Q^2$



for two pumps in series.

* for one pump: $H_p = 22.9 + 10.7Q - 111Q^2$

$$H_p = 2\left(22.9 + 10.7Q - 111Q^2\right)$$

$$2(22.9+10.7Q-111Q^2)=25+85.09Q^2$$

$$\boxed{\begin{aligned} Q &= 0.30\,m^3/s \\ H_p &= 32.7\,m \end{aligned}}$$

* for "N" pumps in series

pump curve ⇒

$$H_p = N\left(22.9+10.7Q-111Q^2\right)$$