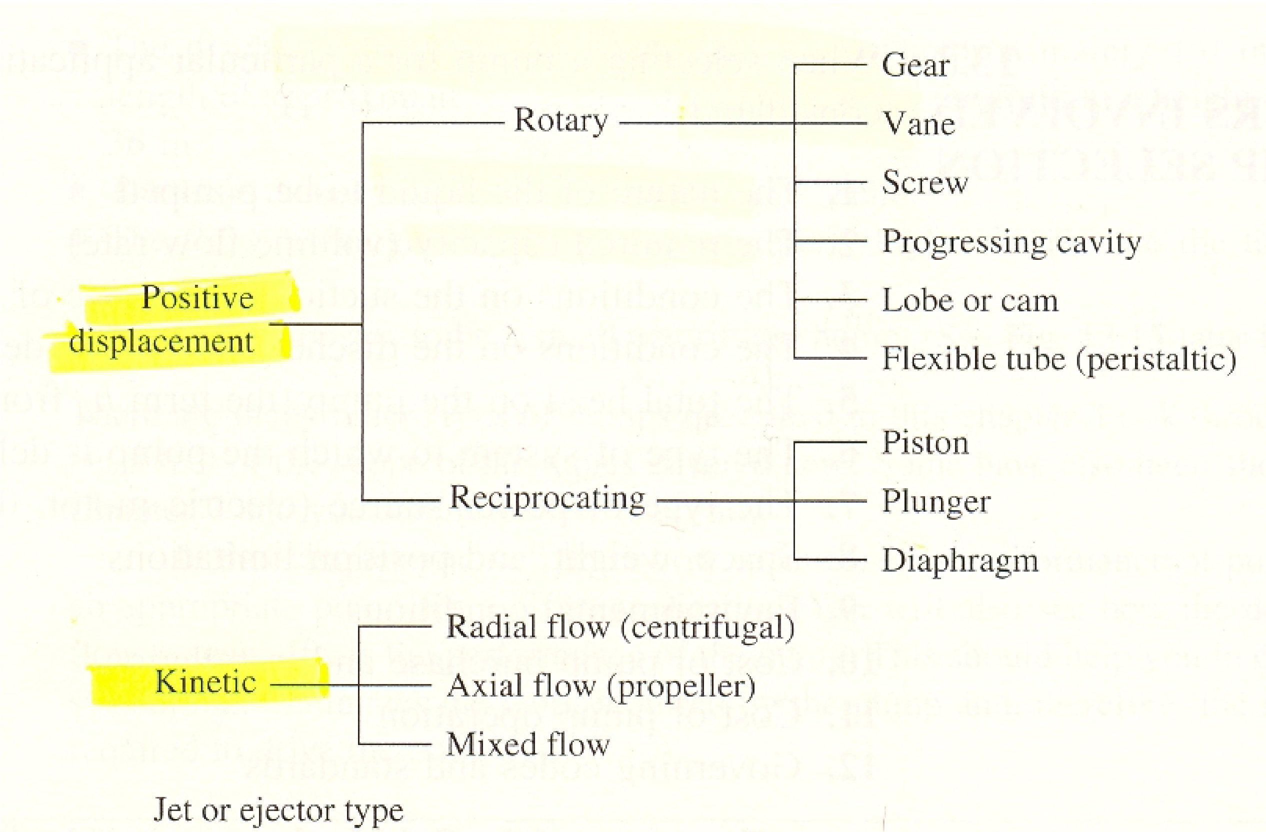
HYDRAULIC PUMPS

Pumps – convert mechanical energy into fluid energy.

Turbines – exactly the opposite, convert fluid energy to mechanical form.

<u>Classification of pumps</u> – *based on the method by which mechanical energy is transferred to the fluid –*

- **Positive-displacement pumps**
- **Kinetic pumps**



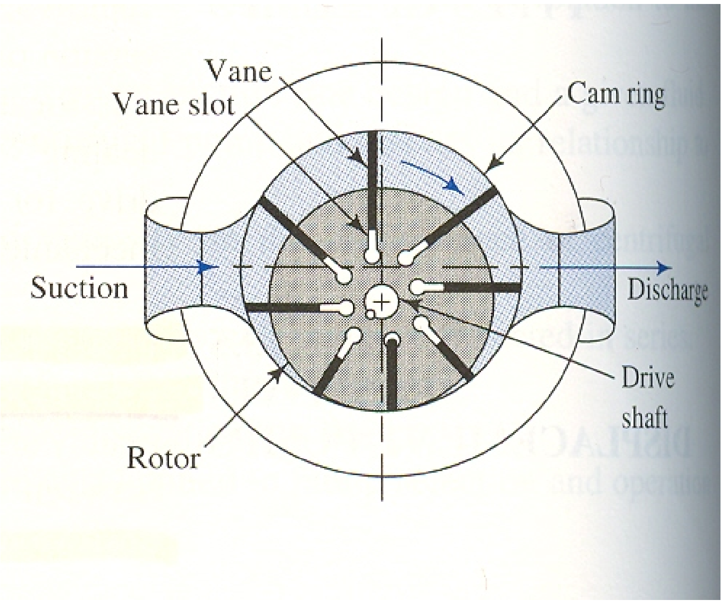
Under positive-displacement -

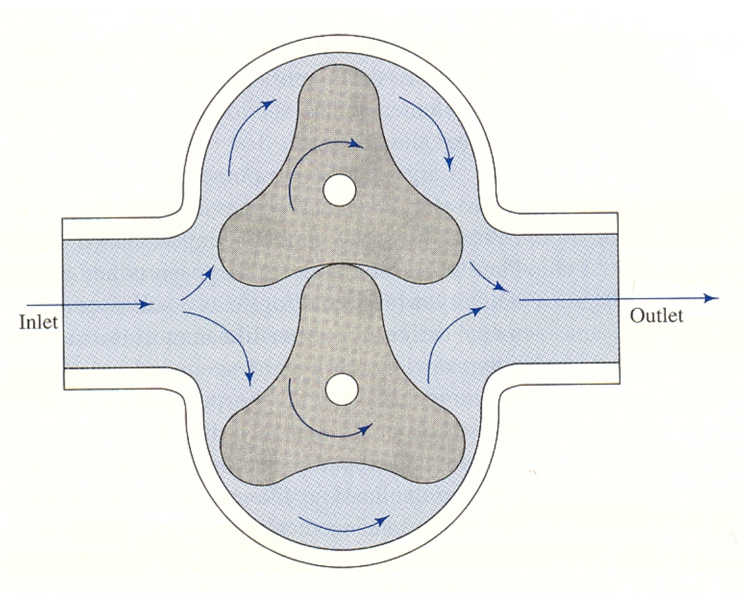
- These pumps discharge a given volume of fluid for each stroke or revolution.
- Energy is added intermittently

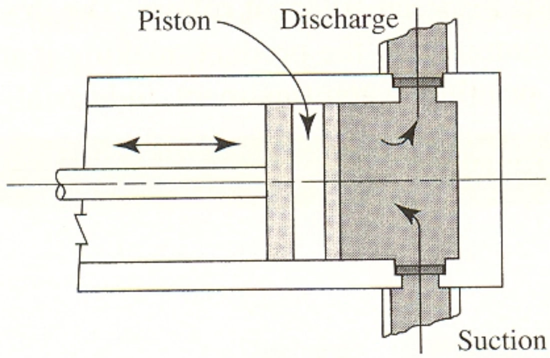
Reciprocating action – pistons, plungers, diaphragms, and bellows.

Rotary action – vanes, screws, lobes.

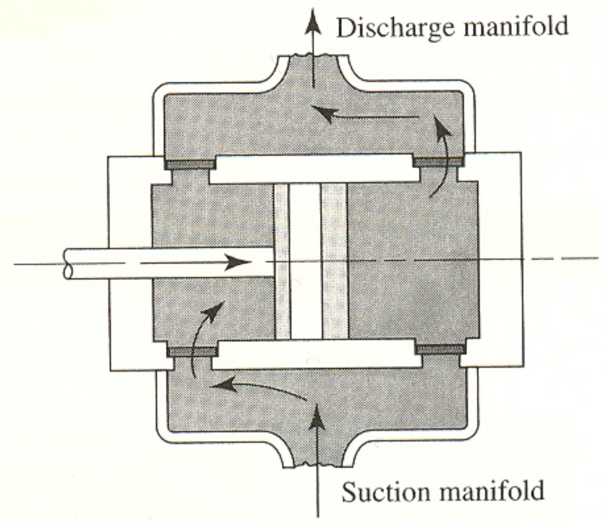
<u>Types of positive displacement pumps –</u>



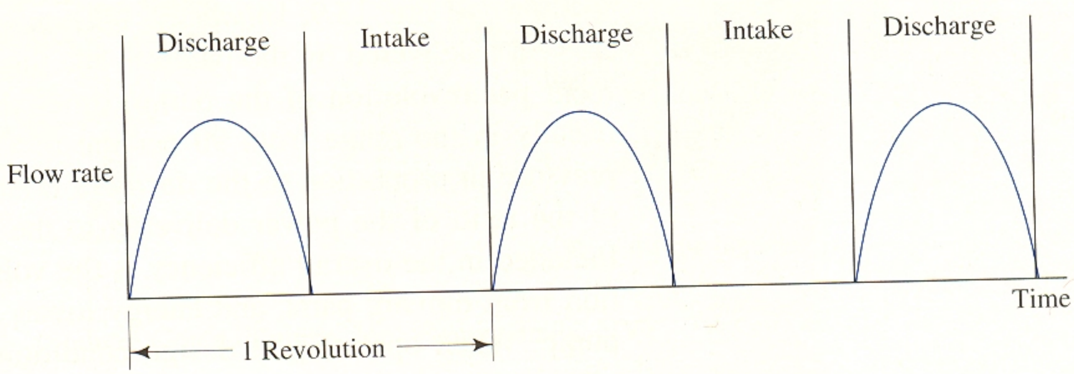




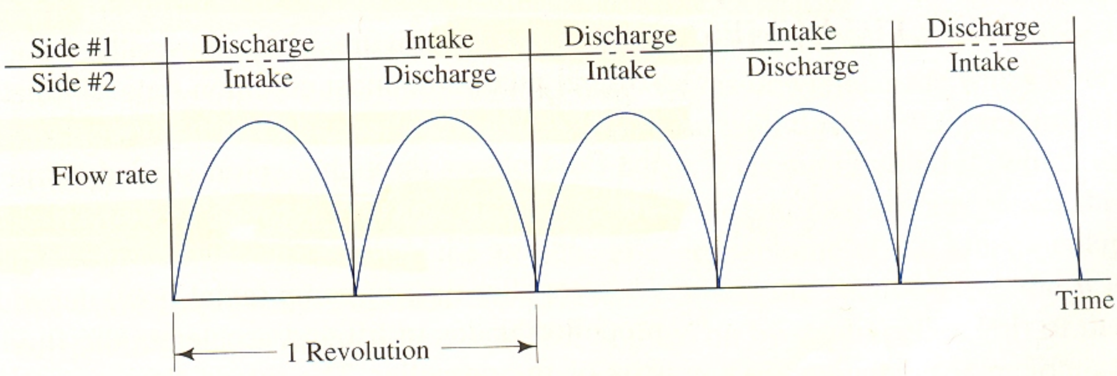
(a) Single acting—simplex



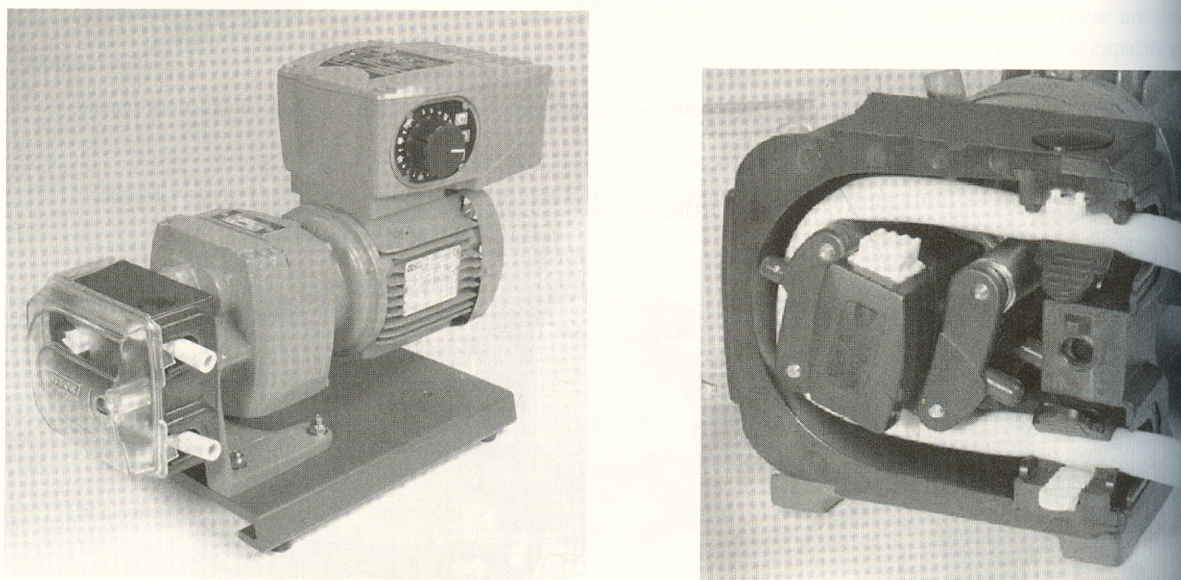
(b) Double acting—duplex



(a) Single-acting pump—simplex



(b) Double-acting pump—duplex



(a) Peristaltic pump with variable-speed drive system

(b) Peristaltic pump with case open to show tubing and rotating drive rollers

FIGURE 13.7 Peristaltic pump. (Source: Watson-Marlow Bredel Pumps, Wilmington, MA)

<u>Peristaltic pumps-</u>

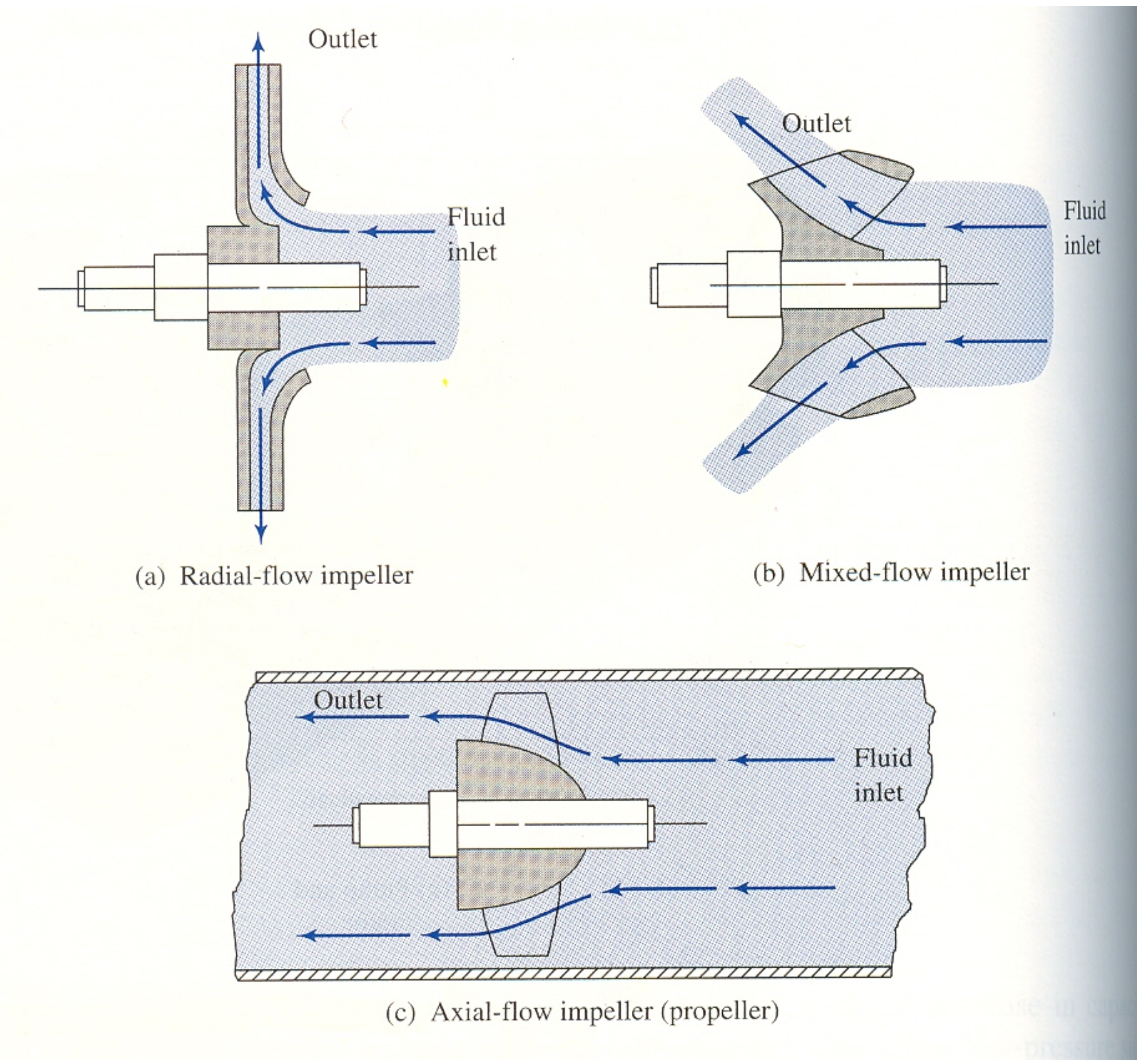
- Fluid captured within flexible tube
- Tube is routed between rollers – rollers squeeze tube and move liquid as parcels

<u>**Avoids contact of liquid with mechanical parts**</u>

Kinetic Pumps

- Transforms kinetic energy to static pressure – adds energy via rotating impeller
- Fluid enters through the center of an impeller and is thrown outwards by the vanes

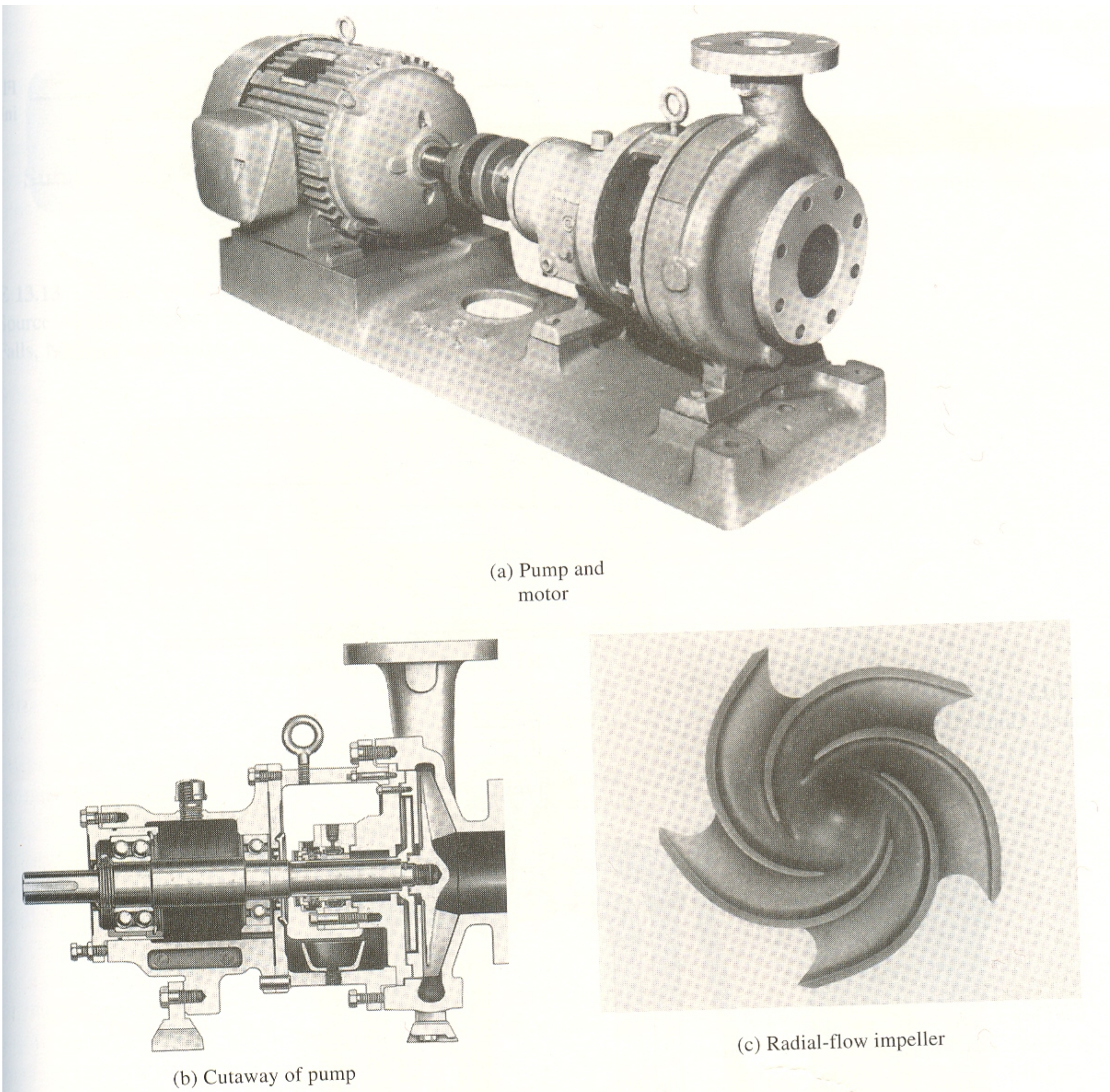
Figure 13.11



(a) Radial-flow impeller
(b) Mixed-flow impeller
(c) Axial-flow impeller (propeller)

Types of Kinetic pumps –

Centrifugal



(a) Pump and motor

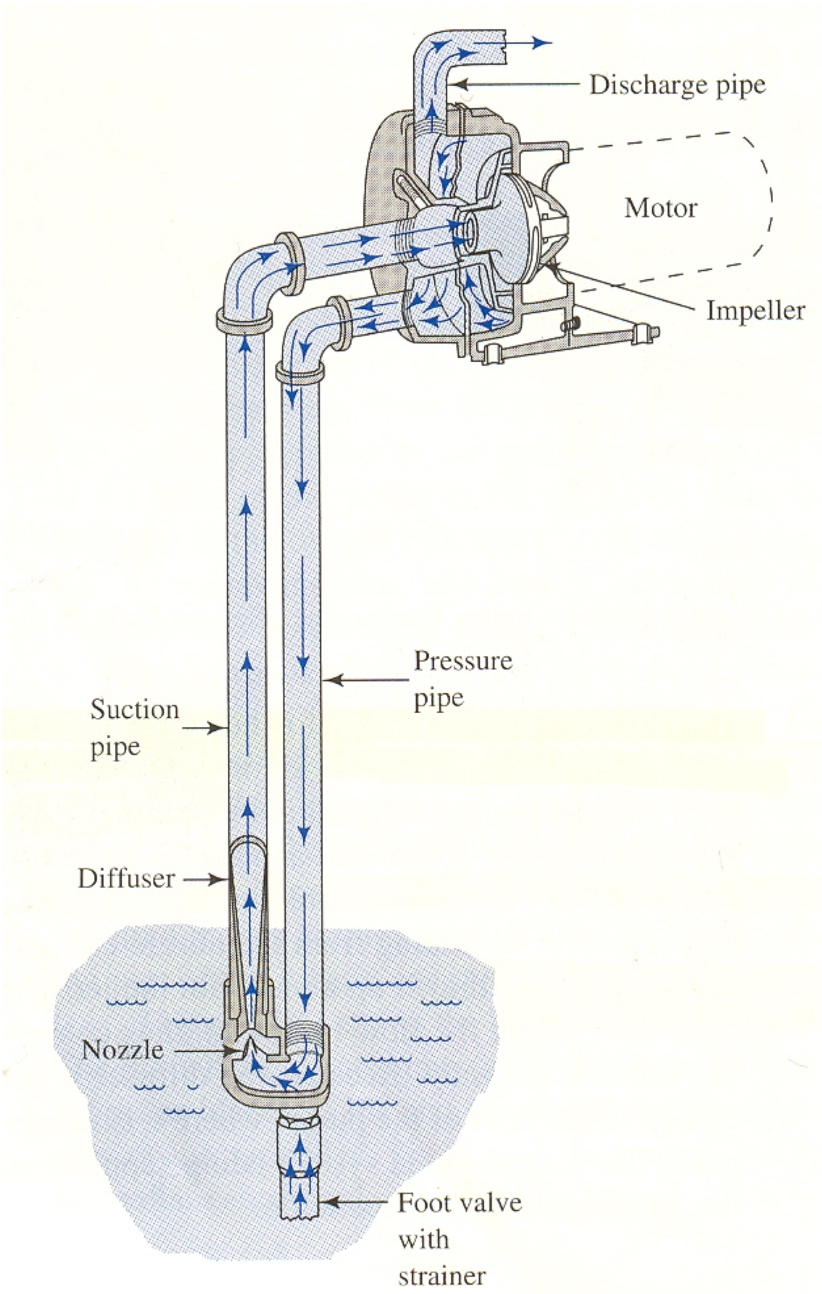
(b) Cutaway of pump

(c) Radial-flow impeller

FIGURE 13.10 Centrifugal pump. (Source: Goulds Pumps, Inc., Seneca Falls, NY)

Jet

- Used for household water systems.
- Composed of centrifugal pump and jet assmebly
- Suction is created by the jet in the suction pipe



Comparisons between the two types –

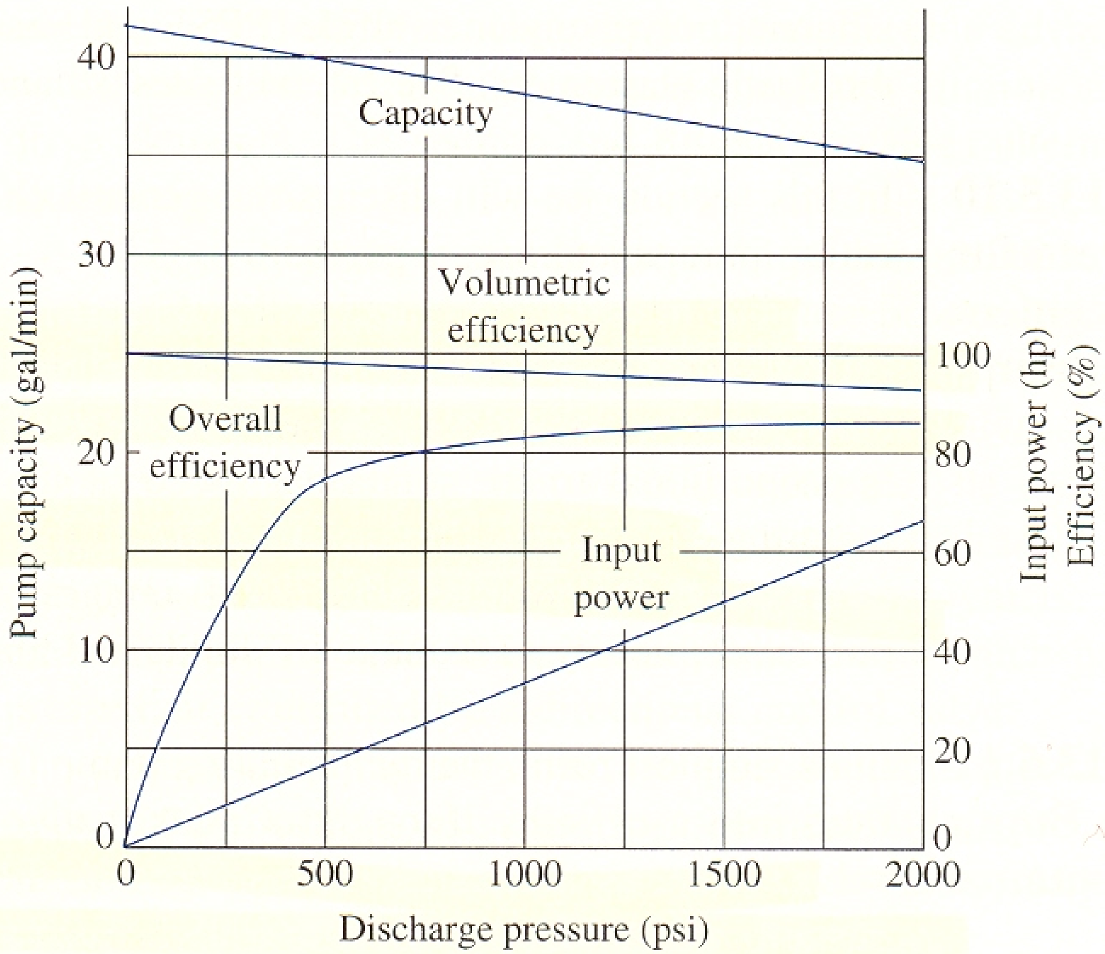
Characteristic	**Positive-displacement**	**Kinetic**
Flow rate	Low	High
Pressure rise	High	Low
Self priming	Yes	No
Outlet stream	Pulsing	Steady
Works with high viscosity fluids	Yes	No

Pump selection depends on –

- Discharge
- Head requirement
- Horsepower requirements of the pump

So we need to know their performance characteristics – referred to as ***performance curves***

Performance curve for a positive displacement type of pump

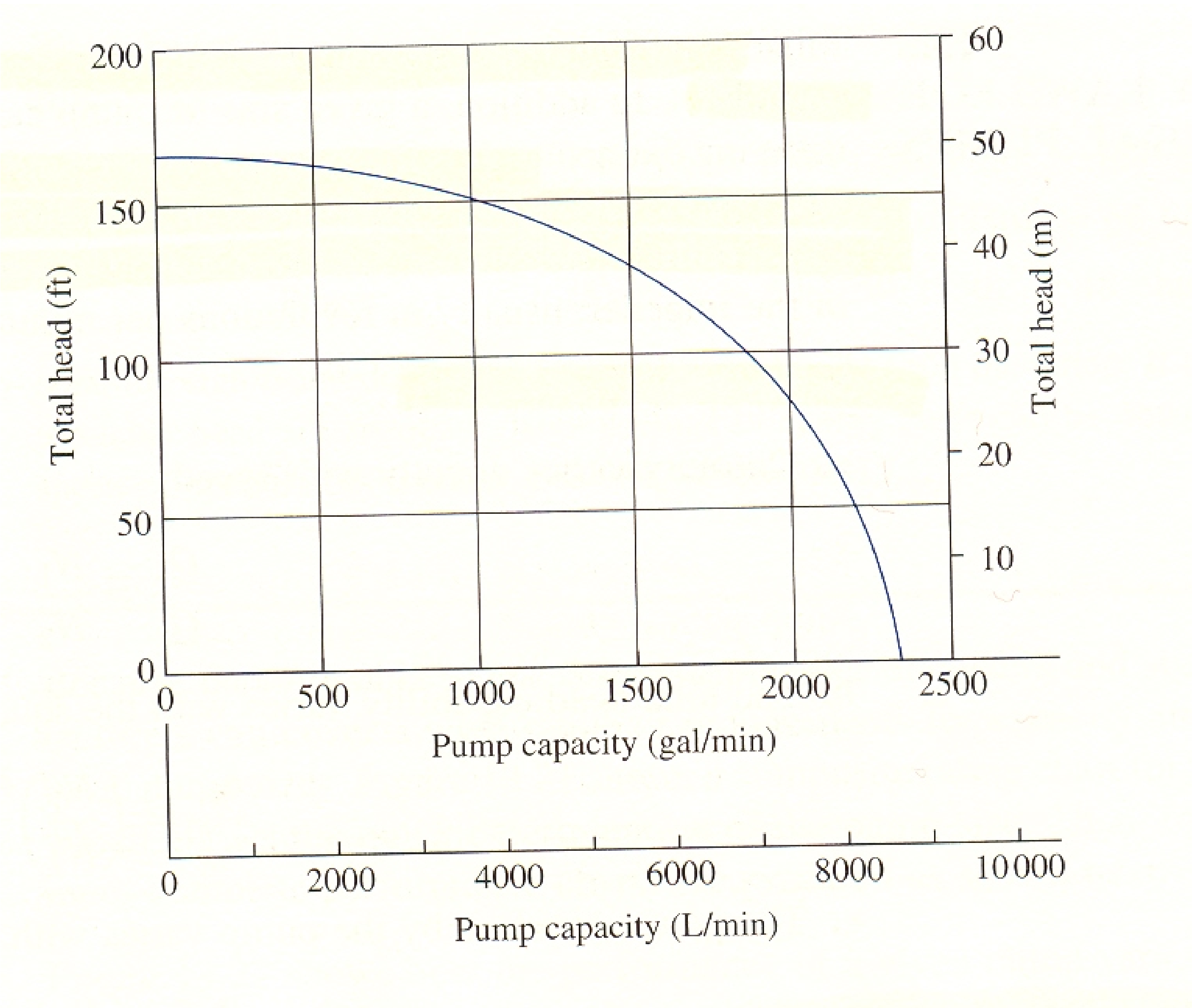


- As pressure increases there is slight decrease in capacity due to internal leakage from the high pressure side.
- Power needed varies linearly with pressure.
- Volumetric efficiency = flow rate delivered/theoretical flow rate (90 to 100%). Theoretical flow rate based on displacement per revolution times the speed of rotation.

- Overall efficiency = power delivered to fluid / power supplied to pump.

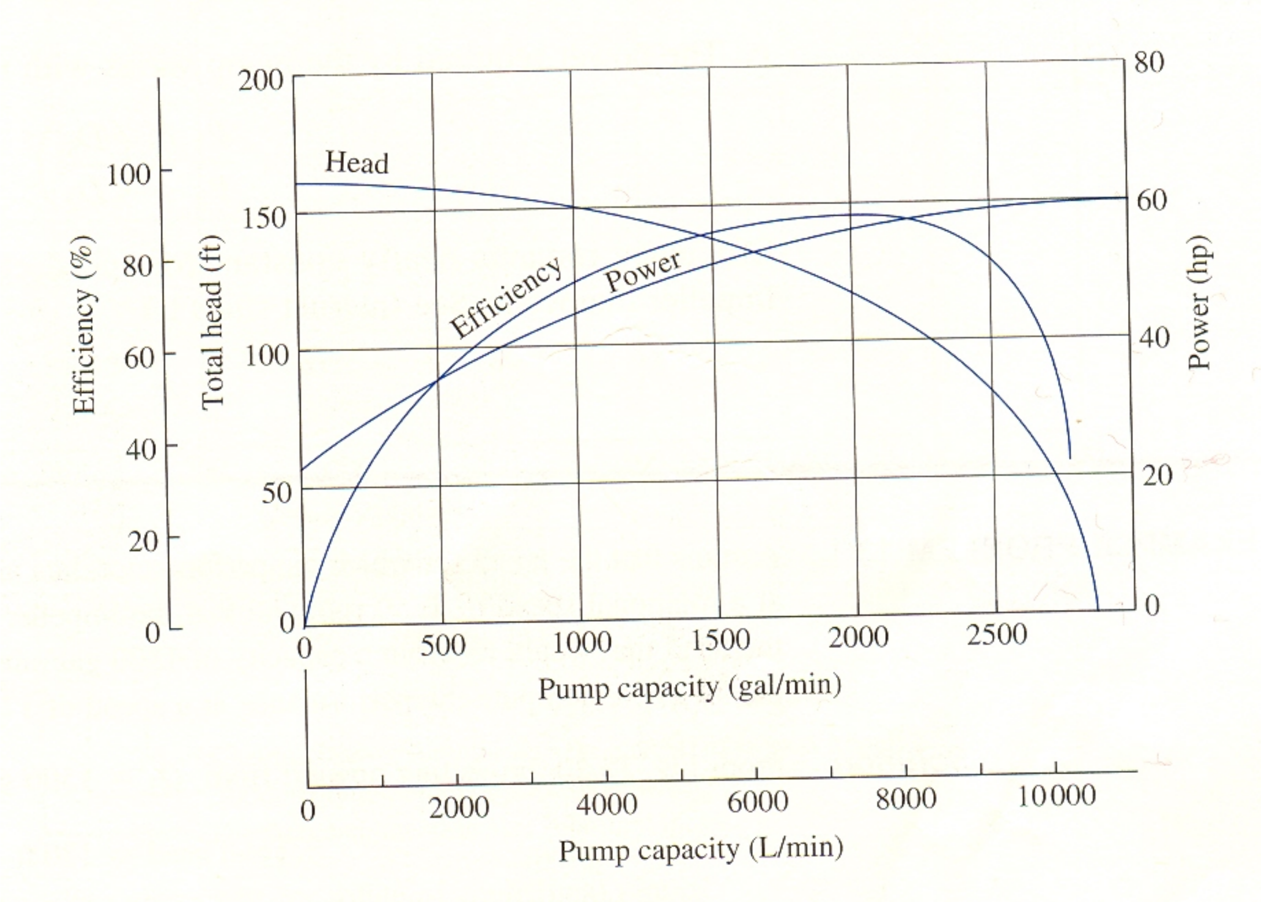
Performance curves for a Centrifugal Pump –

Head versus pump capacity



- Capacity decreases with increasing head
- At "cut-off" head flow is stopped completely and all energy goes to maintaining the head.
- Typical operating conditions well below "cut-off" head.

Head, capacity, efficiency, and power needed



- Normal operation should be in the vicinity of the peak efficiency

Pump designation –

Centrifugal pumps can be operated at ***various speeds (rpm)*** and with various ***impeller sizes***

Larger impellers and speeds provide – greater discharge and head!

Pumps can be designated as -
A x B – C

C – size of impeller (inches)

A – diameter of **discharge** pipe (inch)
B – diameter of **suction** pipe (inch)

e.g., Pump –

2 x 3 – 10

<u>Capacity versus head for impeller sizes (2 x 3 – 10)</u>

Speed = 3500 rpm

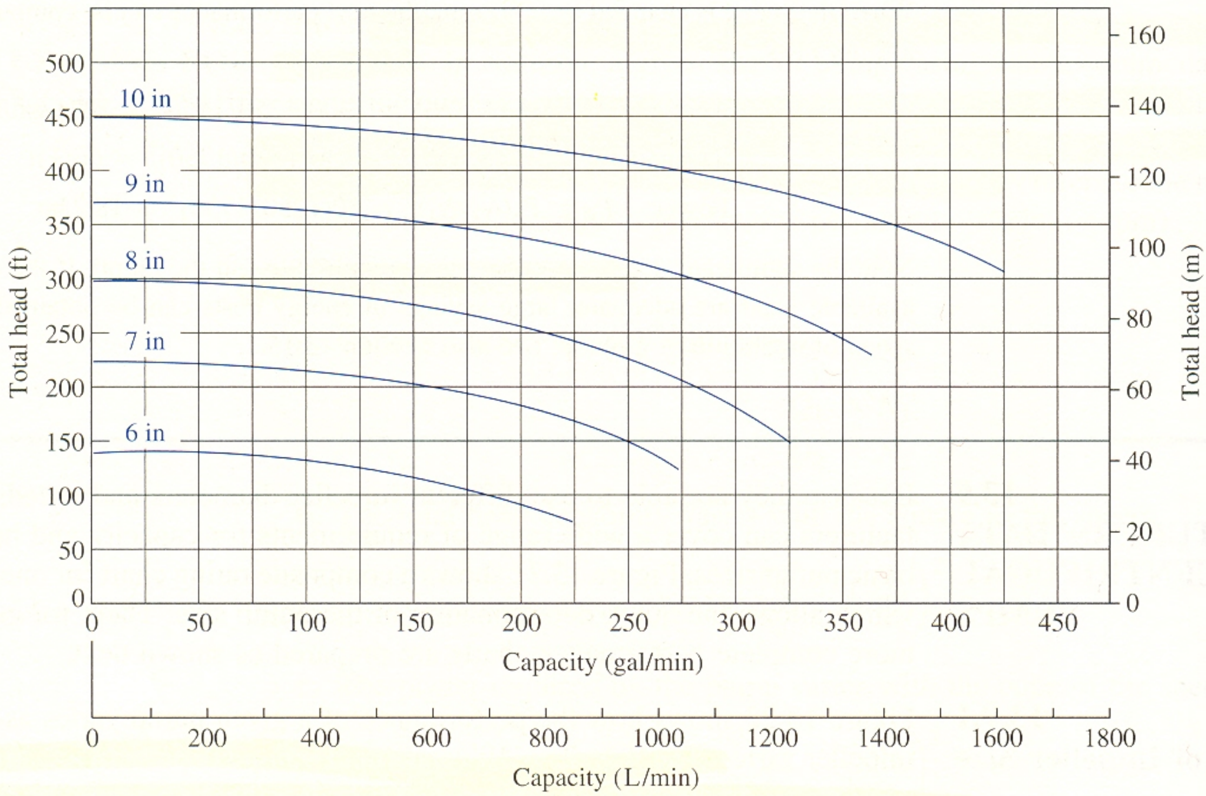
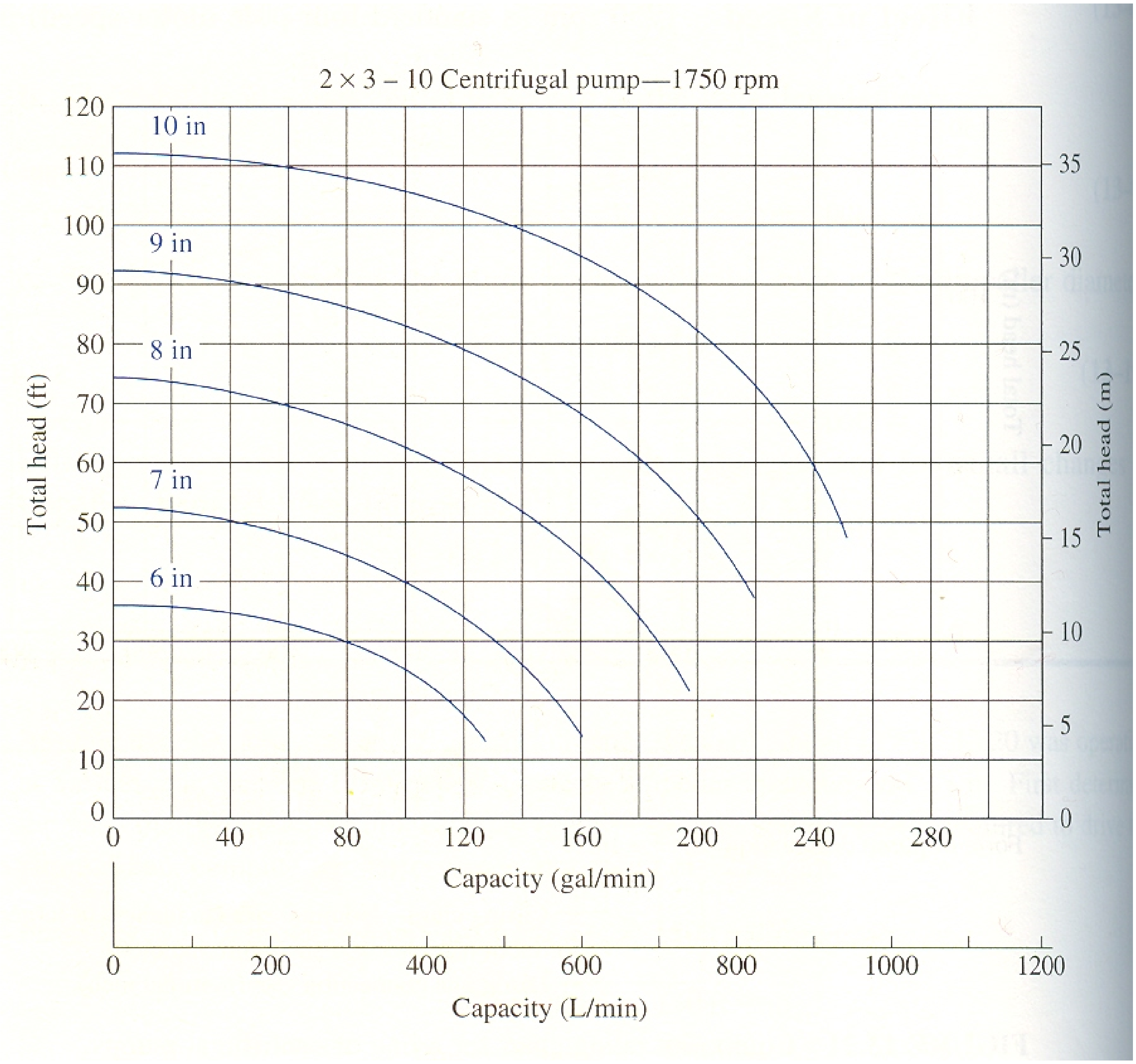


FIGURE 13.22 Illustration of pump performance for different impeller diameters. Performance chart for a 2 × 3 − 10 centrifugal pump at 3500 rpm.

Capacity versus head for impeller sizes (2 x 3 – 10)

Speed = 1750 rpm



<u>Capacity versus head for impeller sizes with horsepower (2 x 3 – 10)</u>

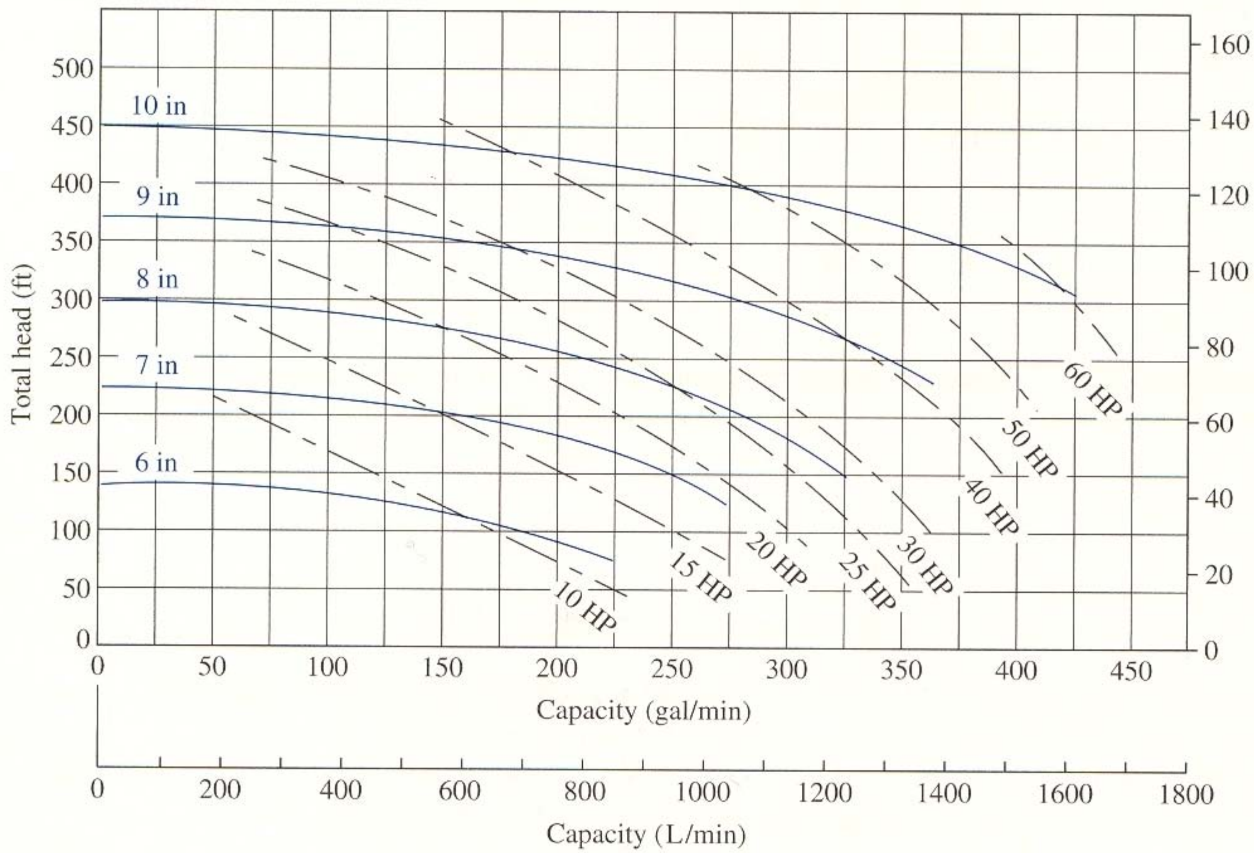


FIGURE 13.24 Illustration of pump performance for different impeller diameters with power required. Performance chart for a 2 × 3 − 10 centrifugal pump at 3500 rpm.

<u>Capacity versus head for impeller sizes with efficiency (2 x 3 – 10)</u>

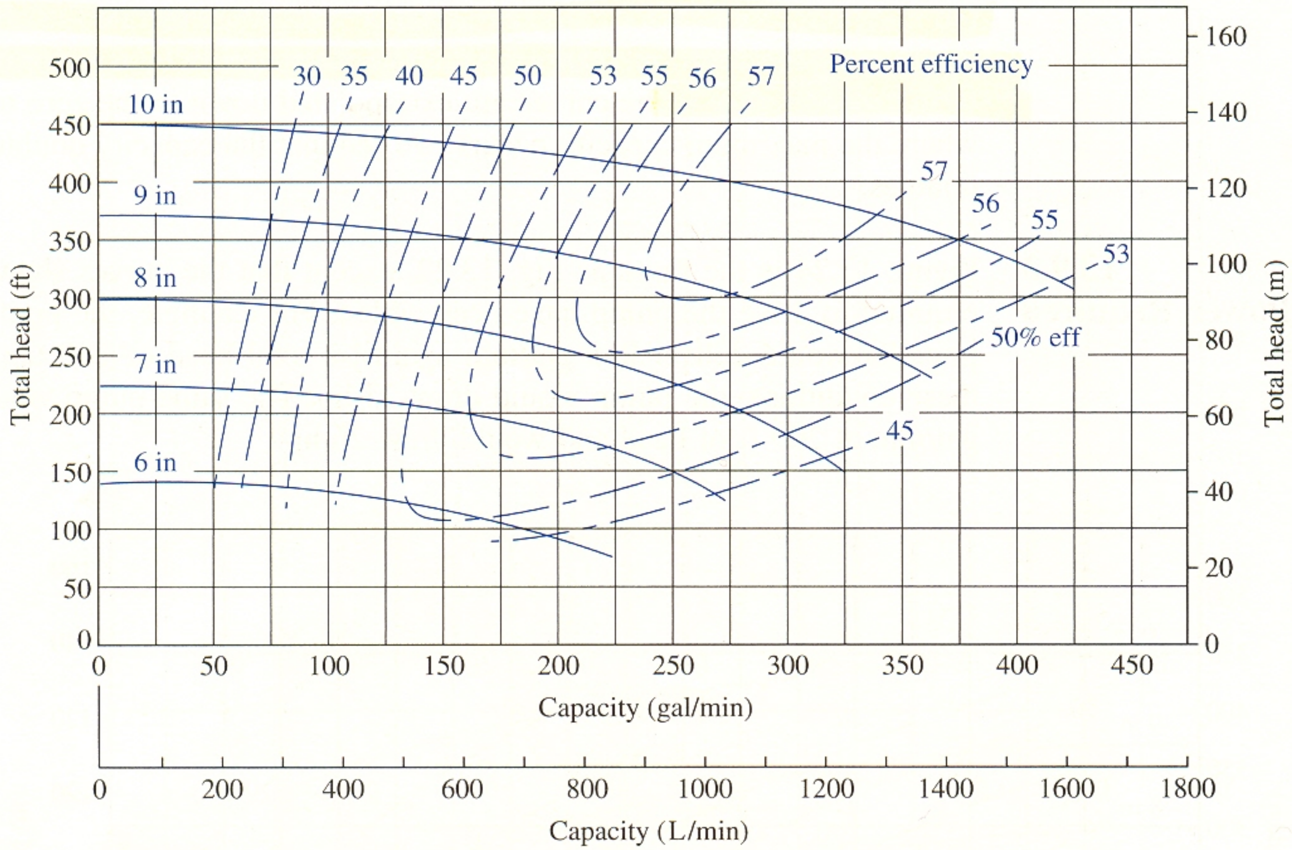


FIGURE 13.25 Illustration of pump performance for different impeller diameters with efficiency. Performance chart for a 2 × 3 − 10 centrifugal pump at 3500 rpm.

Composite graph

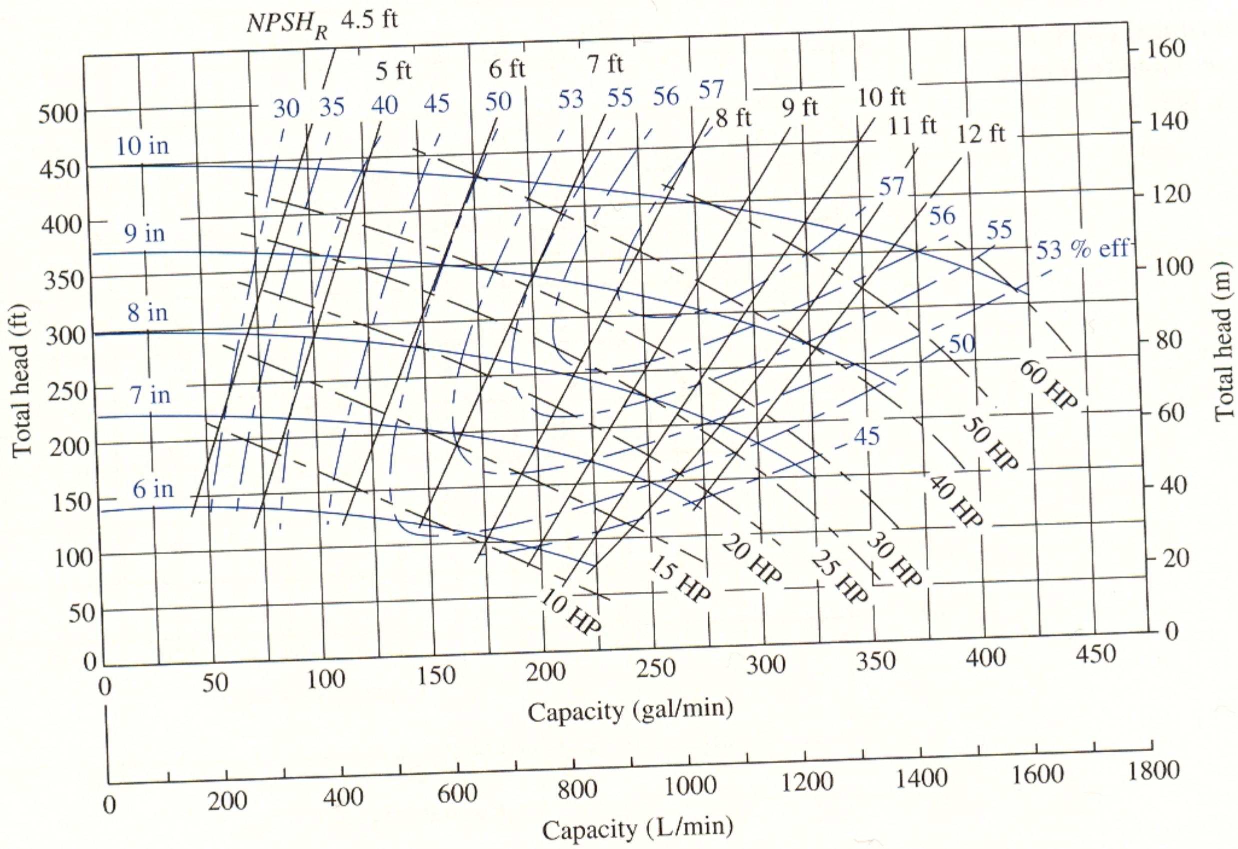


FIGURE 13.27 Composite pump performance chart for a 2 × 3 − 10 centrifugal pump at 3500 rpm. (Source: Goulds Pumps, Inc., Seneca Falls, NY)

Affinity laws for centrifugal pumps

*Equations that relate the **speed** and **impeller size** to the **head**, **capacity** and **power** of the pump –*

Speed varies –

Capacity -

$$\frac{Q_1}{Q_2} = \left(\frac{N_1}{N_2}\right)$$

Total head -

$$\frac{h_{a1}}{h_{a2}} = \left(\frac{N_1}{N_2}\right)^2$$

Power -

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

Impeller diameter varies –

Capacity -

$$\frac{Q_1}{Q_2} = \left(\frac{D_1}{D_2}\right)$$

Total head -

$$\frac{h_{a1}}{h_{a2}} = \left(\frac{D_1}{D_2}\right)^2$$

Power -

$$\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^3$$

Head situation at the suction end

Static suction head (h_s) – vertical distance between the center line of inlet and the free level of the fluid source

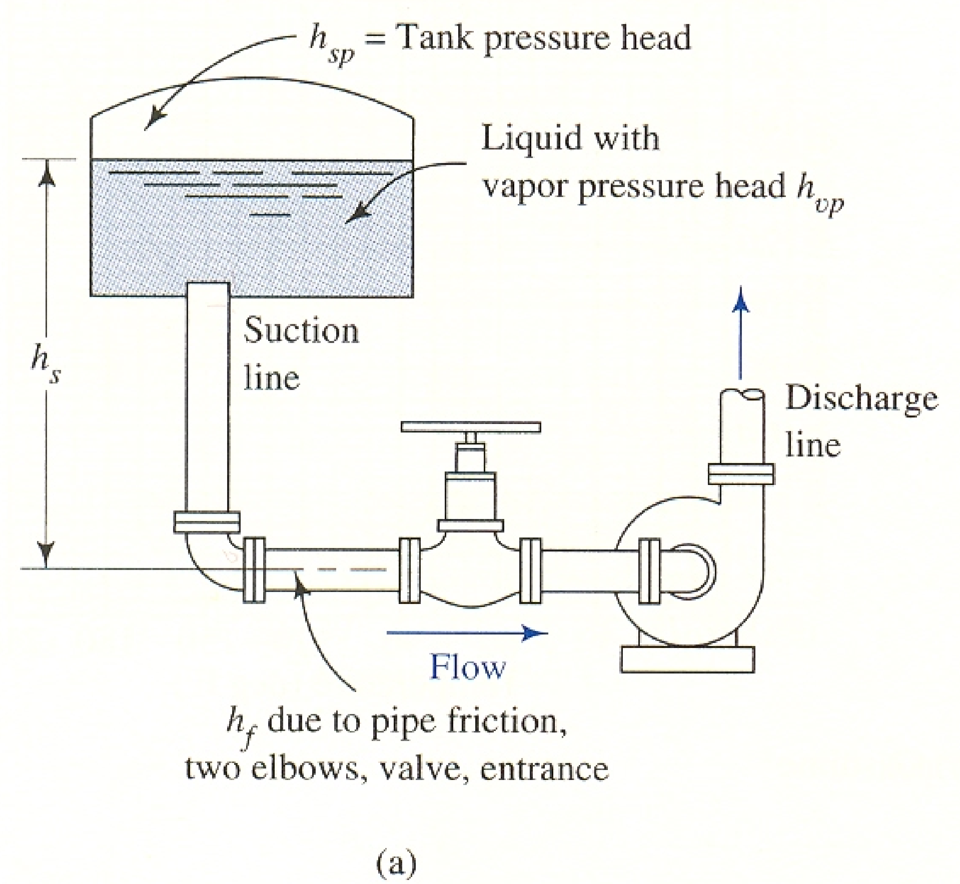
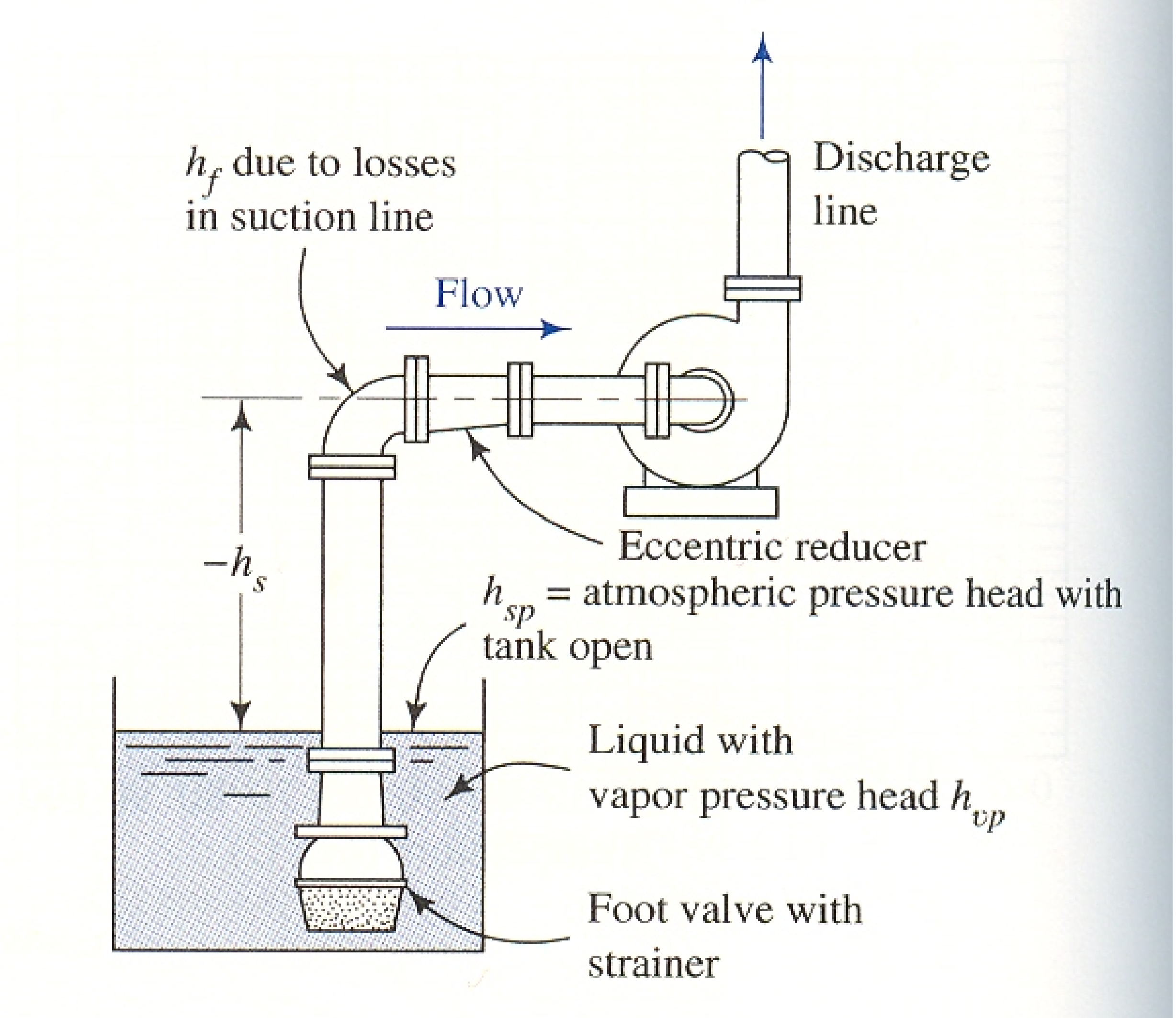


Figure 13.38

- When fluid level is ABOVE inlet - static head is positive

- When fluid level is BELOW inlet – static head is negative (***static suction lift***)



(b)

Dynamic suction head (H_s) =

Static suction head minus the friction head

Static discharge head

- vertical distance between the pump centerline and the free level of the fluid in the discharge tank

Dynamic discharge head =

Static discharge head + friction head + velocity head

Net Positive Suction Head Required ($NPSH_R$)

Minimum head required in the suction line to prevent ***cavitation***.

- Cavitation – formation of small bubbles of water when the pressure in the suction tube is too low. Vapor bubbles form at suction inlet and travel to impeller.

- These bubbles then collapse after the impeller when the pressure increases.

- The collapse of the bubbles releases energy that may cause severe erosion of the pump or the discharge lines

Cavitation can cause –

- Decrease in discharge
- Noise, rattling sound
- Erosion and eventual destruction of the pump

This can be avoided by ensuring that the pressure head at the inlet end is **greater than** the $NPSH_R$ for the pump.

$NPSH_R$ is predetermined by manufacturers for pumps under various operating conditions of discharge and total head.

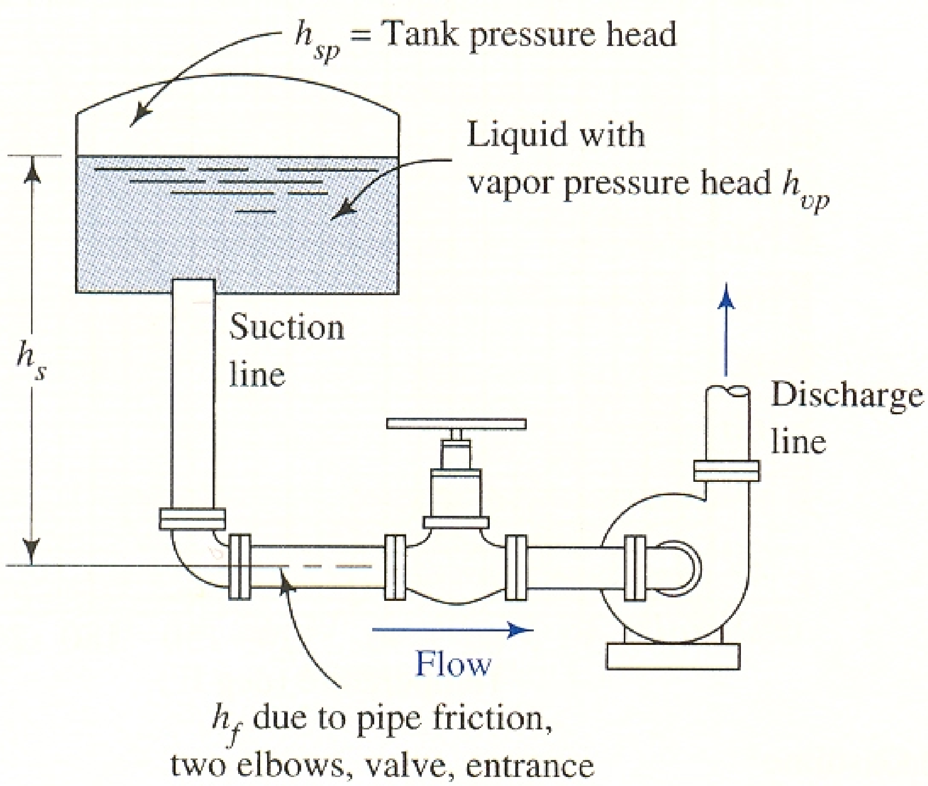
Available Net positive suction Head = $NPSH_A$

$NPSH_A$ should be at least 10% greater than $NPSH_R$

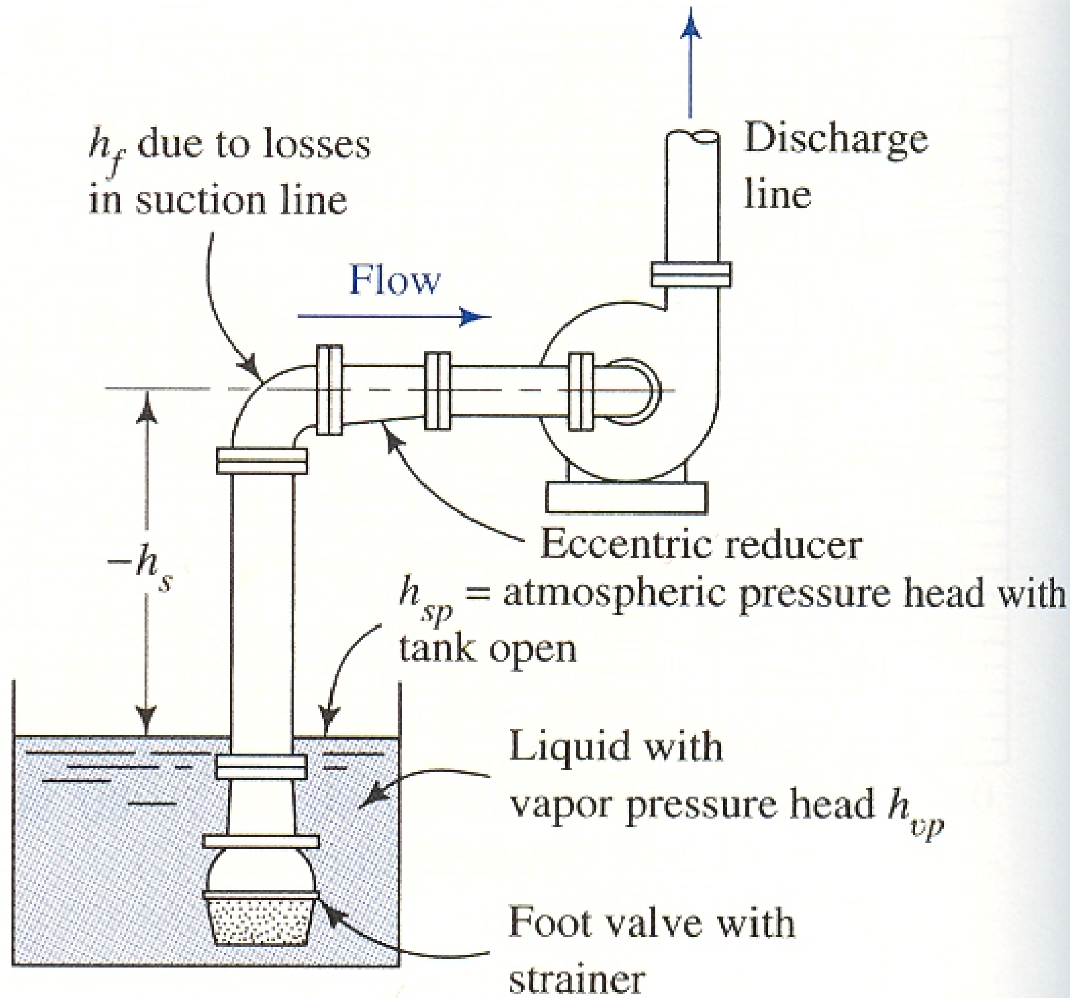
Greater margin (100%) in case of critical/emergency installations.

$$NPSH_A = h_{sp} \pm h_s - h_f - h_{vp}$$

NOTE - $NPSH_A$ and $NPSH_R$ are always expressed in absolute terms – so add the atmospheric pressure to the gage pressure!



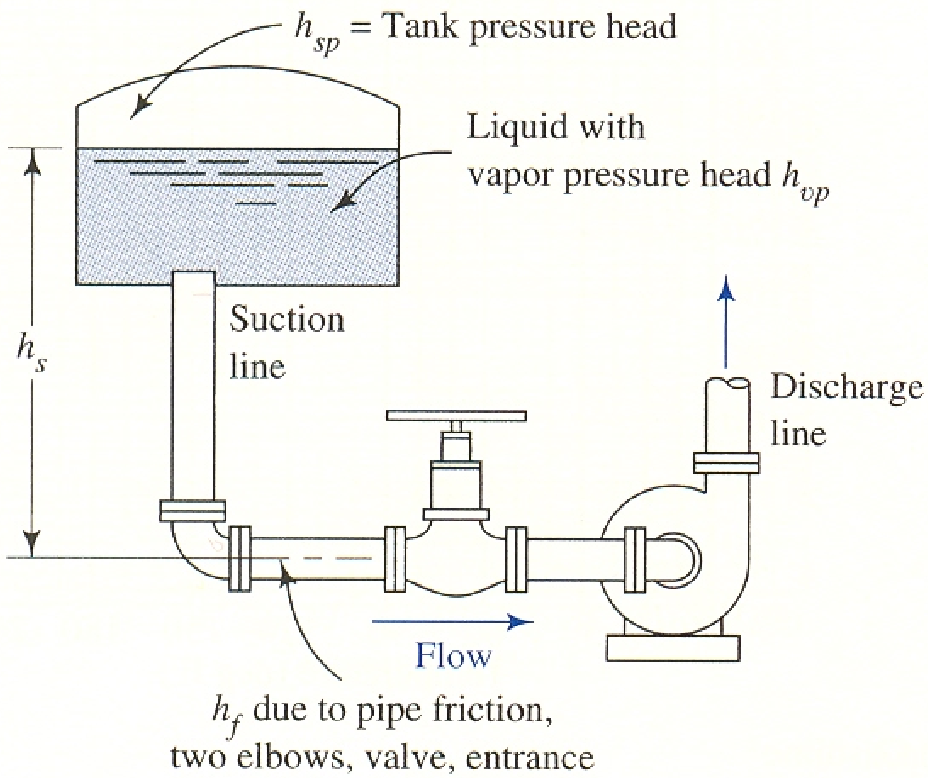
(a)



h_f due to losses
in suction line
Discharge
line
Flow
$-h_s$
Eccentric reducer
h_{sp} = atmospheric pressure head with
tank open
Liquid with
vapor pressure head h_{vp}
Foot valve with
strainer

(b)

Example 13.3



(a)

Determine the available NPSH
Water at 70C
p_{sp} = - 20kpa
p_{atm} = 100.5 kpa
h_s = +2.5 m
pipe is 1 ½ inch schedule 40 steel pipe, 12 m length
elbow is standard, valve is fully open globe valve
flow rate = 95 L/min

p_{abs} in tank = p_{atm} + p_{sp}
= 100.5 – 20

= 80.5 kpa

$\mathbf{h_{sp}} = p/\gamma$
$= 80.5 \times 10^3\ N/m^2 / 9.59 \times 10^3\ N/m^3$
= **8.39 m**

v = Q/A = 1.21 m/s
$N_r = 1.20 \times 10^5$
D/ε = 889

f = 0.0225, ft = 0.021

h_f = pipe friction + elbows + valve + entrance

= 1.19 m

$\mathbf{h_{vp}}$ **= 3.25** m at 70C

therefore –

$\mathbf{NPSH_A}$ = 8.39 + 2.5 – 1.19 – 3.25 = **6.45 m**

$NPSH_A > 1.10\ NPSH_R$

Therefore $\mathbf{NPSH_R < 5.86\ m}$