Topic V: Pumps and Pumping of Liquids

Pumps and pumping of liquids: pump efficiency; pump and system head: total head, suction head, discharge head, NPSH head; pump capacity, pump horsepower; parameters involved In Pump selection; types of pumps, pumps characteristic curves; affinity laws of centrifugal pumps**.**

Topic V: Pumps and Pumping of Liquids

- **Pumps:** Devices for supplying energy or head to overcome energy losses.
- As shown in the previous topic, if the pump is placed between two points 1 and 2 in a pipeline, the mechanical energy balance becomes:

$$g(z_2 - z_1) + \frac{1}{2}\left(\bar{u}_2^2 - \bar{u}_1^2\right) + \frac{P_2 - P_1}{\rho} = w_p - w_f$$

w_p : specific work done by pump on the liquid

- No pump is not 100% efficient, the efficiency of the pump is defined as:

$$\eta = \frac{w_p}{W_{total}} = \frac{\dot{m} w_p}{\dot{W}_{total}} = \frac{\dot{w}_p}{\dot{W}_{total}}$$

Where W_{total} is the total specific work supplied to the motor of the pump.

Topic V: Pumps and Pumping of Liquids

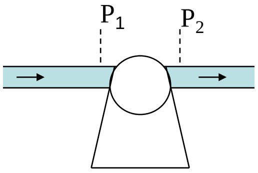
$\dot{m} = \rho Q$: Mass flow rate of the pumped liquid

$\dot{w}_p$: Power added to the liquid by the pump

$\dot{W}_{total}$: Power supplied to the motor of the pump

Topic V: Pumps and Pumping of Liquids

Example. The motor which drives a pump is supplied by 2.8 horsepower. The pressure at the suction side of the pump is 30 psia and the pressure at the discharge side is 100 psia. The pump is pumping 50 gpm. What is the efficiency of the pump?



$$\dot{W}_{total} = 2.8\,hp$$

$$Q = 50\frac{\text{gal}}{\text{min}}\frac{1\,ft^3}{7.48\,\text{gal}} = 6.6845\frac{ft^3}{\text{min}}$$

Apply MEB across the pump is:

$$g(z_2 - z_1) + \frac{1}{2}\left(\bar{u}_2^2 - \bar{u}_1^2\right) + \frac{P_2 - P_1}{\rho} = w_p - w_f$$

$$z_2 = z_1;\ \bar{u}_2 = \bar{u}_1\ ;\ w_f \approx 0 \Rightarrow w_p = \frac{P_2 - P_1}{\rho}$$

$$P_2 - P_1 = 100 - 30 = 70\ psia = 70\frac{lbf}{in^2}\frac{144 in^2}{ft^2} = 10080\frac{lbf}{ft^2}$$

Topic V: Pumps and Pumping of Liquids

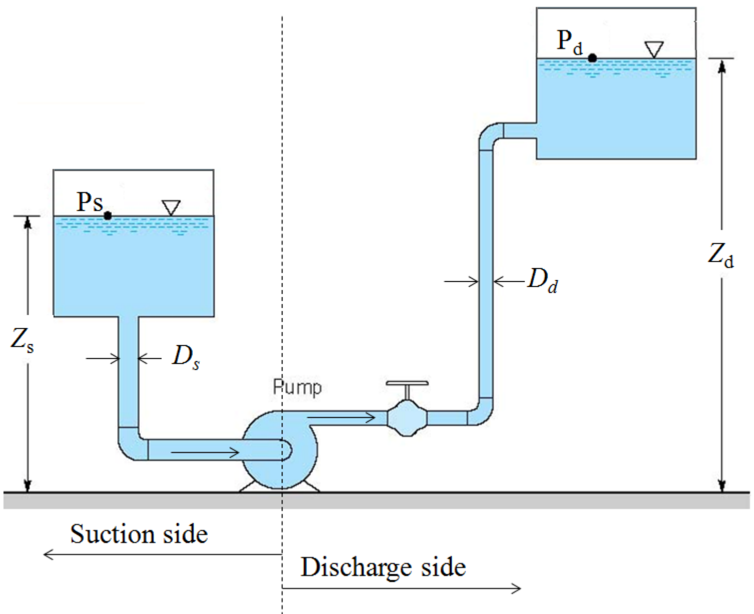
$$\eta = \frac{\dot{m} w_p}{\dot{W}_{total}} = \frac{\rho Q \frac{P_2 - P_1}{\rho}}{\dot{W}_{total}} = \frac{Q(P_2 - P_1)}{\dot{W}_{total}}$$

$$Q(P_2 - P_1) = (6.6845)(10080) = 67379.8 \,\tfrac{\text{lbf.ft}}{\text{min}} \frac{1\,\text{hp}}{3300 \,\tfrac{\text{lbf.ft}}{\text{min}}}$$

$$= 2.04\,\text{hp}$$

$$\eta = \frac{Q(P_2 - P_1)}{\dot{W}_{total}} = \frac{2.04}{2.8} = 0.73 = \%73$$

Topic V: Pumps and Pumping of Liquids



Topic V: Pumps and Pumping of Liquids

- **Pump system heads**:

A. Suction head (h_s): it works in favor of the pump

$$h_s = Z_s + \frac{P_s}{\rho g} - h_{fs}$$

Z_s : Suction static head, if it has negative value it will be Suction static lift.

P_s : gas absolute pressure above the liquid in the tank of the suction side.

h_{fs} : head losses due to friction and fittings in the suction side.

Topic V: Pumps and Pumping of Liquids

- **Pump system heads**:

B. Discharge head (h_d): it works against the pump

$$h_d = Z_d + \frac{P_d}{\rho g} + h_{fd}$$

Z_d : discharge static head, if it has negative value it will be Suction static lift.

P_d : gas absolute pressure above the liquid in the tank of the discharge side.

h_{fd} : head losses due to friction and fittings in the discharge side.

Topic V: Pumps and Pumping of Liquids

• **Pump system heads**:

C. Total head (h_p): $h_p = h_d - h_s = \dfrac{w_p}{g}$

This definition can be obtained by applying the head form of mechanical energy balance between one point (1) at the free surface of the suction tank and another point (2) at the free surface of the discharge tank:

$$(Z_d - Z_s) + \frac{1}{2g}\left(\bar{u}_2^2 - \bar{u}_1^2\right) + \frac{P_d - P_s}{\rho g} = h_p - h_f$$

$$\bar{u}_2 \approx 0 \quad ; \quad \bar{u}_f \approx 0$$

h_f is the total head losses in the suction and discharge sides:

$$h_f = h_{fs} + h_{fd}$$

Topic V: Pumps and Pumping of Liquids

• **Pump system heads**:

C. Total head (h_p):

$$(Z_d - Z_s) + \frac{P_d - P_s}{\rho g} = h_p - (h_{fs} + h_{fd})$$

Rearrange the equation as:

$$h_p = Z_d - Z_s + \frac{P_d}{\rho g} - \frac{P_s}{\rho g} + h_{fs} + h_{fd}$$

$$= \left(Z_d + \frac{P_d}{\rho g} + h_{fd}\right) - \left(Z_s + \frac{P_s}{\rho g} - h_{fs}\right)$$

$$= h_d - h_s$$

Topic V: Pumps and Pumping of Liquids

D. Net Positive Suction Head (*NPSH*):

In order to avoid cavitation (creating vapor bubbles in the suction side), the available NPSH is defined as below:

$$NPSH = h_s - \frac{P^v}{\rho g} > 0$$

- **The available *NPSH* must be greater than zero, otherwise cavitation will occur and the pump will be damaged.**
- **$NPSH_{available}$ > $NPSH_{required}$ (given by the manufacturer of the pump.**
- **If the suction tank is at boiling conditions ($P_s = P^v$):**

$$NPSH = h_s - \frac{P^v}{\rho g} = Z_s + \frac{P_s}{\rho g} - h_{fs} - \frac{P^v}{\rho g} = Z_s - h_{fs}$$

In such conditions, the static suction head must be positive and greater than h_{fs} to have positive NPSH.

Topic V: Pumps and Pumping of Liquids

- **Effect of flow rate on the system heads**:

As flow rate increses $\boldsymbol{h_{fs}}$ and $\boldsymbol{h_{fd}}$ increses then:

- The suction head ($\boldsymbol{h_s}$) will decrease.

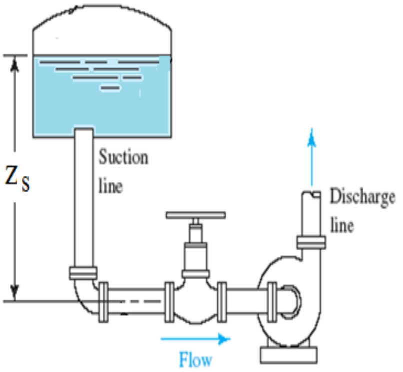
- The discharge head ($\boldsymbol{h_d}$) will increase.

- The total head ($\boldsymbol{h_p}$) which the pump is required to impart the flowing liquid increases.

- The available net positive suction head (***NPSH***) will decease.

Topic V: Pumps and Pumping of Liquids

Example. Determine suction head and the available *NPSH* for the system shown in the figure . The liquid reservoir is a closed tank with a pressure of -20 kPa above water at 70°C (the vapor pressure is 31.2 kPa, density is 978 kg/m3, and kinematic viscosity is 4.13 $\times 10^{-7}$ m^2/s). The atmospheric pressure is 100.5 kPa. The water level in the tank is 2.5 m above the pump inlet. The pipes in the suction side is a 1.5-in Schedule 40 steel pipe with a total length of 12.0 m. The elbow is standard 90° and the valve is a fully open globe valve. The flow rate is 95 L/min.



Topic V: Pumps and Pumping of Liquids

$$P_{s,gage} = -20\,\text{kPa} \;\; ; P_{atm} = 100.5\,\text{kPa} \;\; ; P^{v} = 31.2\,\text{kPa},$$

$$\rho = 978\,\text{kg/m}^3 \; ; \; \nu = 4.13\times 10\text{-}7\,\text{m}^2/\text{s}$$

$$Z_s = 2.5\,\text{m} \; ; \; L = 12.0\,\text{m}.$$

$$P_s = -20 + 100.5 = 80.5\,\text{kPa} = 80.5\times 10^3\, Pa$$

For 1.5-in Schedule 40 steel pipe: $D = 1.610\,\text{in} = 0.0409\,\text{m}$

$$\varepsilon = 4.6\times 10^{-5}\,\text{m}$$

The flow rate is 95 L/min: $Q = 95\,\dfrac{\text{L}}{\text{min}} = 1.583\times 10^{-3}\,\text{m}^3/\text{s}$

$$u = \frac{4Q}{\pi D^2} = \frac{4(1.583\times 10^{-3})}{\pi (0.0409)^2} = 1.21\,\text{m/s}$$

Topic V: Pumps and Pumping of Liquids

$$h_s = Z_s + \frac{P_s}{\rho g} - h_{fs} \quad ; \quad NPSH = h_s - \frac{P^v}{\rho g}$$

Head losses in the suction side (h_{fs} **):**

- Friction in the pipes: $(h_f)_{pipe} = 4f \frac{L}{D}\frac{u^2}{2g}$

$$\left.\begin{aligned} &\mathrm{Re} = \frac{\rho u D}{\mu} = 1.2\times10^5 (turbulent) \\ &\varepsilon / D = 0.001 \end{aligned}\right\rangle from\, Moody\, diagram: f = 0.0055$$

$$(h_f)_{pipe} = 4f \frac{L}{D}\frac{u^2}{2g} = 0.4817\, m$$

- Sudden Contraction: $K_c = 0.5$

$$(h_f)_{contraction} = K_c \frac{u^2}{2g} = 0.037\,\mathrm{m}$$

Topic V: Pumps and Pumping of Liquids

- 90º standard elbow: $K_b = 0.9$

$$(h_f)_{elbow} = K_b \frac{u^2}{2g} = 0.067\,\mathrm{m}$$

- Wide open globe valve: $K_v = 10$

$$(h_f)_{valve} = K_v \frac{u^2}{2g} = 0.746\,\mathrm{m}$$

$$h_{fs} = (h_f)_{pipe} + (h_f)_{contraction} + (h_f)_{elbow} + (h_f)_{valve}$$
$$= 0.4817 + 0.037 + 0.067 + 0.746 = 1.33\,\mathrm{m}$$

$$h_s = 2.5 + \frac{80.5\times10^3}{(978)(9.81)} - 1.33 = 9.56\,\mathrm{m}$$

$$h_s = Z_s + \frac{P_s}{\rho g} - h_{fs} \quad ; \quad NPSH = h_s - \frac{P^v}{\rho g}$$

Topic V: Pumps and Pumping of Liquids

$$NPSH = h_s - \frac{P^v}{\rho g} = 9.56 - \frac{31.2 \times 10^3}{(978)(9.81)} = 6.3\text{m}$$

Thus, a pump operating in this system must have a required NPSH less than 6.3 m. In other words, for such system search for a pump in the market with required NPSH less than 6.3

Exercise. What happen is the static lift is 4 m (Z_s= -4 m)?

Topic V: Pumps and Pumping of Liquids

Parameters Involved In Pump selection:

- When selecting a pump for a particular application, the following factors must be considered:

1. The nature of the liquid to be pumped(viscosity, density, suspended solids, corrosive,..etc)
2. The required capacity (volume flow rate)
3. The conditions on the suction (inlet) side of the pump
4. The conditions on the discharge (outlet) side of the pump
5. The total head on the pump (the term from the energy equation)
6. The type of system to which the pump is delivering the fluid
7. The type of power source (electric motor, diesel engine, steam turbine, etc.)
8. Space, weight, and position limitations
9. Environmental conditions
10. Cost of pump purchase and installation
11. Cost of pump operation
12. Governing codes and standards

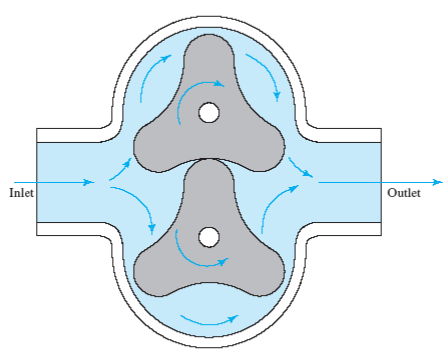
Topic V: Pumps and Pumping of Liquids

Types of pumps: Pumps are typically classified as either **positive displacement** or **kinetic pumps**.

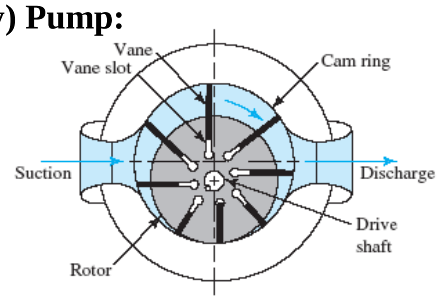
- Positive displacement
  - Rotary
    - Gear
    - Vane
    - Screw
    - Progressing cavity
    - Lobe or cam
    - Flexible tube (peristaltic)
  - Reciprocating
    - Piston
    - Plunger
    - Diaphragm
- Kinetic
  - Radial flow (centrifugal)
  - Axial flow (propeller)
  - Mixed flow
- Jet or ejector type

Topic V: Pumps and Pumping of Liquids

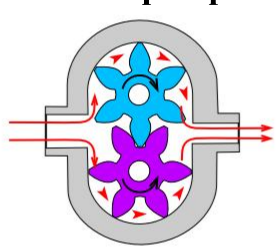
Positive-Displacement (Rotary) Pump:



"Lobe pump"



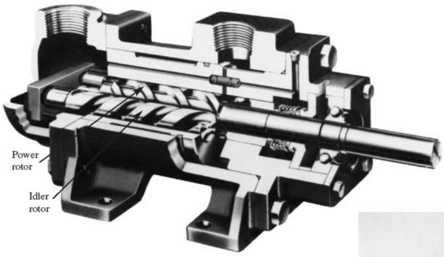
"Vane pump"



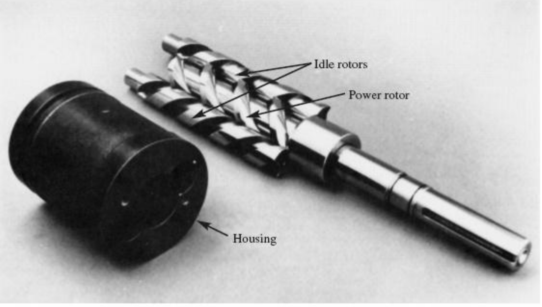
"Gear pump"

Topic V: Pumps and Pumping of Liquids

Positive-Displacement (Rotary) Pump:



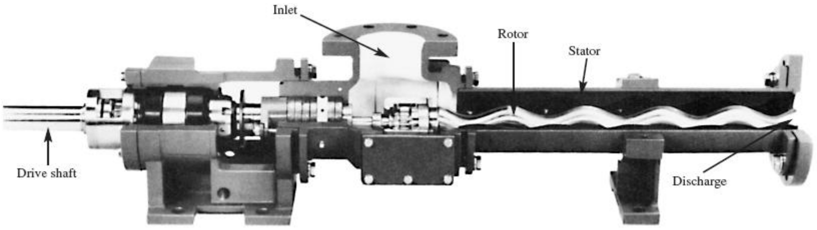
(a) Cutaway of pump assembly



"Screw pump"

Topic V: Pumps and Pumping of Liquids

Positive-Displacement (Rotary) Pump:

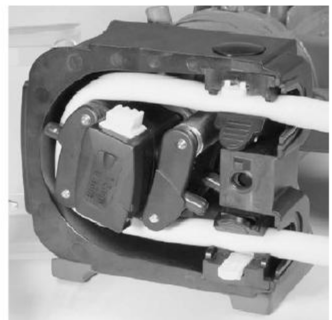


"Progressing cavity pump"

Topic V: Pumps and Pumping of Liquids

Positive-Displacement (Rotary) Pump:

(a) Peristaltic pump with variable-speed drive system

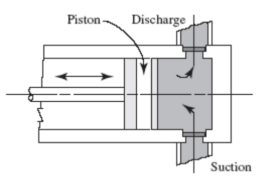


(b) Peristaltic pump with case open to show tubing and rotating drive rollers

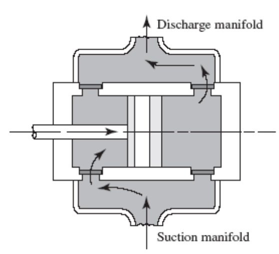
"Peristaltic Pump"

Topic V: Pumps and Pumping of Liquids

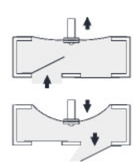
Positive-Displacement (Reciprocating) Pump:



(a) Single acting—simplex

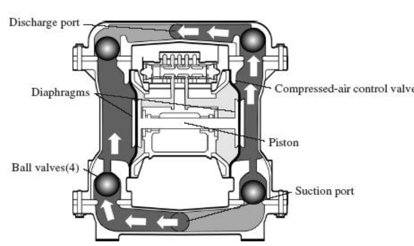


(b) Double acting—duplex



Diaphragm pump

(a) Diaphragm pump with nonmetallic housing



(b) Diagram of the flow through a double-piston diaphragm pump

Topic V: Pumps and Pumping of Liquids

Positive-Displacement Pump:

- Positive-displacement pumps ideally deliver a fixed quantity of fluid with each revolution of the pump rotor or drive shaft.
- Most positive-displacement pumps can handle liquids over a wide range of viscosities.
- The operating characteristics of positive-displacement pumps make them useful for handling such fluids as water, hydraulic oils in fluid power systems.
- Some disadvantages of some designs include pulsating output, susceptibility to damage by solids and abrasives, and need for a relief valve.

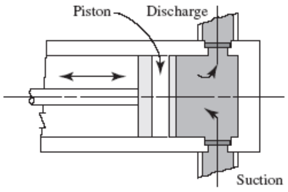
Topic V: Pumps and Pumping of Liquids

Reciprocating Pump Performance:

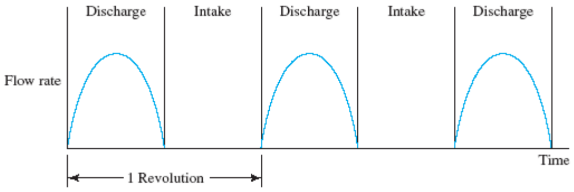
- In its simplest form, the reciprocating pump employs a piston that draws fluid into a cylinder through an intake valve as the piston draws away from the valve.
- Then, as the piston moves forward, the intake valve closes and the fluid is pushed out through the discharge valve.
- Such a pump is called *simplex*, and its curve of discharge versus time is illustrated in the next two slides.

Topic V: Pumps and Pumping of Liquids

Piston Pump Performance:



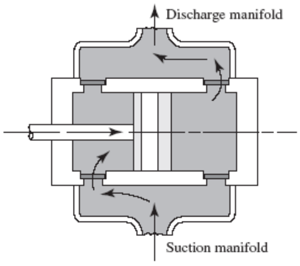
(a) Single acting—simplex



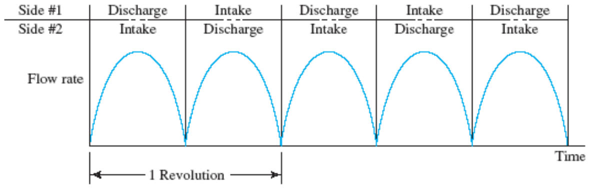
(a) Single-acting pump—simplex

Topic V: Pumps and Pumping of Liquids

Piston Pump Performance:



(b) Double acting—duplex



(b) Double-acting pump—duplex

Topic V: Pumps and Pumping of Liquids

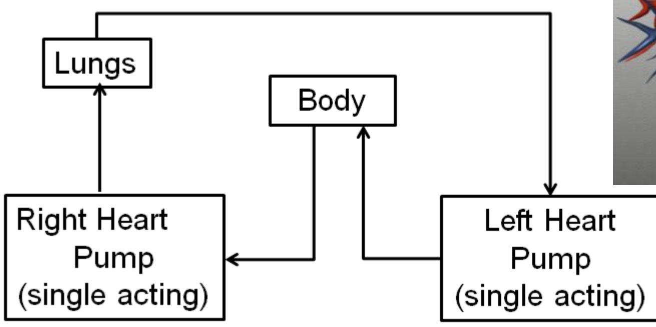
Heart is a reciprocating pump…….

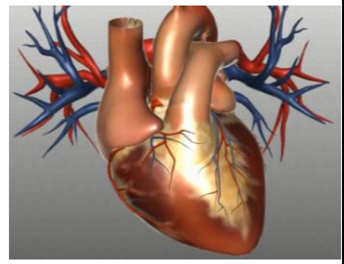
بسم الله الرحمن الرحيم

{أَفَلَمْ يَسِيرُوا فِي الأَرْضِ فَتَكُونَ لَهُمْ قُلُوبٌ يَعْقِلُونَ بِهَا أَوْ آذَانٌ يَسْمَعُونَ بِهَا

فَإِنَّهَا لا تَعْمَى الأَبْصَارُ وَلَكِنْ تَعْمَى الْقُلُوبُ الَّتِي فِي الصُّدُورِ}

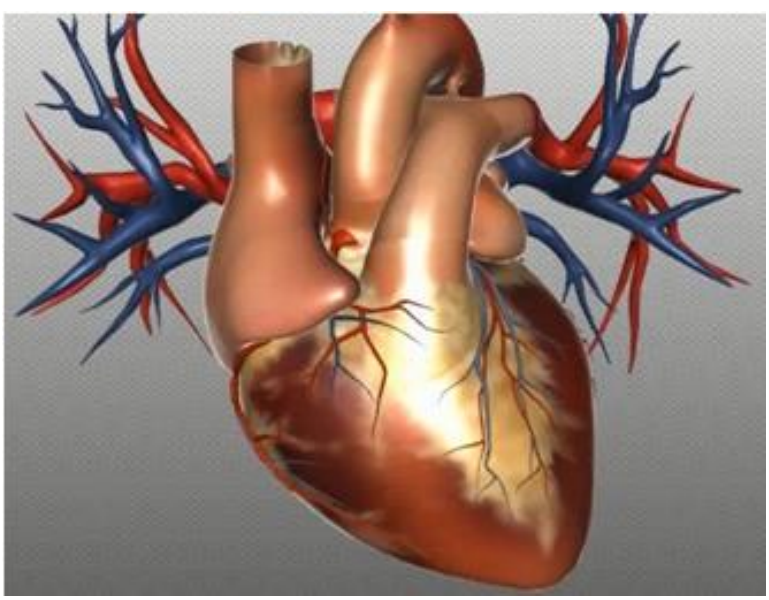
سورة الحج آية رقم 46





Topic V: Pumps and Pumping of Liquids

Heart is a reciprocating pump…….

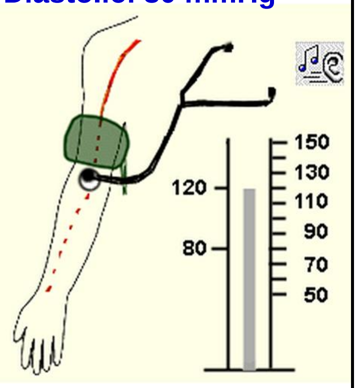


Topic V: Pumps and Pumping of Liquids

Blood pressure measurement:

Initially the cuff is inflated to a level higher than the systolic pressure. Thus the artery is completely compressed, there is no blood flow, and no sounds are heard. The cuff pressure is slowly decreased. At the point where **the systolic pressure exceeds the cuff pressure**, the sounds are first heard and blood passes in **turbulent flow** through the partially constricted artery. sounds will continue to be heard as the cuff pressure is further lowered. However, when the cuff pressure reaches diastolic pressure, the sounds disappear and blood passes in **laminar flow** .

Normal blood pressure:
Systolic: 120 mm Hg
Diastolic: 80 mmHg



Topic V: Pumps and Pumping of Liquids

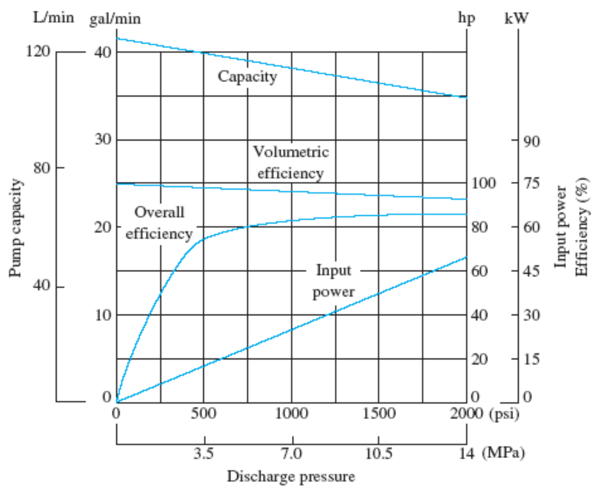
Characteristic Curves of Positive-Displacement Pumps

- Characteristic performance curves of positive-displacement pumps are usually plots of capacity, efficiency, and power versus discharge pressure.
- As pressure is increased, a slight decrease in capacity occurs due to internal leakage from the high-pressure side to the low-pressure side.
- *Volumetric efficiency* is a measure of the ratio of the volume flow rate delivered by the pump to the theoretical delivery, based on the displacement per revolution of the pump, times the speed of rotation.

Topic V: Pumps and Pumping of Liquids

Characteristic Curves of Positive-Displacement Pumps

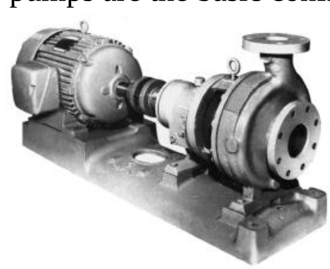
The figure below shows an example of such Characteristic Curves :



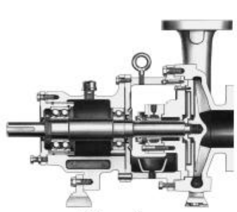
Topic V: Pumps and Pumping of Liquids

Kinetic Pumps: *Kinetic pumps* add energy to the fluid by accelerating it through the action of a rotating *impeller*.

• The most common type of kinetic pumps are the basic configurations of a radial flow centrifugal pump:



(a) Pump and motor



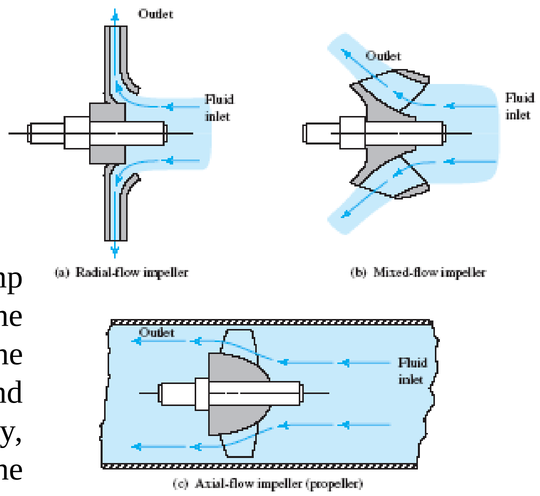
(b) Cutaway of pump

(c) Radial-flow impeller

Topic V: Pumps and Pumping of Liquids

Kinetic Pumps:

The basic design of radial, axial, and mixed-flow impellers:



• The propeller type of pump (axial flow) depends on the hydrodynamic action of the propeller blades to lift and accelerate the fluid axially, along a path parallel to the axis of the propeller

Topic V: Pumps and Pumping of Liquids

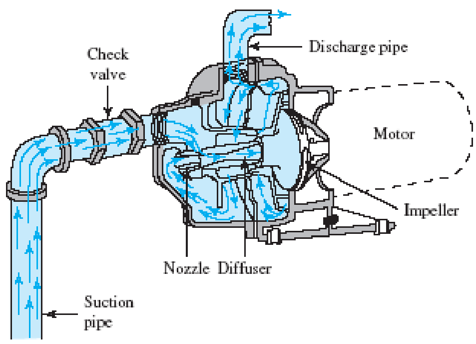
Kinetic Pumps:

- **Examples of kinetic pumps are:**

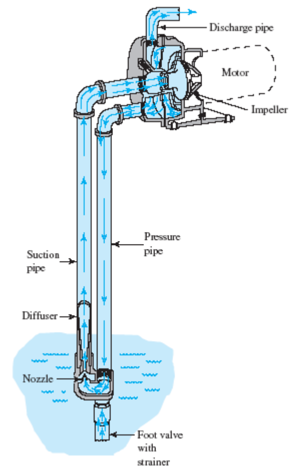
1. Jet Pumps
2. Submersible Pumps
3. Small Centrifugal Pumps
4. Self-priming Pumps
5. Vertical Turbine Pumps
6. Centrifugal Grinder Pumps

Topic V: Pumps and Pumping of Liquids

Kinetic Pumps:



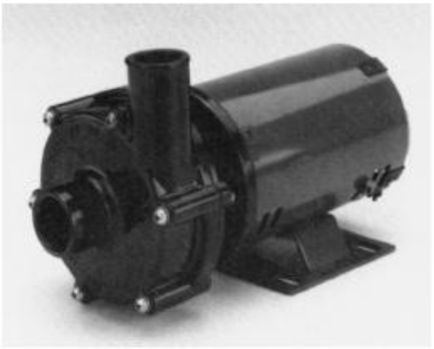
"Shallow-well jet pump"



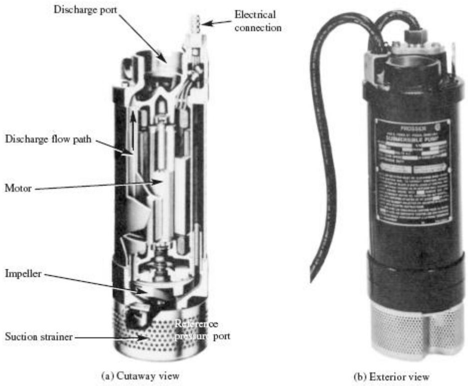
"Deep-well jet pump"

Topic V: Pumps and Pumping of Liquids

Kinetic Pumps:



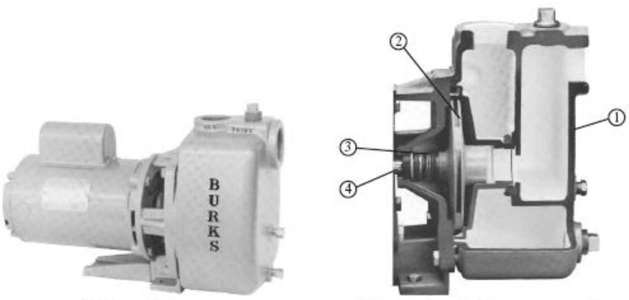
"Centrifugal pump with integral motor"



"Portable submersible pump"

Topic V: Pumps and Pumping of Liquids

Kinetic Pumps:



(a) Pump with motor (b) Cutaway view showing pump construction

(1) Suction inlet casing
(2) impeller,
(3) mechanical shaft seal
(4) shaft.

"Self-priming pump"

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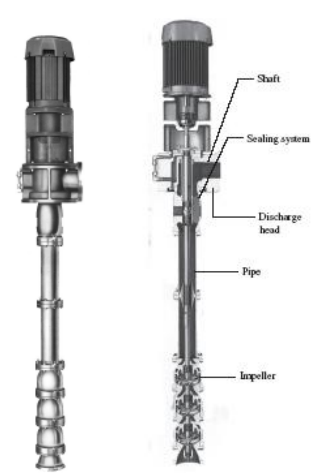
Kinetic Pumps:

(a) Exterior view (b) Grinder cutters

"Centrifugal grinder pump"



(a) Exterior view (b) Cutaway view showing pump construction

"Vertical-turbine pump"

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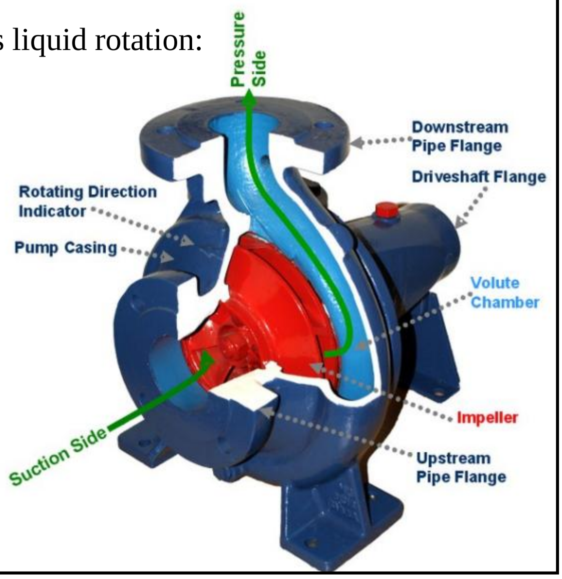
Centrifugal pump and conservation of angular momentum:

- In centrifugal pump, there is liquid rotation:



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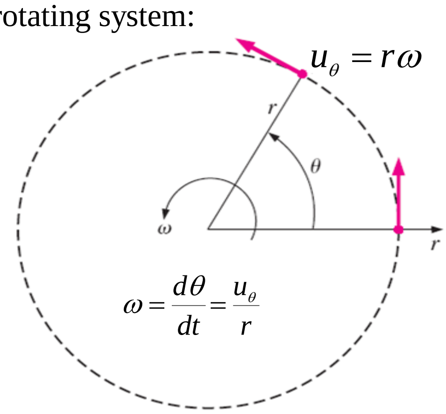
Centrifugal pump and conservation of angular momentum:

- Angular momentum is defined for rotating system:

$$\omega: \text{Anngular velocity}: \omega = \frac{d\theta}{dt}$$

$$\text{Tangential velocity}: u_\theta = r\frac{d\theta}{dt}$$

$$= r\omega$$



- θ-momentum balance:

$$\frac{d(mu_\theta)}{dt} = \sum F_\theta$$

- Multiply θ-momentum balance by r:

$$\frac{d(mru_\theta)}{dt} = \sum rF_\theta$$

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Centrifugal pump and conservation of angular momentum:

mru_θ : is called angular momentum of rotating body. **Angular momentum** is also called **moment-of-momentum .**

$\sum \vec{r} \times \vec{F}_\theta \equiv \mathbf{T}_{net}$: net torque acting on the body

- Thus, the conservation of angular momentum of rotating rigid body is: $\Rightarrow \dfrac{d(mru_\theta)}{dt} = T_{net}$
- In centrifugal pump, we have continuous flow of liquid(open system, the angular momentum balance will be:

$$\frac{dmru_\theta)}{dt} = \underbrace{(ru_\theta \dot{m})_{in}}_{\text{rate of angular momentum in}} - \underbrace{(ru_\theta \dot{m})_{out}}_{\text{rate of angular momentum out}} + T_{net}$$

Topic V: Pumps and Pumping of Liquids

Centrifugal pump and conservation of angular momentum:

- In centrifugal pump, we have steady-state flow, hence, the angular momentum balance becomes:

$$\frac{dmru_\theta)}{dt} = 0 = (ru_\theta \dot{m})_{in} - (ru_\theta \dot{m})_{out} + T_{net}$$

$$\Rightarrow T_{net} = (ru_\theta \dot{m})_{out} - (ru_\theta \dot{m})_{in}$$

- Steady-state mass balance says: $\dot{m}_{out} = \dot{m}_{in}$

$$\Rightarrow T_{net} = \dot{m}\left[(ru_\theta)_{out} - (ru_\theta)_{in}\right]$$ **"Euler's Turbine Equation"**

$$\dot{m} = \rho Q$$

$$u_\theta = r\omega$$

Topic V: Pumps and Pumping of Liquids

Centrifugal pump and conservation of angular momentum:

Example. A centrifugal water pump impeller rotates at 1800 rpm. Water enters the impeller blades at radius of 1 in and leaves at a radius of 6 in. The total flow rate is 100 gpm. What is the steady state torque exerted on the rotor. Neglect friction.

$$T_{net} = \dot{m}\left[(ru_\theta)_{out} - (ru_\theta)_{in}\right]$$

But $u_{\theta,out} = \omega r_{out}$; $u_{\theta,in} = \omega r_{in}$

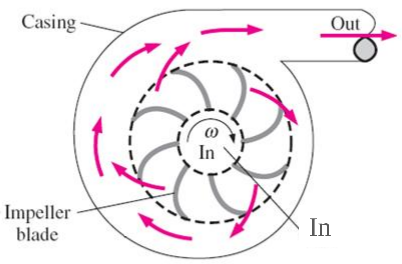
$$\Rightarrow T_{net} = \rho Q \omega\left[r^2_{out} - r^2_{in}\right]$$

$\rho = 1.94\ \text{slug/ft}^3$; $Q = 100$ gpm

$\omega = (2\pi)(1800)$ rad/min

$r_{out} = 6$ in ; $r_{in} = 1$ in

$T_{net} = 26.8\ N.m$



Topic V: Pumps and Pumping of Liquids

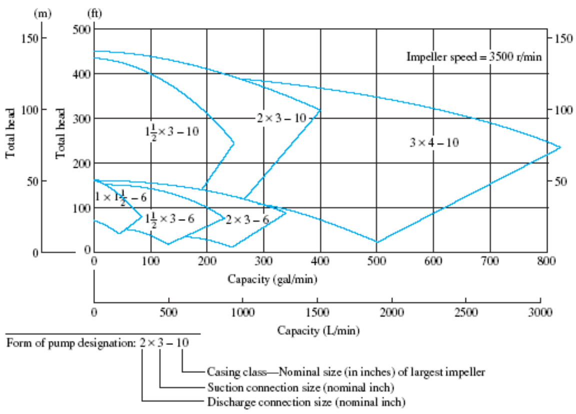
General comparison between piston and centrifugal pumps:

Property	Piston pump	Centrifugal pump
Capacity (Discharge flow rate)	Low	High
Discharge pressure	High	Low
Variable nearly constant	Discharge flow rate	Discharge pressure
Self-priming	Yes	No
Number of moving and wearing parts	Many	small
Nature of discharge flow	Pulsating	Steady
Work well on high-viscosity liquids	Yes	No
Work well on suspended –solid solutions	No	Yes
Angle between suction and discharge lines	0^o	90^o

Topic V: Pumps and Pumping of Liquids

Manufacturers' Data for Centrifugal Pumps

- A composite rating chart which allows a quick determination of the centrifugal pump size:



Topic V: Pumps and Pumping of Liquids

Characteristic Curves of Centrifugal Pumps

- Because centrifugal pumps are not positive-displacement types, there is a strong dependency between capacity and the pressure that must be developed by the pump.
- This makes their characteristic curves somewhat more complex.
- The typical performance characteristic curves for centrifugal pump are its total head, efficiency, and power plots versus the capacity or discharge *Q*.

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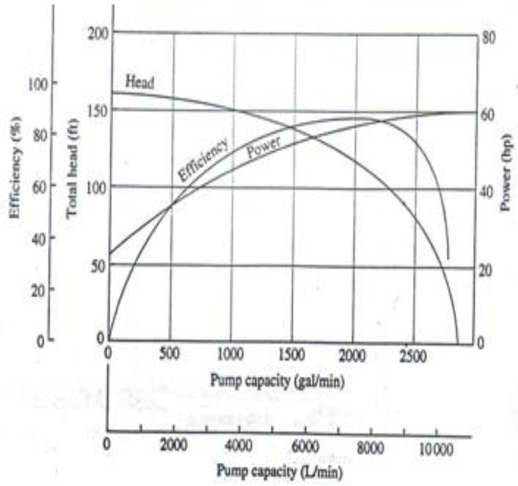
Characteristic Curves of Centrifugal Pumps

Example of the characteristic curves of some centrifugal pump:



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Characteristic Curves of Centrifugal Pumps

- Net positive suction head required (*NPSHR*) is an important factor to consider in applying a pump.
- Pump performance is affected strongly by size of impeller and its rotational speed (rpm). Thus, they must be include in the composite performance charts.

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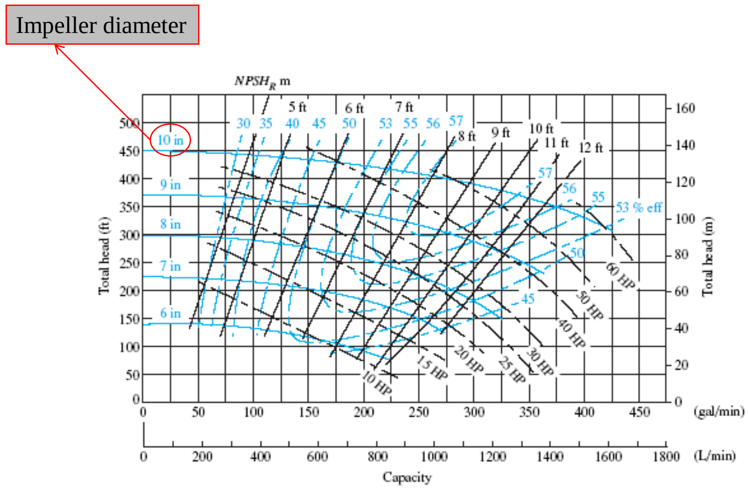
Some characteristic Curves of Centrifugal Pumps



Performance chart of 2×3-10 centrifugal Pump at 3500 rpm

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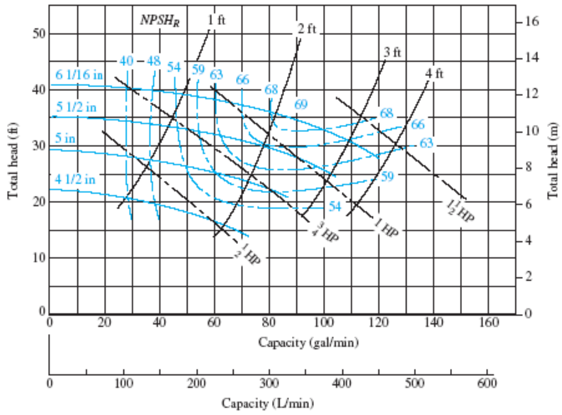
Some characteristic Curves of Centrifugal Pumps



Performance chart of 1.5×3-6 centrifugal Pump at 1750 rpm

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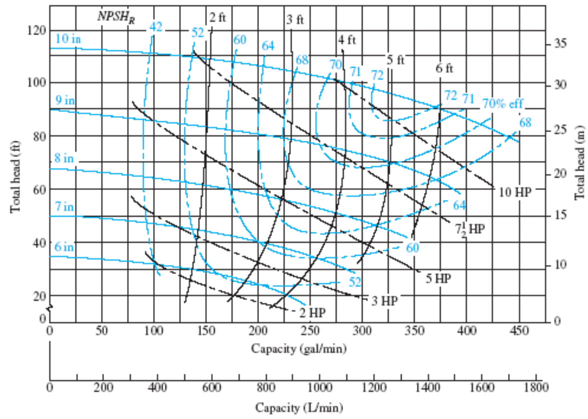
Some characteristic Curves of Centrifugal Pumps



Performance chart of 3×4-10 centrifugal Pump at 1750 rpm

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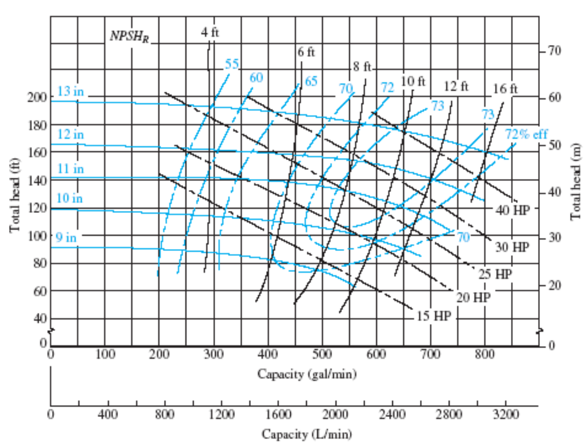
Some characteristic Curves of Centrifugal Pumps



Performance chart of 3×4-13 centrifugal Pump at 1750 rpm

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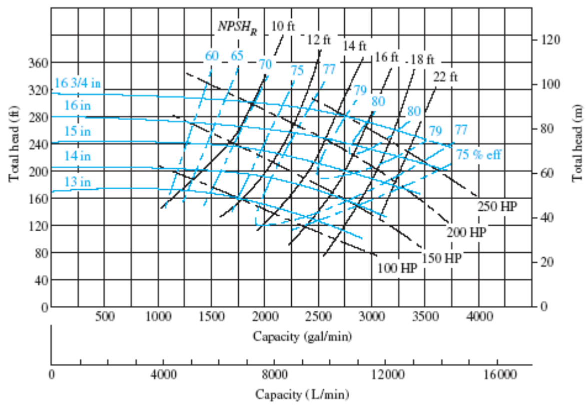
Some characteristic Curves of Centrifugal Pumps



Performance chart of 6×8-17 centrifugal Pump at 1780 rpm

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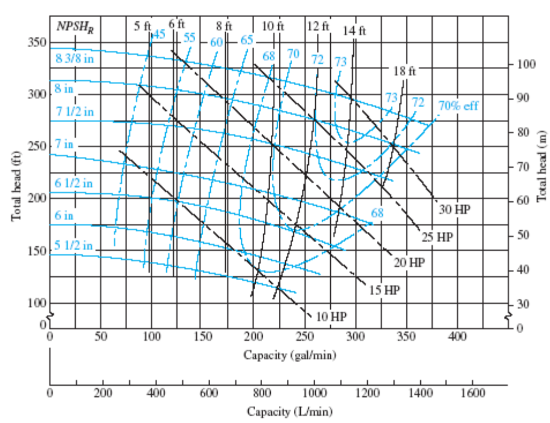
Some characteristic Curves of Centrifugal Pumps



Performance chart of 2×3-8 centrifugal Pump at 3560 rpm

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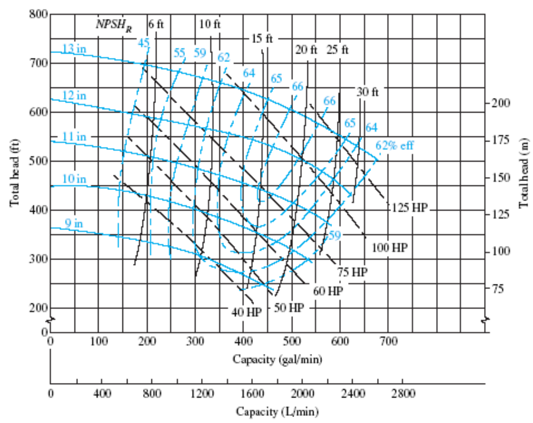
Some characteristic Curves of Centrifugal Pumps



Performance chart of 1.5×3-13 centrifugal Pump at 3560 rpm

Topic V: Pumps and Pumping of Liquids

Centrifugal Pumps relationships(Affinity Laws)

- It is important to understand the manner in which capacity, head, efficiency, and power vary when either **impeller speed (*N*)** or **impeller diameter (*D*)** is varied.
- The following centrifugal pump relationships are derived from **dimensional analysis**:

Pump capacity: $Q = C_1 N D^3$ $\quad C_1$ is constant

Pump total head: $h_p = C_2 N^2 D^2$ $\quad C_2$ is constant

Pump power:

$$\dot{W}_p = \dot{m} W_p = \rho Q (h_p g) = \rho g Q h_p$$
$$= \rho g (C_1 N D^3)(C_2 N^2 D^2)$$
$$= C_3 \rho N^3 D^5 \qquad \text{Where } C_3 = g C_2 C_3$$

Topic V: Pumps and Pumping of Liquids

Centrifugal Pumps relationships(Affinity Laws)

Net Positive Suction Head Required (NPSHR):

$$NPSHR = C_2\, N^2 D^2 \qquad C_2 \text{ is constant}$$

Efficiency remains nearly constant for speed changes and for small changes in impeller diameter.

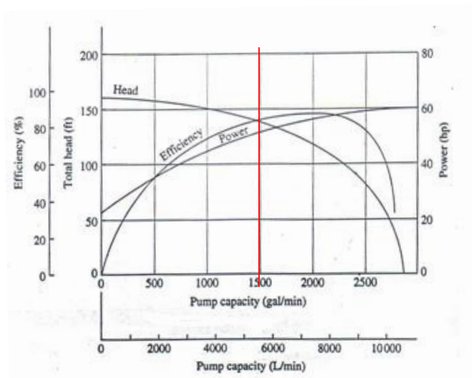
- Now to go from case 1 with D_1 and N_1 to Case 2 with D_2 and N_2:

$$\frac{(Q)_2}{(Q)_1} = \left(\frac{N_2}{N_1}\right)\left(\frac{D_2}{D_1}\right)^3 \qquad \frac{(h_p)_2}{(h_p)_1} = \left(\frac{N_2}{N_1}\right)^2\left(\frac{D_2}{D_1}\right)^2$$

$$\frac{(NPSHR)_2}{(NPSHR)_1} = \left(\frac{N_2}{N_1}\right)^2\left(\frac{D_2}{D_1}\right)^2 \qquad \frac{(\dot{W}_p)_2}{(\dot{W}_p)_1} = \left(\frac{N_2}{N_1}\right)^3\left(\frac{D_2}{D_1}\right)^5$$

Topic V: Pumps and Pumping of Liquids

Example. Assume that the centrifugal pump for which the performance data are plotted in the given performance chart was operating at a rotational speed of 1750 rpm and that the impeller diameter was 330 mm.



(a) Determine the head that would result in a capacity of 1500 gal/min and the power required to drive the pump.

(b) Compute the performance at a speed of 1250 rpm using the same impeller.

Topic V: Pumps and Pumping of Liquids

(a) Determine the head that would result in a capacity of 1500 gal/min) and the power required to drive the pump.

From the chart, projecting upward from capacity Q_1= 1500 gal/min) gives:

Pump total head: $(h_p)_1 = 130\ ft$

Pump power: $(\dot{W}_p)_1 = 50\,hp$

Pump efficiency: $\xi = 82\%$

(b) Compute the performance at a speed of 1250 rpm using the same impeller diameter.

$$(Q)_1 = 1500\,gal/\min\ ;\ D_2 = D_1\ ;\ N_1 = 1750\,rpm;\ N_2 = 1250\,rpm$$

$$(Q)_2 = \left(\frac{N_2}{N_1}\right)\left(\frac{D_2}{D_1}\right)^3 (Q)_1 = \left(\frac{1250}{1750}\right)1500 = 1071\,\text{gpm}$$

$$(h_p)_2 = \left(\frac{N_2}{N_1}\right)^2\left(\frac{D_2}{D_1}\right)^2 (h_p)_1 = \left(\frac{1250}{1750}\right)^2 130 = 66.3\ ft$$

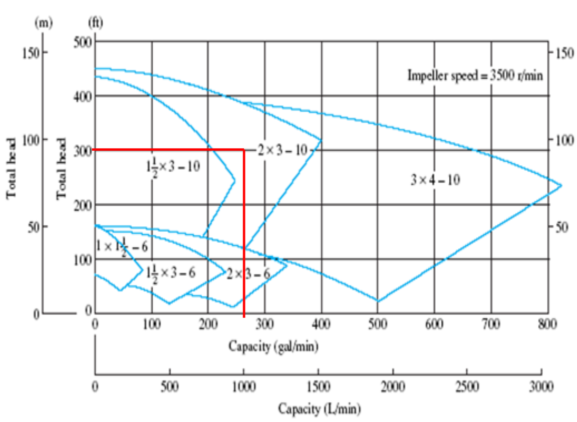
$$(\dot{W}_p)_2 = \left(\frac{N_2}{N_1}\right)^3\left(\frac{D_2}{D_1}\right)^5 (\dot{W}_p)_1 = \left(\frac{1250}{1750}\right)^3 50 = 18.2\,hp$$

Topic V: Pumps and Pumping of Liquids

Example. A centrifugal pump must deliver at least 250 gpm of water at a total head of 300 ft of water. Specify a suitable pump. List its performance characteristics.

2×3-10 centrifugal pump is suitable for this duty. Because this pump with a 0.23 m (9-in) impeller will deliver approximately 275 gal/min) at 300 ft of head. At this operating point:,

- **The efficiency would be 57%**, near the maximum for this type of pump.
- Approximately **37 hp would be required**.
- The ***NPSHR*** at the suction inlet to the pump is approximately **9.2 ft of water.**



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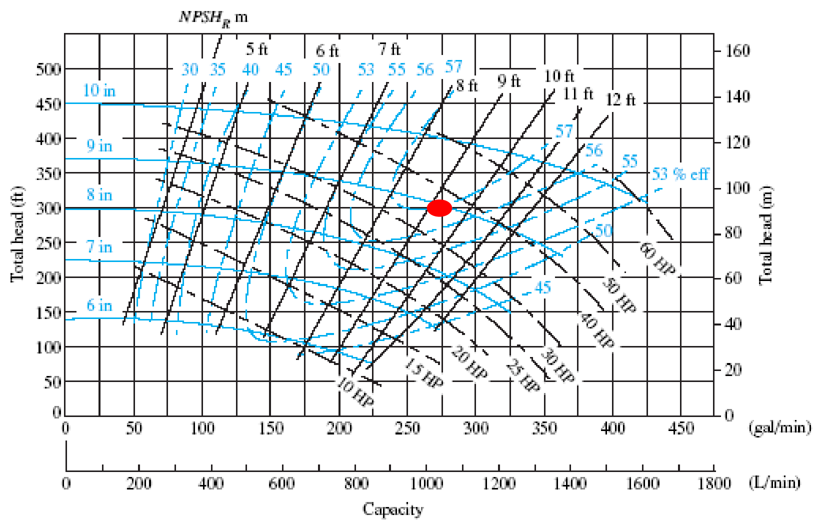
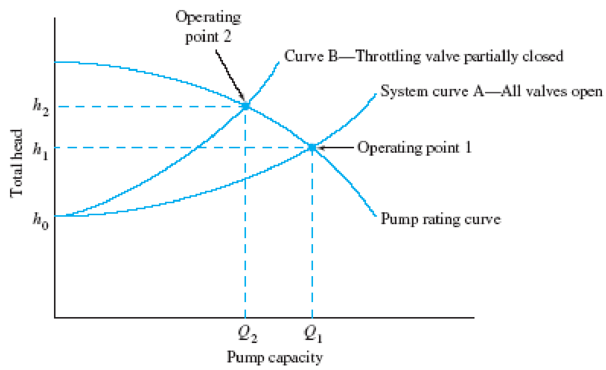


Performance chart of 2×3-10 centrifugal Pump at 3500 rpm

Topic V: Pumps and Pumping of Liquids

The Operating Point of a Pump:

- The operating point of a pump is defined as the volume flow rate it will deliver when installed in a given system.



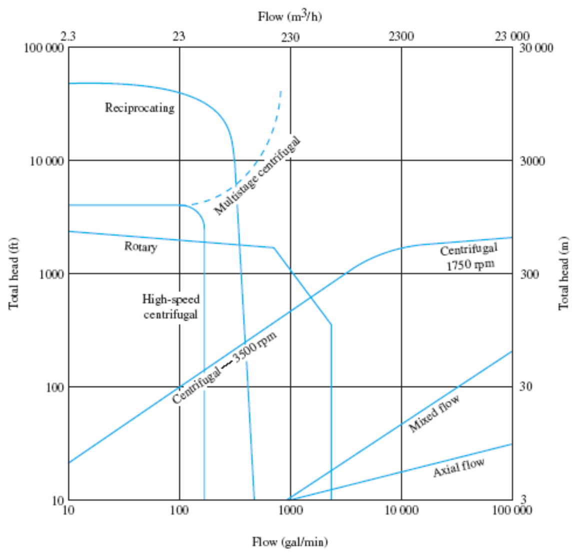
- We have noticed that as flow rate increases the total system head decreases due the increase in the head losses.
- In contrast, as flow rate increases the pump head decreases:

$$\dot{W}_p = \dot{m}W_p = \rho Q(h_p g) = \rho g Q h_p$$

$$h_p = \frac{\dot{W}_p}{\rho g Q}$$

Topic V: Pumps and Pumping of Liquids

Useful charts for pump selection:



Topic V: Pumps and Pumping of Liquids

Useful chart for kinetic pump selection: