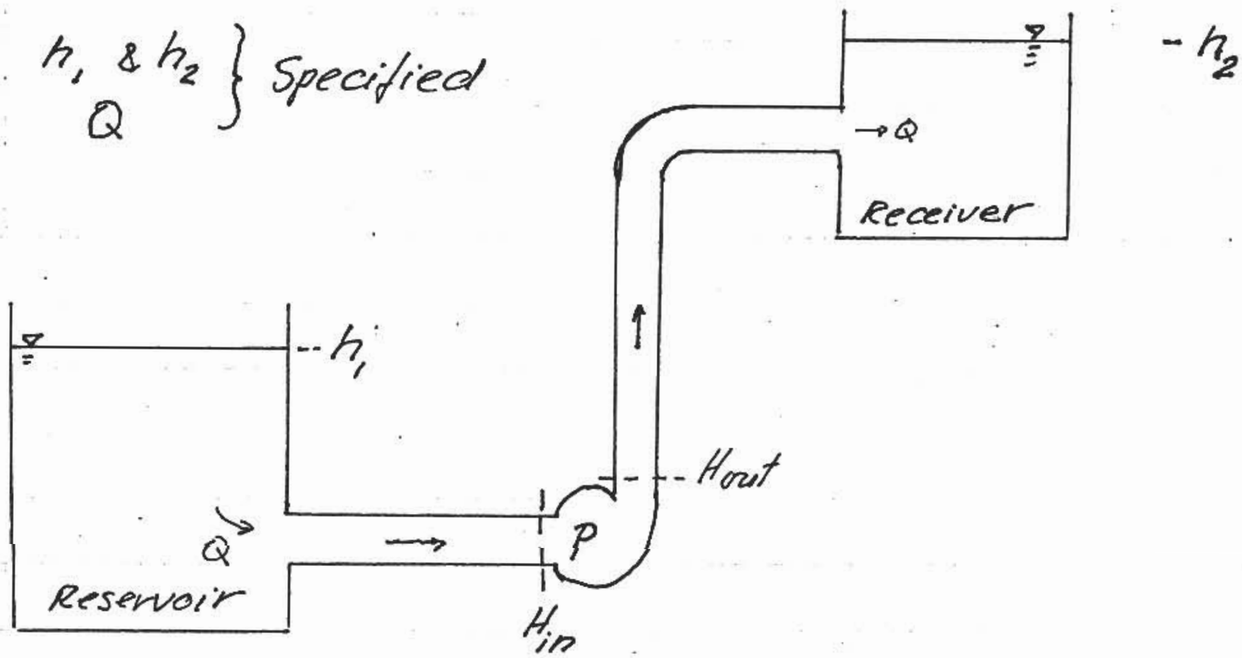
# LECTURE # 18

## 1.060 ENGINEERING MECHANICS II

## PUMP SPECIFICATION AND REQUIREMENTS

If we need to transport water from a lower to a higher elevation, i.e. when $H_1$ = head in reservoir < $H_2$ = receiving head, we have to force the water "up the hill", we need help in the form of a pump.

$h_1$ & $h_2$, $Q$ } Specified




## Determination of Pump Head, $H_p = H_{out} - H_{in}$

Standard pipe flow analysis from reservoir to pump inflow section gives

$$H_{in} = h_1 - \Delta H_{res \to pump} = h_1 - \sum_{res \to pump}\left(\Delta H_f + \Delta H_{minor}\right) =$$

$$h_1 - \sum_{res \to pump}\left[\left(K_{Lm} + f\frac{l}{D}\right)\frac{Q^2/A^2}{2g}\right]$$

And from Pump to Receiver we have

$$H_{out} = h_2 + \Delta H_{pump \to receiver} =$$

$$h_2 + \sum_{pump \to rec.}\left[\left(K_{Lm} + f\cdot\frac{l}{D}\right)\frac{Q^2/A^2}{2g}\right]$$

[Note difference in sign of head loss terms. For pump to receiver sign is "+" since we proceed <u>against</u> the flow from $h_2$ to pump!]

<u>Pump Head</u> = $\underline{H_p} = H_{out} - H_{in} =$

$$\left(h_2 - h_1\right) + \sum_{all}\left(\Delta H_f + \Delta H_{minor}\right) =$$

(<u>elevation difference</u> + <u>all head losses</u>) between receiver and reservoir.

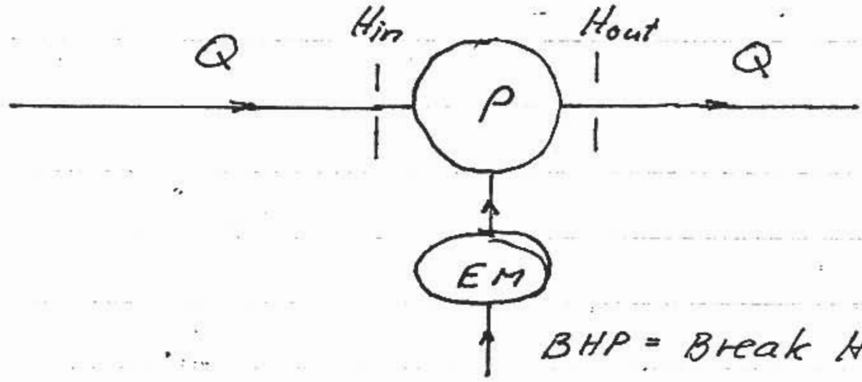
<u>Specification of Pump</u>

Discharge <u>Q in gpm</u> [1 g(allon) = $3.875 \cdot 10^{-3} m^3$ p(er) m(inute) = 60 seconds]

Pump Head $H_p$ in ft [1 ft = 0.305 m]

Diameter of in/outflow pipes in inches (0.0254 m)

# Pump Power Requirements




BHP = Break Horse Power = Power supplied to Electro Motor driving the pump

Rate of Mechanical Energy supplied by the Pump to the Flow $= \dot{E}_{out} - \dot{E}_{in} = \rho g Q [H_{out} - H_{in}] = \underline{\rho g Q H_p = \dot{E}_p}$

$$[\dot{E}_p] = \frac{\text{Energy}}{\text{Time}} = \frac{Nm}{s} = \text{Watts} : 1 \text{ Horse Power (HP)} = 745 \text{ Watts}$$

BHP = Power going into pump = (Power supplied to Flow) + (losses, e.g. heat)

$$\dot{E}_p = \rho g Q H_p = \eta \, BHP$$

or

$$\underline{BHP} = \text{Power to Pump} = \frac{\dot{E}_p}{\eta} = \underline{\frac{\rho g Q H_p}{\eta}}$$

$\underline{\eta \leq 1}$ - Pump Efficiency

The best pump for the job is the one with max. $\eta$

## Types of pumps

Centrifugal Pump : Large Head

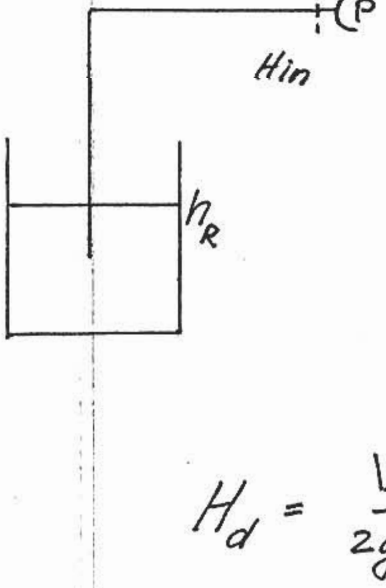
Propeller Pump : Low Head - large discharge

You call a pump manufacturer armed with

$Q$ (gpm), $H_p$ (ft) and some idea about $D$ (inches)

He/She will tell you which is the best they have based on maximizing $\eta$ and give you BHP, electromotor requirements. But, for Centrifugal Pump there is one more thing to consider:

## Net Positive Suction Head (NPSH)




$$H_{in} = \frac{V_{in}^2}{2g} + \frac{p_{CG,in}}{\rho g} + z_{CG,in} = h_R - \Delta H_{R \to P}$$

Inside pump local velocities may be high, i.e. pressure may be low. At "danger" point inside pump, $p = p_d$ must be greater than $p_{vapor}$

$$H_d = \frac{V_d^2}{2g} + \frac{p_d}{\rho g} + \cancel{z_d} \approx H_{in} = \frac{V_{in}^2}{2g} + \frac{p_{in}}{\rho g} + \cancel{z_{in}}$$

or

$$\frac{V_{in}^2}{2g} + \frac{p_{in}}{\rho g} \geqslant \frac{V_d^2}{2g} + \frac{p_{vapor}}{\rho g}$$

Thus, to prevent cavitation in the pump we must require that

$$\frac{V_{in}^2}{2g} + \frac{p_{in} - p_{vapor}}{\rho g} \geqslant (NPSH)_{required}$$

[Note: $V_{in}^2/2g + p_{in}/\rho g$ is obtained from pipe flow analysis that produced inflow head $H_{in} = V_{in}^2/2g + p_{in}/\rho g + z_{in}$, i.e. $V_{in}^2/2g + p_{in}/\rho g = H_{in} - z_{in} = H_{in} - z_p$, but in $H_{in}$ the pressure is <u>gauge</u> pressure. So, when you look up $p_{vapor}$, e.g. Table B.2, you have to convert it from absolute pressure to gauge pressure or adjust $p_{in}$ from gauge to absolute pressure. The important point is that $p_{in}$ and $p_{vapor}$ have to both be either gauge or absolute pressures]

From your pipe flow analysis you have

$$\frac{V_{in}^2}{2g} + \frac{p_{in}}{\rho g} - \frac{p_{vapor}}{\rho g} = (H_{in} - z_{in}) - \frac{p_{vapor}}{\rho g} = NPSH_{act.}$$

and you must have

$$NPSH_{actual} > NPSH_{required}.$$

to prevent cavitation

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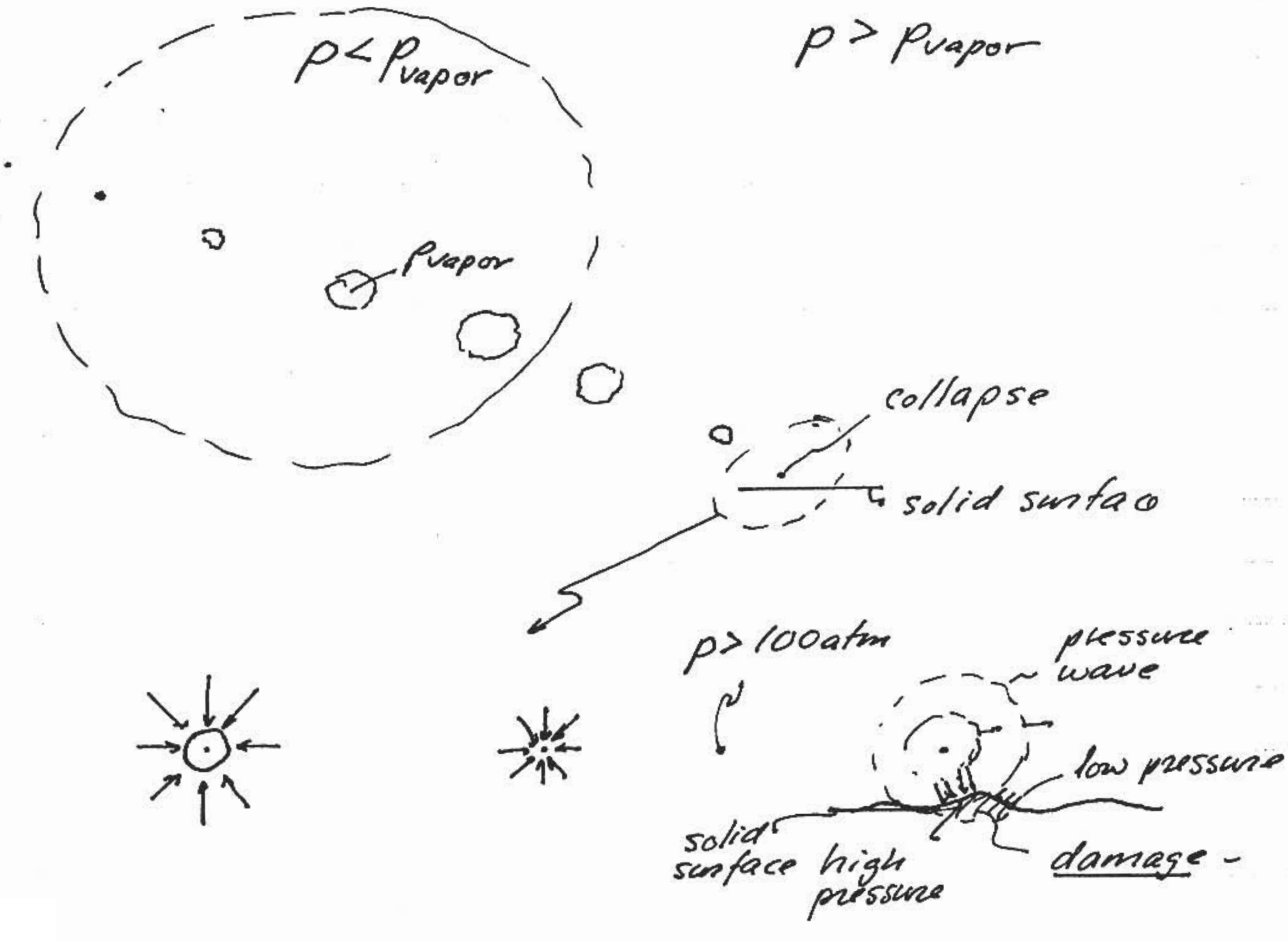
## NOTE ON CAVITATION

Whenever the pressure in a liquid falls below the vapor pressure cavitation is likely. Cavitation manifests itself by the formation of small "bubbles" (cavity) within the liquid, and so long as the "bubbles" stay within a region where the pressure is lower than vapor pressure the bubbles will grow in size. When the bubbles leave the low pressure region an enter a region where the pressure is larger than vapor pressure, the bubbles will decrease in size and eventually collapse, i.e. disappear. Immediately before the collapse of a babble, the liquid surrounding the vanishing bubble is moving towards the point of collapse. When the bubble has disappeared. liquid is in motion toward the point of collapse, but it has nowhere to go! To stop the momentum of the liquid moving towards the point of collapse requires an enormous force [$\Delta$momentum = Force $\times$ $\Delta$time] since the collapse of the bubble is ~ instantaneous. This force, a pressure that may be as large as 100 atmospheres or more, can cause enormous damage to nearby solid surface, e.g. concrete on spillways, bras in ship propellers, steel in pump impellers.

The sequence of events described above is illustrated in the sketch below




Cavitation must not occur anywhere in Hydraulic Structures and Machinery. To check and make sure that cavitation will not occur we need to determine the pressure (its lowest value) in the system and compare it with the liquid's vapor pressure.

## Vapor Pressure

Vapor pressure of a liquid can be found in Tables. Table B-2 in the text (p. 497) gives the vapor pressure of water as a function of temperature. Since vapor pressure is a thermodynamic property, it is always report in terms of ABSOLUTE PRESSURE.

For water $p_{v,abs} = 1.013 \cdot 10^5$ Pa for a Temperature of 100°C. This should not surprise you, since $p_{atm}$ (absolute) $= 1.013 \cdot 10^5$ Pa and water boils (which is the same as cavitation) at 100°C.

For temperatures in the vicinity of 10°C $p_{v,abs} \approx 1.2 \cdot 10^3$ Pa, i.e. approximately $10^{-2} p_{atm}$ (abs).

Since we generally use $p$ (gauge) in hydraulic computation, we must convert $p_{vapor,abs}$ to gauge pressure

$$\underline{p_v} = \text{gauge vapor pressure} = \underline{p_{vapor,abs} - p_{atm,abs}}$$

Notice that gauge pressure can be NEGATIVE without causing cavitation, but it cannot drop below a value of $p_{gauge} \sim -0.99\, p_{atm,abs}$.