APPLIED MECHANICS OF FLUID D203 QUESTION 9 2004

(a) (i) Explain the importance of the Net Positive Suction Head (NPSH) for a pump installation.

(ii) Use the energy equation to derive an expression for NPSH for the case where the pump inlet is situated at a small elevation above the inlet water supply surface.

(b) A centrifugal pump produced the performance data shown in the table when running at 1500 rev/min with an atmospheric pressure of 100 $kN/m^2$ and water vapour pressure of 3.36 $kN/m^2$. The pump is required to deliver water from a sump to a reservoir whose level is 58 m above that of the sump. The suction pipe is 250 mm diameter and its effective length, after allowing for fittings is 12 m. The pump inlet is 3 m above the water level in the sump. The delivery pipe is also 250 mm diameter with an effective length of 110 m. The Darcy friction factor f for both pipes may be assumed to be 0.025.

(i) Generate a system demand curve for this application.

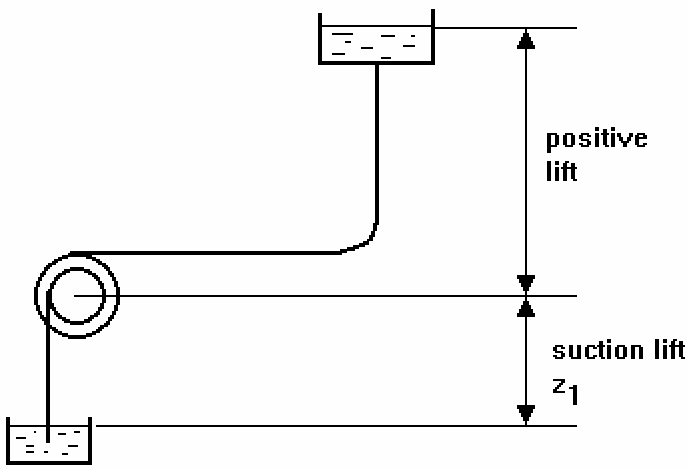
(ii) Calculate the discharge, efficiency and NPSH for the pump when running at 1500 rev/min.

(iii) Calculate the most economical speed of operation for the pump in this application and determine the discharge, efficiency and NPSH when operating at this speed. *Note.* The Darcy friction factor f is used in the following formula for friction head loss in a pipe $h_f = f\dfrac{Lv^2}{2gD}$ where the symbols have their usual meanings.

| $Q\,m^3/s$ | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 |
|---|---|---|---|---|---|---|
| H m | 70.6 | 69.6 | 67.8 | 64.1 | 57.8 | 49.0 |
| P kW | 80 | 106 | 128 | 146 | 163 | 176 |

(a) (i) The NPSH is important to determine the possibility of cavitation in the pump. When a liquid cavitates, it turns into a vapour and then suddenly changes back into a liquid with a load cracking sound. The bubbles of vapour cause damage to the metalwork by eroding it away. The main reason for cavitation is due to the local pressure falling below the vapour pressure of the liquid. The vapour pressure is raised with temperature and is more likely to occur in hot liquids. In pumps and turbines, the drop in pressure is often due to the wake set up behind the impeller. The system design is also important to prevent a vacuum forming due to restrictions on the suction side of the pump or negative heads on the outlet side of the turbine. An important parameter used for determining the likelihood of cavitation in pumps is the Net Positive Suction Head.

(a) (ii) Consider a pump delivering liquid from a tank on the suction side into a tank on the outlet side through a pipe.




Dynamic head = $h_d$ = positive lift + head loss
Suction head = $h_{suc}$ = suction lift + head loss

The head loss could include loss at entry, loss in fittings and bends as well as pipe friction.

$h_{suc} = z_1 + h_{f1} + v_1^2/2g$

The Net Positive Suction Head is the amount by which the absolute pressure on the suction side is larger than the vapour pressure (saturation pressure) of the liquid.

NPSH = absolute inlet head - vapour pressure head

Absolute inlet head = $p_a/\rho g - h_s$ where $p_a$= atmospheric pressure and $h_s = p_s/\rho g$

The vapour pressure varies with temperature and for water is found in thermodynamic temperatures under the heading $p_s$. (for saturation pressure).

Vapour pressure as a head is $p_s/\rho g$

$$NPSH = (p_a/\rho g - h_{suc}) - p_s/\rho g = (p_a - p_s)/\rho g - h_{suc}$$

(b) N =1500 rev/min $p_a$ = 100 kPa $p_s$ = 3.36 kPa $z_1$ = 3 m positive lift = 55 m $f$ =0.025

$A = \pi D^2/4 = \pi (0.25)^2/4 = 0.049087 \text{ m}^2$

$v = Q/A = Q/0.049087 = 20.372Q$

Suction pipe L = 12 m D = 0.25 m $f$ =0.025

$$h_f = f\frac{Lv^2}{2gD} = 0.025\frac{12v^2}{2g \times 0.25} = \frac{1.2v^2}{2g}0.0612v^2 = 25.38Q^2$$

Delivery pipe L = 110 m D = 0.25 m $f$ =0.025

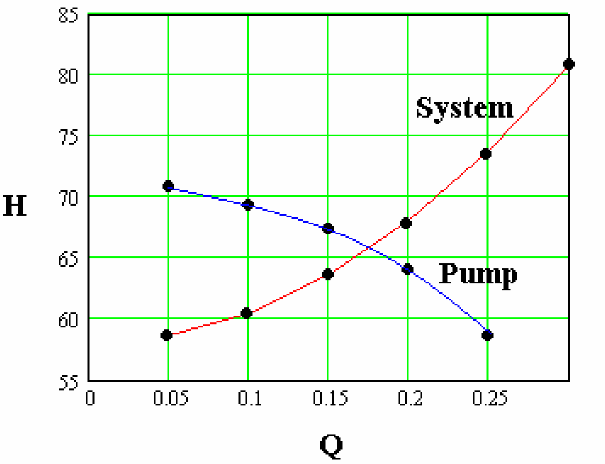
$$h_f = f\frac{Lv^2}{2gD} = 0.025\frac{110v^2}{2g \times 0.25} = \frac{11v^2}{2g} = 0.5607v^2 = 232.7\,Q^2$$

Total lift = 58 + losses and assuming only pipe friction losses

Total lift = 58 + 232.7 $Q^2$ + 20.372Q = 58 + 253 $Q^2$

Evaluate for same flow rates as in table.

| | | | | | | |
|---|---|---|---|---|---|---|
| Q $m^3/s$ | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 |
| H m | 58.63 | 60.53 | 63.7 | 68.1 | 73.8 | 80.8 |




Plot both heads to get the demand curve.

(ii) The matching point is

Q = 0.175 $m^3/s$ and H = 66 m

The power will be 136 kW

Water Power = $\rho QgH$

WP = 997 x .175 x 9.81 x 66 = 113 kW

Efficiency = 113/136 = 83%

$h_{suc} = z_1 + h_{f1} = 3 + h_f = 3 + 25.38Q^2 = 3 + (25.38 \times 0.175^2) = 3.777$ m

NPSH = $(p_a - p_s)/\rho g - h_{suc} = (100 \times 10^3 - 3.36 \times 10^3)/(997 \times 9.81) - 3.777$

NPSH = 6.1 m

(iii) Calculate the efficiency for the table. WP = $\rho QgH$

| | | | | | | |
|---|---|---|---|---|---|---|
| Q$m^3/s$ | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 |
| H m | 70.6 | 69.6 | 67.8 | 64.1 | 57.8 | 49.0 |
| P kW | 80 | 106 | 128 | 146 | 163 | 176 |
| WP (kW) | 34.5 | 68.1 | 99.5 | 125.4 | 141.3 | 143.8 |
| η % | 43 | 64.2 | 77.7 | 85.9 | 86.7 | 81.7 |

Optimal efficiency occurs at Q = 0.25, H = 57.8, N = 1500

The specific speed $N_s = NQ^{1/2}/H^{3/4} = 1500 \times 0.25^{1/2}/57.8^{3/4} = 35.8$

We need the same specific speed at the matching point Q = 0.175 $m^3/s$ and H = 66 m

$35.8 = N_2 \times 0.175^{1/2}/66^{3/4} = 0.018\,N_2$

$N_2$ = 1980 rev/min