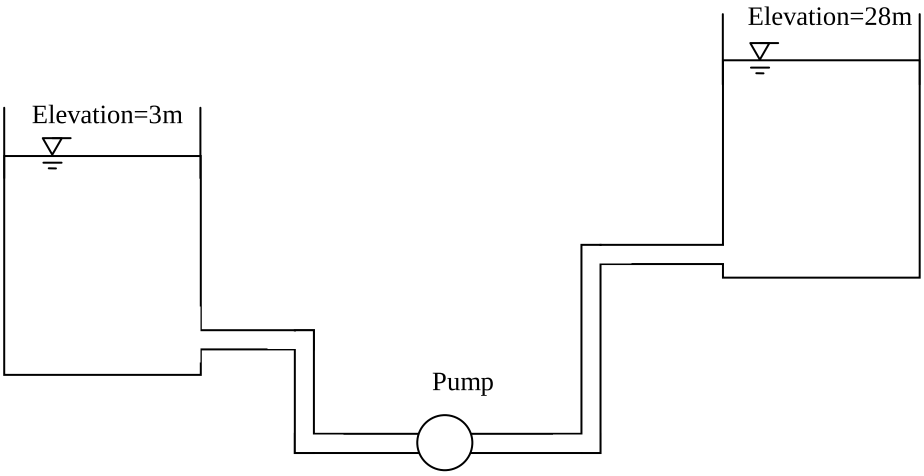
Tutorial No.5

Problem1

A pump is to be used to pump water as shown below:



a) Use the following data to develop an equation for total dynamic head (TDH) of the form $Ht – H_{stat} + C\ Q^2$

Where, Ht =total dynamic head (m)
H_{stat} =static head (m)
C =constant
Q =discharge (m^3/s)

Pipe	Diameter, D (mm)	Length, L (m)	Friction factor, f	Minor loss coeff, $\sum K$
Suction	350	7	0.020	2.0
Delivery	500	30	0.020	3.2

b) Determine the flow rate, head, efficiency, and pump power input if a pump with the following characteristics is used:

Discharge, Q (m^3/s)	Head, H (m)	Efficiency, n (%)
0.00	40.0	-
0.10	39.0	-
0.15	38.0	-
0.20	35.5	54
0.25	32.5	64
0.30	29.0	73
0.35	25.5	80
0.40	21.0	85
0.45	17.0	89
0.50	12.5	90
0.55	8.5	87
0.60	4.0	81

Problem 2

If two pumps with the same characteristics as above are used to work for the same system as in problem (1), determine flow rate, head, efficiency and power input when the pump:

a- Connected in series

b- Connected in parallel

Problem 3

A centrifugal pump operates at a speed of 1150 rpm and discharges 2.3 m^3/min against a head of 120 kPa. The power required is 8.2 kW. Compute (a) the efficiency of the pump, (b) the discharge, head and power if the pump speed was changed to 1750 rpm.

Problem 4

What is the maximum permissible difference in elevation between the water surface in an intake structure and the intake of the pump under the following circumstances:

Altitude – 1000 m

Max water temp – 25°C

Flow – 2m^3/min

Intake pipe – 150 mm

Entrance loss – $V^2/2g$

$NPSH_{reqd}$ = 40kPa = 40/9.81 = 4.08 m

Table1 : Barometric Pressure vs Altitude

Altitude		Pressure	
m	ft	kPa	ft of H2O
0	0	101	33.9
305	1000	98	32.8
457	1500	96	32.1
610	2000	94	31.5
1220	4000	88	29.2
1830	6000	81	27.2
2439	8000	75	25.2
3049	10000	70	23.4
4573	15000	57	19.2

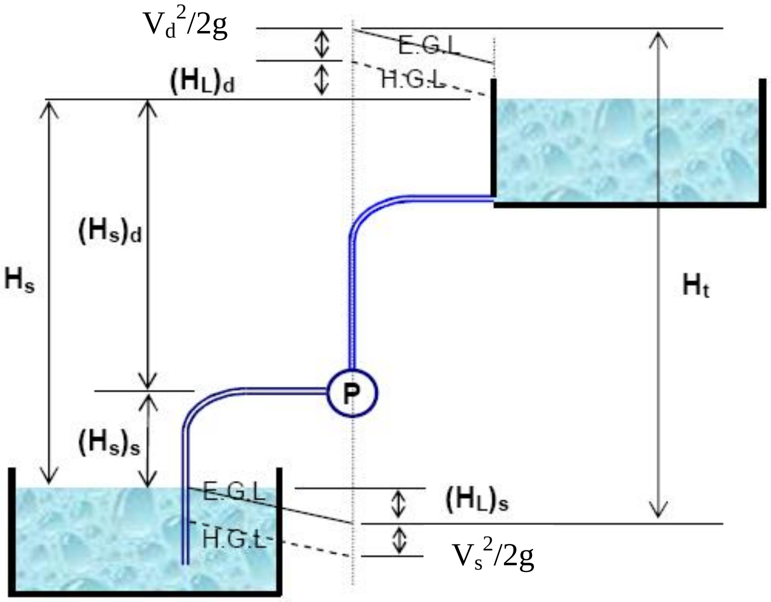
Table2 : Vapor Pressure of Water vs Altitude

Temperature		Pressure	
°C	°F	kPa	ft of H2O
0	32	0.61	0.204
4.4	40	0.84	0.281
10.0	50	1.23	0.411
15.6	60	1.76	0.591
21.1	70	2.50	0.838
26.7	80	3.50	1.17
32.2	90	4.81	1.61
37.8	100	6.54	2.19
43.3	110	8.81	2.95
48.9	120	11.70	3.91
54.4	130	15.30	5.13
60.0	140	19.90	6.67

problem 1

solution

a)



$H_t = H_{static} + h_s + h_d + V_d^2/2g$

$H_t = H_{static} + C\,Q^2$

$\rightarrow C = (C_1+C_2+C_3)$

$h_f = \frac{8\,f\,L}{\pi^2\,gD^5}\,Q^2$

$V_d^2/2g = \frac{Q2}{2gA2} = \frac{Q2}{2g(\pi^2\frac{D^4}{16})} = \frac{16\,Q2}{2g\pi^2D^4} = \frac{8}{g\pi^2D^4}\,Q^2$ (v=Q/A)

$h_m = \sum K\,(V_d^2/2g) = \frac{8\,(\sum K)}{g\pi^2D^4}\,Q^2$

$C_{suction} = \frac{8\,f\,L}{\pi^2\,gD^5} + \frac{8\,(\sum K)}{g\pi^2D^4}$

$= \frac{8\,(0.02)\,(7)}{\pi^2\,(9.81)\,(0.35)^5} + \frac{8\,(2)}{\pi^2\,(9.81)\,(0.35)^4} = 2.2 + 11.012 = 13.2$

$C_{discharge} = \frac{8\,f\,L}{\pi^2\,gD^5} + \frac{8\,(\sum K)}{g\pi^2D^4} + \frac{8}{g\pi^2D^4}$

$= \frac{8\,(0.02)\,(30)}{\pi^2\,(9.81)\,(0.5)^5} + \frac{8\,(3.2)}{\pi^2\,(9.81)\,(0.5)^4} + \frac{8}{\pi^2\,(9.81)\,(0.5)^4}$

$= 1.58 + 4.23 + 1.32 = 7.13$

$C = C_{suction} + C_{discharge} = 13.2 + 7.13 = 20.33 = 20.5$

$H_{static} = 28 - 3 = 25$ m

$\mathbf{H_t = 25 + 20.5\,Q^2}$

b)

Discharge, Q (m^3/s)	Head, H (m)	Efficiency, n (%)	*H_t (m)*
0.00	40.0	-	*25*
0.10	39.0	-	*25.19*
0.15	38.0	-	*25.42*
0.20	35.5	54	*25.76*
0.25	32.5	64	*26.18*
0.30	29.0	73	*26.71*
0.35	25.5	80	*27.33*
0.40	21.0	85	*28.04*
0.45	17.0	89	*28.85*
0.50	12.5	90	*29.75*
0.55	8.5	87	*30.75*
0.60	4.0	81	*31.84*

problem 2 (Pumps in series & Pumps in parallel) (page 57,58)

solution

Pumps in series: $Q = Q_A + Q_B$ $H = H_A = H_B$

Pumps in parallel: $Q = Q_A = Q_B$ $H = H_A + H_B$

Discharge, Q (m^3/s)	Head, H (m)	Efficiency, n (%)	*Pumps In series 2H (m)*	*Pumps In parallel 2Q (m)*	*H_t (m)*
0.00	40.0	-	*80*	*0*	*25*
0.10	39.0	-	*78*	*0.2*	*25.19*
0.15	38.0	-	*76*	*0.3*	*25.42*
0.20	35.5	54	*71*	*0.4*	*25.76*
0.25	32.5	64	*65*	*0.5*	*26.18*
0.30	29.0	73	*58*	*0.6*	*26.71*
0.35	25.5	80	*51*	*0.7*	*27.33*
0.40	21.0	85	*42*	*0.8*	*28.04*
0.45	17.0	89	*34*	*0.9*	*28.85*
0.50	12.5	90	*25*	*1*	*29.75*
0.55	8.5	87	*17*	*1.1*	*30.75*
0.60	4.0	81	*8*	*1.2*	*31.84*

problem 3 (Page 56)

Given: N_1= 1150 rpm Q=2.3 m^3/min H=120 kPa = 12.23 m

P_{in}= 8.2 KW

Find a) η b) Q , H when N_2 = 1750 rpm

Solution

a) $P_{in} = \frac{P_{out}}{\eta} = \frac{\gamma\ Q\ H}{\eta}$

$$\eta = \frac{\gamma\ Q\ H}{P_{in}} = \frac{9.81\left(\frac{2.3}{60}\right)(12.33)}{8.2} = 56\ \%$$

b) N_2 = 1750

$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$ → $\frac{2.3}{Q_2} = \frac{1150}{1750}$ → Q_2 = 3.5 m^3/min

$\frac{H_1}{H_2} = \frac{N_1^2}{N_2^2}$ → $\frac{12.23}{H_2} = \frac{1150^2}{1750^2}$ → H_2 = 28.3 m

$\frac{P_1}{P_2} = \frac{N_1^3}{N_2^3}$ → $\frac{8.2}{P_2} = \frac{1150^3}{1750^3}$ → P_2 = 29 kw

problem 4 (Cavitation) (page 64)

Altitude – 1000 m
Max water temp – 25°C
Flow – 2m^3/min
Intake pipe – 150 mm
Entrance loss – $V^2/2g$
$NPSH_{reqd}$ = 40kPa = 40/9.81 = 4.08 m

Z= ?

Solution

$$NPSH_{available} = \frac{P_b}{\gamma} - Z - h_L + \frac{P_v}{\gamma}$$

Z= h_s

- P_b @ 1000 m

$$\frac{94 - P_b}{610 - 1000} = \frac{94-88}{610-1220} \quad \text{(interpolation)}$$

P_b = 90.16 kPa

- $h_L = V^2/2g$, $V = Q/A = \frac{2/60}{(\pi/4)(0.15)^2}$ = V = 1.89 m/sec

$h_L = 1.89^2/2(9.81)$ = 0.18 m

P_V @ 25 ^{0}C

$$\frac{3.5 - P_v}{1.7} = \frac{1}{5.6}$$

P_v = 3.2 kPa

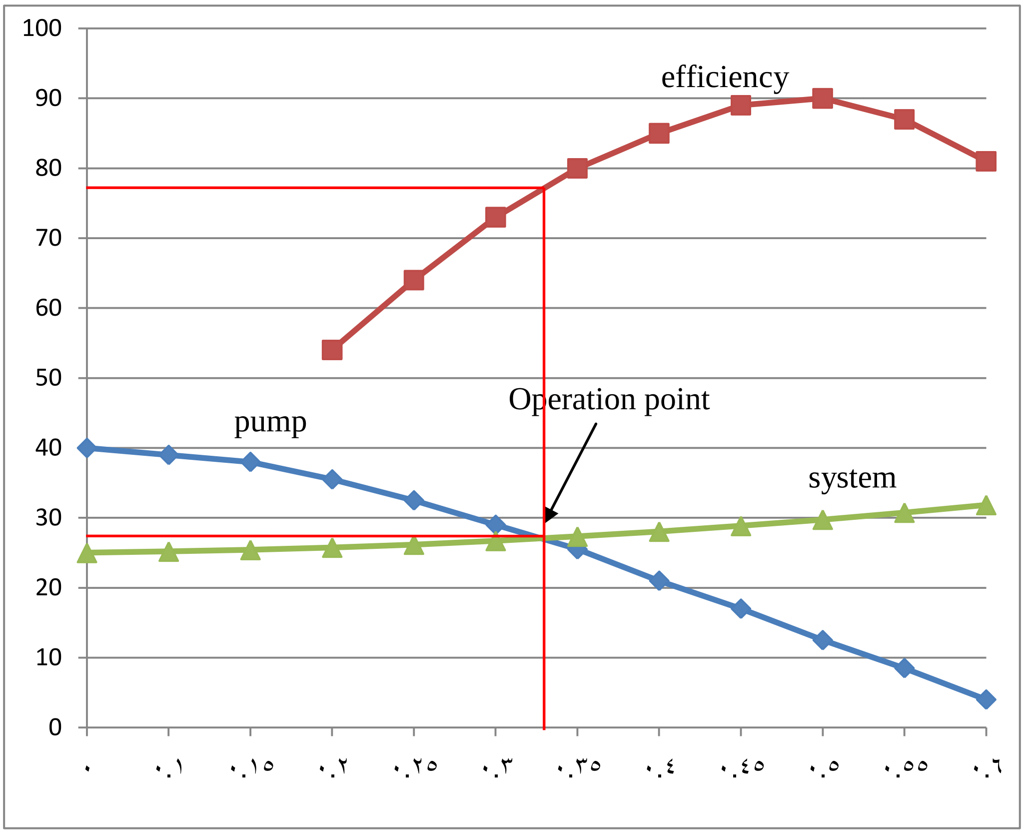
NPSH$_{available}$ = $\frac{P_b}{\gamma} - Z - h_L + \frac{P_v}{\gamma}$

→ 4.08 = $\frac{90.16}{9.81} - Z - 0.18 + \frac{8.2}{9.81}$

→ Z = 4.6 m

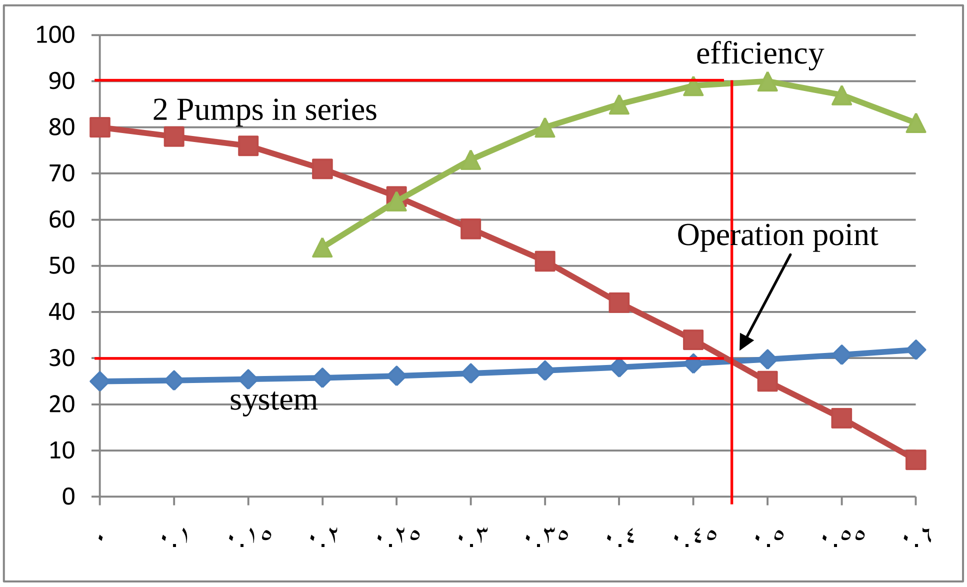
NPSH$_{available}$ = $\frac{P_b}{\gamma} + Z - h_L + \frac{P_v}{\gamma}$

→ in case water intake has a high elevation than the pump



$Power_{out}$ *(Kw) =* $\boldsymbol{\gamma}$ *H Q* *(Operation Point)*
$Power_{in}$ *(Kw) =*$Power_{out}/\eta$

$Power_{out}$ = 9.18 (28) (0.33) = 84.82 kw
$Power_{in}$ = 84.82/0.78 = 108.74 kw



$Power_{out}$ *(Kw) =* $\boldsymbol{\gamma}$ *H Q* *(Operation Point)*
$Power_{in}$ *(Kw) =*$Power_{out}/\eta$