5.1.5

Balancing energy from reservoir A to reservoir B:

$H_A + H_P = H_B + h_L$; (Eq'n 4.2), $H_B - H_A = 20$m; and

$h_L = h_f + [\sum K](V)^2/2g$; $K_e = 0.5$; $K_d = 1.0$ (exit coef.)

$V = Q/A = 4.08$ m/s; $e/D = 0.60\text{mm}/800\text{mm} = 0.00075$

$N_R = DV/\nu = [(0.80)(4.08)]/(1.00\times10^{-6}) = 3.26 \times 10^6$;

From Moody; **$f = 0.0185$**; solving the energy eq'n;

$H_P = 20\text{m}+[0.0185(100/0.80)+1.5]\cdot[(4.08)^2/2g] = 23.2\text{m}$

$P_o = \gamma QH_P = (9.79 \text{ kN/m}^3)(2.05 \text{ m}^3\text{/sec})(23.2 \text{ m})$

$P_o = 466$ kW; $\mathbf{P_m = P_o/e} = 466/[(0.8)(0.74)] = \mathbf{787\ kW}$

5.5.1

A spreadsheet is easily programmed to determine the relationship between Q and H_{SH} (system). Applying Equation 5.19 including minor losses, which are now significant ($h_v = 0.125(Q)^2$ where Q is in cfs), yields $H_{p(sys)} = H_s + h_L = H_s + h_f + h_v$ and the spreadsheet below.

Q (cfs)	H_p (ft)	h_f (ft)	h_{valve} (ft)	H_s (ft)	H_{SH} (ft)
0	300.0	0.0	0.0	120.0	120.0
5	295.5	8.1	3.1	120.0	131.2
10	282.0	29.2	12.5	120.0	161.7
15	259.5	61.9	28.1	120.0	210.0
17.5	242.5*	82.4	38.3	120.0	240.6
20	225.5	105.4	50.0	120.0	275.4
25	187.5	159.3	78.1	120.0	357.4
30	138.0	223.2	112.5	120.0	455.7
35	79.5	296.9	153.1	120.0	570.0

*Interpolated from the pump characteristics.

From the table (or a graph), the intersection of the pump characteristic curve and the system curve is at:

$Q \approx 17.5$ cfs and $H_P \approx 242$ ft

5.5.4

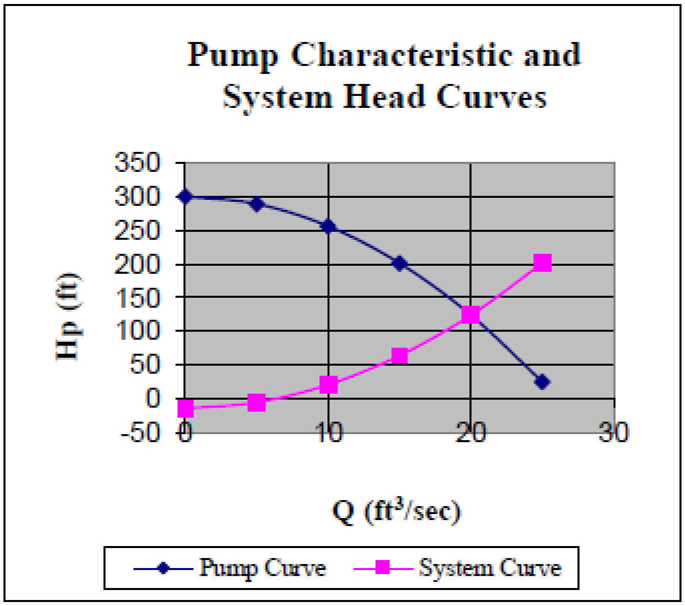
Applying Equation 5.19 (but including minor losses) yields $H_{SH} = H_s + h_L$; where $h_L = h_f + [\sum K](V)^2/2g$; and $K_e = 0.5$, $K_{v1} = 2.5$, $2{*}K_{v2} = 20$, & $K_d = 1.0$ Also, from Table 3.4, $h_f = KQ^2$ where $K = (0.0252 \cdot f \cdot L)/(D^5)$

This leads to the spreadsheet shown below:

Pipeline Data			Reservoir Data		
L =	13800	ft	E_A =	14.7	ft
D =	1.75	ft	E_B =	0	ft
f =	0.016		H_s =	-14.7	ft
$h_f = KQ^m$			Minor Losses		
K =	0.339		ΣK =	24.0	
m =	2.0		g =	32.2	ft/sec^2

Q (ft^3/s)	H_p (ft)	h_f* (ft)	h_{minor} (ft)	H_s (ft)	H_{SH} (ft)
0	300	0.0	0.0	-14.7	-14.7
5	289	8.5	0.8	-14.7	-5.5
10	256	33.9	1.5	-14.7	20.8
15	201	76.3	2.3	-14.7	63.9
20	124	135.6	3.1	-14.7	124.0
25	25	211.9	3.9	-14.7	201.1

* From Table 3.4



From the table or graph, the intersection of the pump characteristic curve and the system curve is at:

Q = 20 ft^3/sec and **H_P = 124 ft.** Also, the velocity is:

V = Q/A = 4(20 cfs)/[π(1.75 ft)^2] = **8.32 ft/sec**

5.6.3

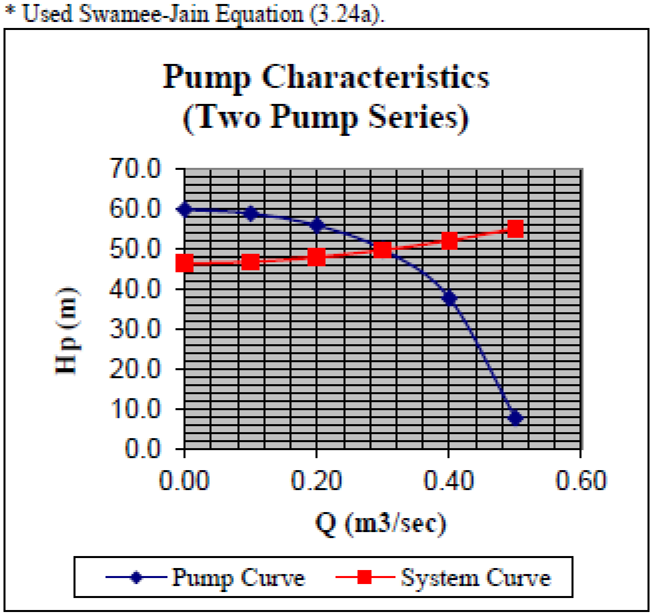
Applying Equation 5.19 yields $H_{SH} = H_s + h_f$; where $h_f = f(L/D)V^2/2g$ and f is found from the Swamee-Jain equation (3.24a) using (e/D) and $N_R = VD/\nu$. The heads are doubles for two identical pumps connected in series. The spreadsheet solution is show below:

Pipeline Data			**Reservoir Data**		
L =	1000	m	E_A =	52.1	m
D =	0.50	m	E_B =	98.7	m
e =	0.045	mm	H_s =	46.6	m
e/D =	0.00009		Minor Losses		
T =	20˚C		ΣK =	0.00	
ν =	1.00E-06		g =	9.81	m/sec^2

Two Pumps in Series

Q (m^3/s)	$2H_p$ (m)	V (m/sec)	N_R	f*	H_{SH} (m)
0.00	60.0	0.00	0.00E+00	0.0000	46.6
0.10	59.0	0.51	2.55E+05	0.0157	47.0
0.20	56.0	1.02	5.09E+05	0.0143	48.1
0.30	50.0	1.53	7.64E+05	0.0137	49.9
0.40	38.0	2.04	1.02E+06	0.0133	52.2
0.50	8.0	2.55	1.27E+06	0.0131	55.3

* Used Swamee-Jain Equation (3.24a).



From the table or graph, the intersection of the pump characteristic curve and the system curve is at:

Q = 0.30 m^3/sec and **$H_p \approx 50$ m.** Each pump passes the full flow but half the head, thus from EQ'n 5.4:

$P_o = \gamma Q H_p = (9.79 kN/m^3)(0.30\ m^3/s)(25 m) =$ **73.4 kW**

5.6.5

For two pumps in series, double the pump head for each value of Q, and for two in parallel, double the Q for each value of Hp. Applying Equation 5.19 including minor losses yields $H_{SH} = H_s + h_f + [\sum K](V)^2/2g$; where $K_e = 0.5$, $K_v = 2.5$, and $K_d = 1.0$ (exit coefficient), and $h_f = KQ^m$ (Table 3.4) where $K = (0.0826 \cdot f \cdot L)/(D^5)$ and $m = 2$. This leads to the spreadsheet below:

Pipeline Data			Reservoir Data		
L =	1860	m	E_A =	45.5	m
D =	0.50	m	E_B =	92.9	m
f =	0.020		H_s =	47.4	m
$h_f = KQ^m$			Minor Losses		
m =	2.00		ΣK =	4.00	
K =	98.3		g =	9.81	m/sec^2

Two Pumps in Series

Q (m^3/s)	$2H_p$ (m)	h_f (m)	h_{minor} (m)	H_s (m)	H_{SH} (m)
0.00	182.8	0.0	0.0	47.4	47.4
0.15	179.6	2.2	0.1	47.4	49.7
0.30	170.2	8.8	0.5	47.4	56.7
0.45	154.4	19.9	1.1	47.4	68.4
0.60	131.8	35.4	1.9	47.4	84.7
0.75	105.2	55.3	3.0	47.4	105.7
0.90	72.6	79.6	4.3	47.4	131.3
1.05	31.4	108.4	5.8	47.4	161.6

Two Pumps in Parallel

2Q (m^3/s)	H_p (m)	h_f (m)	h_{minor} (m)	H_s (m)	H_{SH} (m)
0.00	91.4	0.0	0.0	47.4	47.4
0.30	89.8	8.8	0.5	47.4	56.7
0.60	85.1	35.4	1.9	47.4	84.7
0.90	77.2	79.6	4.3	47.4	131.3
1.20	65.9	141.6	7.6	47.4	196.6
1.50	52.6	221.2	11.9	47.4	280.5
1.80	36.3	318.6	17.1	47.4	383.1

For two in series (graph): **$Q \approx 0.75\ m^3/s$; $H_p \approx 105$ m**

Two in parallel (graph): **$Q \approx 0.60\ m^3/s$; $H_p \approx 85$ m**

Loop	Pipe	*Q* (m^3/sec)	*K* (sec^2/m^5)	h_f (m)	h_f/Q (sec/m^2)	New Q (m^3/sec)
3	*GH*	0.033	1894	2.10	63.1	0.033
(clockwise)	*HF*	0.063	3068	12.17	193.2	0.063
	EG	0.008	3068	0.20	25.0	0.008
			$\sum h_{fc}$ =	14.48	281.4	$\equiv\sum(h_{fc}/Q_c)$
(counter)	*EF*	0.087	1894	14.34	164.8	0.087
			$\sum h_{fcc}$ =	14.34	164.8	$\equiv\sum(h_{fcc}/Q_{cc})$
				ΔQ =	0.0002	

Pipe	*Q* (m^3/sec)	*Q* (L/sec)	Length (m)	Diameter (m)	h_f (m)	Δ*P* (kPa)
AB	0.2043	204.3	300	0.30	8.1	79.0
AD	0.0957	95.7	250	0.25	3.8	37.6
BC	0.0796	79.6	350	0.20	12.0	117.6
BG	0.1246	124.6	125	0.20	10.5	102.8
GH	0.0332	33.2	350	0.20	2.1	20.4
CH	0.0296	29.6	125	0.20	0.6	5.8
DE	0.0957	95.7	300	0.20	14.9	145.6
EG	0.0083	8.3	125	0.15	0.2	2.1
EF	0.0872	87.2	350	0.20	14.4	140.9
HF	0.0628	62.8	125	0.15	12.1	118.5