4.4.1

The Hardy-Cross method could be employed, but since there is only one loop a direct solution is possible.

a) With e_1 = 2.0 mm, e_2 = 1.25 mm, and $\nu = 1.00 \times 10^{-6}$ m²/sec (20°C) assuming complete turbulence:

e_1/D_1 = 0.002/0.40 = 0.005; thus; **f = 0.03** and e_2/D_2 = 0.00125/0.5 = 0.0025; thus; **f = 0.025;**

$h_L = h_f = f(L/D)(V^2/2g)$; and based on conservation of energy, $h_{L1} = h_{L2}$. Therefore,

$(0.030)(100/0.40)[(V_1)^2/2g] = (0.025)(100/0.50)[(V_2)^2/2g]$

$V_1 = Q_1/A_1 = Q_1/[(\pi/4)(0.40)^2] = 7.96 \cdot Q_1$; $V_2 = Q_2/A_2 = Q_2/[(\pi/4)(0.50)^2] = 5.09 \cdot Q_2$; and substituting

$(0.030)(100/0.40)[(7.96 \cdot Q_1)^2/2g] = (0.025)(100/0.50)[(5.09 \cdot Q_2)^2/2g]$; which yields $Q_1 = 0.522 \cdot Q_2$

Now from mass balance, $Q_1 + Q_2 = 0.936$ m³/s; substituting yields: **Q_2 = 0.615 m³/s; Q_1 = 0.321 m³/s.**

Checking the friction factors; $N_R = DV/\nu$; $V_1 = 7.96 \cdot Q_1$ = 2.56 m/sec; and $V_2 = 5.09 \cdot Q_2$ = 3.13 m/sec;

$N_{R1} = D_1V_1/\nu = [(0.40)(2.56)/ (1.00 \times 10^{-6}) = 1.02 \times 10^6$; f = 0.03 OK

$N_{R2} = D_2V_2/\nu = [(0.5)(3.13)/ (1.06 \times 10^{-6}) = 1.57 \times 10^6$; f = 0.025 OK ; and the head loss is

h_L $= f(L/D)(V^2/2g) = (0.030)(100/0.40)[(2.56)^2/2g] =$ **2.51 m** (using pipe 1 parameters)

b) Find the equivalent pipe to replace Branches 1 and 2, let D = 0.6 m, e = 2 mm, thus from e/D; f = 0.028

$[(D_E^5)/(f_E \cdot L_E)]^{1/2} = [(D_1^5)/(f_1 \cdot L_1)]^{1/2} + [(D_2^5)/(f_2 \cdot L_2)]^{1/2}$; from Equation (3.47)

$[(0.6^5)/(0.028 \cdot L_E)]^{1/2} = [(0.4^5)/(0.03 \cdot 100)]^{1/2} + [(0.5^5)/(0.025 \cdot 100)]^{1/2}$; L_E = 95.8 m and from Table 3.4

h_{fAB} $= [(0.0826 \cdot f \cdot L)/D^5]Q^2 = [(0.0826 \cdot 0.028 \cdot 95.8)/(0.6)^5](0.936)^2 =$ **2.50 m**

Flow in pipe branches, h_{f1} = 2.50 m $=[(0.0826 \cdot 0.03 \cdot 100)/(0.4)^5]Q_1^2$; **$Q_1$ = 0.321 m³/s**

h_{f2} = 2.50 m $= [(0.0826 \cdot 0.025 \cdot 100)/(0.5)^5]Q_2^2$; **$Q_2$ = 0.615 m³/s**; same thing from $Q_1 + Q_2$ = 0.936 m³/s

4.4.3

a) $P_F = P_A - P_{AB} - P_{BC} - P_{CH} - P_{HF}$ = 489.5 – 80.3 – 119.4 – 5.9 – 116.5 = **167.4 kPa**

This is the same pressure obtained in the example problem through a different path. It should not be surprising since energy was balanced as part of the process. Occasionally slight variations occur due to rounding error or computations end before the network is balanced completely.

b) **The lowest total energy in the system is at node F.** This is true because all flows move toward F (i.e., all network flows are incoming), and water always moves toward the point of least total energy.

c) **One possible solution is to increase some pipe sizes**, perhaps a few critical pipes where head losses are the greatest. It may also be possible to clean or ream out pipes to make them less resistant to flow. Another possibility is to replace some existing pipes with newer/smoother pipes to reduce the friction loss.

d) The following spreadsheet represents computer software used to analyze Example 4.8.

Storage Tank		Network Inflows	
Elevation (m)		(m^3/sec)	
A =	50.00	A =	0.300
Junction Elevations		Network Outflows	
All	0.00	(m^3/sec)	
		C =	0.050
Roughness (e, in m)		F =	0.150
All	0.000260	G =	0.100

Pipe	Q (m^3/sec)	Length (m)	Diameter (m)	e/D	F	K (sec^2/m^5)
AB	0.200	300	0.30	0.00087	0.0190	193
AD	0.100	250	0.25	0.00104	0.0198	419
BC	0.080	350	0.20	0.00130	0.0210	1894
BG	0.120	125	0.20	0.00130	0.0210	676
GH	0.020	350	0.20	0.00130	0.0210	1894
CH	0.030	125	0.20	0.00130	0.0210	676
DE	0.100	300	0.20	0.00130	0.0210	1623
GE	0.000	125	0.15	0.00173	0.0226	3068
EF	0.100	350	0.20	0.00130	0.0210	1894
HF	0.050	125	0.15	0.00173	0.0226	3068

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)
1 *(clockwise)*	*AB*	0.200	193	7.74	38.7	0.205
	BG	0.120	676	9.74	81.2	0.125
	GE	0.000	3068	0.00	0.0	0.005
			$\sum h_{fc}$ =	17.48	119.9	$\equiv\sum(h_{fc}/Q_c)$
1 *(counter)*	*AD*	0.100	419	4.19	41.9	0.095
	DE	0.100	1623	16.23	162.3	0.095
			$\sum h_{fcc}$ =	20.42	204.2	$\equiv\sum(h_{fcc}/Q_{cc})$
				ΔQ =	-0.0045	

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)
2 *(clockwise)*	*BC*	0.080	1894	12.12	151.5	0.077
	CH	0.030	676	0.61	20.3	0.027
			$\sum h_{fc}$ =	12.73	171.8	$\equiv\sum(h_{fc}/Q_c)$
2 *(counter)*	*BG*	0.125	676	10.49	84.2	0.127
	GH	0.020	1894	0.76	37.9	0.023
			$\sum h_{fcc}$ =	11.25	122.1	$\equiv\sum(h_{fcc}/Q_{cc})$
				ΔQ =	0.0025	

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 *(clockwise)*	*GH*	0.023	1894	0.96	42.6	0.036
	HF	0.050	3068	7.67	153.4	0.063
			$\sum h_{fc}$ =	8.63	196.0	$\equiv\sum(h_{fc}/Q_c)$
3 *(counter)*	*GE*	0.005	3068	0.06	14.0	-0.008
	EF	0.100	1894	18.94	189.4	0.087
			$\sum h_{fcc}$ =	19.00	203.3	$\equiv\sum(h_{fcc}/Q_{cc})$
				ΔQ =	-0.0130	

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)
1 *(clockwise)*	*AB*	0.205	193	8.10	39.6	0.204
	BG	0.127	676	10.92	85.9	0.127
			$\sum h_{fc}$ =	19.01	125.5	$\equiv\sum(h_{fc}/Q_c)$
1 *(counter)*	*AD*	0.095	419	3.82	40.0	0.096
	DE	0.095	1623	14.79	154.9	0.096
	EG	0.008	3068	0.22	25.9	0.008
			$\sum h_{fcc}$ =	18.83	220.8	$\equiv\sum(h_{fcc}/Q_{cc})$
				ΔQ =	0.0003	

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)
2 *(clockwise)*	*BC*	0.077	1894	11.37	146.7	0.080
	CH	0.027	676	0.51	18.6	0.030
			$\sum h_{fc}$ =	11.88	165.3	$\equiv\sum(h_{fc}/Q_c)$
2 *(counter)*	*BG*	0.127	676	10.87	85.7	0.125
	GH	0.036	1894	2.39	67.2	0.033
			$\sum h_{fcc}$ =	13.26	153.0	$\equiv\sum(h_{fcc}/Q_{cc})$
				ΔQ =	-0.0022	

Loop	Pipe	Q (m³/sec)	K (sec²/m⁵)	h_f (m)	h_f/Q (sec/m²)	New Q (m³/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 (m³/sec)	Q (L/sec)	Length (m)	Diameter (m)	h_f (m)	ΔP (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