Purpose: a) Calculate pump power when the bypass valve is completely closed w/ minimum flow rate of 275 gpm, efficiency 70%

b) assuming pump power remains the Same, calculate total flow rate if by pass valve is 1/4, 1/2, 3/4, an fully open.

Drawing: Separate page

Sources: Mott., Untener, Applied fluid Mechanics, 7th edition Pearson Education 2015

Design consideration: - incompressible fluid
- isothermal
- steady state

Data + Variables: Separate pages

Procedure: used from pretest

Calculations: Separate

Summary + analysis: at end of a + b calculations

Test 3 pretest

11/20/21

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1) I think I understand the test prompt and do not have questions at this time. However, I expect that to change before I complete the test.

Procedure

2) a) 1) place points & reference
2) use bernoullis equation to find pumphead
3) plug in known values, cancel any terms necessary
4) compute energy losses

✩ some k values given, others found in book $h_L = k\frac{V^2}{2g} \rightarrow$ used for gate valves, pipe, check valve, elbows, tees, exchanger, reduction & enlargement

5) compute pump power

$$P_A = \gamma Q h_A \qquad P_{input} = P_A/\eta = \frac{\gamma Q h_A}{\eta}$$

6) Find reynolds number for friction factor

$$R_e = \frac{\rho V D}{\mu} \qquad D/\varepsilon$$

Other possible needed equations:

$$V = \frac{4Q}{\pi D^2} \qquad Q = VA$$

$\rightarrow$ find diameter of pipes inside from book

I am not 100% sure if the steps are in the correct order, but I am pretty sure those will be the necessary equations to do the problem. What I am not sure of is which of the valves, elbows, tees, sudden reduction / enlargement need to be included in the energy losses. Are we considering all losses in the whole system?

Procedure

b) 1) Pick points and reference (will be used again from part A)

2) Start with bernoullis and plug in known values / cancel anything necessary

3) compute pipe energy losses using

$h_L = f \frac{L}{D} \frac{V^2}{2g}$ → for each type of loss

4) Reynolds number and relative roughness are needed to find friction factor

$Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$ $\quad D/\varepsilon$

5) remember conservation of mass $Q_1 = Q_4 = Q_2 + Q_3$

6) Set up excel spreadsheet

1) guess friction factor
2) calculate flow rate (equation is previously derived)
3) compute reynolds number
4) find friction factor from Moodys chart using Re
5) compare new f to old f
6) repeat until % diff is near zero
7) this excel formula will need to be repeated with K values for each opening

3/4 = 35 1/2 = 160 1/4 = 900 fully = 8

By changing friction factor in excel and L/D for the energy losses when the valve opening changes, it will give you a changing flow rate. I am not 100% sure how or if conservation of mass comes into play since it is only one flow rate per opening change

Data & Variables:

Water

- 160°F
- $\gamma = 61\ lb/ft^3$
- $\rho = 61\ lb/ft^3$
- (η) Dynamic viscosity $= 8.28\times10^{-6}$
- (ν) Kinematic Visc $= 4.37\times10^{-6}$
- $Q = 275 gpm = 0.613\ ft^3/s$

1" = 0.0874 ft
3" = 0.2557 ft
4" = 0.3355 ft
} ID

1" = 0.006 ft^2
3" = 0.05132 ft^2
4" = 0.0884 ft^2
} flow Area

ε (steel pipe) $= 1.5\times10^{-4}$ ft

Le/D

3/4 open = 35
fully open = 8
1/2 open = 160
1/4 open = 900

↳ redone on another page

1" = 30/0.0874 = 343.25
3" = 48/0.2557 = 187.72
4" = 10/0.3355 = 29.81

K

Square-edged inlet = 0.5
elbow = 30ft

$V = Q/A$

1" = 0.613/0.006 = 102.17 ft/s
3" = 0.613/0.05132 = 11.94 ft/s
4" = 0.613/0.0884 = 6.93 ft/s

$Re = VD/\nu$

$1" = \frac{102.17 \times 0.0874}{4.37\times10^{-6}} = 2{,}043{,}400$

$3" = \frac{11.94 \times 0.2557}{4.37\times10^{-6}} = 698{,}640.3$

$4" = \frac{6.93 \times 0.3355}{4.37\times10^{-6}} = 532040.05$

D/ε

1" = $0.0874/1.5\times10^{-4} = 582.67$
3" = $0.2557/1.5\times10^{-4} = 1704.67$
4" = $0.3355/1.5\times10^{-4} = 2236.67$

Data + Variables:

$N_R > 4000$, so flow is turbulent

$$f_T = \frac{0.25}{\left(\log\left(\frac{1}{3.7 D/\varepsilon}\right)\right)^2}$$

$$1'' = \frac{0.25}{\left(\log\left(\frac{1}{3.7(582.67)}\right)\right)^2} = 0.0225$$

$$3'' = \frac{0.25}{\left(\log\left(\frac{1}{3.7(1704.67)}\right)\right)^2} = 0.0173$$

$$4'' = \frac{0.25}{\left(\log\left(\frac{1}{3.7(2236.67)}\right)\right)^2} = 0.0163$$

K

1" = 343.25(0.0225)
= 7.72

3" = 187.72(0.0173)
= 3.25

4" = 29.81(0.0163)
= 0.486

$K = (L_e/D)\, f_T$

gate Valve

fully open = 8(f_T)

1" = 8(0.0225) = 0.18
3" = 8(0.0173) = 0.1384
4" = 8(0.0163) = 0.1304

3/4 open = 35(f_T)

1" = 35(0.0225) = 0.7875
3" = 35(0.0173) = 0.6055
4" = 35(0.0163) = 0.5705

1/2 open = 160(f_T)

1" = 160(0.0225) = 3.6
3" = 160(0.0173) = 2.768
4" = 160(0.0163) = 2.608

Checkvalve (swing) = 100 f_T
3" = 100(0.0173) = 1.73

Tees: flow thru branch = 60 f_T

3"-3" = 60(0.0173) = 1.038
3"-1" = 60(0.0225) = 1.35

Elbows:
1" = 30(0.0225) = 0.675
3" = 30(0.0173) = 0.519

1/4 open = 900(f_T)
1" = 900(0.0225) = 20.25
3" = 900(0.0173) = 15.57
4" = 900(0.0163) = 14.67

$$\frac{V^2}{2g} \qquad \frac{V_1^2}{2g} = \frac{102.17^2}{2(32.2)} = 162.09\text{ ft} \quad (1")$$

$$\frac{V_3^2}{2g} = \frac{11.94^2}{64.4} = 2.21\text{ ft} \quad (3")$$

$$\frac{V_4^2}{2g} = \frac{6.93^2}{64.4} = 0.746\text{ ft} \quad (4")$$

$$\cancel{\frac{P_1}{\gamma}}^{0} + \cancel{\frac{V_1^2}{2g}}^{0} + z_1 + h_A = \cancel{\frac{P_2}{\gamma}}^{0} + \frac{V_2^2}{2g} + z_2 + h_L$$

$$h_A = (z_2 - z_1) + \frac{V_2^2}{2g} + h_L$$

Losses:

4"	3"	1"
✓ gate valve	✓ 3 gate	✓ 2 elbows
✓ entrance	✓ check	sudden reduction
✓ 10 ft pipe	✓ 3 elbows	gate → closed
	✓ 2 tees	sudden enlargement
	✓ exchanger	30 ft pipe
	48 ft pipe	2 tees

(4") $h_L = 0.1304(0.746) + 0.5(0.746) + 0.486(0.746) = 0.833$

(3") $h_L = 3(0.1384 \cdot 2.21) + 1.73(2.21) + 3(0.519 \cdot 2.21) + 2(1.038 \cdot 2.21) + (12 \cdot 2.21) + (3.25 \cdot 2.21)$

$= 46.47$

(1") I assume 1" line to not be considered b/c the valve is closed

$h_L = 47.303$

$h_A = (15-4.5) + 2.21 + 47.303$

$h_A = 10.5 + 49.513$

$h_A = 60.013 \text{ ft}$

$\text{Power} = (0.613 \text{ ft}^3/\text{s})(61 \text{ lb}/\text{ft}^3)(60.013 \text{ ft})$

$\text{Power} = 2244.07 \text{ lb ft}/\text{s}$

$2244.07 \frac{\text{lbft}}{\text{s}} \left(\frac{0.0018 \text{hp}}{1 \text{ lbft}/\text{s}} \right) = \underline{4.04 \text{ hp}}$

$\text{Efficiency} = \frac{4.04}{0.70} = \underline{5.77 \text{ hp}}$

B) $\cancel{\frac{P_A}{\gamma}} + \cancel{\frac{V_A^2}{2g}}^{\,0} + z_1 + h_A = \cancel{\frac{P_B}{\gamma}} + \frac{V_B^2}{2g} + z_B + h_L$

$\frac{V_B^2}{2g} = (z_1 - z_2) + (h_A - h_L)$

Branch 2

4 gate valves – 2 3", 2 4"
2 elbows – 3"
2 tees – 3"
exchanger
check valve – 4"
3" & 4" pipe

$$\frac{V^2}{2g} = f_1 \frac{L_1}{D_1}\frac{V_1^2}{2g} + 2(f_1)\left(\frac{Le}{D}\right)_{gv}\left(\frac{V_1^2}{2g}\right) + f_1\left(\frac{Le}{D}\right)_{cv}\left(V_1^2/2g\right) + 2(f_2)\left(\frac{Le}{D}\right)_{tee}\left(V_2^2/2g\right)$$
$$+ 2(f_2)\left(\frac{Le}{D}\right)_{elb}\left(\frac{V_2^2}{2g}\right) + 2(f_2)\left(\frac{Le}{D}\right)_{gv}\left(\frac{V_2^2}{2g}\right) + K_{exc}\left(\frac{V_2^2}{2g}\right) + f_2 \frac{V_2^2}{2g}\frac{L_2}{D_2}$$
$$+ f_4 \frac{V_4^2}{2g}\frac{L_4}{D_4}$$

$$\frac{V^2}{2g} = f_1 \frac{L_1}{D_1}\left(\frac{16Q_1^2}{\pi^2 D_1^4}\right) + 2(f_1)\left(\frac{Le}{D}\right)_{gv}\left(\frac{16Q_1^2}{\pi^2 D_1^4}\right) + f_1\left(\frac{Le}{D}\right)_{cv}\left(\frac{16Q_1^2}{\pi^2 D_1^4}\right) + 2(f_2)\left(\frac{Le}{D}\right)_{tee}\left(\frac{16Q_2^2}{\pi^2 D_2^4}\right)$$
$$+ 2(f_2)\left(\frac{Le}{D}\right)_{elb}\left(\frac{16Q_2^2}{\pi^2 D_2^4}\right) + 2(f_2)\left(\frac{Le}{D}\right)_{gv}\left(\frac{16Q_2^2}{\pi^2 D_2^4}\right) + K_{exc}\left(\frac{16Q_2^2}{\pi^2 D_2^4}\right) + f_2\frac{L_2}{D_2}\left(\frac{16Q_2^2}{\pi^2 D_2^4}\right)$$
$$+ f_4\left(\frac{16Q_4^2}{\pi^2 D_4^2}\right)\left(\frac{L_4}{D_4}\right)$$

$$\frac{V^2}{2g} = \left(f_1\frac{L_1}{D_1} + 2f_1\left(\frac{Le}{D}\right)_{gv} + f_1\left(\frac{Le}{D}\right)_{cv} + f_4\frac{L_4}{D_4}\right)\frac{8}{g\pi^2}\frac{Q_1^2}{D_1^4} + \left(K_{exc} + 2f_2\left(\frac{Le}{D}\right)_{tee}\right.$$
$$\left. + 2f_2\left(\frac{Le}{D}\right)_{elb} + 2f_2\left(\frac{Le}{D}\right)_{gv} + f_2\frac{L_2}{D_2}\right)\frac{8}{g\pi^2}\frac{Q_2^2}{D_2^4}$$

$$\frac{V_2}{2g} = f_1\left(\frac{L_1+L_4}{D_1} + 2\left(\frac{Le}{D}\right)_{gv} + \left(\frac{Le}{D}\right)_{cv}\right)\frac{8}{g\pi^2}\frac{Q_1^2}{D_1^4} + \left(K_{exc} + 2f_2\left(\frac{Le}{D}\right)_{tee} + 2f_2\left(\frac{Le}{D}\right)_{elb} +\right.$$
$$\left. 2f_2\left(\frac{Le}{D}\right)_{gv} + f_2\left(\frac{L_2}{D_2}\right)\right)\frac{8}{g\pi^2}\frac{Q_2^2}{D_2^4}$$

Branch 3

$$\frac{V^2}{2g} = f_1\left(\frac{L_1+L_4}{D_1} + 2f_1\left(\frac{Le}{D}\right)_{gv} + f_1\left(\frac{Le}{D}\right)_{cv}\right)\frac{8}{g\pi^2}\frac{Q_1^2}{D_1^4} + \left(2f_3\left(\frac{Le}{D}\right)_{elb} + f_3\left(\frac{Le}{D}\right)_{gv}\right)$$
$$\frac{8}{g\pi^2}\frac{Q_3^2}{D_3^4}$$

$$Q_1 = Q_2 + Q_3$$

Plug in branch 2:

$$\frac{V_2^2}{2g} = f_1\left(\frac{10ft}{0.2557ft} + 2(18) + 100\right)\frac{8}{32.2\pi^2}\frac{Q_1^2}{0.2557^4}$$

$$+ (12) + f_2\left(2(160) + 2(30) + 2(8) + \left(\frac{8ft}{0.2557}\right)\right)\frac{8}{32.2\pi^2}\frac{Q_2^2}{0.2557^2}$$

$$\frac{V_2^2}{2g} = f_1(913.37)(Q_1^2) + 12 + f_2(1338.4)(Q_2^2)$$

Branch 3:

$$\frac{V_2^2}{2g} = f_1(913.37)(Q_1^2) + f_3(2(30) + 8)\frac{8}{g\pi^2}\frac{Q_3^2}{D_3^4}$$

$$\frac{V_2^2}{2g} = f_1(913.37)(Q_1^2) + f_3(29335.8)(Q_3^2)$$

$$\frac{4Q}{\pi D^2} = f_1(913.37)(Q_1^2) + 12 + f_2(1338.4)(Q_2^2)$$

$$19.47Q_2 = f_1(913.37)(Q_1^2) + 12 + f_2(1338.4)(Q_2^2)$$

$$Q_2 = \sqrt{\frac{f_1(913.37)(Q_1^2) + 12 + f_2(1338.4)}{19.47}}$$

$$\frac{4Q}{\pi D^2} = f_1(913.37)(Q_1^2) + f_3(29335.8)(Q_3^2)$$

$$\frac{4Q_3}{\pi(0.0874)^2} = f_1(913.37)(Q_1^2) + f_3(29335.8)(Q_3^2)$$

$$53.06\,Q_3 = f_1(913.37)(Q_1^2) + f_3(29335.8)(Q_3^2)$$

$$Q_3 = \sqrt{\frac{f_1(913.37)(Q_1)^2 + f_3(29335.8)}{53.06}}$$

Summary: a) Power of the pump at 70% efficiency is 5.77hp.

b) I am unable to give a summary for part b due to the fact that my excel was incorrect.

Analysis: a) Many factors were needed in order to find pump power. After finding all necessary variables, calculating Re, V, D/ε, f_T, $V^2/2g$, and losses, we were able to apply it to the power + efficiency equations to arrive at the solution. The power was a little different when the 70% efficiency was applied.

b) this part Killed me. I was finally able to grasp the process necessary to find Q, but I struggled with the actual final equation for Q. Of course, this was the one needed for excel. Due to my calculation struggles, I was unable to finish the problem in its entirety