Unit 2 Exam

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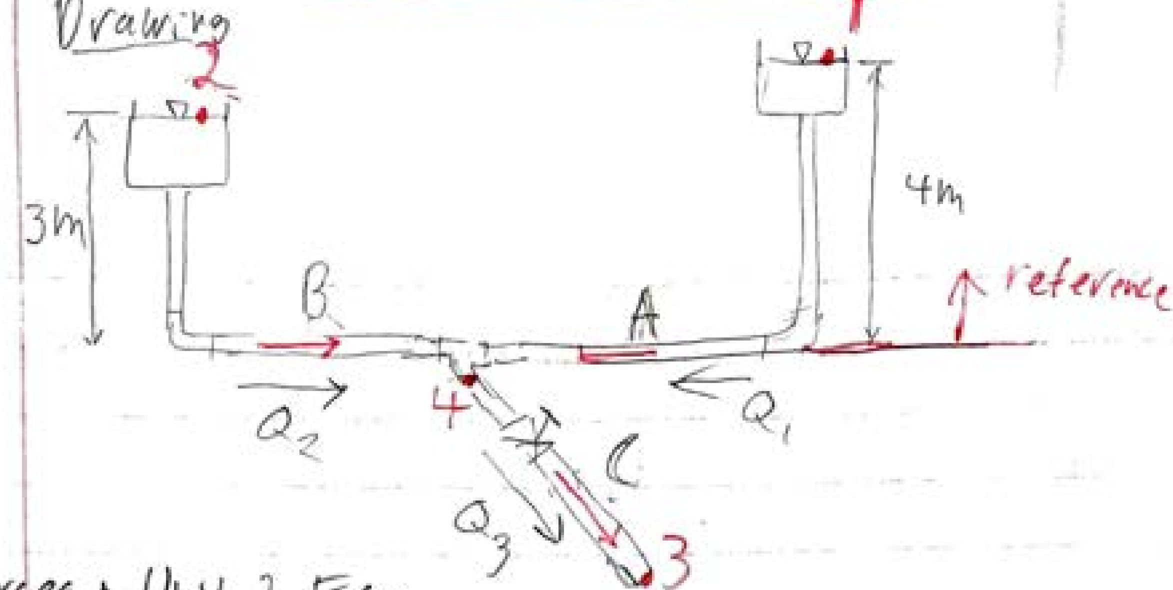
Problem 1

Purpose:

To Compute the total flow rate exiting the System of gutters, Check the Velocity of System to Check if it exceeds the critical velocity of 3 m/s, and to compute the pressure exit of the tee.

Drawing



Sources: Unit 2 Exam

Design Considerations:

The following must be assumed:

1) Incompressible fluid
2) Isothermal process
3) Steady State

Data and variables

$L_A = 10m$ $L_B = 9m$ $L_C = 10m$ $z_1 = 4m$ $z_2 = 3m$

$D = 0.750\,in$ $K_{entrance} = 0.5$ $\frac{L_e}{D}_{elbow} = 30$ $\varepsilon = 4.6 \times 10^{-5} m$

L_e/D_{tee}: 60 $K_{value} = 2$ (read from graph of K vs. S/D)

Procedure Part 1

$$\cancel{\frac{P_A}{\gamma}} + \cancel{\frac{V_A^2}{2g}} + z_A = \cancel{\frac{P_B}{\gamma}} + \frac{V_B^2}{2g} + \cancel{z_B} + h_{LAB}$$

- P_A and P_B are at atmospheric pressure
- z_B is at ground level
- $V_A = 0$

$$z_A = \frac{V_B^2}{2g} + h_{LAB}$$

$$\frac{V_B^2}{2g} = z_A - h_{LAB}$$

$$Q_1 + Q_2 = Q_3$$

$$\frac{V_B^2}{2g} = z_A - h_{L_{AB}}$$

Branch 1

$$\frac{V_3^2}{2g} = z_1 - h_{L_{13}}$$

Branch 2

$$\frac{V_3^2}{2g} = z_2 - h_{L_{23}}$$

Branch 1

$$\frac{V_3^2}{2g} = z_1 - \Bigg(\underbrace{\left[K_{ent}\frac{V_1^2}{2g}\right]}_{\text{elbow: ec}} + \underbrace{\left[f\frac{L_A}{D_A}\cdot\frac{V_1^2}{2g}\right]}_{\text{pipe A}} + \underbrace{\left[f_D\left(\frac{L_e}{D}\right)_{elbow}\frac{V_1^2}{2g}\right]}_{\text{elbow}} + \underbrace{\left[f\left(\frac{L_e}{D}\right)_{tee}\frac{V_3^2}{2g}\right]}_{\text{tee}}$$

$$+ \underbrace{\left[K_{valve}\frac{V_3^2}{2g}\right]}_{\text{valve}} + \underbrace{\left[f\frac{L_C}{D}\cdot\frac{V_3^2}{2g}\right]}_{\text{pipe 2}} \Bigg)$$

Branch 2.

$$\frac{V_3^2}{2g} = z_2 - \Bigg(\underbrace{\left[K_{ent}\frac{V_2^2}{2g}\right]}_{\text{entrance}} + \underbrace{\left[f\frac{L_B}{D}\cdot\frac{V_2^2}{2g}\right]}_{\text{pipe B}} + \underbrace{\left[f\left(\frac{L_e}{D}\right)_{elbow}\frac{V_2^2}{2g}\right]}_{\text{elbow}} + \underbrace{\left[f\left(\frac{L_e}{D}\right)_{tee}\frac{V_3^2}{2g}\right]}_{\text{tee}}$$

$$+ \underbrace{\left[K_{valve}\frac{V_3^2}{2g}\right]}_{\text{valve}} + \underbrace{\left[f\frac{L_C}{D}\cdot\frac{V_3^2}{2g}\right]}_{\text{pipe C}} \Bigg)$$

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

Sub in $V = \frac{4Q}{\pi D^2}$ in a velocities

Branch 1

$$\frac{16Q_3^2}{\pi^2 D^4}\cdot\frac{1}{2g} = Z_1 - \underbrace{\left[K_{ent}\frac{16Q_1^2}{\pi^2 D^4}\cdot\frac{1}{2g}\right]}_{\text{entrance}} - \underbrace{\left[f\frac{L_A}{D}\cdot\frac{16Q_1^2}{\pi^2 D^4}\cdot\frac{1}{2g}\right]}_{\text{pipe a}} - \underbrace{\left[f\left(\frac{Le}{D}\right)_{elbow}\frac{16Q_1^2}{\pi^2 D^4}\cdot\frac{1}{2g}\right]}_{\text{elbow}} -$$

$$- \left[f\left(\frac{Le}{D}\right)_{tee}\frac{16Q_3^2}{\pi^2 D^4}\cdot\frac{1}{2g}\right] - \left[K_{valve}\frac{16Q_3^2}{\pi^2 D^4}\cdot\frac{1}{2g}\right] - \left[f\frac{L_C}{D}\cdot\frac{16Q_3^2}{\pi^2 D^4}\cdot\frac{1}{2g}\right]$$

$$\frac{8Q_3^2}{\pi^2 D^4 g} = Z_1 - \left[K_{ent}\frac{8Q_1^2}{\pi^2 D^4 g}\right] - \left[f\frac{L_A}{D}\cdot\frac{8Q_1^2}{\pi^2 D^4 g}\right] - \left[f\left(\frac{Le}{D}\right)_{elbow}\frac{8Q_1^2}{\pi^2 D^4 g}\right] -$$

$$- \left[f\left(\frac{Le}{D}\right)_{tee}\frac{8Q_3^2}{\pi^2 D^4 g}\right] - \left[K_{valve}\frac{8Q_3^2}{\pi^2 D^4 g}\right] - \left[f\frac{L_C}{D}\cdot\frac{8Q_3^2}{\pi^2 D^4 g}\right]$$

$$\frac{8Q_3^2}{\pi^2 D^4 g} = Z_1 - \left[Q_1^2\cdot\frac{8}{\pi^2 D^4 g}\left(K_{ent} + f\frac{L_A}{D} + f\left(\frac{Le}{D}\right)_{elb}\right)\right] - \left[Q_3^2\cdot\frac{8}{\pi^2 D^4 g}\left(f\left(\frac{Le}{D}\right)_{tee} + K_{valve} + f\frac{L_C}{D}\right)\right]$$

$$0 = Z_1 - \left[Q_1^2\cdot\frac{8}{\pi^2 D^4 g}\left(K_{ent} + f\frac{L_A}{D} + f\left(\frac{Le}{D}\right)_{elbow}\right)\right] - \left[Q_3^2\cdot\frac{8}{\pi^2 D^4 g}\left(f\left(\frac{Le}{D}\right)_{tee} + K_{valve} + f\frac{L_C}{D} + 1\right)\right]$$

$$D = \frac{0.750}{12\,in/ft}\cdot\frac{1m}{3.281ft} = 0.019m \qquad \frac{D}{\varepsilon} = \frac{0.019m}{4.6\times10^{-5}m} = 414$$

Friction factor is only function of relative roughness

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7\left(\frac{D}{\varepsilon}\right)}\right)\right]^2} = \frac{0.25}{\left[\log\left(\frac{1}{3.7\cdot 414}\right)\right]^2} = 0.0246$$

$$0 = 4m - \left[Q_1^2 \cdot \frac{8}{\pi^2 \cdot 0.019m^4 \cdot 9.81 m/s^2}\left(0.5 + \left(0.0246 \cdot \frac{10m}{0.019m}\right) + (0.0246 \cdot 30)\right)\right.$$

$$- \left[Q_3^2 \cdot \frac{8}{\pi^2 \cdot 0.019m^4 \cdot 9.81 m/s^2}\left((0.0246 \cdot 60) + 2 + \left(0.0246 \cdot \frac{10m}{0.019}\right) + 1\right)\right]$$

$$0 = 4m - (Q_1^2 \cdot 8916037.53) - (Q_3^2 \cdot 10948720.42)$$

Branch 2

Sub in $Q = VA$ for Velocities

$$\frac{Q_3^2}{D^4 2g} = Z_2 - \left[K_{ent} \cdot \frac{16Q_2^2}{\pi^2 D^4 2g}\right] - \left[f \frac{L_B}{D} \frac{16Q_2^2}{\pi^2 D^4 2g}\right] - \left[f\left(\frac{Le}{D}\right)_{elbow} \frac{16Q_2^2}{\pi^2 D^4 2g}\right] - \left[f\left(\frac{Le}{D}\right)_{tee} \frac{16Q_3^2}{\pi^2 D^4 2g}\right] -$$

$$- \left[K_{valve} \frac{16Q_3^2}{\pi^2 D^4 2g}\right] - \left[f \frac{L_C}{D} \frac{16Q_3^2}{\pi^2 D^4 2g}\right]$$

$$0 = Z_2 - \left[K_{ent} \frac{8Q_2^2}{\pi^2 D^4 g}\right] - \left[f \frac{L_B}{D} \frac{8Q_2^2}{\pi^2 D^4 g}\right] - \left[f\left(\frac{Le}{D}\right)_{elbow} \frac{8Q_2^2}{\pi^2 D^4 g}\right] - \left[f\left(\frac{Le}{D}\right)_{tee} \frac{8Q_3^2}{\pi^2 D^4 g}\right]$$

$$- \left[K_{valve} \frac{8Q_3^2}{\pi^2 D^4 g}\right] - \left[f \frac{L_C}{D} \frac{8Q_3^2}{\pi^2 D^4 g}\right] - \left(\frac{8Q_3^2}{\pi^2 D^4 g}\right)$$

$$0 = Z_2 - \frac{8Q_2^2}{\pi^2 D^4 g}\left(K_{ent} + f\frac{L_B}{D} + f\left(\frac{Le}{D}\right)_{elbow}\right) - \frac{8Q_3^2}{\pi^2 D^4 g}\left(f\left(\frac{Le}{D}\right)_{tee} + K_{valve} + f\frac{L_C}{D} + 1\right)$$

$$0 = 3m - \frac{8Q_2^2}{\pi^2 \cdot 0.019m^4 \cdot 9.81 m/s^2}\left(0.5 + 0.0264\left(\frac{9}{0.019m}\right) + 0.0264 \cdot 30\right)$$

$$- \frac{8Q_3^2}{\pi^2 \cdot 0.019m^4 \cdot 9.81 m/s^2}\left(0.0264 \cdot 60 + 2 + 0.0264 \frac{19m}{0.019m} + 1\right)$$

$$0 = 3m - (Q_2^2 \cdot 8063330.43) - (Q_3^2 \cdot 10948720.42)$$

Branch 1

$$0 = 4m - (Q_1^2 \cdot 8{,}916{,}037.57) - (Q_3^2 \cdot 10{,}948{,}720.42)$$

Branch 2

$$0 = 3m - (Q_2^2 \cdot 8{,}083{,}330.43) - (Q_3^2 \cdot 10{,}948{,}720.42)$$

Solve for Q_1

$$Q_1^2 \cdot 8916037.57 = 4m - Q_3^2 \cdot 10948720.42$$

$$Q_1 = \sqrt{\frac{4m - Q_3^2 \cdot 10948720.42}{8916037.57}}$$

Solve for Q_2

$$Q_2 = \sqrt{\frac{3m - Q_3^2 \cdot 10948720.42}{8083330.43}}$$

$$Q_3 = Q_1 + Q_2$$

Calculations part 1

Need to use an iterative process in excel to get Q_1, Q_2, Q_3

1. Guess Q_3
2. Solve Q_1 and Q_2 using Q_3
3. Use Q_1 and Q_2 to calculate Q_3 using $Q_3 = Q_1 + Q_2$
4. Compare new Q_3 to guessed Q_3. If not the same (% diff > 1%), then I will go back to step one with the new Q_3 and repeat the process.

$$\% \text{ diff} = \frac{Q_{3\,old} - Q_{3\,new}}{Q_{3\,old}}$$

After iterative process in excel

$Q_1 = 0.000363\ m^3/s$ $Q_2 = 0.000146\ m^3/s$ $Q_3 = 0.0005082\ m^3/s$

$$V_1 = \frac{4Q_1}{\pi D^2} = \frac{4 \cdot 0.000363\,m^3/s}{\pi \cdot (0.01905\,m)^2} = 1.274\,m/s$$

$$V_2 = \frac{4Q_2}{\pi D^2} = \frac{4 \cdot 0.000146\,m^3/s}{\pi \cdot (0.01905\,m)^2} = 0.512\,m/s$$

$$V_3 = \frac{4Q_3}{\pi D^2} = \frac{4 \cdot 0.0005082\,m^3/s}{\pi \cdot (0.01905\,m)^2} = 1.783\,m/s$$

V_1, V_2, V_3 do not exceed the critical velocity of 3 m/s meaning the pipesand opening of the valve are correct for the application.

Procedure Part 2

$$\cancel{\frac{P_1}{\gamma}} + \cancel{\frac{V_1^2}{2g}} + z_1 = \frac{P_4}{\gamma} + \frac{V_4^2}{2g} + \cancel{z_4} + h_{L14}$$

$$\frac{P_4}{\gamma} = z_1 - \frac{V_4^2}{2g} \cancel{+h_{L14}}$$

$$P_4 = \gamma\left(z_1 - \frac{V_4^2}{2g} - h_{L14}\right)$$

$$P_4 = \gamma\left(z_1 - \frac{V_4^2}{2g} - \left[K_{ent}\frac{V_1^2}{2g}\right] - \left[f\frac{L_1}{D}\cdot\frac{V_1^2}{2g}\right] - \left[f\left(\frac{L_e}{D}\right)_{elbow}\frac{V_1^2}{2g}\right] - \left[f\left(\frac{L_e}{D}\right)_{tee}\frac{V_3^2}{2g}\right]\right.$$

$V_3 = V_4$

$$P_4 = \gamma\left(z_1 - \frac{V_3^2}{2g} - \left[f\left(\frac{L_e}{D}\right)_{tee}\frac{V_3^2}{2g}\right] - \left[K_{ent}\frac{V_1^2}{2g}\right] - \left[f\frac{L_A}{D}\frac{V_1^2}{2g}\right] - \left[f\left(\frac{L_e}{D}\right)_{elbow}\frac{V_1^2}{2g}\right]\right.$$

$$P_4 = \gamma\left(z_1 - \underbrace{\frac{V_3^2}{2g}}_{V_{at\,4}}\left[1 + \underbrace{f\left(\frac{L_e}{D}\right)_{tee}}_{tee}\right] - \frac{V_1^2}{2g}\left[\underbrace{K_{ent}}_{ent} + \underbrace{f\frac{L_A}{D}}_{pipe\,A} + \underbrace{f\left(\frac{L_e}{D}\right)_{elbow}}_{elbow}\right]\right.$$

Need specific weight of water. I will assume 10°C, so $\gamma = 9.81\ KN/m^3$

Calculations Part 2:

$$P_4 = 9.81\frac{KN}{m^3}\left(4m - \underbrace{\frac{(1.783\,m/s)^2}{2\cdot 9.81\,m/s^2}\left[1+0.0264(60)\right]}_{0.226} - \underbrace{\frac{(1.274\,m/s)^2}{2\cdot 9.81\,m/s^2}\left[0.5+0.0264\frac{10m}{0.019m}+0.0264\cdot 30\right]}_{0.9226}\right.$$

$$P_4 = 23.797\ \frac{KN}{m^2}$$

$$P_4 = 23.797\ KPa$$

Summary

The total flow rate exiting the system of gutters is $0.0005082\ m^3/s$. The velocities in the system were 1.274 m/s, 0.512 m/s, 1.783 m/s which do not exceed the critical velocity of 3 m/s. The pressure at the exit of the tee is 23.797 KPa

Materials:

- Water

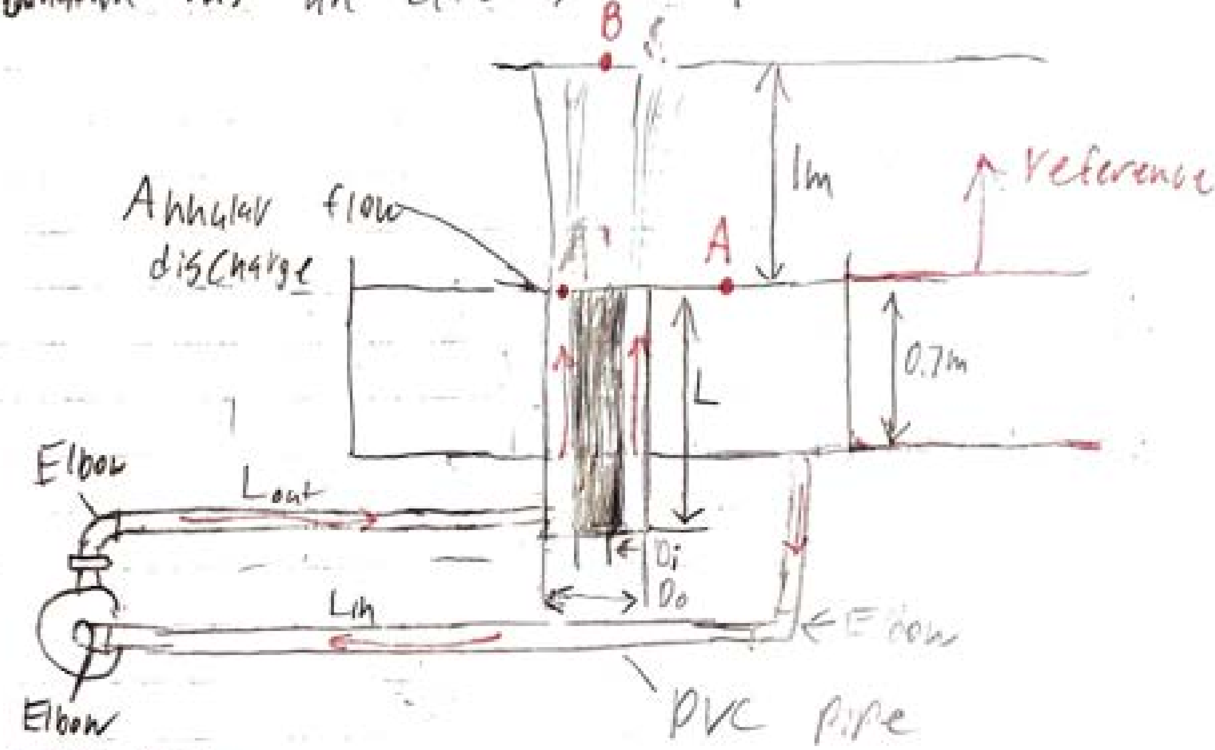
Analysis

Since the velocities of the water do not exceed 3 m/s, the 3/4" pipe and half open valve are adequate for the application.

Test 2 Problem 2

Purpose: To compute the Pump Power required for the system so that water exiting the annulus will reach a height of 1 meter and to compute the electrical power requirements if the pump-motor combination has an efficiency of 92%.

Drawing



Sources: Unit 2 Exam

Design Considerations

The following must be assumed.

1) Incompressible fluid
2) Isothermal Process
3) Steady State

Data and Variables

$L_{out} = 18m$ $L_{in} = 20m$ $L_{annular} = 1.80m$ $D_o = 0.1m$ $D_i = 0.07m$

$K_{expansion} = 2$ $Le/D_{elbow} = 30$ $K_{entrance} = 0.5$

Assuming water at 10°C $\gamma = 9.81\ KN/m^3$ $\nu = 1.3 \times 10^{-6}\ m^2/s$

$\varepsilon = 3.0 \times 10^{-7} m$ $\eta_A = 0.92$

Procedure / Calculations:

$$\frac{\cancel{P_A}}{\gamma} + \frac{\cancel{V_A^2}}{2g} + \cancel{z_A}^{0} + h_A = \frac{\cancel{P_B}}{\gamma} + \frac{\cancel{V_B^2}}{2g} + z_B + h_{LAB}$$

- P_A and P_B are atmospheric
- $V_A = 0$, V_B must also be zero at top of water exiting the annulus

z_A is at reference

$$h_A = z_B + h_{LAB}$$

Losses: Major: Loss in inlet pipe, loss in outlet pipe, loss in annulus
Minor: Entrance loss, 3 elbows, expansion loss, 3 elbows

$$h_A = z_B + \underbrace{\left[f\frac{L_{in}}{D}\frac{V_1^2}{2g}\right]}_{inlet} + \underbrace{\left[f\frac{L_{out}}{D}\frac{V_1^2}{2g}\right]}_{outlet} + \underbrace{\left[f\frac{L_{annu}}{D'_{annul}}\frac{V_2^2}{2g}\right]}_{annular} + \underbrace{\left[K_{ent}\frac{V_1^2}{2g}\right]}_{entrance} + \underbrace{\left[K_{exp}\frac{V_1^2}{2g}\right]}_{expansion} + \underbrace{\left[3f\left(\frac{L_e}{D}\right)_{elbow}\frac{V_1^2}{2g}\right]}_{elbow}$$

Substitute in $V = \frac{4Q}{\pi D^2}$

$$h_A = z_B + \left[f\frac{L_{in}}{D}\cdot\frac{16Q^2}{\pi^2 \cdot D^4}\frac{1}{2g}\right] + \left[f\frac{L_{out}}{D}\cdot\frac{16Q^2}{\pi^2 D^4 \cdot 2g}\right] + \left[f\frac{L_{annul}}{D'_{annul}}\frac{16Q^2}{\pi^2 \cdot D^4_{annul} \cdot 2g}\right] + \left[K_{ent}\frac{16Q^2}{\pi^2 D^4 2g}\right] + \left[K_{exp}\frac{16Q^2}{\pi^2 D^4 \cdot 2g}\right]$$

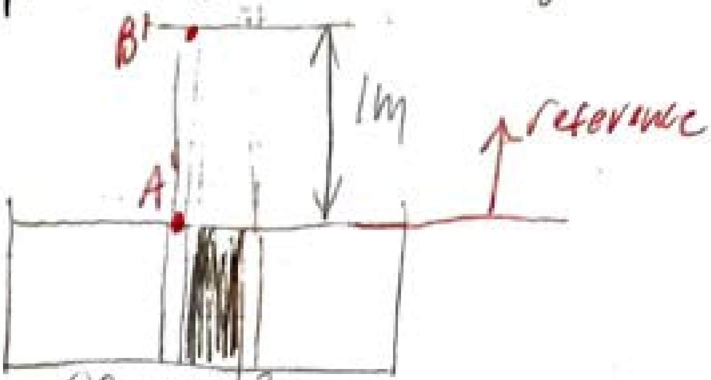
$$+ \left[3f\left(\frac{L_e}{D}\right)_{elbow}\frac{16Q_1^2}{\pi^2 D^4 2g}\right]$$

$$h_A = z_B + \left[f_1\frac{L_{in}}{D}\frac{8Q^2}{\pi^2 D^4 g}\right] + \left[f_1\frac{L_{out}}{D}\frac{8Q^2}{\pi^2 D^4 g}\right] + \left[f_2\frac{L_{annul}}{D'_{annul}}\frac{8Q^2}{\pi^2 D^4_{annul} g}\right] + \left[K_{ent}\frac{8Q^2}{\pi^2 D^4 g}\right] + \left[K_{exp}\frac{8Q^2}{\pi^2 D^4 g}\right] + \left[3f_1\left(\frac{L_e}{D}\right)_{elbow}\frac{8Q^2}{\pi^2 D^4 g}\right]$$

$$h_A = z_B + f_1\frac{8Q^2}{\pi^2 D^4 g}\left(\frac{L_{in}}{D} + \frac{L_{out}}{D} + 3\left(\frac{L_e}{D}\right)_{elbow}\right) + \left(f_2\frac{L_{annul}}{D_{annul}}\frac{8Q^2}{\pi^2 D^4_{annul} g}\right) + \frac{8Q^2}{\pi^2 D^4 g}\left(K_{ent} + K_{exp}\right)$$

- To find the flow rate of the system, I first need to determine the velocity necessary to achieve the 1m required height of the water exiting the fountain.
- After I find that velocity, I can use the area of the annular discharge to find the flowrate.

I will apply Bernoulli's equation again between 2 points; A' at the exit of the annular discharge and B' at the top of the water exiting the fountain.



$$\cancel{\frac{P_{A'}}{\gamma}} + \frac{V_{A'}^2}{2g} + \cancel{Z_{A'}} = \cancel{\frac{P_{B'}}{\gamma}}^{0} + \cancel{\frac{V_{B'}^2}{2g}}^{0} + Z_{B'}$$

Pressure at A' and B' must be atmospheric pressure
Velocity at B' must be zero
- $Z_{A'}$ is at reference so it must also be zero

$$\frac{V_{A'}^2}{2g} = Z_{B'} \rightarrow V_{A'}^2 = 2g \cdot Z_{B'} \rightarrow V_{A'} = \sqrt{2g \cdot Z_{B'}}$$

$$V_{A'} = \sqrt{2 \cdot 9.81 \frac{m}{s^2} \cdot 1m} \qquad V_{A'} = 4.43\ m/s$$

Now I need to use the inside and outside diameters of the annular discharge to find the area.
I can use the area of the annular discharge and the required velocity to reach 1 meter to determine the flow rate of the system

$$A = \frac{\pi}{4}(D_o^2 - D_i^2)$$

$$A = \frac{\pi}{4}(0.1m^2 - 0.07m^2) \quad A = 0.004\ m^2$$

$$Q = VA = 4.43\ m/s \cdot 0.004\ m^2$$

$$Q = 0.0177\ m^3/s$$

Using the flowrate and critical velocity, I can determine the pipe diameters needed for the inlet and outlet pipes

$$Q = VA \rightarrow A = \frac{Q}{V} \rightarrow \frac{\pi}{4} \cdot D^2 = \frac{Q}{V} \rightarrow D^2 = \frac{4Q}{\pi V} \quad D = \sqrt{\frac{4Q}{\pi V}}$$

$$D = \sqrt{\frac{4 \cdot 0.0177 m^3/s}{\pi \cdot 3 m/s}} = 0.0868 m = 86.8 mm$$

Going to table G.3 in the appendix, I find that the closest commercial pipe size that is larger than the diameter I need is 100mm with 93mm or 0.093m inside diameter.

-Using the new pipe size, I need to calculate the Velocity, Renold's Number, Relative Roughness, and friction factor of the pipe

$$V = \frac{4 \cdot 0.0177 m^3/s}{\pi (0.093m)^2} = 2.611 m/s \leftarrow$$ Less than critical velocity, good.

$$R_e = \frac{VD}{\nu} = \frac{2.611 \frac{m}{s} \, 0.093m}{1.3 \times 10^{-6} m^2/s} = 186850, \quad 1.87 \times 10^5$$

$$\frac{D}{\varepsilon} = \frac{0.093 m}{3.0 \times 10^{-7}} = 310,000$$

$$F_1 = \frac{0.25}{\left[\log\left(\frac{1}{3.7\left(\frac{D}{\varepsilon}\right)} + \frac{5.74}{Re^{0.9}}\right)\right]^2} = \frac{0.25}{\left[\log\left(\frac{1}{3.7 \cdot 310,000} + \frac{5.74}{186850^{0.9}}\right)\right]^2}$$

$$F_1 = 0.01578$$

Next, I need to Calculate the Wetted Perimeter of the annular discharge path
I then Can use the Area and wetted Perimeter to find the hydraulic radius

- From the hydraulic radius, I can find the diameter which I can use to calculate Ronalds Number, relative roughness, and friction factor.

$$Wp = \pi(D_o + D_i) = \pi(0.1m + 0.07m) = 0.534m$$

$$\text{Hydraulic Radius } R = \frac{A}{Wp} = \frac{0.004m^2}{0.534m} = 0.0075m$$

$$D = 4R = 0.0075m \cdot 4 = 0.02999m$$

$$Re = \frac{VD}{\nu} = \frac{4.43\,m/s \cdot 0.02999m}{1.3 \times 10^{-6}\,m^2/s} = 102218 \quad 1.02 \times 10^5$$

$$\frac{D}{\varepsilon} = \frac{0.02999m}{3.0 \times 10^{-7}} = 99{,}999.99933$$

$$F_2 = \frac{0.25}{\left[\log\left(\frac{1}{3.7 \cdot 99999.99933} + \frac{5.74}{102218^{0.9}}\right)\right]^2}$$

2.7 1.77

$$F_2 = 0.0178$$

Now with the flow rate, Diameters, and friction factors, I can solve for the pump head, h_A.

$$h_A = Z_B + f_1 \frac{8Q^2}{\pi^2 D^4 g}\left(\frac{L_{in}}{D} + \frac{L_{out}}{D} + 3\left(\frac{L_e}{D}\right)_{elbow}\right) + f_2 \frac{L_{annul}}{D_{annul}} \frac{8Q^2}{\pi^2 D_{annul}^4 g} + \frac{8Q^2}{\pi^2 D^4 g}\left(K_{ent} + K_{exp}\right)$$

$$h_A = 1m + 0.01578 \frac{8\cdot(0.0177\,m^3/s)^2}{\pi^2(0.093m^4)\cdot 9.81\frac{m}{s^2}}\left(\frac{20m}{0.093m} + \frac{18m}{0.093m} + 3\cdot 30\right) +$$

$$+ 0.0178 \frac{1.80m}{0.0299m} \cdot \frac{8(0.0177\,m^3/s)^2}{\pi^2(0.0299m^4)\cdot 9.81m/s^2} +$$

$$+ \frac{8\cdot(0.0177\,m^3/s)^2}{\pi^2(0.093m^4)\cdot 9.81\frac{m}{s^2}}(0.5+2)$$

$$h_A = 1m + 2.57m + 34.38m + 0.869m$$

$$h_A = 38.82m$$

- Now using the pump head, I can calculate power required

$$P = \gamma \cdot Q \cdot h_A$$

$$P = 9.81\frac{kN}{m^3} \cdot 0.0177\frac{m^3}{s} \cdot 38.82m \quad \frac{kN\cdot m}{s} = \frac{kJ}{s} = 1kW$$

$$P = 6.756kW$$

- It is stated that the pump-motor combination has an efficiency of 92% or $\eta_A = 0.92$.
- Using this efficiency and pump requirements of the system, I can calculate the required electrical power.

$$P_m = \frac{P_r}{\eta_A} = \frac{6.756\,kW}{0.92}$$

$$P_m = 7.34\,kW$$

Summary:

The power required for the system is 6.756 kW.
The electrical power required for the pump-motor combination with an efficiency of 92% is 7.34 kW

Materials:

Water

Analysis:

- This problem required that I calculate the required velocity in the annular discharge passage so that the water exiting it would reach the 1 meter specified height. Using that velocity and and the area of the annular passage, I could find the required flow rate of the system needed so that the water would reach 1 meter exiting the annular path. With flow rate and the critical velocity, I was then able to choose a commercial pipe size for the application. At this point, I was able to calculate all the necessary values to find the pump head, power, and electrical power.

I pledge to follow the Honor Code and to obey all rules for taking exams and performing homework assignments as specified by the instructor

Jacob Leonard

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7/2/23