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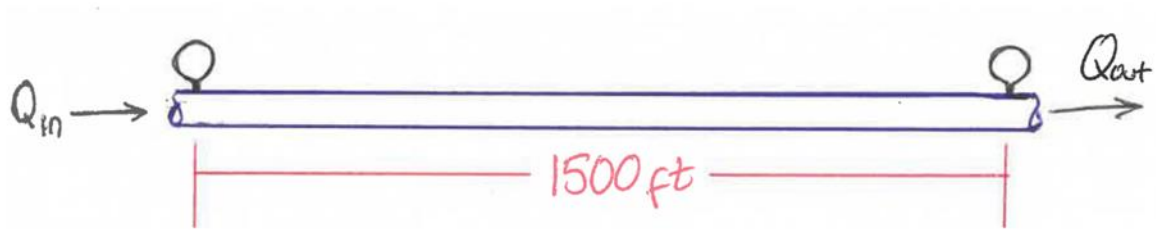
Exam 3

MET 330

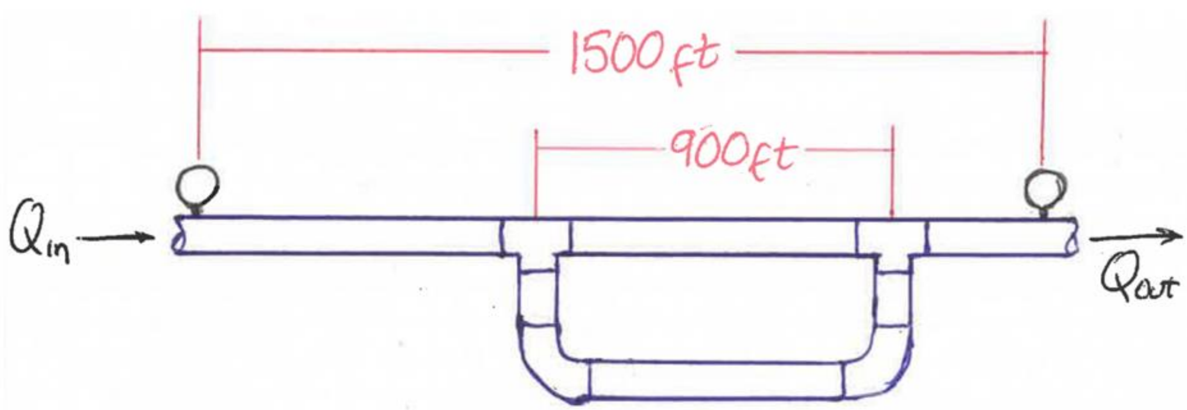
Purpose:

Given a standard pipe of 2", determine the pressure difference between the point due only to friction losses. Then changing to a parallel pipe system that is maintaining the pressure difference, determine the change in flow rate due to the addition of the parallel pipe, and the new various loss items (tees, elbows, etc).

Drawings and Diagrams:



Scenario 1



Scenario 2

Sources:

Applied Fluid Mechanics, 7th edition by Robert L. Mott and Joseph A. Untener

Design Considerations:

Water is an incompressible fluid.

The system is undergoing an isothermal process

The system is assumed to be steady-state

The reducers are a 50-60 degrees, the expansion is at 20 degrees, and the elbows are long-radius elbows.

Data and Variables:

$$\gamma_{H2O} = \mathbf{62.4}\frac{\text{lb}}{\text{ft}^3}$$

$$\rho_{H2O} = \mathbf{1.94}\frac{\text{lb} * \text{s}^2}{\text{ft}^4}$$

$$Q_{scenario1} = \mathbf{65}\frac{\text{gal}}{\textbf{min}}$$

$$D_{2\text{"SteelPipe}} = \mathbf{0.1723}\text{ft}$$

$$A_{2\text{"SteelPipe}} = \mathbf{0.023316}\text{ft}^2$$

$$V_{scenario1} = \mathbf{6.017833}\frac{\text{ft}}{\text{s}}$$

$$\eta_{H2O} = \mathbf{2.35 * 10^{-5}}\frac{\text{lb} * \text{s}}{\text{ft}^2}$$

$$\varepsilon_{steel} = \mathbf{1.5 * 10^{-4}}\,\text{ft}$$

$$D_{1.5\text{"SteelPipe}} = \mathbf{0.1342}\text{ft}$$

$$A_{1.5\text{"SteelPipe}} = \mathbf{0.0141447}\text{ft}^2$$

Procedure:

In the straight pipe scenario, draft Bernoulli's equation for the system. Knowing that the intake velocity will be the (close enough to) the same as the exiting velocity, and the system is completely horizontal, the velocity head and elevation terms may be eliminated. The only loss to consider in this scenario will be friction. Solve the equation for P1-P2, henceforth referred to as DeltaP, and save the term.

In scenario 2, there are now 2 branches. The top branch will be branch 1, and the bottom branch will be branch 2. In turn, when referring to the respective attributes of the system, they will be labeled accordingly – Q1 for the flow rate of branch 1. As with scenario 1, the points of interest will be at the far ends of the 1500ft length of pipe, which will have the same pressure drop as scenario 1.

A bernoulli's equation will need to be generated for each branch, starting at point 1 and moving through either path to get to point 2. The pipe system now has two Tees, two reducers (assumed at 50-60 degrees), two long-radius elbows, and two expansion points (assumed at 20 degrees). Along with, the points between the Tees are now 1.5" steel pipe while the exterior 600ft remain to be 2" steel pipe. As the flow rate into the system will be the flow rate coming out, V1=V2 and the velocity head can be removed from both branch equations. Along with, the points 1 and 2 remain on the same height in the horizontal plane, and so Z1 and Z2 may be eliminated from both equations.

In branch 1, the Q1 must be isolated. In turn, in the branch 2 equation, the Q2 must be isolated. These equations will need to be input into the Qtotal equation, Qtotal=Q1+Q2. This will leave the friction factor for the 2" steel pipe, friction factor for the 1.5" steel pipe (both branch 1 and 2), and Qtotal as the only unknown terms.

Moving to Excel, guess values for these terms. Compare the chosen Qtotal to the generated Qtotal. Derive friction factor for the 2" steel pipe by taking the generated Qtotal and dividing by the area to get Velocity for the 2" pipe, then calculate Reynold's number, and determine the "actual" friction factor for the 2" portion of the pipe system. Derive the 1.5" steel pipe friction factor by the same method, but using Q1. Repeat for Q2. Manipulate the values progressively until all % differences for Qtotal, F2", F1.5"(Branch1), and F1.5"(Branch2) are under 1%.

Double-check the theory by driving the F1.5"(Branch2) towards a larger value (at least 10x larger) and verifying that the Qtotal drops to a value close to the GPM of scenario 1. This simulates closing branch 2.

Calculations:

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Problem 2

Data

$\gamma_{H2O} = 62.4\ lb/ft^3$

$Q = 65 \frac{gal}{min} \cdot \frac{1\ ft^3/s}{449 \frac{gal}{min}} = 0.144766 \frac{ft^3}{s}$

$\rho_{H2O} = 1.94 \frac{lb \cdot s^2}{ft^4}$

$D_{2''} = 0.1723 ft$ $\quad D_{1½''} = 0.1342 ft$ $\quad f_{T_{2''}} = 0.019$

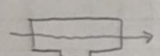
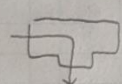
$\eta_{H2O} = 2.35 \cdot 10^{-5} \frac{lb \cdot s}{ft^2}$ $\quad \epsilon_{steel} = 1.5 \times 10^{-4} ft$ $\quad f_{T_{1½''}} = 0.02$

Equations

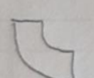
$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L \qquad h_{L_{minor}} = k \cdot \frac{V^2}{2g}$$

$$Q = V \cdot A$$

$$Re = \frac{\rho \cdot V \cdot D}{\eta} \qquad h_{FR} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

 $k = 20 \cdot f_T$  $k = 60 \cdot f_T$

*as they were used in exam 2, assuming elbows are long radius elbows

 $k = 20 \cdot f_T$

Thinking

so we need a gradual contraction, then gradual expansion

Contraction:

$\frac{D_1}{D_2} = \frac{2'' steel}{1½'' steel} = 1.2839$ @ 50-60° [assumed – gradual not specified]

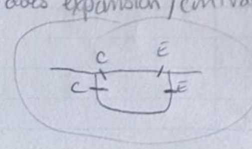
$k \approx 0.055$

expansion:

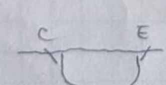
$\frac{D_2}{D_1} = \frac{2'' steel}{1½'' steel} = 1.2839$ @ 20° [assumed]

$k \approx 0.2$

→ does expansion/contraction happen

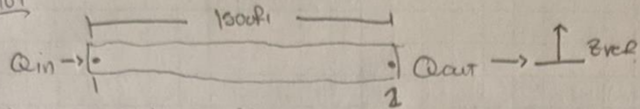


after TEE or



?

Scenario 1



$$V = \frac{Q}{A} = \frac{0.144766\ ft^3/s}{0.0233163\ ft^2}$$

$$A_{2''} = \frac{\pi (0.1723ft)^2}{4} = 0.0233163ft^2$$

$V =$ ~~5.079653 ft/s~~ $6.20879\ ft/s$

entered in calc wrong.

$$\frac{P_1}{\gamma} + \cancel{\frac{V_1^2}{2g}} + \cancel{z_1} = \frac{P_2}{\gamma} + \cancel{\frac{V_2^2}{2g}} + \cancel{z_2} + h_{L_{1-2}}$$

$$P_1 - P_2 = h_{L_{1-2}} \cdot \gamma$$

$$h_{L_{1-2}} = h_{L_{FR}} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

$$Re = \frac{\rho \cdot V \cdot D}{\eta} = \frac{1.94 \frac{lb \cdot s^2}{ft^4} \cdot \cancel{5.07965\ ft/s} \cdot 0.1723ft}{2.35 \cdot 10^{-5} \frac{lb \cdot s}{ft^2}} = \cancel{7.225 \cdot 10^5}$$

Re (w/ correct velocity) $= 8.83 \cdot 10^5$

$$\frac{D}{\varepsilon} = \frac{0.1723ft}{1.5 \cdot 10^{-4} ft} = 1148.67$$

- from Moody chart (figure 8.7)

~~$f \approx 0.021$~~ $f \approx 0.02$

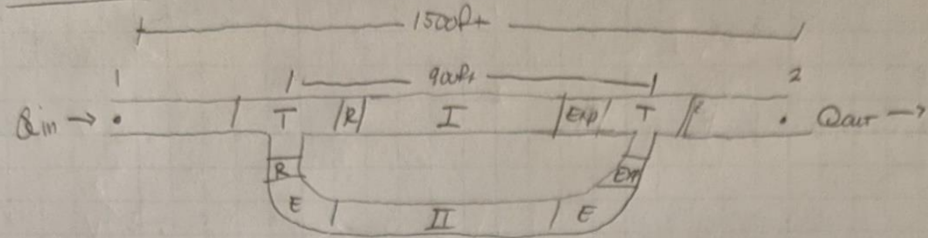
~~$h_{L_{FR}} = 0.021 \cdot \frac{1500ft}{0.1723ft} \cdot \frac{(6.20879\ ft/s)^2}{2 \cdot 32.2\ ft/s^2} = 104.223\ ft$~~

~~$P_1 - P_2 = 104.223ft \cdot 62.4\ lb/ft^3 = 6503.5224\ lb/ft^2 \cdot \frac{1ft^2}{144in^2} = 45.1634\ psi$~~

See: Page 12 for rework.

Rule: velocity for Tee is what comes in

Scenario 2



- R being Reducers @ 60°
- E being long-radius elbows.
- Exp being gradual expansion @ 20°

so Tees are both at 2"
Branches Contain 1½"

$Q_{Total} = Q_I + Q_{II}$

$V^2 = \frac{16 \cdot Q^2}{\pi^2 \cdot D^4}$

Branch I

$$\frac{P_1}{\gamma} + \cancel{\frac{V_1^2}{2g}} + \cancel{z_1} = \frac{P_2}{\gamma} + \cancel{\frac{V_2^2}{2g}} + \cancel{z_2} + h_{L_{12_I}}$$

- reached out to Dr. Ayala & he said reducers usually go after Tees.
- I am assuming in turn, that expansion occurs before the Tee on the right.

- at points 1 & 2, both have 2" steel and Q_{Total}, so $V_1 = V_2$

$$P_1 - P_2 = h_{L_{12_I}} \cdot \gamma$$

$$h_{L_{12_I}} = h_{L_{FR_{2"}}} + h_{L_{FR_{1½"}}} + h_{L_{Tee_{Left}}} + h_{L_{reducer}} + h_{L_{expansion}} + h_{L_{Tee\,right}}$$

$$h_{L_{FR_{2"}}} = f_{2"} \cdot \frac{L}{D} \left(\frac{16 \cdot Q_{Total}^2}{\pi^2 \cdot D_{2"}^4}\right) \div 2g$$

600ft

$$h_{L_{FR_{1½"}}} = f_{1½"} \cdot \frac{L}{D} \cdot \left(\frac{16 \cdot Q_I^2}{\pi^2 \cdot D_{1½"}^4}\right) \div 2g$$

900ft

$$h_{L_{Tee_{Left}}} = 20 \cdot f_{T_{2"}} \cdot \left(\frac{16 \cdot Q_{Total}^2}{\pi^2 \circ D_{2"}^4}\right) \div 2g$$

Unknowns:

$f_{2"}$ $f_{1½"}$

Q_I Q_{Total}

$$h_{L_{reducer}} = 0.055 \cdot \frac{\frac{16 \cdot Q_I^2}{\pi^2 \cdot D_{1½''}^4}}{2g}$$

• since V would normally be the <u>downstream</u> velocity, I will use the small diameter

$$h_{L_{expansion}} = 0.2 \cdot \frac{\frac{16 \cdot Q_I^2}{\pi^2 \cdot D_{1½''}^4}}{2g}$$

• this V is normally <u>ahead</u> of the enlargement, so 1½ pipe

$$h_{L_{Tee_{right}}} = 20 \cdot f_{T_{2''}} \cdot \frac{\frac{16 \cdot Q_I^2}{\pi^2 \cdot D_{2''}^4}}{2g}$$

yikes.

$$P_1 - P_2 = h_{L_{1-2_I}} \cdot \gamma$$

$$= \Big(f_{2''} \cdot \frac{L_{2''}}{D_{2''}} \cdot \frac{16 \cdot Q_{Total}^2}{\pi^2 \cdot D_{2''}^4} \cdot \frac{1}{2g} + f_{1½''} \cdot \frac{L_{1½''}}{D_{1½''}} \cdot \frac{16 \cdot Q_I^2}{\pi^2 \cdot D_{1½''}^4} \cdot \frac{1}{2g}$$

$$+ 20 \cdot f_{T_{2''}} \cdot \frac{16 \cdot Q_{Total}^2}{\pi^2 \cdot D_{2''}^4} \cdot \frac{1}{2g} + 0.055 \cdot \frac{16 \cdot Q_I^2}{\pi^2 \cdot D_{1½''}^4} \cdot \frac{1}{2g}$$

$$+ 0.2 \cdot \frac{16 \cdot Q_I^2}{\pi^2 \cdot D_{1½''}^4} \cdot \frac{1}{2g} + 20 \cdot f_{T_{2''}} \cdot \frac{16 \cdot Q_I^2}{\pi^2 \cdot D_{2''}^4} \cdot \frac{1}{2g} \Big) \cdot \gamma$$

$$= \frac{1}{2g} \cdot \frac{16}{\pi^2} \cdot \gamma \Big(f_{2''} \cdot \frac{L_{2''}}{D_{2''}} \cdot \frac{Q_{Total}^2}{D_{2''}^4} + f_{1½''} \cdot \frac{L_{1½''}}{D_{1½''}} \cdot \frac{Q_I^2}{D_{1½}^4}$$

$$+ 20 \cdot 0.019 \cdot \frac{Q_{Total}^2}{D_{2''}^4} + 0.055 \cdot \frac{Q_I^2}{D_{1½''}^4} + 0.2 \cdot \frac{Q_I^2}{D_{1½''}^4}$$

$$+ 20 \cdot 0.019 \cdot \frac{Q_I^2}{D_{2''}^4} \Big)$$

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$$P_1-P_2=\frac{8\cdot\gamma}{g\cdot\pi^2}\left(f_{2''}\cdot\frac{600ft}{0.1723ft}\cdot\frac{Q_{Total}^2}{0.1723ft^4}+f_{1\frac{1}{2}''}\cdot\frac{900ft}{0.1342ft}\cdot\frac{Q_I^2}{0.1342ft^4}\right.$$

$$+0.380\cdot\frac{Q_{total}^2}{0.1723ft^4}+0.055\cdot\frac{Q_I^2}{0.1342ft^4}+0.2\cdot\frac{Q_I^2}{0.1342ft^4}$$

$$\left.+0.380\cdot\frac{Q_I^2}{0.1723ft^4}\right)$$

Branch 1:
$$\frac{(P_1-P_2)\cdot g\cdot\pi^2}{8\gamma}=f_{2''}\cdot\frac{600ft}{0.1723ft^5}\cdot Q_{Total}^2+f_{1\frac{1}{2}''}\cdot\frac{900ft}{0.1342ft^5}\cdot Q_I^2$$

$$+\frac{0.38}{0.1723ft^4}\cdot Q_{Total}^2+\frac{0.055}{0.1342ft^4}\cdot Q_I^2+\frac{0.2}{0.1342ft^4}\cdot Q_I^2$$

$$+\frac{0.38}{0.1723ft^4}\cdot Q_I^2)$$

Going to generate branch 2 and then decide on what to do.

Branch II

$$\frac{P_1}{\gamma}+\cancel{\frac{V_1^2}{2g}}+\cancel{z_1}=\frac{P_2}{\gamma}+\cancel{\frac{V_2^2}{2g}}+\cancel{z_2}+h_{L_{12_{II}}}$$

$$h_{L_{12_{II}}}=h_{L_{FR_{2''}}}+h_{L_{FR_{1\frac{1}{2}''}}}+h_{L_{Tee_{left}}}+h_{L_{reducer}}+h_{L_{elbow_{left}}}+h_{L_{elbow_{right}}}$$

$$+h_{L_{expansion}}+h_{L_{Tee_{right}}}$$

$$h_{L_{FR_{2''}}}=f_{2''}\cdot\frac{L_{2''}}{D_{2''}}\cdot\frac{\frac{16\cdot Q_{Total}^2}{\pi^2\cdot D_{2''}^4}}{2g}=f_{2''}\cdot\frac{L_{2''}}{D_{2''}}\cdot\frac{8\cdot Q_{Total}^2}{\pi^2\cdot D_{2''}^4\cdot g}$$

$$h_{L_{FR_{1\frac{1}{2}"}}} = f_{1\frac{1}{2}"} \cdot \frac{L_{1\frac{1}{2}"}}{D_{1\frac{1}{2}"}} \cdot \frac{16 \cdot Q_{II}^2}{\pi^2 \cdot D_{1\frac{1}{2}"}^4} \cdot \frac{1}{2g}$$ ✓

$$h_{L_{Tee_{left}}} = 60 \cdot f_{T_{2"}} \cdot \frac{16 \cdot Q_{total}^2}{\pi^2 \cdot D_{2"}^4} \cdot \frac{1}{2g}$$ ✓

$$h_{L_{reducer_{II}}} = 0.055 \cdot \frac{16 \cdot Q_{II}^2}{\pi^2 \cdot D_{1\frac{1}{2}"}^4} \cdot \frac{1}{2g}$$ ✓

$$h_{L_{elbow}} = 20 \cdot f_{T_{1\frac{1}{2}"}} \cdot \frac{16 \cdot Q_{II}^2}{\pi^2 \cdot D_{1\frac{1}{2}"}^4} \cdot \frac{1}{2g}$$ ✓ this ×2 !

$$h_{L_{expansion_{II}}} = 0.2 \cdot \frac{16 \cdot Q_{II}^2}{\pi^2 \cdot D_{1\frac{1}{2}"}^4} \cdot \frac{1}{2g}$$ ✓ · expansion uses velocity before expanding

$$h_{L_{Tee_{right}}} = 60 \cdot f_{T_{2"}} \cdot \frac{16 \cdot Q_{II}^2}{\pi^2 \cdot D_{2"}^4} \cdot \frac{1}{2g}$$ · tees use velocity coming in

$$\frac{P_1 - P_2}{\gamma} = f_{2"} \cdot \frac{660ft \cdot 8 \cdot Q_{total}^2}{0.1723ft^5 \cdot \pi^2 \cdot g} + f_{1\frac{1}{2}"} \cdot \frac{900ft \cdot 8 \cdot Q_{II}^2}{0.1342ft^5 \cdot \pi^2 \cdot g}$$

$$+ \frac{60 \cdot 0.019 \cdot 8 \cdot Q_{total}^2}{\pi^2 \cdot 0.1723ft^4 \cdot g} + \frac{0.055 \cdot 8 \cdot Q_{II}^2}{\pi^2 \cdot 0.1342ft^4 \cdot g}$$

$$+ 2\left(\frac{20 \cdot 0.02 \cdot 8 \cdot Q_{II}^2}{\pi^2 \cdot 0.1342ft^4 \cdot g}\right) + \frac{0.2 \cdot 8 \cdot Q_{II}^2}{\pi^2 \cdot 0.1342ft^4 \cdot g}$$

$$+ \frac{60 \cdot 0.019 \cdot 8 \cdot Q_{II}^2}{\pi^2 \cdot 0.1723ft^4 \cdot g}$$

$$\frac{(P_1 - P_2) \cdot \pi^2 \cdot g}{8\gamma} =$$ next page.

Branch 2: $$\frac{(P_1-P_2)\cdot\pi^2\cdot g}{8\cdot\gamma} = f_{2''}\cdot\frac{600ft\cdot Q_{TOTAL}^2}{0.1723ft^5} + f_{1\frac{1}{2}''}\cdot\frac{900ft\cdot Q_{II}^2}{0.1342ft^5}$$

$$+\frac{1.14\cdot Q_{TOTAL}^2}{0.1723ft^4} + \frac{0.055\cdot Q_{II}^2}{0.1342ft^4} + \frac{0.8\cdot Q_{II}^2}{0.1342ft^4}$$

$$+\frac{0.2\cdot Q_{II}^2}{0.1342ft^4} + \frac{1.14\cdot Q_{II}^2}{0.1723ft^4}$$

$Q_{Total} = Q_I + Q_{II}$

unknowns: $f_{2''}$, $f_{1\frac{1}{2}''}$, Q_I , Q_{II} , Q_{Total}

Thinking

- may solve branch$_I$ equation for Q_I, solve branch$_{II}$ equation for Q_{II}, replace in Q_{Total} equation
  - ugly, but should be doable.

Starting with Branch I

- $$\frac{(P_1-P_2)\cdot g\cdot\pi^2}{8\gamma} - f_{2''}\cdot\frac{600ft}{0.1723ft^5}\cdot Q_{Total}^2 - \frac{0.38}{0.1723ft^4}\cdot Q_{Total}^2 =$$

$$Q_I^2\cdot\left(f_{1\frac{1}{2}''}\cdot\frac{900ft}{0.1342ft^5} + \frac{0.055}{0.1342ft^4} + \frac{0.2}{0.1342ft^4} + \frac{0.38}{0.1723ft^4}\right)$$

- $$\cancel{\frac{(P_1-P_2)\cdot g\cdot\pi^2}{8\gamma} - \left(f_{2''}\cdot\frac{600ft}{0.1723ft^5} - \frac{0.38}{0.1723ft^4}\right)\cdot Q_{Total}^2 =}$$

$$\cancel{Q_I^2\cdot\left(f_{1\frac{1}{2}''}\cdot 20.67785556\times10^6\frac{1}{ft^4}\right)}$$

accidentally added the part being multiplied by $f_{1\frac{1}{2}''}$

$$\cancel{\left[\frac{\frac{(P_1-P_2)\cdot g\cdot \pi^2}{8\cdot \gamma} - Q_{Total}^2\cdot\left(f_{2''}\cdot 3.950731\cdot 10^6\,\frac{1}{ft^4}\right)}{\left(f_{1\frac{1}{2}''}\cdot 20.6778556\cdot 10^6\,\frac{1}{ft^4}\right)}\right]^{-\frac{1}{2}}} = Q_I$$

Moving to branch II

- $$\frac{(P_1-P_2)\cdot g\cdot \pi^2}{8\cdot \gamma} - f_{2''}\cdot\frac{600\,ft\cdot Q_{Total}^2}{0.1723\,ft^5} - \frac{1.14\cdot Q_{Total}^2}{0.1723\,ft^4} =$$

$$Q_{II}^2\cdot\left(f_{1\frac{1}{2}''}\cdot\frac{900\,ft}{0.1342\,ft^5} + \frac{0.055}{0.1342\,ft^4} + \frac{0.8}{0.1342\,ft^4} + \frac{0.2}{0.1342\,ft^4} + \frac{1.14}{0.1723\,ft^4}\right)$$

- $$\frac{(P_1-P_2)\cdot g\cdot \pi^2}{8\,\gamma} - Q_{Total}^2\cdot\left(f_{2''}\cdot\frac{600\,ft}{0.1723\,ft^5} - \frac{1.14}{0.1723\,ft^4}\right) =$$

$$Q_{II}^2\cdot\left(\left(f_{1\frac{1}{2}''}\cdot\frac{900\,ft}{0.1342\,ft^5}\right) + 3929.7569\,\frac{1}{ft^4}\right)$$

· realized I made an error in branch$_I$ and will fix after this.

★ $$Q_{II} = \left[\frac{\frac{(P_1-P_2)\cdot g\cdot \pi^2}{8\cdot \gamma} - Q_{Total}^2\cdot\left(f_{2''}\cdot\frac{600\,ft}{0.1723\,ft^5} - \frac{1.14}{0.1723\,ft^4}\right)}{f_{1\frac{1}{2}''}\cdot\frac{900\,ft}{0.1342\,ft^5} + \underset{4546.1799\,\frac{1}{ft^4}}{3929.7569\,\frac{1}{ft^4}}}\right]^{\frac{1}{2}}$$

Correcting branch I

$$\frac{(P_1-P_2)\cdot g\cdot\pi^2}{8\gamma} - Q_{Total}^2\cdot\left(f_{2''}\cdot\frac{600ft}{0.1723ft^5} - \frac{0.38}{0.1723ft^4}\right) =$$

$$Q_{I}^2\cdot\left(f_{1\frac{1}{2}''}\cdot\frac{900ft}{0.1342ft^5} + 1217.3587\frac{1}{ft^4}\right)$$

$$* \quad Q_I = \left[\frac{\frac{(P_1-P_2)\cdot g\cdot\pi^2}{8\cdot\gamma} - Q_{Total}^2\cdot\left(f_{2''}\cdot\frac{600ft}{0.1723ft^5} - \frac{0.38}{0.1723ft^4}\right)}{f_{1\frac{1}{2}''}\cdot\frac{900ft}{0.1342ft^5} + 1217.3587\frac{1}{ft^4}}\right]^{1/2}$$

Putting it together

$$Q_{Total} = Q_I + Q_{II}$$

$$Q_{Total} = \left[\frac{\frac{(P_1-P_2)\cdot g\cdot\pi^2}{8\cdot\gamma} - Q_{Total}^2\left(f_{2''}\cdot\frac{600ft}{0.1723ft^5} - \frac{0.38}{0.1723ft^4}\right)}{f_{1\frac{1}{2}''}\cdot\frac{900ft}{0.1342ft^5} + 1217.3587\frac{1}{ft^4}}\right]^{1/2} +$$

$$\left[\frac{\frac{(P_1-P_2)\cdot g\cdot\pi^2}{8\cdot\gamma} - Q_{Total}^2\left(f_{2''}\cdot\frac{600ft}{0.1723ft^5} - \frac{1.14}{0.1723ft^4}\right)}{f_{1\frac{1}{2}''}\cdot\frac{900ft}{0.1342ft^5} + 3929.7564\frac{1}{ft^4}}\right]^{1/2}$$

Unknowns now: $f_{2''}$, $f_{1\frac{1}{2}''}$, Q_{Total}

In conjunction w/ excel

$$\frac{P_1 - P_2 \cdot g \cdot \pi^2}{8 \cdot \gamma} \qquad \frac{\cancel{lb}}{\cancel{ft^2}} \cdot \frac{ft}{s^2} \cdot \frac{ft^{\cancel{3}\,2}}{\cancel{lb}} \Rightarrow \frac{ft^2}{s^2}$$

$$Q \quad \frac{ft^3}{s} \Rightarrow \frac{ft^6}{s^2} \cdot \frac{1}{ft^4} = \frac{ft^2}{s^2} \qquad \text{num.} \cdot \frac{ft^4}{1} \Rightarrow \sqrt{\frac{ft^6}{s^2}} = \frac{ft^3}{s} \checkmark$$

testing Q_I with

$Q_{Total} = 0.2$ $\qquad Q_I^2 = -20K$

$f_{2''} = 0.15$ $\qquad$ uhhh.

$f_{1.5''} = 0.2$

seems $f_{2''}$ way too big to start.

changing to 0.02

good, Q_I in excel setup correctly ✓

so, I began thinking about whether my excel method was sufficient and what I could do to be more sure.

- if I take my output Q_{Total}, make a V_{Total}, then get Re from V_{Total} and calculate $f_{2''}$, I can compare my $f_{2''}$ accuracy.

$Q = V \cdot A$

$V = Q/A$

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7 \cdot D/\varepsilon} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

Doing this confirmed my $f_{2''}$ can be closer.

There is now an inherent problem.

The problem statement says what is the

expected <u>increase</u> in flow rate

but currently, my best work yields $Q_{TOTAL} = 0.138\ ft^3/s$,

which is lower than scenario 1's $0.1447\ ft^3/s$ ...

- I am now thinking my $f_{1\frac{1}{2}''}$ needs to be one for branch$_I$ and another for branch$_{II}$, to account for their different flow rates.

womp womp.

Boy, that is going to be painful.

- well, I did it. it isn't pretty. I am mostly confused conceptually.
  → how can the flow rate increase w/ pressure staying the same + more loss-causing objects in the path?
    → each h_L individually would be lesser (because there are more of them totalling the same pressure), and to be lesser, we only have control over <u>velocity</u>

emailed Dr. Ayala :)

after talking with Dr Ayala, he says my method is correct (yay!), so I likely just have errors made that have cascaded through.

Basics: verify data from page 1

data block checks out ✓

Reynolds for scenario 1: $\dfrac{\rho \cdot V \cdot D}{\eta}$

$A_{2''} = \dfrac{\pi \cdot (0.1723 ft)^2}{4} = 0.023316343 ft^2$

$V_{2''} = Q/A = 6.2087781 ft/s$

$Re = \dfrac{1.94 \frac{lb \cdot s^2}{ft^4} \cdot 6.2087781 \frac{ft}{s} \cdot 0.1723 ft}{2.35 \cdot 10^{-5} \frac{lb \cdot s}{ft^2}} = \underline{8.831313 \cdot 10^4}$

uh oh, I have 10^5 on pg 2. may have already found a sizable problem.

$D/\varepsilon = \dfrac{0.1723 ft}{1.5 \cdot 10^{-4} ft} = 1148.6667$

$f = 0.022167$ uh oh

$h_{L_{FR}} = f \cdot \dfrac{L}{D} \cdot \dfrac{V^2}{2g} = 0.22167 \cdot \dfrac{1500 ft}{0.1723 ft} \cdot \left(\dfrac{6.2087781 ft/s}{2 \cdot 32.2 ft/s^2} \right)^2 = 115.515247 ft$

$P_1 - P_2 = h_{L_{FR}} \cdot \gamma = 7208.1514 \dfrac{lb}{ft^2} \cdot \dfrac{1 ft^2}{144 in^2} = \underline{50.0566 psi}$

scenario one ΔP.

Moving to Page 10

$\dfrac{(P_1 - P_2) \cdot g \cdot \pi^2}{8 \cdot \gamma} = 4588.8614 \dfrac{ft^2}{s^2}$ — changed in excel

Dr. Ayala says that if $f_{1\frac{1}{2}''_{II}}$ changed $\rightarrow \infty$, , $Q_{TOTAL} \approx 65 gpm$ of scenario 1 like closing valve.

hm, somehow setting my $f_{1\frac{1}{2}"_{II}} \rightarrow 0.5$ still yields 0.087 ft³/s ≈ 39 gpm.

caught entry error on page 8 in Q_{II} equation

well, I still get 0.087 $\frac{ft^3}{s}$ for Q_I ӥ

testing if B20) − B21 should be + ...

didn't really change anything ӥ

B19 − ((A87^2 should be + ...

changes Q_{Total} to 0.130 ft³/s ≈ 58.37 gpm.

Looks like I made a classic algebra booboo.

in both Q_I & Q_{II} equations, when I pulled out Q_{Total}^2...

Should be:

$$Q_{Total} = \left[\frac{\frac{(P_1-P_2)\cdot g\cdot \pi^2}{8\cdot \gamma} + Q_{Total}^2\cdot\left(f_{2"}\cdot\frac{600ft}{0.1723ft^5} - \frac{0.38}{0.1723ft^4}\right)}{f_{1\frac{1}{2}"}\cdot\frac{900ft}{0.1342ft^5} + 1217.3587\frac{1}{ft^4}}\right]^{1/2} +$$

$$\left[\frac{\frac{(P_1-P_2)\cdot g\cdot \pi^2}{8\cdot \gamma} + Q_{Total}^2\cdot\left(f_{2"}\cdot\frac{600ft}{0.1723ft^5} - \frac{1.14}{0.1723ft^4}\right)}{f_{1\frac{1}{2}"}\cdot\frac{900ft}{0.1342ft^5} + 4546.1799\frac{1}{ft^4}}\right]^{1/2}$$

problem: after returning to excel, when I tweak my Q_{Total} to be the most right & simulate closing branch II, my Q_{Total} (output) stays way too high

like $f_{II} = 0.9$, $Q_{Total} = 99$ gpm

Summary:

The pressure drop is both scenarios is determined to be 50.06psi. Through the use of excel, the total flow rate is expected to improve to 0.188ft^3/s or 84.78GPM, from the 65GPM of scenario 1. Q1 is estimated to be 57.25GPM and Q2 is estimated to be 27.55GPM. The friction factor of the 2" steel pipe is estimated to be 0.022. The friction factor of branch 1 is estimated to be 0.023. The friction factor of branch 2 is estimated to be 0.020

Materials:

600ft of 2" steel pipe

1800ft of 1.5" steel pipe (2 channels of 900ft each)

Two tee joints

Two reducers are 50 degrees

Two long-radius elbows

Two expansion points at 20 degrees

Analysis:

Adding a parallel branch allows more water to flow through, though this will require more caution in ensuring that water hammer does not occur. An interesting consideration would be seeing how different forms of parallel pipelines affect the who and each other. For example: If a third branch was placed directly below the existing branch 2, would it also be able to handle something like the 27GPM of branch 2? Would the values in branch 1 and branch 2 drop slightly?

Another style: If four parallel branches surrounded the main branch (like a squirrel cage rotor), each being 90 degrees apart and equidistant, would they each split the flow evenly? I can't think of a use for such a Frankstein-like design, but it is fun to consider.

Either way, when adding these parallel branches, the volume flow is able to increase and that demands extra consideration for water hammer concerns. Must make building water system demands fairly difficult, given how the system sprawls.