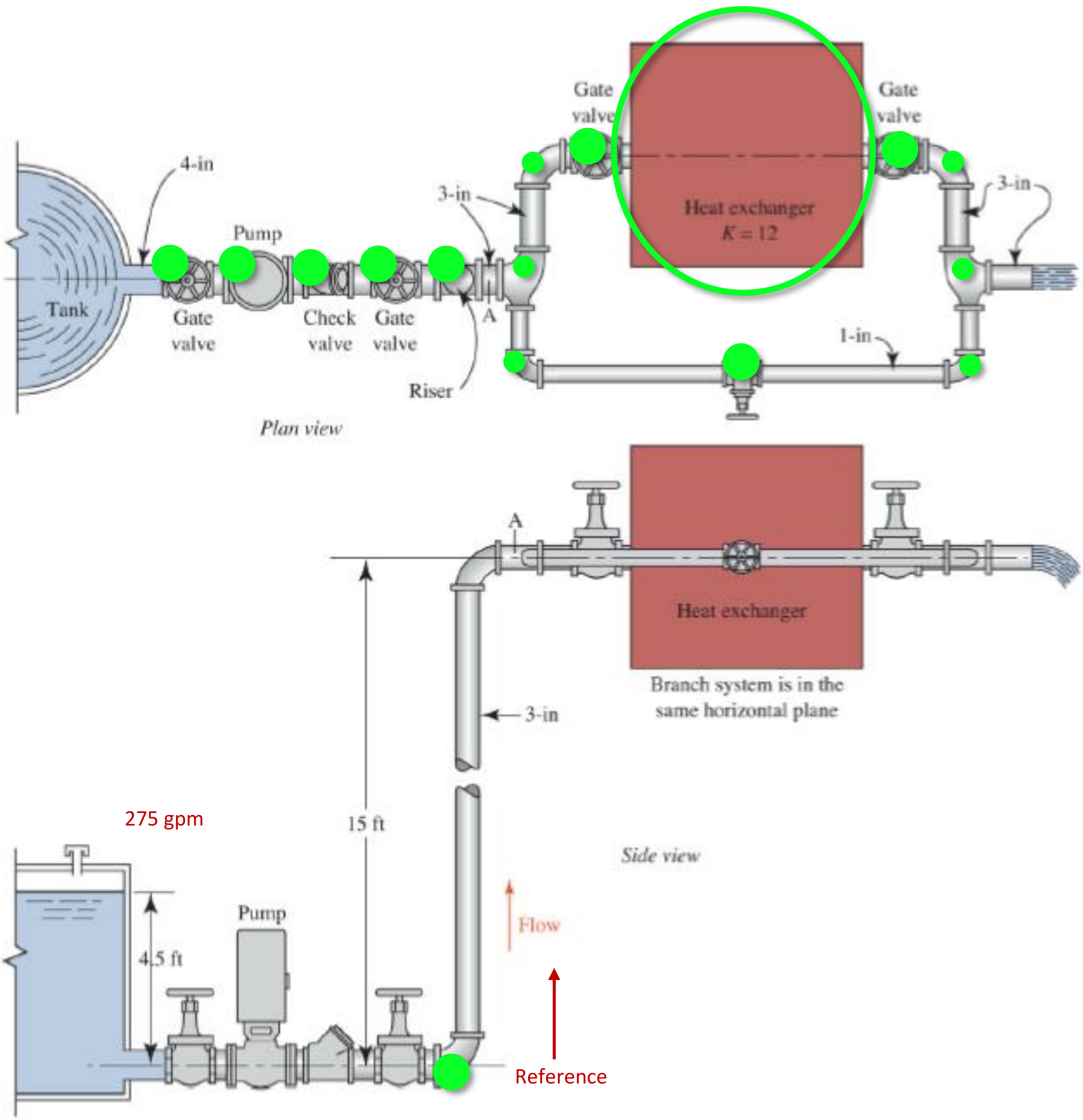
Purpose

Purpose of part A, is to determine the correct specification for a pump that is to supply water movement throughout the identified system for company "A". With the pump efficiency at 70%, the power of the pump is to be calculated when the identified gate valve is at the fully closed position. Also, a required minimal flowrate of 275 gpm must be met through the heat exchanger. Purpose of part B, is to calculate the total flowrate at varying positions of the gate. The gate valve is to be at 1/4 |1/2 |3/4 and fully open. This is to be determined by varying the "K" value of the valve flowrate of 275 gpm should also be met once again.

Drawings & Diagrams



Sources

Mott, R., Untener, J.A. "Applied Fluid Mechanics", 7th edition Pearson Education, Inc, (2015)

Design Considerations

-Series and parallel piping configurations

-Energy losses throughout the system= gate valve | Check Valve | Riser | Elbows | Suction line | Discharge line

-Heat Exchanger interaction with fluid / valves

-Pump flow rate= constant 275 gpm | Pump Efficiency 70%

-Piping lengths= Vertical 15ft | 2x Branch 8ft | Suction line 10ft | Bypass 30ft

-Piping diameters= 1-in | 3-in | 4-in

-Valve Positions= ¼ turn | ½ turn | ¾ turn | Fully opened

Data Variables:

-Calculated Energy Losses / Friction Factors

-Pipe Roughness, Steel, commercial or welded pg. 185= ϵ $1.50\text{x}10^{-4}$

-1-in schedule 40 pipe pg. 500= ID .0874ft | Flow Area .00600ft^2

-3-in schedule 40 pipe pg. 500= ID .2557ft | Flow Area .05132ft^2

-4-in schedule 40 pipe pg. 500= ID .3355ft | Flow Area .08840ft^2

-**Fluid, Water H_2O @ 160^of pg. 489** | γ = 61 lb/ft^3 | ρ = 1.90 slug/ft^3| Dynamic Viscosity $\eta = 8.30\text{x}10^{-6}$ Pas

| Kinematic Viscosity = $4.38\text{x}10^{-6}$

Procedure:

First, review provided sketch of system to determine system components. Part A, utilize to establish h_A & h_L of the system. Then solve for energy losses within heat exchanger/pipe A section of the system. Then pump head would need to be calculated along with energy losses, pipe friction factors throughout the system. After pump head is calculated, using the giving pump efficiency, pump power will be determined. For part B, Bernoulli's would have to be used throughout to establish correct values for flowrates throughout the system and heat exchanger. Conservation of mass would be established, reflecting branch 1 and 2. Utilize calculation results to establish correct the flow rate and "K" values at the ¼, ½, ¾, fully opened position.

Calculations:

Part 1A Solve for h_A + h_L

Calculations Done In Excel

4" $V = 6.93\ ft/s^2$ = f .0174
3" $V = 11.94\ ft/s^2$ = f .0181
1" $V = 107.12\ ft/s^2$ = f .0226
$g = 32.2\ ft/s^2$

4" f_T = .0163
3" f_T = .0173
1" f_T = .0225

①

$$\cancel{\frac{P_A}{\gamma}} + \cancel{\frac{V_1^2}{2g}} + Z_1 + h_A = \cancel{\frac{P_B}{\gamma}} + \frac{V_2^2}{2g} + Z_2 + h_L$$

$$= Z_1 + h_A = Z_2 + h_L \Rightarrow h_A = (Z_2 - Z_1) \frac{V^2}{2g} + h_L$$

② Energy losses

h_L 4" Gate Valve $= 2\left(K \cdot \left(\frac{V^2}{2g}\right)\right) = (8)\left(\frac{6.93^2}{2(32.2)}\right) = 5.968\ ft = \boxed{.097\ ft}$

h_L 3" Check Valve $= (K)\left(\frac{V^2}{2g}\right) = (100)\left(\frac{11.94^2}{2(32.2)}\right) = 221.37\ ft = \boxed{3.83\ ft}$

h_L 4" Pipe $= f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) = .0174\left(\frac{10\ ft}{.3355}\right)\left(\frac{6.93^2}{2(32.2)}\right) = \boxed{.387\ ft}$

h_L 3" Pipe $= f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) = .0181\left(\frac{48\ ft}{.2557}\right)\left(\frac{11.94^2}{2(32.2)}\right) = \boxed{7.521\ ft}$

h_L 3" Elbow $= 4\left(K \cdot \frac{V^2}{2g}\right) = (30)\left(\frac{11.94^2}{2(32.2)}\right) = 66.41\ ft \quad 4(66.41) = 265.64\ ft = \boxed{4.6\ ft}$

h_L 3" gate valve $= 2\left(K \cdot \frac{V^2}{2g}\right) = (8)\left(\frac{11.94^2}{2(32.2)}\right) = 17.7094 \quad 3(17.709) = 53.12\ ft = \boxed{.919\ ft}$

h_L 3" Pipe Tee $= 2\left(K \cdot \left(\frac{V^2}{2g}\right)\right) = 60\left(\frac{11.94^2}{2(32.2)}\right) = 132.82\ ft \quad 2(132.82) = 265.64\ ft = \boxed{4.59\ ft}$

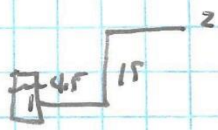
h_L HX $= K\left(\frac{V^2}{2g}\right) = 12\left(\frac{11.94^2}{2(32.2)}\right) = \boxed{26.56\ ft}$

h_L Entrance $= K\left(\frac{V^2}{2g}\right) = .5\left(\frac{6.93^2}{2(32.2)}\right) = \boxed{.372\ ft}$

h_L Total $= .097 + 3.83 + 3.87 + 7.521 + 4.6 + .919 + 4.59 + 26.56 + .372 = \boxed{48.87}$

1

③ Pump Head + Eff.



$\cdot\ h_A = (z_2 - z_1)\ \frac{v^2}{2g} + h_L \implies h_A = (15-4.5)\ 2.21 + 48.81$

$\cdot\ h_A = \boxed{72.16\ ft}$

$\cdot\ P_A = h_A \gamma Q \qquad Q = 275\ gpm = .613\ ft^3/s \ ,\quad \gamma = 61\ lb/ft^3$

$\cdot\ P_A = (72.165\ ft)(.613\ \cancel{ft^3}/s)(61\ lb/\cancel{ft^3}) = 2629.66\ ft\,lb/s$

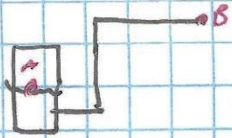
$\cdot\ P_A = \frac{2629.66}{550} = \boxed{4.90\ hp}$

$\cdot\ \underset{Pump}{Efficiency} = \frac{P_A}{P_I} \implies P_I = \frac{P_A}{Eff\ pump}$

$\cdot\ P_I = \frac{4.9}{.7} = \boxed{7.00\ hp}$

2nd attempt

Part B Solve for Q



$h_A = \frac{P_A}{\gamma Q}$ $\quad \Delta z = 10.5$

$\boxed{h_A} + \cancel{\frac{P_1}{\gamma}} + z_1 + \cancel{\frac{v_1^2}{2g}} = \cancel{\frac{P_2}{\gamma}} + \cancel{\frac{v_2^2}{2g}} + z_2 + h_L$

$\frac{P_A}{\gamma Q} = \Delta z + h_L$

$Q = .613$?
$h_A = 70.96$
h_L = branch 1
GV = gate valve
C.V. Check valve
h_X = heat exchanger

Branch 1 A-B — Not sure if it 1 equation or 2, I think its same equation + Branch 2

$h_L = h_L + h_L + h_L + h_L + h_L + h_L + h_L + h_L + h_L$ | Branch 1 $+ h_L + h_L + h_L + h_L + h_L + h_L$

	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	⑮
AB	4"	4"	4"	3"	3"	3"	3"	3"	Tee	3"	3"	hx	3"	3"	Tee
	Entr.	Pipe	G.V.	C.V.	G.V.	Elbow	pipe	Elbow		Elbow	G.V.		G.V.	Elbow	

- $P_A = h_A \gamma Q$
- $h_A = \frac{P_A}{\gamma Q}$

Branch 2 A

- $Q_2 = Q_A + Q_B$

$h_L = h_L + h_L + h_L + h_L + h_L + h_L + h_L + h_L + h_L$ | Branch 2 $+ h_L + h_L + h_L + h_L + h_L + h_L$

	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	⑮
AB	4"	4"	4"	3"	3"	3"	3"	3"	Tee	1"	1"	1"	1"	1"	Tee
	Entr	Pipe	GV	C.V.	G.V.	Elbow	pipe	Elbow		Pipe	Elbow	G.V.	G.V.	Elbow	

Not Need

- $\frac{V_1^2}{2g} = \frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}$

Branch 1

- $\frac{P_A}{\gamma Q} = 10.5 + \underset{\text{①}\ \cancel{\text{Ent}}\ 4''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{②}\ \cancel{\text{Pipe}}\ 4''}{f\frac{L}{D}\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{③}\ \cancel{\text{G.V.}}\ 4''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{④}\ \cancel{\text{C.V.}}\ 3''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{⑤}\ \cancel{\text{G.V.}}\ 3''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{⑥}\ \cancel{\text{Elbow}}\ 3''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} +$

$\underset{\text{⑦}\ \cancel{\text{Pipe}}\ 3''}{f\frac{L}{D}\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{⑧}\ \cancel{\text{Elbow}}\ 3''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{⑨}\ \cancel{\text{Tee}}}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{⑩}\ \cancel{\text{Elbow}}\ 3''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{⑪}\ \cancel{\text{G.V.}}\ 3''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{⑫}\ \cancel{\text{Hx}}}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} + \underset{\text{⑬}\ \cancel{\text{G.V.}}\ 3''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 D^4}} +$

$\underset{\text{⑭}\ \cancel{\text{Elbow}}\ 3''}{K\frac{1}{2g}\frac{16Q^2}{\pi^2 d^4}} + \underset{\text{⑮}\ \cancel{\text{Tee}}}{K\frac{1}{2g}\frac{16Q^2}{\pi d^4}}$

① Ent 4" = 1
② GV 4" = 1
③ Pipe 4" = 1
④ C.V. 3" = 1
⑤ GV 3" = 3
⑥ Elbow 3" = 4
⑦ Tee = 2
⑧ Hx = 1
⑨ Pipe 3" = 1

- 3" ID = .2557
- 4" ID = .3355
- 1" ID = .0874

$\frac{16}{\pi^2 D^4}\frac{1}{2g}$
5.888
1.987
431.4

f
4" = .0174
3" = .0181
1" = .0226

- $\frac{P_A}{\gamma Q} = 10.5 + Q^2\Big(\underset{\text{①}\ \text{Ent}}{(.5)(1.987)} + \underset{\text{②}\ \text{G.V.}\ 4''}{(8)(.0174)(1.987)} + \underset{\text{④}\ \text{C.V.}\ 3''}{(100)(.0181)(5.888)} +$

$\underset{\text{⑤}\ \text{G.V.}\ 3''}{3(8)(.0181)(5.888)} + \underset{\text{⑥}\ \text{Elbow}\ 3''}{4(30)(.0181)(5.888)} + \underset{\text{⑦}\ \text{Tee}}{2(60)(.0181)(5.888)} + \underset{\text{⑧}\ \text{Hx}}{(12)(5.888)}$

$+ \underset{\text{⑧}\ 4''\ \text{Pipe}}{(.0174)(29.81)(1.987)} + \underset{\text{⑨}\ 3''\ \text{Pipe}}{(.0181)(187.72)(5.88)} = \rightarrow$

③

$$\frac{P_A}{\gamma Q} = 10.5 + Q^2\left(.994\right) + (.277) + (10.643) + (2.554) + (12.789) + (12.789) + (70.656) +$$

① Ent ② GV ④ CV ⑤ GV ⑥ Elbow ⑦ Tee ⑧ hx

$$(1.031) + (19.979) \quad \underline{= 131.699}$$

③ 4" pipe ⑨ 3" pipe

* $P_A = 2695.02$
$\gamma = 61$

$$= \frac{2695.02}{61} = 10.5 + Q^3(131.699)$$

$$= \frac{\frac{2695.02}{61} - 10.5}{131.699} = Q^3$$

$$= \sqrt[3]{\frac{\frac{2695.02}{61} - 10.5}{131.699}} = Q$$

* 448.831 gal/min

$$Q_1 = \sqrt[3]{\frac{33.1681}{131.699}} = \underline{.635 \text{ ft}^3/\text{s} \text{ or } 448.831(.635) = 285.01 \text{ gpm}}$$

<u>Conservation of mass</u> $Q_3 = Q_1 + Q_2$

Need Branch 2

① Branch 2

$$h_L \text{ Branch 1 up to Tee} + f\frac{L}{D}\frac{1}{g}\frac{16Q^2}{\pi^2 d^4} + K_L\frac{1}{g}\frac{16Q^2}{\pi^2 d^4} + K_L\frac{1}{2g}\frac{16Q^2}{\pi^2 d^4} + K_L\frac{1}{g}\frac{16Q^2}{\pi^2 d^4} + K_L\frac{1}{g}\frac{16Q^2}{\pi^2 d^4}$$

Pipe 1" Elbow 1" G.V. 1" Elbow 1" Tee 3"

$$15.942 + (.0026)(343.25)(431.4) + 2(30)(.0026)(431.4) + (8)(.0026)(431.4) + (60)(.0181)(5.88)$$

Pipe 1" Elbow 1" G.V. Tee 3"

h_L Branch 2 $=$ 385.00 + 67.298 + 8.973 + 6.386

Pipe 1" Elbow 1" G.V. 1" Tee 3"

h_L Branch 2 $= 467.657 + h_{L1}(15.942) = \boxed{h_L \text{ Total Branch}_2 = 483.59}$

②

$$\frac{P_A}{\gamma Q} = \Delta z + h_L \quad , \quad Q = \sqrt[3]{\frac{\frac{P_A}{61} - \Delta z}{h_L}}$$

$P_A = 2695.02$

$$Q_2 = \sqrt[3]{\frac{\frac{2695.02}{61} - 10.5}{483.59}} = \boxed{.411\ ft^3/s \text{ or } 448.831(.411) = 184.66\ gpm}$$

Conservation of mass $Q_3 = Q_2 + Q_1$

LHS RHS

$Q_3 = 184.66 + 285.01$

$469.67 = 184.66 + 285.01$

h_A	$h_A=(Z_1-Z_2)V^2/2g_1h_L$	72.11	ft	_	_
P_A	$P_A=h_A \Upsilon Q/550$	4.90	hp	_	_
Pump $_{Efficiency}$	$PI=P_A/P_{Eff}$	7.00	hp	_	_

hL_{AB} Total Branch 1	131.755

$$\frac{PA}{\gamma Q}=\Delta Z+hL$$

$$Q=\frac{\sqrt[3]{\frac{P_a-\Delta Z}{61}}}{hL}$$

Q (ft^3/s	0.635
Q (gpm)	284.853

hL_{AB} Total Branch 2	477.216

$$\frac{PA}{\gamma Q}=\Delta Z+hL$$

$$Q=\frac{\sqrt[3]{\frac{P_a-\Delta Z}{61}}}{hL}$$

Q_2 lower (ft^3/s	0.413
Q (gpm)	185.483
Q_1 upper (ft^3/s	0.635
Q (gpm)	284.853
Conservation of Mass $Q_3=Q_1+Q_2$	470.336

Summary:

For part A, the energy losses of the system were calculated from top of the tank water all through the end of the piping of the system following the branch 1 “upper branch”. This included overall piping for the identified diameters, piping elbow, joints and valves. Once energy the losses “h_L“ were calculated, in order to find pump efficiency / power, the pressure head of the system needed to be determined. It was found that in order to deliver the 275-gpm required, if the pump was at 70% efficiency the power needed would be approximately 7hp. For part B, once again energy losses needed to be established for upper branch 1 and also lower branch 2. Once energy losses were calculated, it was found that branch 1 allowed for a flowrate of 284 gpm with branch 2 at the fully open position, allowing for a flowrate of 185 gpm. The narrower piping caused a slower flow through the system within branch two. Conservation of mass was accounted for, setting overall Q1 & Q2 within the system again tabulated Q3. Unfortunately, I was not able to use the iteration method to calculate difference in varying flow with the gate valve opened at different set positions.

Materials:

-1-in schedule 40 pipe

-3-in schedule 40 pipe

-4-in schedule 40 pipe

-Fluid, Water H_2O @ 160^{o}f

-Pump

-Heat exchanger

Analysis:

-Part A, required pump power would be approximately 7hp, to account for all energy losses from tank water through branch 1 “upper” exiting the system.

-Pump head needed to be accounted for along with various sources of energy losses.

-Part B, Pump head needed to be accounted for when calculating for variance in flow rate as gate valve was set at varying positions.

-Was not able to determine correct flow at set position due to human errors while iterating.

-Conservation of mass, was established through the system and calculations

-Calculations determined as water flowed within branch 2 “lower” overall flowrate was “lower” due to the 1” narrower pipe Energy loses / friction appeared to be more apparent.