Name: Austin Goodman.

MET 330 Fluid Mechanics
Dr. Orlando Ayala
Fall 2022
Test 3

Take home – Due Tuesday November 22nd 2022 before midnight.

READ FIRST

1. RELAX!!!! DO NOT OVERTHINK THE PROBLEMS!!!! There is nothing hidden. The test was designed for you to pass and get the maximum number of points, while learning at the same time. HINT: THINK BEFORE TRYING TO USE/FIND EQUATIONS (OR EVEN FIND SIMILAR PROBLEMS)

2. The total points on this test are one hundred (100). Ten (10) points are from your HW assignments, the other eighty (90) points will come from the problem solutions. I will not grade neither give you points for the technical writing, if you still want to present your test following the technical writing, you can follow the attached rubric. Remember that if you are not in the project group, the HW assignments will not be considered on the grading.

3. There are 2 problems, but you are supposed to solve only one. It is your choice. If you solve both, I will grade only one and give you extra 10 points towards the 2nd test for the second problem you solve (if correctly solved). You need to tell me which problem you want me to grade towards this third test. The problem you pick to be graded is worth all 90 points.

4. What you turn in should be only your own work. You cannot discuss the exam with anyone, except me. Call me, skype me, text me, email me, come to my office, if you have any question.

5. I do not read minds. You should be explicit and organized in your answers. Use drawings/figures. If you make a mistake, do not erase it. Rather use that opportunity to explain why you think it is a mistake and show the way to correct the problem.

6. You have to turn in your test ON TIME and ONLY through BLACKBOARD. You must submit your solution as a pdf file and the excel spreadsheet. For the ePortfolio (which is optional) you are supposed to upload this artifact to your Google drive.

7. Do not start at the last minute so you can handle anything that could happen. Late tests will not be accepted. Test submitted through email will not be accepted either.

8. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University you have accepted the responsibility to abide by this code. This is an institutional policy approved by the Board of Visitors. It is important to remind you the following part of the Honor Code:

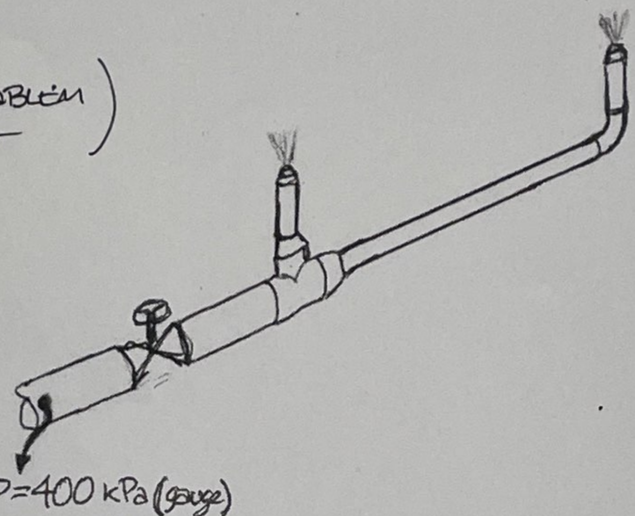
   IX. PROHIBITED CONDUCT
   A. Academic Integrity violations, including:
   1. *Cheating*: Using unauthorized assistance, materials, study aids, or other information in any academic exercise (Examples of cheating include, but are not limited to, the following: using unapproved resources or assistance to complete an assignment, paper, project, quiz or exam; collaborating in violation of a faculty member's instructions; and submitting the same, or substantially the same, paper to more than one course for academic credit without first obtaining the approval of faculty).

   With that said, you are NOT authorized to use any online source of any type, unless is ODU related.

1) The system sketched in the figure is an automatic sprinfler system for a narrow plot of lawn. Water is supply by a main that guarantees a constant pressure of 400 kPa (gauge). The sprinkler pipeline is made of schedule-40 steel pipe. For a wide-open ball valve, determine the flow rate delivered to each sprinkler head. Do not neglect minor losses. The characteristic of the system is as follows:

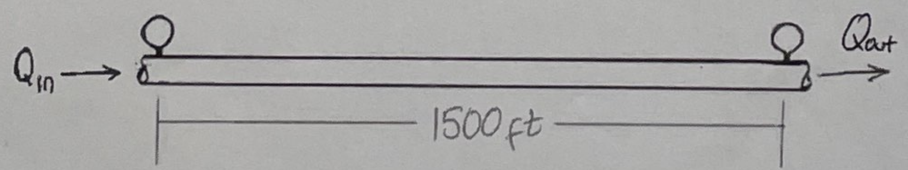
a. From point where pressure is 400 kPa to the T-joint: 1 ½ inches nominal pipe of 6.5 m.
b. From T_joint to 1st sprinkler head: 1 inch nominal pipe of 0.3 m.
c. From T_joint to 2nd sprinkler head: 1 inch nominal pipe of 8.3 m.
d. K of the sprinkler head is 50.

(GRADE THIS PROBLEM FOR THE TEST)

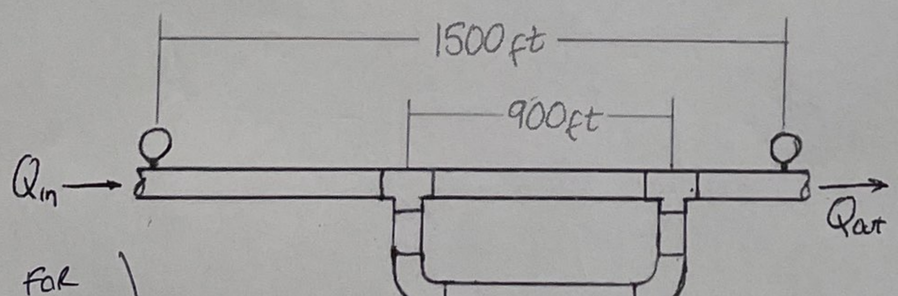


Are the flows through each sprinkler the same? If not, what would you do to make them the same? How does the fluid velocity compare to the critical velocity (3 m/s)? If it is too far off, what would you do?

2) A horizontally laid 2 inches standard steel tubing is 1500 ft long and has water passing through it at a 65 gpm flow rate. Determine the corresponding pressure drop



The pipe is modified by adding a loop made of 1 ½ inches standard steel tubing that is only 900 ft long. What is the expected increase in flow rate through the system for the same pressure as in the original pipe (the one you calculated)? Consider all minor losses.



(GRADE FOR EXTRA CREDIT)

(900) ΔP 50.4 psi

$Q_T = V_1A_1 + V_2A_2$

Problem solution rubric

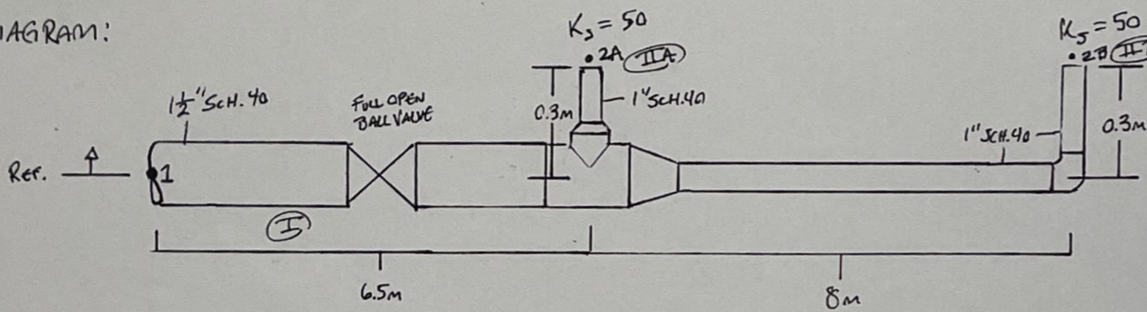
	Exceeds Standard	Meets Standard	Approaches Standard	Needs Attention
	4	3	2	1
	10 points	7 points	4 points	0 points
1. Purpose 5%	The purpose of the section to be answered is clearly identified and stated.	The purpose of the section to be answered is identified, but is stated in a somewhat unclear manner.	The purpose of the section to be answered is partially identified, and is stated in a somewhat unclear manner.	The purpose of the section to be answered is erroneous or irrelevant.
2. Drawings & Diagrams 10%	Clear and accurate diagrams are included and make the section easier to understand. Diagrams are labeled neatly and accurately.	Diagrams are included and are labeled neatly and accurately.	Diagrams are included and are labeled.	Needed diagrams are missing OR are missing important labels.
3. Sources 5%	Several reputable background sources were used and cited correctly.	A few reputable background sources are used and cited correctly.	A few background sources are used and cited correctly, but some are not reputable sources.	Background sources are cited incorrectly.
4. Design considerations (assumptions, safety, cost, etc) 10%	Design is carried out with applicable assumptions and full attention to safety and cost, etc.	Design is generally carried out with assumptions and attention to safety, cost, etc.	Design is carried out with some assumptions and some attention to safety, cost, etc.	Assumptions, safety and cost were ignored in the design.
5. Data and variables 5%	All data and variables are clearly described with all relevant details.	All data and variables are clearly described with most relevant details.	Most data and variables are clearly described with most relevant details.	Data and variables are not described OR the majority lack sufficient detail.
6. Procedure 25%	Procedure is described in clear steps. The step description is in a complete and easy to understand short paragraph.	Procedure is described in clear steps but the step description is not in a complete short paragraph.	Procedure is described in clear steps. The step description is in a complete short paragraph but it is difficult to understand.	Procedure is not described in clear steps at all.
7. Calculations 20%	All calculations are shown and the results are correct and labeled appropriately. The units of all values are shown.	Some calculations are shown and the results are correct and labeled appropriately.	Some calculations are shown and the results labeled appropriately.	No calculations are shown OR results are inaccurate or mislabeled.
8. Summary 5%	Summary describes the design, the relevant information and some future implications.	Summary describes the design and some relevant information.	Summary describes the design.	No summary is written.
9. Materials 5%	All materials used in the design are clearly and accurately described.	Almost all materials used in the design are clearly and accurately described.	Most of the materials used in the design are clearly and accurately described.	Many materials are described inaccurately OR are not described at all.
10. Analysis 10%	The design is discussed and analyzed. Argumentative predictions are made about what might happen in case of change in the operation and how the design could be change.	The design is discussed and analyzed. Argumentative predictions are made about what might happen in case of change in the operation.	The design is discussed and analyzed. No argumentative predictions are made about what might happen in case of change in the operation and how the design could be change.	The design is not discussed and analyzed.

GRADE THIS PROBLEM FOR TEST

PURPOSE: 1) TO DETERMINE THE FOLLOWING:

- FLOW RATE DELIVERED TO EACH SPRINKLER HEAD FOR THE SYSTEM.
- IF THE FLOW RATES ARE NOT THE SAME, HOW I WOULD MODIFY THE SYSTEM DESIGN TO MAKE THEM THE SAME.
- A COMPARISON OF THE FLUID VELOCITY TO CRITICAL VELOCITY AND, IF THERE IS A LARGE DIFFERENCE, WHAT I WOULD DO TO THE SYSTEM.

DRAWING/DIAGRAM:



SOURCES: MOTT AND UNTENER. APPLIED FLUID MECHANICS. 7TH EDITION. PEARSON. 2015.

DESIGN CONSIDERATIONS:
- INCOMPRESSIBLE FLUID – WATER
- ISOTHERMAL SYSTEM
- INCLUDE ALL MINOR LOSSES
- SCHEDULE 40 STEEL PIPE
- ATMOSPHERIC PRESSURE AT SPRINKLER HEADS
- $Q_I = Q_{IIA} + Q_{IIB}$

DATA + VARIABLES:

	$1\frac{1}{2}$" SCH. 40 STEEL (TF.1)	1" SCH. 40 STEEL (TF.1)
$P_1 = 400\ kPa$	$D_I = 0.0409\ m$	$D = 0.0266\ m$ (IIA, IIB)
$\gamma = 9.81 \frac{kN}{m^3}$	$A = 1.314 \times 10^{-3}\ m^2$	$A = 5.574 \times 10^{-4}\ m^2$
$K_v = 150 f_T$	$g = 9.81 \frac{m}{s^2}$	$K_T = 60 f_T,\ 20 f_T$
$L_I = 6.5m$	$L_{IIB} = 8.3m$	$K_C = \frac{D_1}{D_2} = 0.044 f_T$ (FIG. 10.11)
$L_{IIA} = 0.3m$	$K_e = 30 f_T$	$K_s = 50$

MATERIALS:

- WATER
- SCHEDULE 40 STEEL PIPE

PROCEDURE: 1) I START BY CHOOSING MY REFERENCE POINTS FOR THE SYSTEM (SEE DIAGRAM). THEN, I WRITE BERNOULLI'S EQUATION FOR EACH POINT INDIVIDUALLY.

(2A)

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + \cancel{z_1}^{0} = \cancel{\frac{P_{2A}}{\gamma}}^{0} + \frac{V_{2A}^2}{2g} + z_{2A} + h_{L_{1-2A}}$$

$$\frac{P_1}{\gamma} - z_{2A} = \frac{V_{2A}^2 - V_1^2}{2g} + h_{L_{1-2A}}$$

(2B)

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + \cancel{z_1}^{0} = \cancel{\frac{P_{2B}}{\gamma}}^{0} + \frac{V_{2B}^2}{2g} + z_{2B} + h_{L_{1-2B}}$$

$$\frac{P_1}{\gamma} - z_{2B} = \frac{V_{2B}^2 - V_1^2}{2g} + h_{L_{1-2B}}$$

SINCE P_1 AND z_{2A}, z_{2B} ARE KNOWN, I PUT THEM ALL ON ONE SIDE. NOW I WILL NEED TO DETERMINE ENERGY LOSSES FOR EACH EQUATION.

$$h_{L_{1-2A}} = h_{L_I} + h_{L_V} + \vec{h}_{L_T} + h_{L_{IIA}} + h_{L_S}$$

$$h_{L_{1-2B}} = h_{L_I} + h_{L_V} + \vec{h}_{L_T} + h_{L_C} + h_{L_{IIB}} + h_{L_e} + h_{L_S}$$

For $h_{L_{1-2A}} \rightarrow$

$$= f_I \frac{L_I}{D_I}\frac{V_I^2}{2g} + K_V\frac{V_I^2}{2g} + K_T\frac{V_I^2}{2g} + f_{IIA}\frac{L_{IIA}}{D_{IIA}}\frac{V_{IIA}^2}{2g} + K_S\frac{V_{IIA}^2}{2g}$$

$$= f_I \frac{L_I}{D_I}\frac{8}{g\pi^2 D_I^4}Q_I^2 + K_V\frac{8}{g\pi^2 D_I^4}Q_I^2 + K_T\frac{8}{g\pi^2 D_I^4}Q_I^2 + f_{IIA}\frac{L_{IIA}}{D_{IIA}}\frac{8}{g\pi^2 D_{IIA}^4}Q_{IIA}^2 + K_S\frac{8}{g\pi^2 D_{IIA}^4}Q_{IIA}^2$$

$$= \left(f_I\frac{L_I}{D_I} + K_V + K_T\right)\frac{8}{g\pi^2 D_I^4}Q_I^2 + \left(f_{IIA}\frac{L_{IIA}}{D_{IIA}} + K_S\right)\frac{8}{g\pi^2 D_{IIA}^4}Q_{IIA}^2$$

For $h_{L_{1-2B}} \rightarrow$

$$= f_I\frac{L_I}{D_I}\frac{V_I^2}{2g} + K_V\frac{V_I^2}{2g} + K_T\frac{V_I^2}{2g} + K_C\frac{V_I^2}{2g} + f_{IIB}\frac{L_{IIB}}{D_{IIB}}\frac{V_{IIB}^2}{2g} + K_e\frac{V_{IIB}^2}{2g} + K_S\frac{V_{IIB}^2}{2g}$$

$$= f_I\frac{L_I}{D_I}\frac{8}{g\pi^2 D_I^4}Q_I^2 + K_V\frac{8}{g\pi^2 D_I^4}Q_I^2 + K_T\frac{8}{g\pi^2 D_I^4}Q_I^2 + K_C\frac{8}{g\pi^2 D_I^4}Q_I^2 + f_{IIB}\frac{L_{IIB}}{D_{IIB}}\frac{8}{g\pi^2 D_{IIB}^4}Q_{IIB}^2 + K_e\frac{8}{g\pi^2 D_{IIB}^4}Q_{IIB}^2 + K_S\frac{8}{g\pi^2 D_{IIB}^4}Q_{IIB}^2$$

$$= \left(f_I\frac{L_I}{D_I} + K_V + K_T + K_C\right)\frac{8}{g\pi^2 D_I^4}Q_I^2 + \left(f_{IIB}\frac{L_{IIB}}{D_{IIB}} + K_e + K_S\right)\frac{8}{g\pi^2 D_{IIB}^4}Q_{IIB}^2$$

NOW THAT I HAVE MY EQUATIONS FOR ENERGY LOSSES, I CAN PLUG IN ALL KNOWN VALUES, SET EQUAL TO KNOWN VALUES OF BERNOULLI'S EQUATIONS, AND SOLVE FOR THE FLOW RATE AT EACH SPRINKLER HEAD. SEE DATA + VARIABLES SECTION FOR VALUES USED BELOW.

For $h_{L_{1-2A}} \rightarrow$

$$= \left(f_I\left(\frac{6.5\,m}{0.0409\,m}\right) + 150f_I + 60f_I\right)\frac{8}{\left(9.81\frac{m}{s^2}\pi^2(0.0409\,m)^4\right)}Q_I^2 + \left(f_{IIA}\left(\frac{0.3\,m}{0.0266}\right) + 50\right)\frac{8}{\left(9.81\pi^2(0.0266)^4\right)}Q_{IIA}^2$$

$$= (368.924f_I)\,29527.6\,Q_I^2 + (11.2782f_{IIA} + 50)\,165042\,Q_{IIA}^2$$

For $h_{L_{1-2B}} \rightarrow$

$$= \left(f_I\left(\frac{6.5\,m}{0.0409\,m}\right) + 150f_I + 20f_I + 0.094f_I\right)\frac{8}{\left(9.81\pi^2(0.0409)^4\right)}Q_I^2 + \left(f_{IIB}\left(\frac{8.3}{0.0266}\right) + 30f_{IIB} + 50\right)\frac{8}{\left(9.81\pi^2(0.0266)^4\right)}Q_{IIB}^2$$

$$= (328.968f_I)\,29527.6\,Q_I^2 + (342.03f_{IIB} + 50)\,165042\,Q_{IIB}^2$$

NOW I WILL SET EACH EQUATION EQUAL TO BERNOULLI'S AND SOLVE FOR INDIVIDUAL FLOW RATES. I WILL CHANGE EACH VELOCITY TO $\frac{8}{g\pi^2 D^4} Q^2$ TO SOLVE.

FOR BRANCH I-IIA, $\frac{P_1}{\gamma} - Z_{2A} = \frac{V_{2A}^2}{2g} - \frac{V_1^2}{2g} + h_{L_{1-2A}}$

$$\frac{P_1}{\gamma} - Z_{2A} = 165042\, Q_{IIA}^2 - 29527.6\, Q_I^2 + (368.924 f_I)29527.6\, Q_I^2 + (11.2782 f_{IIA} + 50)165042\, Q_{IIA}^2$$

$$\rightarrow 165042\, Q_{IIA}^2 + (11.2782 f_{IIA} + 50)165042\, Q_{IIA}^2 = \frac{P_1}{\gamma} - Z_{2A} - (368.924 f_I)29527.6\, Q_I^2 + 29527.6\, Q_I^2$$

$$\rightarrow 165042\, Q_{IIA}^2 + 1861376.6844 f_{IIA}\, Q_{IIA}^2 + 8252100\, Q_{IIA}^2 = \frac{P_1}{\gamma} - Z_{2A} - 10893440.3024 f_I Q_I^2 + 29527.6\, Q_I^2$$

$$\rightarrow 1861376.6844 f_{IIA}\, Q_{IIA}^2 + 8417142\, Q_{IIA}^2 = \frac{P_1}{\gamma} - Z_{2A} - 10893440.3024 f_I Q_I^2 + 29527.6\, Q_I^2$$

$$\rightarrow Q_{IIA}^2 (1861376.6844 f_{IIA} + 8417142) = \frac{P_1}{\gamma} - Z_{2A} - 10893440.3024 f_I Q_I^2 + 29527.6\, Q_I^2$$

$$\rightarrow \quad Q_{IIA} = \sqrt{\frac{\left(\left(\frac{P_1}{\gamma} - Z_{2A}\right) - 10893440.3024 f_I Q_I^2 + 29527.6\, Q_I^2\right)}{(1861376.6844 f_{IIA} + 8417142)}}$$

FOR BRANCH I-IIB, $\frac{P_1}{\gamma} - Z_{2B} = \frac{V_{2B}^2}{2g} - \frac{V_1^2}{2g} + h_{L_{1-2B}}$

$$\frac{P_1}{\gamma} - Z_{2B} = 165042\, Q_{IIB}^2 - 29527.6\, Q_I^2 + (328.968 f_I)29527.6\, Q_I^2 + (342.03 f_{IIB} + 50)165042\, Q_{IIB}^2$$

$$\rightarrow 165042\, Q_{IIB}^2 + (342.03 f_{IIB} + 50)165042\, Q_{IIB}^2 = \frac{P_1}{\gamma} - Z_{2B} - (328.968 f_I)29527.6\, Q_I^2 + 29527.6\, Q_I^2$$

$$\rightarrow 165042\, Q_{IIB}^2 + 56449315.26 f_{IIB}\, Q_{IIB}^2 + 8252100\, Q_{IIB}^2 = \frac{P_1}{\gamma} - Z_{2B} - 9713635.5168 f_I Q_I^2 + 29527.6\, Q_I^2$$

$$\rightarrow 56449315.26 f_{IIB}\, Q_{IIB}^2 + 8417142\, Q_{IIB}^2 = \frac{P_1}{\gamma} - Z_{2B} - 9713635.5168 f_I Q_I^2 + 29527.6\, Q_I^2$$

$$\rightarrow Q_{IIB}^2 (56449315.26 f_{IIB} + 8417142) = \frac{P_1}{\gamma} - Z_{2B} - 9713635.5168 f_I Q_I^2 + 29527.6\, Q_I^2$$

$$\rightarrow \quad Q_{IIB} = \sqrt{\frac{\left(\left(\frac{P_1}{\gamma} - Z_{2B}\right) - 9713635.5168 f_I Q_I^2 + 29527.6\, Q_I^2\right)}{(56449315.26 f_{IIB} + 8417142)}}$$

I CANNOT DIRECTLY SOLVE FOR ANY FLOW RATES BECAUSE EACH EQUATION IS A FUNCTION OF THE OTHER. THEREFORE, I WILL HAVE TO USE THE ITERATION METHOD. BUT FIRST, I WILL ESTABLISH THE THIRD EQUATION.

THE THIRD EQUATION IS AS FOLLOWS,

$$Q_I = Q_{IIA} + Q_{IIB} \quad \text{(CONSERVATION OF MASS EQUATION)}$$

$$Q_I = \sqrt{\frac{\left(\left(\frac{P_1}{\gamma} - z_{2A}\right) - 10893440.3024 f_I Q_I^2 + 29527.6 Q_I^2\right)}{(1861376.6844 f_{IIA} + 8417142)}} + \sqrt{\frac{\left(\left(\frac{P_1}{\gamma} - z_{2B}\right) - 9713635.5168 f_I Q_I^2 + 29527.6 Q_I^2\right)}{(56449315.26 f_{IIB} + 8417142)}}$$

I WILL ENTER THE EQUATIONS INTO EXCEL IN SEPARATE CELLS AND GUESS ALL FRICTION FACTORS (f_I, f_{IIA}, f_{IIB}) AS WELL AS GUESS A VALUE FOR Q_I. I WILL THEN COMPUTE Q_{IIA} AND Q_{IIB} USING GUESSED VALUES AND PLUG THE FLOW RATES INTO THE Q_I EQUATION. TO GET THE CORRECT FRICTION FACTOR VALUES AND FLOW RATES I WILL RUN ITERATIONS BY COMPARING PERCENTAGE DIFFERENCE FOR FLOW RATE AND FRICTION FACTORS UNTIL PERCENTAGE DIFFERENCE IS NEARLY "0."

MET330 Test 3: Problem 1

Austin Goodman
18-Nov-22

Input Data		
Specific Weight=	9.81	kN/m^3
Kinematic Viscosity=	1.15E-06	m^2/s
Pressure 1=	400	kPa
Z_2=	0.3	m
Pipe length = L_{IIB}=	8.3	m
Pipe length = L_{IIA}=	0.3	m
Pipe length = L_I=	6.5	m
D_{IIB}=	0.0266	m
D_{IIA}=	0.0266	m
D_I=	0.0409	m
Wall Roughness=	4.60E-05	m
K valve=	150	fT
K elbow=	30	fT
K sprinkler=	50	
K contraction=	0.044	fT
Le/D tee 1, 2=	60	20
D_{IIB}/e=	578.26	
D_{IIA}/e=	578.26	
D_I/e=	889.13	
g=	9.81	m/s^2

ITERATION 1

f_{IIB}= 0.01
f_{IIA}= 0.01
f_I= 0.01

Sub-Iteration	Q_I (m3/s)	Q_{IIB} (m3/s)	Q_{IIA} (m3/s)	(NEW) Q_I (m3/s)	%diff Q_I
1	0.010000	0.001937432	0.001963844	0.003901276	-60.99%
2	0.003901	0.002095667	0.002157482	0.004253149	9.02%
3	0.004253	0.002090507	0.002151213	0.004241721	-0.27%
4	0.004242	0.002090682	0.002151426	0.004242108	0.01%
5	0.004242	0.002090676	0.002151419	0.004242095	0.00%

V_{IIB} (m/s)	V_{IIA} (m/s)	V_I (m/s)	Re_{IIB}	Re_{IIA}	Re_I
3.76213	3.87143	3.22882	8.70E+04	8.95E+04	1.15E+05

NEW f_{IIB}	NEW f_{IIA}	NEW f_I	%diff f_{IIB}	%diff f_{IIA}	%diff f_I
0.02485	0.02480	0.02250	-148.48%	-147.95%	-125.01%

ITERATION 2

f_{IIB}= 0.02485
f_{IIA}= 0.02480
f_I= 0.02250

Sub-Iteration	Q_I (m3/s)	Q_{IIB} (m3/s)	Q_{IIA} (m3/s)	(NEW) Q_I (m3/s)	%diff Q_I
1	0.01000	0.001482114	0.001495017	0.002977132	-70.23%
2	0.00298	0.001987742	0.002134621	0.004122363	38.47%
3	0.00412	0.001947973	0.002085545	0.004033518	-2.16%
4	0.00403	0.00195155	0.002089965	0.004041515	0.20%
5	0.00404	0.001951231	0.002089572	0.004040803	-0.02%
6	0.00404	0.00195126	0.002089607	0.004040867	0.00%

V_{IIB} (m/s)	V_{IIA} (m/s)	V_I (m/s)	Re_{IIB}	Re_{IIA}	Re_I
3.51125	3.76020	3.07561	8.12E+04	8.70E+04	1.09E+05

NEW f_{IIB}	NEW f_{IIA}	NEW f_I	%diff f_{IIB}	%diff f_{IIA}	%diff f_I
0.02498	0.02485	0.02259	-0.53%	-0.22%	-0.40%

ITERATION 3

f_{IIB}= 0.02498
f_{IIA}= 0.02485
f_I= 0.02259

Sub-Iteration	Q_I (m3/s)	Q_{IIB} (m3/s)	Q_{IIA} (m3/s)	(NEW) Q_I (m3/s)	%diff Q_I
1	0.01000	0.001478541	0.001491125	0.002969666	-70.30%
2	0.00297	0.001987003	0.002134634	0.004121636	38.79%
3	0.00412	0.001946872	0.002085097	0.004031969	-2.18%

4	0.00403	0.001950498	0.002089578	0.004040076	0.20%
5	0.00404	0.001950173	0.002089177	0.004039351	-0.02%
6	0.00404	0.001950202	0.002089213	0.004039416	0.00%

V_{IIB} (m/s)	V_{IIA} (m/s)	V_I (m/s)	Re_{IIB}	Re_{IIA}	Re_I
3.50935	3.75950	3.07455	8.12E+04	8.70E+04	1.09E+05

NEW f_{IIB}	NEW f_{IIA}	NEW f_I	%diff f_{IIB}	%diff f_{IIA}	%diff f_I
0.02498	0.02485	0.02259	0.00%	0.00%	0.00%

In Upstream Piping:	Q_I =	64.0247	gpm	f_I = 0.02259	V_I =	3.07455	m/s
At 1st Sprinkler Head:	Q_{IIA} =	33.114	gpm	f_{IIA} = 0.02485	V_{IIA} =	3.75950	m/s
At 2nd Sprinkler Head:	Q_{IIB} =	30.9107	gpm	f_{IIB} = 0.02498	V_{IIB} =	3.50935	m/s

Therefore, the volume flow rate delivered to the first sprinkler head is Q_{IIA} = 33.114 gpm and the volume flow rate delivered to the second sprinkler head is Q_{IIB} = 30.9107 gpm. The volume flow rate in the upstream piping is Q_I = 64.0247 gpm.

When looking at the flow rates at each sprinkler, it is worth noting that they are not the equal. To make the flow rates the same, I would recommend either increasing the energy losses in pipe IIA or reducing the energy losses in pipe IIB. Reducing energy losses in pipe IIB could be achieved by increasing the pipe diameter. However; we would have to choose from commercially available pipe sizes so there is a low probablility that we would be able to make the flow rate of IIA and IIB exactly the same using this method. The solution with a better chance of producing the desired result would be to increase energy losses for pipe IIA by adding a mechanical component, such as a valve, that could restrict the flow and adjust energy loss to equal the energy loss in IIB. (See hand calculations for determining K value of proposed valve in branch IIA)

When comparing the fluid velocities for each pipe to critical velocity (3 m/s), all three of the fluid velocities for this system are above critical velocity with pipe I velocity being the closest. To prevent fluid velocities from being higher than critical velocity, I would recommend increasing the pipe sizes. However; it is worth noting that if this is done and the pressure at P1 remains constant at 400kPa, then the flow rates will increase for each piping section due to less frictional energy losses.

AS DISCUSSED, I WOULD INCLUDE A VALVE IN PIPE IIA IN ORDER TO MAKE THE FLOW RATES FOR Q_{IIA} AND Q_{IIB} EQUAL. TO DETERMINE THE VALVE REQUIRED, I WILL NEED TO SOLVE FOR THE K VALUE OF THE PROPOSED VALVE. SINCE Q_{IIA} AND Q_{IIB} WILL BE EQUAL, I CAN USE THE ENERGY LOSS EQUATIONS FROM PREVIOUS STEPS AND INCLUDE A VALVE FOR PIPE IIA LOSSES AS FOLLOWS,

TO MAKE $Q_{IIA} = Q_{IIB}$,

$$\left(f_{IIA}\frac{L_{IIA}}{D_{IIA}} + K_s + K_v\right)\frac{8}{g\pi^2 D_{IIA}^4}Q_{IIA}^2 = \left(f_{IIB}\frac{L_{IIB}}{D_{IIB}} + K_e + K_s\right)\frac{8}{g\pi^2 D_{IIB}^4}Q_{IIB}^2$$

PLUGGING IN VALUES PREVIOUSLY DETERMINED AND KEEPING IN MIND THAT $Q_{IIA} = Q_{IIB}$,

$$\left(0.02485\left(\frac{0.3m}{0.0266m}\right) + 50 + K_v\right)\frac{8}{9.81\pi^2(0.0266)^4} = \left(0.02498\left(\frac{8.3m}{0.0266m}\right) + 30(0.02498) + 50\right)\frac{8}{9.81\pi^2(0.0266)^4}$$

$$\rightarrow (50.2803 + K_v)165042 = 9662204.2052$$

$$\rightarrow 8298361.2726 + 165042K_v = 9662204.2052$$

$$\rightarrow \underline{\underline{K_v = 8.264}}$$

THEREFORE, PLACING A VALVE IN IIA TO EQUALIZE FLOW RATES WOULD REQUIRE THE PROPOSED VALVE TO HAVE A K VALUE OF 8.264.

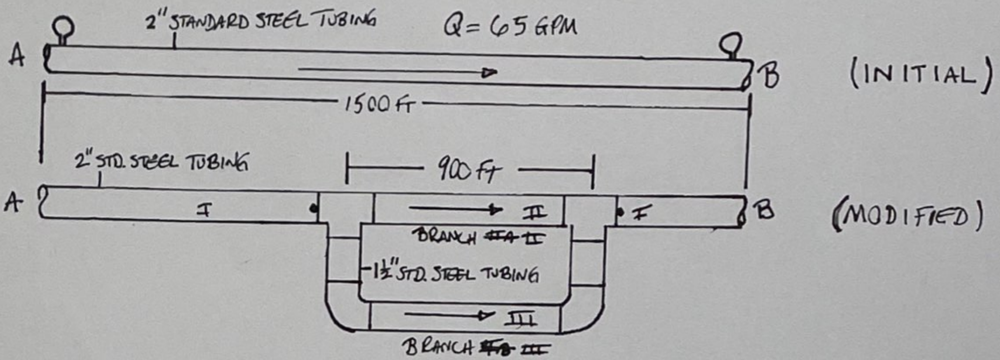
SUMMARY: THE VOLUME FLOW RATE DELIVERED TO THE FIRST SPRINKLER HEAD (IIA) IS 33.114 GPM. THE FLOW RATE DELIVERED TO THE SECOND SPRINKLER (IIB) IS 30.911 GPM. AN ITERATION APPROACH WAS USED TO DETERMINE THE FLOW RATES BECAUSE I WAS LEFT WITH 3 EQUATIONS AND 3 UNKNOWNS AFTER SOLVING BY HAND. THE FLOW RATES AT EACH SPRINKLER WERE NOT THE SAME, THEREFORE, A VALVE WITH $K_v = 8.264$ WOULD HAVE TO BE INSTALLED IN PIPE IIA TO CORRECT THIS. THE FLUID VELOCITY IN ALL PIPE SECTIONS IS HIGHER THAN CRITICAL VELOCITY SO I WOULD RECOMMEND INCREASING PIPE SIZES TO CORRECT THIS.

ANALYSIS: THE FLOW RATE AT SPRINKLER IIB IS SLIGHTLY LESS THAN THE FLOW RATE AT SPRINKLER IIA DUE TO MORE ENERGY LOSSES BEING PRESENT. ADDING THE PROPOSED VALVE WITH K VALUE OF 8.264 WILL CORRECT THIS FOR THE CURRENT SYSTEM CONFIGURATION IF INSTALLED IN PIPE IIA. IN ORDER TO BRING ALL FLOW RATES DOWN TO CRITICAL VELOCITY, THE PIPE DIAMETERS SHOULD BE INCREASED GIVEN UPSTREAM PRESSURE REMAINS CONSTANT. AN IDEAL SYSTEM DESIGN WOULD BE TO REDESIGN LAYOUT SO THAT THE TWO LEGS GOING TO THE SPRINKLER HEADS WOULD BE THE SAME LENGTH AND SIZE WITH THE EXACT SAME ENERGY LOSSES. IF POSSIBLE, THIS WOULD ENSURE EACH SPRINKLER HEAD RECEIVES THE SAME FLOW RATE AND THE VELOCITY OF THE FLUID IN EACH WOULD BE NEARLY IDENTICAL. THEREFORE, THERE WOULD BE NO NEED TO INSTALL MECHANICAL DEVICE TO ADJUST ENERGY LOSSES AND EQUALIZE FLOW RATES.

PURPOSE: 2) TO DETERMINE THE FOLLOWING:

- THE PRESSURE DROP ACROSS THE SYSTEM FOR INITIAL PIPING SYSTEM (SERIES CONFIGURATION)
- THE EXPECTED INCREASE IN VOLUME FLOW RATE FOR MODIFIED PIPING SYSTEM (PARALLEL CONFIGURATION) USING PRESSURE DIFFERENCE FROM INITIAL SERIES SYSTEM CONFIGURATION.

DRAWINGS/DIAGRAMS:



SOURCES: MOTT AND UNTENER. APPLIED FLUID MECHANICS. 7TH EDITION. PEARSON. 2015.

DESIGN CONSIDERATIONS:

- INCOMPRESSIBLE FLUID - WATER
- ISOTHERMAL SYSTEMS
- ALL MINOR LOSSES SHALL BE INCLUDED
- STANDARD STEEL TUBING

DATA + VARIABLES:

$Q_1 = 65\,GPM \cdot \frac{1\,ft^3/s}{449\,GPM} = 0.144766\,\frac{ft^3}{s}$

$L_1 = 1500\,ft$

$\gamma_w = 62.4\,\frac{lb}{ft^3}$

$\varepsilon =$ ~~$1.5\times10^{-4}\,ft$~~ $5\times10^{-6}\,ft$ (TUBING, T.8.2)

$\nu = 1.21\times10^{-5}\,\frac{ft^2}{s}$

2 in STEEL TUBING (TABLE G.1)

$D = 0.1558\,ft$

$A = 1.907\times10^{-2}\,ft^2$

1½" STEEL TUBING (TABLE G.1)

$D = 0.1142\,ft$

$A = 1.024\times10^{-2}\,ft^2$

MATERIALS:

- WATER
- STANDARD STEEL TUBING (2", 1½")

PROCEDURE: 2) TO SOLVE THE FIRST PART OF THIS PROBLEM, I WILL START BY SETTING UP BERNOULLI'S EQUATION AND THEN SOLVE FOR THE CHANGE IN PRESSURE FROM A TO B.

$$\frac{P_A}{\gamma} + \frac{V_A^2}{2g} + z_A = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + z_B + h_{L_{A-B}} \rightarrow \frac{P_A}{\gamma} - \frac{P_B}{\gamma} = h_{L_{A-B}}$$

VELOCITIES AT BOTH POINTS ARE ASSUMED TO BE THE SAME DUE TO GIVEN SYSTEM DESIGN. THERE IS NO CHANGE IN HEIGHT, SO THOSE CANCEL AS WELL. THE ONLY ENERGY LOSSES IN THIS SYSTEM ARE THE OVERALL LENGTH OF THE PIPE ITSELF, BEFORE I SOLVE ENERGY LOSSES I WILL NEED TO FIND VELOCITY AND FRICTION FACTOR OF THE PIPE,

$$V = \frac{Q}{A} \rightarrow \frac{0.144766 \frac{ft^3}{s}}{1.907 \times 10^{-2}\, ft^2} \rightarrow V = 7.5913 \frac{ft}{s}$$

$$R_e = \frac{vD}{\nu} \rightarrow \frac{(7.5913 \frac{ft}{s})(0.1558\, ft)}{(1.21 \times 10^{-5} \frac{ft^2}{s})} \rightarrow R_e = 97746, \quad \frac{D}{\epsilon} = \frac{0.1558}{1.5 \times 10^{-4}} = 1038.7$$

$$\text{USING } R_e = 97746, \frac{D}{\epsilon} = 1038.7 \rightarrow f = 0.0225$$

$$h_{A-B} = f \frac{L}{D} \frac{v^2}{2g} \rightarrow 0.0255 \left(\frac{1500\, ft}{0.1558\, ft}\right)\left(\frac{7.5913^2\, ft/s}{2(32.2 \frac{ft}{s^2})}\right) = 193.844\, ft$$

NOW THAT I FOUND ENERGY LOSS, I WILL PLUG IT INTO MODIFIED BERNOULLI'S EQUATION TO SOLVE FOR ΔP,

$$\frac{P_A - P_B}{\gamma_w} = h_{L_{A-B}} \rightarrow \Delta P = h_{L_{A-B}} \cdot \gamma_w \rightarrow 193.844\, ft \left(62.4 \frac{lb}{ft^3}\right) = 12095.9 \frac{lb}{ft^2}$$

$$\Delta P = 12095.9 \frac{lb}{ft^2} \cdot \frac{1\, ft^2}{144\, in^2} = 83.999 \frac{lb}{in^2} \rightarrow \Delta P_{A-B} = 84\, psi$$

THE PRESSURE DROP ACROSS ACROSS THE PIPE IS 84 psi.

FOR THE NEXT PART OF THIS PROBLEM, I WILL BEGIN BY WRITING THE EQUATIONS FOR THE ENERGY LOSSES, PLUGGING DATA IN AND SIMPLIFYING AS MUCH AS POSSIBLE.

$$\frac{\Delta P}{\gamma} = \frac{12095.9\ psf}{\rho g} = f_I \frac{L_I}{D_I}\frac{V_I^2}{2g} + f_{II}\frac{L_{II}}{D_{II}}\frac{V_{II}^2}{2g}$$

$$\rightarrow 12095 \frac{lb}{ft^2} = f_I\left(\frac{600\ ft}{0.1558\ ft}\right)\left(\frac{1.94 \frac{slug}{ft^3} V_I^2}{2}\right) + f_{II}\left(\frac{900\ ft}{0.1558\ ft}\right)\left(\frac{1.94 \frac{slug}{ft^3} V_{II}^2}{2}\right)$$

$$\rightarrow 12095.9 \frac{lb}{ft^2} = 3735.56 f_I V_I^2 + 5603.34 f_{II} V_{II}^2$$

$$\rightarrow 2.1587 = 0.6667 f_I V_I^2 + f_{II} V_{II}^2 \quad (A)$$

NOW I WILL WRITE EQUATION INCLUDING MODIFIED BRANCH,

$$\frac{\Delta P}{\gamma} = \frac{12095.9\ psf}{\rho g} = f_I \frac{L_I}{D_I}\frac{V_I^2}{2g} + f_{III}\frac{L_{III}}{D_{III}}\frac{V_{III}^2}{2g}$$

$$\rightarrow 12095.9 \frac{lb}{ft^2} = f_I\left(\frac{600\ ft}{0.1558\ ft}\right)\left(\frac{1.94 \frac{slugs}{ft^3} V_I^2}{2}\right) + f_{III}\left(\frac{900\ ft}{0.1142\ ft}\right)\left(\frac{1.94 \frac{slugs}{ft^3} V_{III}^2}{2}\right)$$

$$\rightarrow 12095.9 \frac{lb}{ft^2} = 3735.56 f_I V_I^2 + 7644.48 f_{III} V_{III}^2$$

$$\rightarrow 1.5823 = 0.4887 f_I V_I^2 + f_{III} V_{III}^2 \quad (B)$$

KEEPING IN MIND THE PRINCIPLES OF CONSERVATION OF MASS,

$$Q_I = Q_{II} + Q_{III} \longrightarrow A_I V_I = A_{II} V_{II} + A_{III} V_{III}$$

$$\rightarrow (1.907\times10^{-2}\ ft^2) V_I = (1.907\times10^{-2}\ ft^2) V_{II} + (1.024\times10^{-2}\ ft^2) V_{III}$$

$$\rightarrow V_I = V_{II} + 0.53697 V_{III} \quad (C)$$

SOLVING FOR REYNOLD'S NUMBERS EQUATIONS AND RELATIVE ROUGHNESS,

$$\frac{\varepsilon}{D_{III}} = \frac{5\times10^{-6}\ ft}{0.1142\ ft} = 0.000044, \quad R_{e_{III}} = \frac{\rho V_{III} D_{III}}{\eta} = \frac{(1.94 \frac{slugs}{ft^3})(V_{III})(0.1142\ ft)}{(2.35\times10^{-5}\ \frac{lb\cdot s}{ft^2})}$$

$$= 9427.57 V_{III}$$

$$\frac{\varepsilon}{D_{I,II}} = \frac{5\times10^{-6}\ ft}{0.1558\ ft} = 0.000032, \quad R_{e_{I,II}} = \frac{\rho V D}{\eta} = \frac{(1.94 \frac{slugs}{ft^3})(V_{I,II})(0.1558\ ft)}{(2.35\times10^{-5}\ \frac{lb\cdot s}{ft^2})}$$

$$= 12861.8 V_{I,II}$$

NOW I WILL SOLVE FOR VELOCITIES IN THE BRANCHES USING THE EQUATIONS I HAVE ESTABLISHED AND GUESS A VELOCITY TO GET STARTED, AFTER SOLVING WITH THIS VALUE I WILL PLUG CALCULATED VELOCITY INTO V_I TO EVALUATE. ITERATIONS WILL LIKELY BE REQUIRED.

$$Re_{I,II} = 12861.8\,V_{I,II} \rightarrow 12861.8(7.5913\,\tfrac{ft}{s}) = 97637.8\ ,\ \frac{\varepsilon}{D_{I,II}} = 0.000032$$

$$\rightarrow f_{I,II} = 0.018 \quad \text{(USING MOODY'S)}$$

$$\text{USING (A)} \rightarrow 2.1587 = 0.6667(0.018)(7.5913\,\tfrac{ft}{s})^2 + f_{II}\,V_{II}^2 \qquad \text{GUESS } f_{II} = 0.018$$

$$V_{II} = \sqrt{\frac{1.46713}{0.018}} = 9.0281\,\tfrac{ft}{s}$$

$$\text{USING (B)} \rightarrow 1.5827 = 0.4887(0.018)(7.5913\,\tfrac{ft}{s})^2 + f_{III}\,V_{III}^2$$

$$V_{III} = \sqrt{\frac{1.07537}{0.018}} = 7.72935\,\tfrac{ft}{s}$$

$$\text{USING (C)} \rightarrow V_I = (9.0281\,\tfrac{ft}{s}) + 0.53697(7.72935\,\tfrac{ft}{s}) = 13.1785\,\tfrac{ft}{s}$$

WHEN COMPARING MY CALCULATED VELOCITY TO MY GUESSED VELOCITY, IT IS OFF BY ALMOST DOUBLE. FOR EASE OF COMPLETING ITERATIONS I WILL CONTINUE THE PROBLEM IN EXCEL. I WILL CONTINUE TO PERFORM ITERATIONS BY EVALUATING THE PERCENTAGE DIFFERENCE BETWEEN MY VELOCITIES AND FIND NEW FRICTION FACTORS. I WILL THEN USE NEW VELOCITY TO CALCULATE THE TOTAL FLOW RATE USING FLOW AREA AND CONVERSION FACTOR OF $1\,ft^3/s = 449\,GPM$.

AFTER PERFORMING ITERATIONS IN EXCEL, $V_I = 10.27473513\,\tfrac{ft}{s}$

$$Q_I = V_I A_I \rightarrow (10.27473513\,\tfrac{ft}{s})(0.01907\,ft^2)(449\,\tfrac{GAL}{MIN}) = 87.9767\,GPM$$

$$\text{EXPECTED INCREASE, } \Delta Q = 87.9767\,GPM - 65\,GPM = 22.9767\,GPM$$

$$\underline{\Delta Q = 22.9767\,GPM}$$

MET330 Test 3: Problem 2		

Austin Goodman
22-Nov-22

Input Data		
Specific Weight=	62.4	lb/ft3
Kinematic Viscosity=	1.21E-05	ft2/s
DeltaP=	12095.9	lb/ft2
Pipe length = L_{III}=	900	ft
Pipe length = L_{II}=	900	ft
Pipe length = L_{I}=	600	ft
DIII=	0.1142	ft
D_{II}=	0.1558	ft
D_{I}=	0.1558	ft
Wall Roughness=	5.00E-06	ft
K elbow=	30	fT
Le/D tee 1, 2=	60fT	20fT
DIII/e=	22840.00	
DII/e=	31160.00	
DI/e=	31160.00	
g=	32.2	ft/s2
Density, p =	1.94	slugs/ft3
Area, AI =	0.01907	ft2

ITERATION 1

f_{III}= 0.018
f_{II}= 0.018
f_{I}= 0.018

Sub-Iteration	VI (ft/s)	VIII (ft/s)	VII (ft/s)	(NEW) VI (ft/s)	%diff V_I
1	7.591300	7.72934876	9.028139328	13.17856773	73.60%
2	10.384934	5.933026148	6.930099707	10.11595676	-2.59%
3	10.250445	6.046242669	7.062331248	10.30898217	0.57%
4	10.279714	6.021909801	7.033911591	10.2674965	-0.12%
5	10.273605	6.027002169	7.039859239	10.27617859	0.03%
6	10.274892	6.025930108	7.038607122	10.27435081	-0.01%
7	10.274621	6.026155524	7.038870397	10.27473513	0.00%

NEW fIII	NEW fII	NEW fI	ReIII	ReII	ReI
0.02036	0.01842	0.01709	5.69E+04	9.06E+04	1.32E+05

New Total Flow Rate, Q_I = 87.9767 gpm

Expected Increase, Delta Q = 22.9767 gpm

Based on my calculations, the new total flow rate for the modified system design would be 87.9767 gpm. This means that the expected increase in total system flow rate after adding the parallel branch would be roughly 22.9767 gpm, given that pressure remains constant from the previous design.

SUMMARY: THE CORRESPONDING PRESSURE DROP FOR THE INITIAL DESIGN IS 84 psi. THE EXPECTED INCREASE IN FLOW RATE THROUGH THE MODIFIED SYSTEM DESIGN IF THE PRESSURE IS THE SAME FROM THE INITIAL DESIGN WOULD BE 22.9767 GPM. THE FIRST PART OF THE PROBLEM WAS SOLVED BY USING BERNOULLI'S EQUATION AND SOLVING FOR THE ENERGY LOSSES DUE TO THE CHANGE IN PRESSURE BEING DIRECTLY RELATED TO ENERGY LOSSES. THE SECOND PART WAS SOLVED BY USING BERNOULLI'S EQUATION FOR EACH PATH KNOWING THE PRESSURE DROP ACROSS THE SYSTEM. THEREFORE, I WAS ABLE TO OBTAIN EQUATIONS FOR THE VELOCITY IN EACH PIPE AND RUN ITERATIONS BASED ON PERCENTAGE DIFFERENCE OF OLD VELOCITY TO NEWLY CALCULATED VELOCITY. I THEN UTIZIZED THE CONSERVATION OF MASS EQUATION TO DETERMINE FLOW RATE AND WAS ABLE TO DETERMINE INCREASE IN FLOW RATE USING THE CALCULATED RESULT.

ANALYSIS: THE NEW FLOW RATE IN THE MODIFIED BRANCH IS HIGHER THAN THE INITIAL DUE TO AN INCREASE IN FLOW AREA FOR A 900 ft SECTION AND BECAUSE THE PRESSURE WAS UNCHANGED. THE VELOCITY OF THE FLUID IN BOTH DESIGNS IS VERY HIGH, THEREFORE INCREASING OVERALL PIPE DIAMETERS SHOULD HELP REDUCE VELOCITY AND ALSO REDUCE ENERGY LOSSES.