Name: ____.

MET 330 Fluid Mechanics
Dr. Orlando Ayala
Spring 2024
Test 1

Take home – Due Tuesday February 9th 2024 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, and ten (10) other points are based on the basis of technical writing. The other eighty (80) points will come from the problem solutions. For the technical writing I will follow the attached rubric.
3. There is only one problem with 3 different parts, each one is worth 80/3 of the total grade.
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 only one file and it has to be a pdf file. For the ePortfolio (which is optional) you are supposed to upload this artifact to your Google drive. I will provide more instructions later.
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:

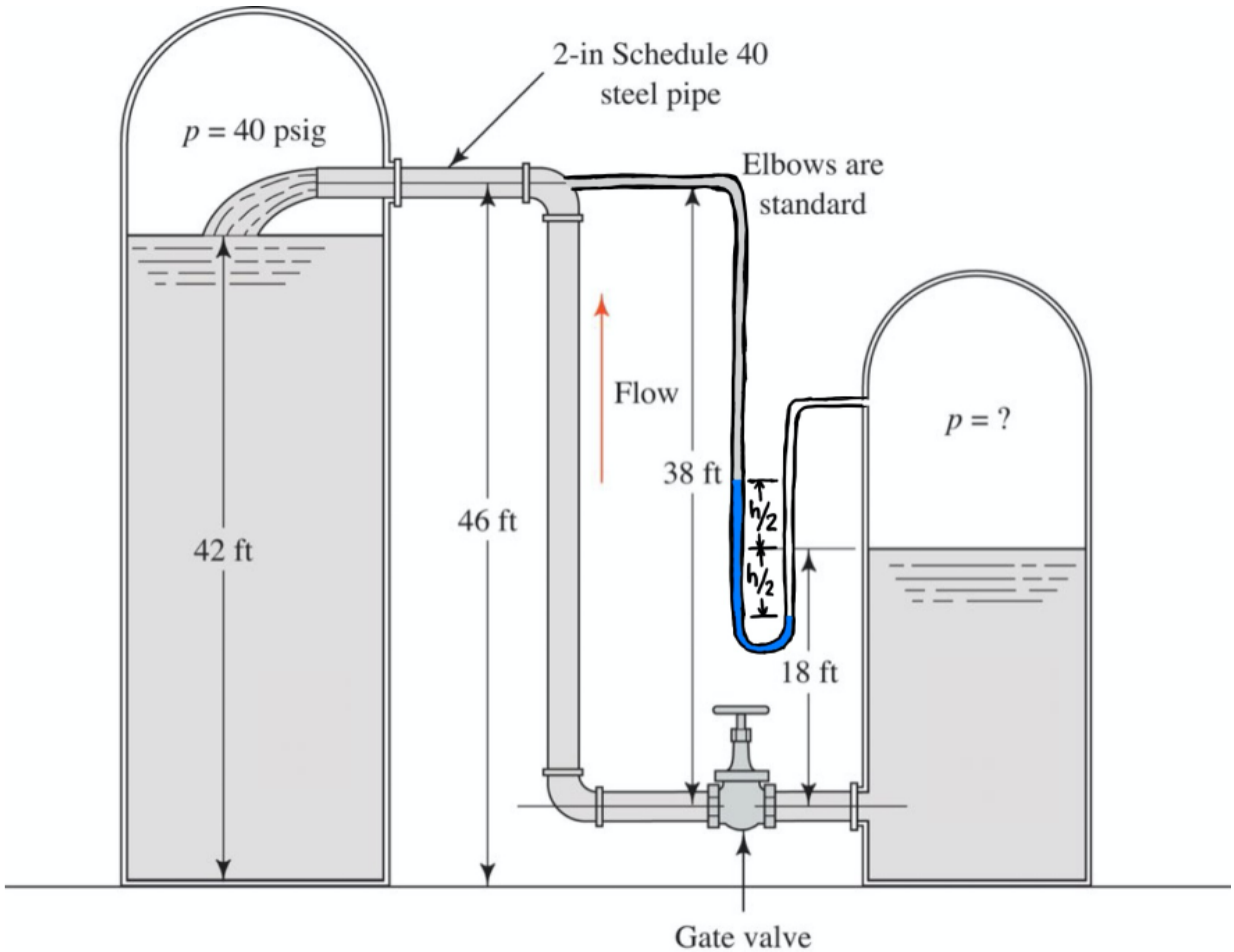
   IX. PROHIBITED CONDUCT

   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.

The system shown below is used to transport ethyl alcohol from one tank to the other. The temperature is 77 F. The length of pipe for each of the horizontal sections is 36 ft. The manometric fluid is mercury. Pressurized air controls the pressure in the tanks.



1. What is the required air pressure in the tank on the right in order to deliver 250 gpm of ethyl alcohol. Solve this problem by hand and also create an excel spreadsheet with its solution. Make sure the excel solutions match the hand calculations.

   What is the manometer reading shown in the picture?

2. Now, at some point of the system operation, the air pressure in the tank on the right start to drop. At what air pressure the flow of ethyl alcohol in the system stops? Note that at that specific moment, all pipes remain filled with ethyl alcohol.

   What will be the new manometer reading at that moment there is no flow?

3. Using the spreadsheet you created in the 1st part, determine the air pressure in the tank on the right for several flow rates. Make a plot of pressure versus flow rate. Using the plot, determine the flow rate when the air pressure is 75 psi.

Problem solution rubric

	Exceeds Standard 4 10 points	Meets Standard 3 7 points	Approaches Standard 2 4 points	Needs Attention 1 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.

A

PURPOSE

In the system shown below, compute the pressure in the right tank in order to have a ethyl alcohol flow rate from right to left tanks of 250gpm. Also, we will compute the manometer reading "h".

If the pressure in the right tank start to drop, what would be the air pressure in that tank so the flow of ethyl alcohol stops. Also, we will compute the manometer reading "h" for such situation.

Finally, by using the equations in the 1st part, plot the required air pressure in the right tank for different flow rates. Then, with the graph determine the flow rate if the pressure in the tank is 75psig.

SOURCES

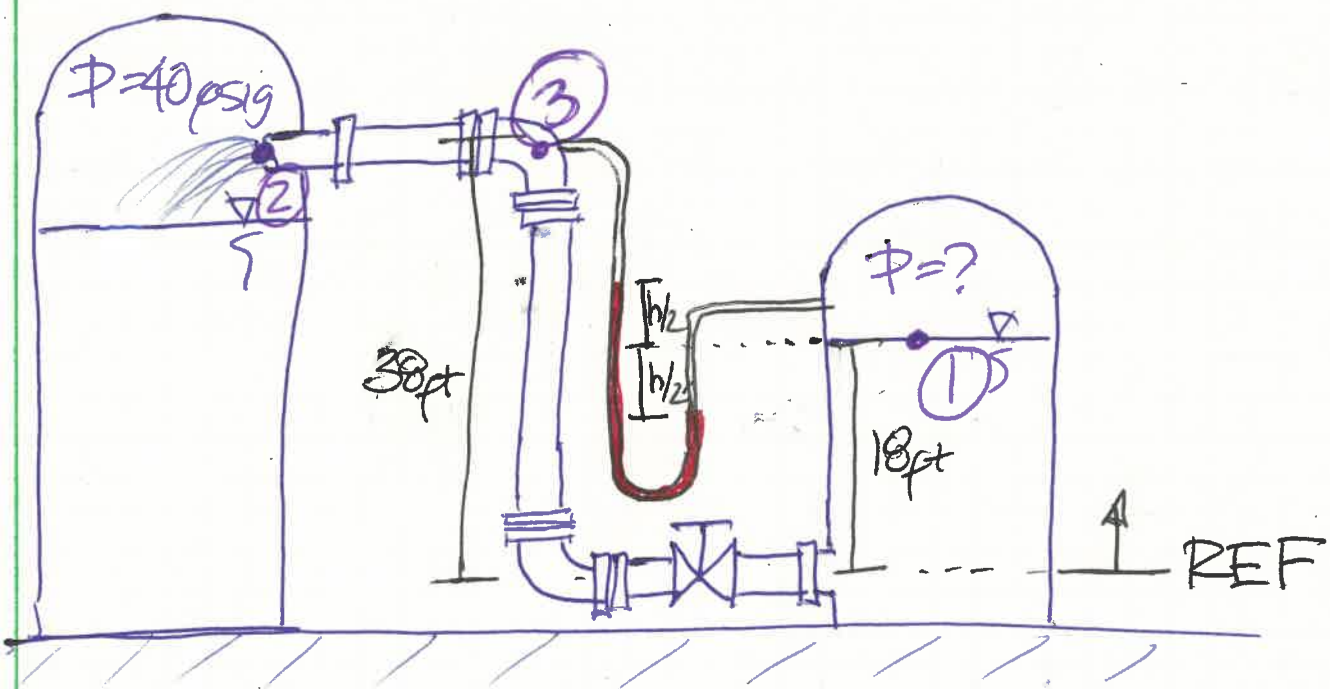
Mott, R., Untener, J.A., "Applied Fluid Mechanics," 7th edition, Pearson Education Inc (2015).

DESIGN CONSIDERATIONS

- Constant properties
- Incompressible fluids (except the air)
- Isothermal conditions

B

DRAWINGS & DIAGRAMS



MATERIALS

- Ethyl alcohol @ 77°F
- Mercury @ 77°F
- Air @ 77°F

DATA & VARIABLES

- All distances in figure
- $\gamma_{alc} = 49.01\ lb/ft^3$
- $\nu_{alc} = 1.37 \times 10^{-5}\ ft^2/s$
- $\gamma_{Hg} = 844.9\ lb/ft^3$
- $D_i = 0.1723\ ft$ } table A-7
- $A_i = 0.0233\ ft^3$ } table A-7
- $\varepsilon = 1.5 \times 10^{-4}\ ft$ table 8-2

- $\Delta z = 20\ ft$
- $Q = 250\ gpm = 0.557\ ft^3/s$
- $P_2 = 40\ psig$

$K_{valve} = 8 f_T$

$K_{elbow} = 30 f_T$ (2 of them)

$K_{ent} = 0.5$

PROCEDURE

6

For the 1st part, I will apply Bernoulli's from points 1 and 2 (shown in figure). Both points at the ethyl alcohol surfaces in the tanks (because I know the most there & I am being asked for the pressure in one of them). Once I apply it, I will solve for P_1. For the manometer reading, I will use the "gamma*h" equation. I will need to look at the geometry for the vertical distances in that equation.

For the 2nd part, since the flow stops, I will only use the "gamma*h" equation in the pipe section and in the manometer section.

Lastly, for the 3rd part, I will use the equations I derive in the 1st part to obtain the pressure P_1 for different flow rates. Then, simply read from a plot the flow rate at 75 psig in the right tank.

CALCULATIONS

Applying Bernoulli's:

$$\frac{P_1}{\gamma_{alc}} + \cancel{\frac{V_1^2}{2g}}^{0} + z_1 = \frac{P_2}{\gamma_{alc}} + \frac{V_2^2}{2g} + z_2 + h_{L_{1-2}}$$

Solving for P_1:

$\boxed{D}$

$$P_1 = P_2 + \gamma_{alc}\left[(z_2 - z_1) + \frac{V_2^2}{2g} + h_{L_{1\to2}}\right]$$

I know some of the terms in the equation. The ones that I am missing can be computed as:

- $V_2 = \frac{4Q}{\pi D_i^2}$ (from $Q = VA = V\frac{\pi}{4}D_i^2$)

$$= \frac{4\times 0.557\,ft^3/s}{\pi\times(0.1723\,ft)^2} = 23.875\,ft/s$$

- $h_{L_{pipe}} = f\frac{L}{D_i}\frac{V_2^2}{2g}$; f ⟨ $Re = \frac{VD}{\nu} = \frac{23.875\,ft/s \times 0.1723\,ft}{1.37\times10^{-5}\,ft^2/s} = 3\times10^5$; $D/\varepsilon = 1140.67$

from Moody chart

$f = 0.02019$

and $f_T = 0.01899$

$$= 0.02019\,\frac{110\,ft}{0.1723\,ft}\,\frac{(23.875\,ft/s)^2}{2\times32.2\,ft/s^2} = 114.086\,ft$$

- $h_{L_{ent}} = K_{ent}\frac{V^2}{2g} = 0.5\times\frac{(23.875\,ft/s)^2}{2\times32.2\,ft/s^2} = 4.426\,ft$

- $h_{L_{elbows}} = 2K_{elb}\frac{V^2}{2g} = 2\times30\times0.01899\times\frac{(23.875\,ft/s)^2}{2\times32.2\,ft/s^2} = 10.084\,ft$

- $h_{L_{valve}} = K_{valv}\frac{V^2}{2g} = 8\times0.01899\,\frac{(23.875\,ft/s)^2}{2\times32.2\,ft/s^2} = 1.345\,ft$

All these losses give us a total energy losses $\boxed{E}$ of:

$$h_{L_{TOTAL}} = 129.9414 \, ft$$

Thus, for P_1:

$$P_1 = 40 \frac{lb}{in^2} + 49.01 \frac{lb}{ft^3} \left[20 \, ft + \underbrace{\frac{(23.875 \, ft/s)^2}{2 \times 32.2 \, ft/s^2}}_{8.8511 \, ft} + 129.9414 \, ft \right] \frac{1 \, ft^2}{144 \, in^2}$$

$$\cancel{\boxed{P_1 = 94.045 \, psig}}$$

For the manometer reading, I will start from point ③ and move through the manometer until I get to point ①. All while use the "sammach" equation:

$$P_3 + \left(38 \, ft - 18 \, ft - \frac{h}{2}\right) \times \gamma_{alc} + h \times \gamma_{Hg} = P_1$$

(the column of air does not affect pressure)

Manipulating:

$$-\frac{h}{2} \gamma_{alc} + h \gamma_{Hg} = (P_1 - P_3) - 20 \, ft \times \gamma_{alc}$$

$$h\left(\gamma_{Hg} - \frac{\gamma_{alc}}{2}\right) = (P_1 - P_3) - \gamma_{alc} \times 20 \, ft$$

$$h = \frac{[(P_1 - P_3) - \gamma_{alc} \times 20 \, ft]}{\left(\gamma_{Hg} - \frac{\gamma_{alc}}{2}\right)}$$

We need P_3, for that I use Bernoulli's again: F

$$P_3 = P_1 - \gamma_{alc}\left[(z_3 - z_1) + \frac{V_3^2}{2g} + h_{L_{1-3}}\right]$$

In this case, the energy losses include 74 ft of pipe, one and a half elbows, the valve, and the the tank entrance. Following similar procedure as before, we get:

$$h_{L_{1-3}} = 90.083\ ft$$

Knowing $(z_3 - z_1) = 20\ ft$, $\frac{V_3^2}{2g} = 8.8511\ ft$, we get:

$$\underline{P_3 = 53.566\ psig}$$

Plugging this into the equation for "h", we get:

$$h = \frac{\left[(94.045 - 53.566)\frac{lb}{in^2}\left(\frac{144\ in^2}{1\ ft^2}\right) - 49.01\frac{lb}{ft^3} \times 20\ ft\right]}{\left(844.9\frac{lb}{ft^3} - \frac{49.01}{2}\frac{lb}{ft^3}\right)}$$

$$\boxed{h = 5.91\ ft}$$

See also the excel spreadsheet in the tab labeled "1st part", which follow the procedure presented here.

For the 2nd part, since the fluid is not flowing anymore, I can use the "sammarh" equation. I will move from point ② to ① but now through the pipe: G

$$P_2 + 38_{ft}\,\gamma_{alc} - 18_{ft}\,\gamma_{alc} = P_1$$

Thus,

$$P_1 = P_2 + 20_{ft}\,\gamma_{alc}$$

$$= 40\,psig + 20_{ft} * 49.01\,\frac{lb}{ft^3}\left(\frac{1\ ft^2}{144\ in^2}\right)$$

$$\boxed{P_1 = 46.807\ psig}$$

The equation for the manometer is still valid:

$$h = \frac{[(P_1 - P_3) - \gamma_{alc} \times 20_{ft}]}{\left(\gamma_{Hg} - \frac{\gamma_{alc}}{2}\right)}$$

Looking at the equation above:

$$P_1 = P_2 + 20_{ft}\,\gamma_{alc}$$

and knowing that in this situation $P_2 = P_3$, we get $P_1 = P_3 + 20_{ft}\,\gamma_{alc}$, thus $(P_1 - P_3) = \gamma_{alc} \times 20_{ft}$. Plugging this into the equation for "h", we get:

$$\boxed{h = 0_{ft}}$$

H

Please, go to the "2nd part" tab in excel to see the calculations following the described procedure.

Regarding the 3rd part, I used the spreadsheet of the 1st part, changed the flow rate value from 0 to 250 (with intervals of 25 gpm) and plot P_1 vs Q. See "3rd part" tab in excel file. With that I can read the flow rate I would obtain if $P_1 = 75$ psig:

$$\boxed{Q \cong 190 \text{ gpm}}$$

<u>SUMMARY</u>

The air pressure in the right tank to obtain 250 gpm is 94.045 psig. The manometer reading for this case in $h = 5.91$ ft.
The maximum air pressure at which there is no flow rate is 46.81 psig.
The flow rate when $P_1 = 75$ psig is 190 gpm

ANALYSIS

I

As the pressure in the right tank decreases, the flow rate between the tanks decrease as well. The manometer reading "h" will also get affected as it adjusts to the new pressure differential. At 190 gpm (or $P_1 = 75$ psig),
$h \cong 3.4$ ft.

DATA

Q=	**250**	**gpm**	0.55700233 ft3/s
p2=	40	psig	
gamma_a=	49.01	lb/ft3	
nu_a=	1.37E-05	ft2/s	
gamma_m=	844.9	lb/ft3	
L_vertical=	38	ft	
L_horizontal=	36	ft	
L_total=	110	ft	
Di=	0.1723	ft	
Ai=	0.02333	ft2	
e=	1.50E-04	ft	
K_valve=	8	*fT	
K_elbow=	30	*fT	2 of them
K_entrance=	0.5		
deltaZ=	20	ft	
g=	32.2	ft/s2	

$$P_1 = P_2 + \gamma_a\left[(z_2 - z_1) + \frac{V_2^2}{2g} + h_{L_{1-2}}\right]$$

$$P_3 = P_1 - \gamma_a\left[(z_3 - z_1) + \frac{V_3^2}{2g} + h_{L_{1-3}}\right]$$

$$h = \frac{\left[(P_1 - P_3) - \gamma_a \times 20_{ft}\right]}{\left(\gamma_m - \frac{\gamma_a}{2}\right)}$$

CALCULATE ENERGY LOSSES WHOLE SYSTEM

V2=	23.8749389	ft/s
Re=	3.00E+05	
D/e=	1148.67	
f=	0.02019	
fT=	0.01899	
hL_pipe=	114.08656	ft
hL_entrance=	4.42556451	ft
hL_elbow=	10.0846454	ft
hL_valve=	1.34461939	ft
hL_TOTAL=	129.94139	ft

CALCULATE AIR PRESSURE

p_AIR= 94.0445927 psig

CALCULATE ENERGY LOSSES UP TO THE ELBOW

hL_pipe=	76.7491407	ft	8.85112901
hL_entrance=	4.42556451	ft	
hL_elbow=	7.56348406	ft	
hL_valve=	1.34461939	ft	
hL_TO-ELBOW=	90.0828086	ft	

PRESSURE AT ELBOW (MANOMETER CONNECTION)

p_elbow= 53.5657574 psig

MANOMETER READING

h= 5.91026552 ft

DATA

Q=	**0**	**gpm**	0 ft3/s
p2=	40	psig	
gamma_a=	49.01	lb/ft3	
nu_a=	1.37E-05	ft2/s	
gamma_m=	844.9	lb/ft3	
L_vertical=	38	ft	
L_horizontal=	36	ft	
L_total=	110	ft	
Di=	0.1723	ft	
Ai=	0.02333	ft2	
e=	1.50E-04	ft	
K_valve=	8	*fT	
K_elbow=	30	*fT	2 of them
K_entrance=	0.5		
deltaZ=	20	ft	
g=	32.2	ft/s2	

$$P_1 = P_2 + \gamma_a\left[(z_2 - z_1) + \frac{V_2^2}{2g} + h_{L_{1-2}}\right]$$

$$P_3 = P_1 - \gamma_a\left[(z_3 - z_1) + \frac{V_3^2}{2g} + h_{L_{1-3}}\right]$$

$$h = \frac{\left[(P_1 - P_3) - \gamma_a \times 20_{ft}\right]}{\left(\gamma_m - \frac{\gamma_a}{2}\right)}$$

CALCULATE ENERGY LOSSES WHOLE SYSTEM

V2=	0	ft/s
Re=	0.00E+00	
D/e=	1148.67	
f=	0.00000	
fT=	0.01899	
hL_pipe=	0	ft
hL_entrance=	0	ft
hL_elbow=	0	ft
hL_valve=	0	ft
hL_TOTAL=	0	ft

CALCULATE AIR PRESSURE

p_AIR= 46.8069444 psig

CALCULATE ENERGY LOSSES UP TO THE ELBOW

hL_pipe=	0	ft
hL_entrance=	0	ft
hL_elbow=	0	ft
hL_valve=	0	ft
hL_TO-ELBOW=	0	ft

PRESSURE AT ELBOW (MANOMETER CONNECTION)

p_elbow= 40 psig

MANOMETER READING

h= -6.929E-16 ft

Q (gpm)	p_AIR (psi)	h (ft)
0	46.8069444	0
25	47.3872446	0.07184634
50	48.9288644	0.26385421
75	51.3925343	0.57138662
100	54.7688037	0.99332762
125	59.053464	1.5291803
150	64.2441894	2.17866999
175	70.3395246	2.94162486
200	77.3384815	3.81792825
225	85.2403491	4.80749618
250	94.0445927	5.91026552