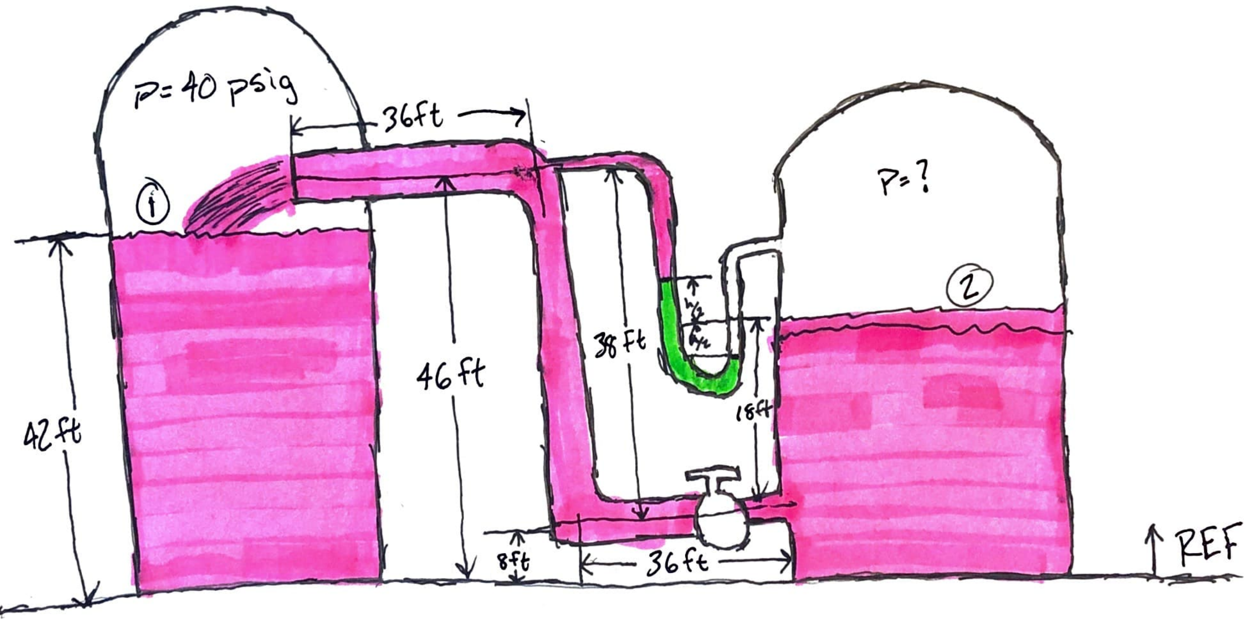
Robert Knupp
MET 330
Test 1
10/4/2021

Purpose:
- Determine the required air pressure in the right tank in order to get Q = 250 gpm of ethyl alcohol. Find manometer deflection.
- Find air pressure in the right tank when flow stops. Find manometer deflection at this instance.
- Use the excel spreadsheet created in part 1 to solve for p_2 for several flow rates. Plot them and determine what the flow rate would be with a p_2 of 75 psi.

Drawings & Diagrams:



Sources: Mott & Untener, Applied Fluid Mechanics, 7th Edition, Pearson, 2015

Design Considerations: For this problem I assume:
- Incompressible Fluids
- Steady State
- Isothermal at 77°F
- Constant Properties
- Stagnant fluid (for part 2)

Data & Variables: $V_1 = 0\ ft/s$ $V_2 = 0\ ft/s$ $p_1 = 40\ psig = 5760\ psfg$

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$\varnothing$ 2in schedule 40 steel pipe $= 2.067" = .17225\ ft$

$Q = 250\ gpm = 0.557\ ft^3/s$ $A_{pipe} = \frac{\pi D^2}{4} = .0233\ ft^2$

$\rho_{EA} = 1.53\ slug/ft^3$ $\gamma_{EA} = 49.01\ lb/ft^3$ $\eta_{EA} = 2.10 \times 10^{-5}\ lbs/ft$

$\rho_{Hg} = 26.26\ slug/ft^3$ $\gamma_{Hg} = 844.9\ lb/ft^3$ $\eta_{Hg} = 3.20 \times 10^{-5}\ lbs/ft$

$f_T = 0.019$ $L_e/D_{Gate} = 8$ $\varepsilon = 1.5 \times 10^{-4}\ ft$ $L_{pipe} = (36(2) + 38) = 110\ ft$

Materials: • Ethyl Alcohol • 2" Schedule 40 steel pipe
• Mercury

Procedure: 1) To solve part 1 we need to first find the velocity at which the fluid is flowing at $Q = .557\ ft^3/s$

$$Q = VA$$

$$V_{EA} = \frac{Q}{A} = \frac{0.557\ ft^3/s}{0.0233\ ft^2} = 23.906\ ft/s$$

Once we have the velocity of the Ethyl Alcohol we can use that to find all energy losses and minor losses throughout the system.

• First we find the Reynold's Number

$$N_R = \frac{\rho v D}{\eta} = \frac{(1.53\ slug/ft^3)(23.906\ ft/s)(.17225\ ft)}{2.10 \times 10^{-5}\ lbs/ft}$$

$$\therefore N_R = 300{,}011.762$$

$\therefore$ Flow is turbulent

• Now that we have Reynold's Number we can find the friction factor for the turbulent flow through the pipes.

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7(D/\varepsilon)} + \frac{5.74}{N_R^{.9}}\right)\right]^2} = \frac{0.25}{\left[\log\left(\frac{1}{3.7\left(\frac{.17225}{1.5\times10^{-4}}\right)} + \frac{5.74}{300{,}011.762^{.9}}\right)\right]^2}$$

$$\therefore f = \frac{0.25}{\left[\log(2.3536 \times 10^{-4} + 6.75286 \times 10^{-5})\right]^2} = \frac{.25}{12.381}$$

$$f = 0.0202$$

Procedure Cont':

- Now that we know the friction factor (f) for the turbulent flow through the steel pipe we can find all of our energy losses throughout the system.

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- Entrance Loss: $h_{L_E} = K\left(\frac{V_{EA}^2}{2g}\right) = .5\left(\frac{23.906\ ft/s^2}{2(32.2\ ft/s^2)}\right)$

$K_{square\text{-}edged} = .5$

[redacted]

$h_{L_E} = 4.437\ ft$

- Gate Valve: $K = \left(\frac{L_e}{D}\right) f_t = 8(0.019) = 0.152$

$\therefore\ h_{L_{Gate}} = .152\left(\frac{(23.906\ ft/s)^2}{2(32.2\ ft/s^2)}\right)$

$h_{L_{Gate}} = 1.349\ ft$

- Elbows: $K = 30 f_t = 30(0.019) = 0.57$

$\therefore\ h_{L_{Elbow}} = .57\left(\frac{(23.906\ ft/s)^2}{2(32.2\ ft/s^2)}\right)$

$h_{L_{Elbow}} = 5.058\ ft$ (x2 for both Elbows)

- Loss through pipe: $h_{L_{pipe}} = f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$

$= .0202\left(\frac{110}{.17225}\right)\left(\frac{23.906^2}{2(32.2)}\right)$

$h_{L_{pipe}} = 114.476\ ft$

$\therefore$ Total Energy Loss: $h_{L_{Total}} = h_{L_E} + h_{L_{gate}} + h_{L_{Elbow}}(2) + h_{L_{pipe}}$

$\therefore\ h_{L_{total}} = 4.437 + 1.349 + 2(5.058) + 114.476$

$h_{L_{Total}} = 130.378\ ft$

Procedure Cont': Once we know the total energy loss ($h_{L\,Total}$) for the system we can write Bernoulli's equation to solve for the pressure in the right tank (P_2).

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$$\frac{P_1}{\gamma_{EA}} + z_1 + \cancel{\frac{v_1^2}{2g}} + h_{L\,Total} = \frac{P_2}{\gamma_{EA}} + z_2 + \cancel{\frac{v_2^2}{2g}}$$

$$\therefore P_2 = \left(\frac{P_1}{\gamma_{EA}} + (z_1 - z_2) + h_{L\,Total}\right)\gamma_{EA}$$

$$P_2 = \left(\frac{5760\ psfg}{49.01\ lb/ft^3} + (42ft - 26ft) + 130.378\ ft\right) 49.01\ lb/ft^3$$

$$P_2 = (117.527 + 16 + 130.378\ ft)\ 49.101$$

$$P_2 = 12,958\ psfg \text{ or } 90\ psig$$

Now we know the pressure of the air at the top of the tank on the right we can use

$$\Delta p = \gamma h$$

to find the deflection in the manometer.

$$P_1 + \gamma_{EA}(20 - h/2) + \gamma_{Hg}(h/\cancel{2}(2)) = P_2$$

$$5760 + 49.01(20 - h/2) + 844.9h = 12,958$$

$$\therefore 5760 + 980.02 - 24.505h + 844.9h = 12,958$$

$$6,740.02 + 820.395h = 12,958$$

$$820.395h = 6,217.98$$

$$\therefore \boxed{h = 7.579\ ft}$$

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Procedure Cont': 2) To find the pressure in the tank on the right when flow stops we use

$$\Delta p = \gamma h$$

$$\therefore P_2 - P_1 = \gamma_{EA}(\Delta h)$$

$$P_2 = (49.01)(16) + 5760$$

$$P_2 = 6{,}544.16 \text{ psf}$$

Once we know the new pressure in the tank on the right we can use

$$\Delta p = \gamma h$$

for the manometer

$$p_1 + \gamma_{EA}(20 - h/2) + \gamma_{Hg}\left(\frac{h}{\cancel{2}}(\cancel{2})\right) = P_2$$

$$5760 + 49.01(20 - h/2) + 844.9h = 6{,}544.16$$

$$\therefore 5760 + 980.02 - 24.505h + 844.9h = 6{,}544.16$$

$$6{,}740.02 + 820.395h = 6{,}544.16$$

$$h = \frac{-195.86}{820.395}$$

$$h = \boxed{-.239 \text{ ft}}$$

Which means it is .239 ft higher on the right side of the manometer.

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Procedure Cont': 3) For part 3 we just need to use the excel Sheet we created for part 1 across many different flow rates to determine what the flow rate would be at 75 psi.

(See excel sheet for graph)

It appears that at 75 psi the flow rate would be about 210 gpm

Summary: 1) For part 1 once all of the losses were added up throughout the system Bernoulli's equation gave us a pressure value of $p_2 = 12{,}958$ psfg or 90 psig
Then the h was found to be 7.579 ft

2) In part 2 the flow was stopped we no longer had to user Bernoulli's equation. $\Delta P = \gamma h$ worked for this part and we came out to $p_2 = 6{,}544.16$ psf or 45.446 psi
We then used the same equation to find the manometer deflection at part 1 which came out to $h = -.239$ ft

3) We already had the excel sheet from part 1 so it was very easy to throw the data into a scatter plot and see that if the psi = 75 then the flow rate would be about 210 gpm.

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Analysis: From this problem we learned that the pressure from the right tank greatly effects the flow rate we see throughout the system. The largest loss in this problem came from going through the entire length of pipe. We also observed that as the pressure in the right tank got larger the value of h in the manometer also increased eventually becoming negative where it began to move up the right side of the manometer when the flow was stopped. The data in my excel sheet differed from my answers, but I chalked that up to rounding. If the pressure in the right tank were to ever drop below 45.446 psi it would begin to backflow from the tank on the left.