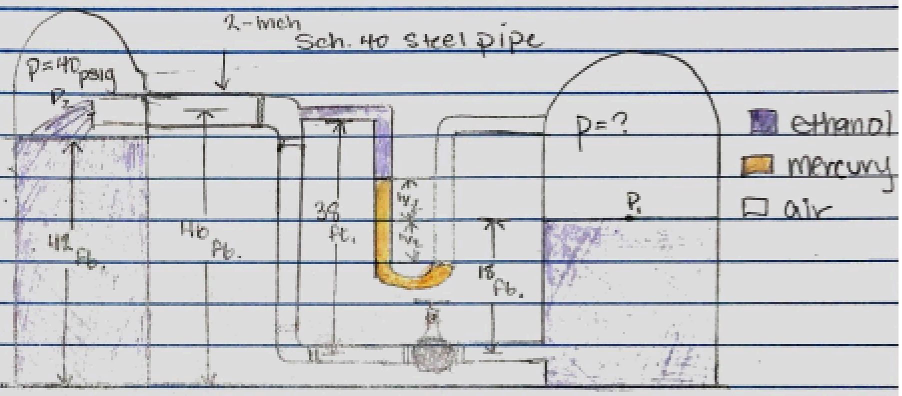
Ethan Kishnevskiy Fluid Mechanics Test 1 2/9/2024

Purpose

To determine the required air pressure for a flow rate of 250 gallons per minute to the left tank as well as the manometer reading at the pressure found.

Drawings & Diagrams



Sources

A. Ulener, J. & L. Mott, R. (2022). Applied Fluid Mechanics. (8th Edition) [EPUB]. Pearson.

Design Considerations

- Incompressible Fluids
- Steady-State Flow
- Isothermal
- 77° F

Data and Variables

$\gamma_{EA} = 49.01\ lb/ft^3$ } Specific weight

$\rho_{EA} = 1.53\ slugs/ft^3$ $\rho_{air} = 2.28 \cdot 10^{-3}\ slugs/ft^3$ at 80° F } densities
$\rho_{Hg} = 26.26\ slugs/ft^3$

$P_2 = 40\ psig$ $V_1 = 0$ $Q = 250\ gal/min$ $A_{pipe} = 0.021\ ft^2$ } Bernoulli's Equation
$z_1 = 8\ ft$
$d_{pipe} = 0.17\ ft$ $z_2 = 38\ ft$

Data and Variables (cont)

$g = 32.2 \; ft/s^2$ $\varepsilon = 1.5 \cdot 10^{-4}$ $l_T = 110 \; ft$

$\eta = 2.15 \cdot 10^{-5}$ $\nu = 1.37 \cdot 10^{-5}$

Procedure

First, I will write out and identify the parts of Bernoulli's Equation that are known. I will then solve for the missing variables in order to find the pressure in the origin tank on the right. I will then identify and calculate all sources of loss, major and minor. After this, I will adjust parameters in an excel spreadsheet to solve problems 2 & 3.

Calculations

$$\frac{V_1^2}{2g} + \frac{P_1}{\gamma_{EA}} + z_1 = \frac{V_2^2}{2g} + \frac{P_2}{\gamma_{EA}} + z_2 + h_L$$

Know	Need
$V_1 = 0$	V_2 [ft/s]
$P_2 = 40$ [psig]	P_1 [psig]
$z_1 = 8$ [ft]	h_L [ ]
$z_2 = 38$ [ft]	

$$Q_2 = V_2 A_2 \rightarrow V_2 = \frac{0.557 \, [ft^3/s]}{0.021 \, [ft^2]} = 25.53 \, [ft/s] \leftarrow V_2$$

Calculations (continued)

Sources of loss: 2 elbows, entrance, exit, friction, valve

$$h_L = 8f \cdot \frac{V_2^2}{2g} + \left(f \cdot \frac{L}{D} \cdot \frac{V_2^2}{2g}\right) + \left(2 \cdot 20 f \cdot \frac{V_2^2}{2g}\right) + \left(1.0 \cdot \frac{V_2^2}{2g}\right) + \left(0.5 \cdot \frac{V_2^2}{2g}\right)$$

$$N_R = \frac{v_2 \cdot D \cdot \rho_{EA}}{\eta} = 310{,}019.28 > 4000 \therefore \text{Turbulent}$$ Reynold's Number

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7(D/\epsilon)} + \frac{5.74}{N_R^{0.9}}\right)\right]^2} = 0.02$$ Friction Factor

$$h_L = 8(0.02) \cdot \frac{25.53^2}{2 \cdot 32.2} + \left(0.02 \cdot \frac{110}{0.17} \cdot \frac{25.53^2}{2 \cdot 32.2}\right) + \left(2 \cdot 20 \cdot 0.02 \cdot \frac{25.53^2}{2 \cdot 32.2}\right) + \left(1.0 \cdot \frac{25.53^2}{2 \cdot 32.2}\right) + \left(0.5 \cdot \frac{25.53^2}{2 \cdot 32.2}\right)$$

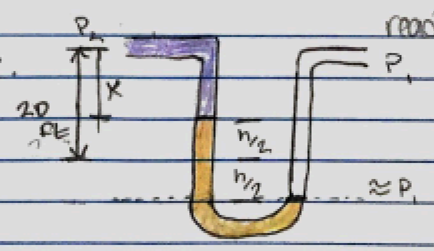
$$h_L = 178.907$$ h_L

We now have one equation and one variable.
Rearranging and solving for P_1:

$$P_1 = 10.4774 \text{ psig}$$

$$P_1 = P_2 + \rho_{air} g h_1 - \rho_{Hg} g h - \rho_{EA} g x$$ manometer reading

change in air pressure is negligible.
$\therefore$ can be ignored



$$\begin{cases} P_1 = P_2 + \rho_{Hg} g h - \rho_{EA} g x \\ 20 = h/2 + x \end{cases}$$

Solving by substitution: $h = 11.875$ ft., $x = 8.125$ ft.

Calculations (continued)

$Q = 0 \therefore V_2 = 0$

According to spreadsheet:

$$P_1 = 1510.23 \text{ psig at } Q = 0$$

$P_1 = P_2 - \rho_{Hg} g h - \rho_{EA} g x$

$29 = h_2 + x$

$$h = 0.05 \text{ ft} \quad x = 28.95 \text{ ft.}$$

Wrong

$$\frac{V_1^2}{2g} + \frac{P_1}{\gamma_{EA}} + z_1 = \frac{V_2^2}{2g} + \frac{P_2}{\gamma_{EA}} + z_1 + h_L$$

Q3
$P_1 = 75$ psig

$$V_2 = \sqrt{\left(\frac{V_1^2}{2g} + \frac{P_1}{\gamma_{EA}} + z_1 - \frac{P_2}{\gamma_{EA}} - z_2 - h_L\right) \cdot 2g}$$

$$Q = A_2 V_2 = A_2 \sqrt{\left(\frac{V_1^2}{2g} + \frac{P_1}{\gamma_{EA}} + z_1 - \frac{P_2}{\gamma_{EA}} - z_2 - h_L\right) \cdot 2g}$$

The above is wrong for not factoring h_L which has V_2 as a component.

Correct Eq:

$$V_2 = \sqrt{\left(\frac{\frac{V_1^2}{2g} + \frac{P_1}{\gamma_{EA}} + z_1 - \frac{P_2}{\gamma_{EA}} - z_2}{1 + 8f + f \cdot L/D + 2 \cdot 20f + 1.0 + 0.5}\right) 2g}$$

(I can prove this but it is not what is being asked)

$Q = A V_2 = A_2$

The flow rate is the opposite direction since 75 is way below the 1510.3 psig for Q=0.

Summary

For Question 1, the required psig is 10,774 psig.

For Question 2, the mercury would be 11.875 ft.

For Question 3, the flow would be in the opposite direction.

Analysis

The important part of the question is to use Bernoullis Equation. From this, we can find the pressure through manipulation. Darcy's equation as well as Reynold's number and the friction factor equations were paramount to finding h_L, and by extension P_1.

I enjoyed this problem.