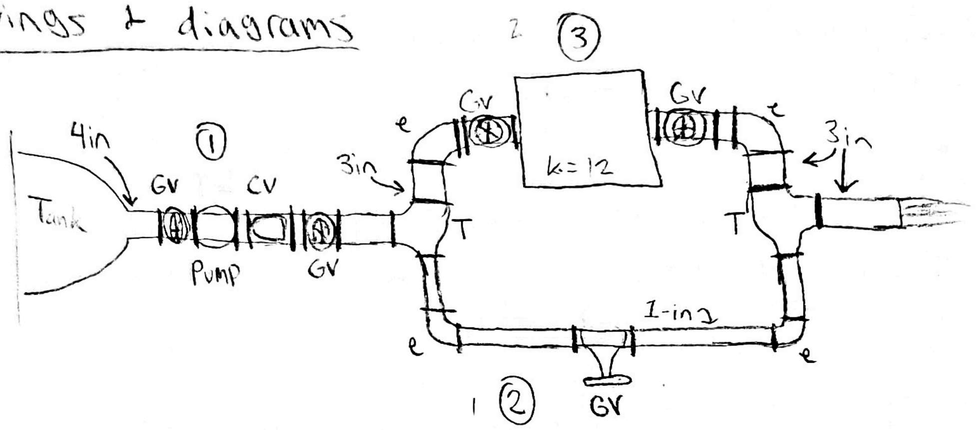
Stephanie Broussard 1

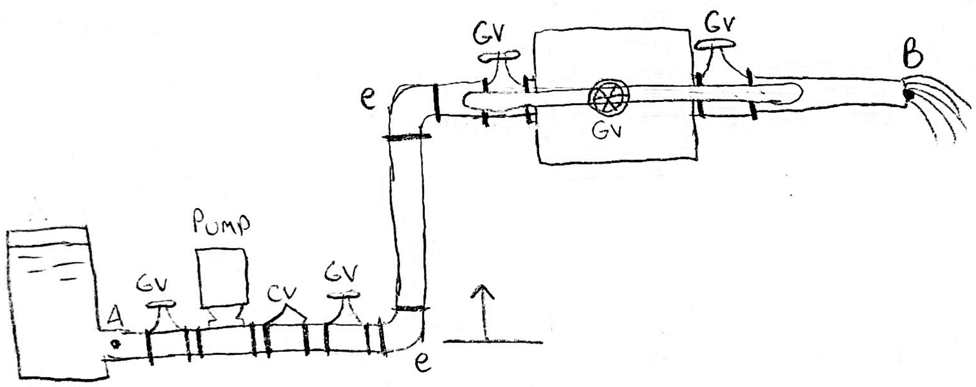
Test 3

Purpose

The purpose of this problem is to specify the required pump for a system. The pump power and total flow rate will need to be calculated.

Drawings & diagrams





Sources

Mott, R.L., Untener, J.A., "Applied Fluid Mechanics" 7th ed. Pearson Edu. (2015)

Design Considerations

- Incompressible fluid
- Isothermal fluid
- Steady state

Data & Variables

- Kinematic viscosity for water @ 160°F = 4.38×10^{-6} ft²/s
- $L_1 = 10$ ft • $L_d = 40$ ft • $L_2 = 30$ ft • $L_3 = 8$ ft
- $D_1 = 0.3355$ ft • $D_2 = 0.0874$ ft • $D_3 = 0.2557$ ft
- $A_1 = 0.0884$ ft² • $A_2 = 0.006$ ft² • $A_3 = 0.05132$ ft²
- $\varepsilon = 1.5 \times 10^{-4}$ ft $Q = \geq 275$ gpm • Le/D-elbow = 30
- Le/D-GV (fully open) = 8 • Le/D-GV (3/4 open) = 35 • Le/D-GV (1/2 open) = 160
- Le/D-GV (1/4 open) = 900 • Le/D-GV (closed) = 10,000 • Le/D CV = 100
- Le/D Tees = 60 • $f_{T_1} = 0.016$ • $f_{T_2} = 0.022$ • $f_{T_3} = 0.017$
- tank height = 4.5 ft • γ_{water} @ 160°F = 61 lb/ft³ • $g = 32.2$ ft/s²

Procedure

To begin this problem, I will start by using Bernoulli's equation and manipulating it to solve for h_A. I then find the velocity, Reynolds number, friction factor, and the energy loss due to friction for the 3 pipes. Onces those are found I move onto the minor losses. I have to calculate the losses for the elbows, gate valves (open & close) the check valves, and the Tee's. Once they are found I need to add them up for the total h_L. Bernoulli's equation can now be solved to find h_A. Once it is found I can then calculate the pump power. In the next part of the problem, I use excel to solve for the different flow rates. I find the k value for a fully open, 3/4 open, 1/2 open, 1/4 open gate valve. I then calculate the new h_L and h_A to find the flow rates.

Calculations

$$h_A + \frac{P_A}{\gamma} + \frac{V_A^2}{2g} + \cancel{z_A} = \cancel{\frac{P_B}{\gamma}} + \cancel{\frac{V_B^2}{2g}} + z_B + h_{L_{AB}}$$

$$\hookrightarrow h_A = \frac{-P_A}{\gamma} + \frac{V_A^2}{2g} + z_B + h_{L_{AB}}$$

Since the flow rate has to be at least 275, I chose to do 290 gpm which is 0.646 ft³/s

$$V_1 = \frac{0.646\ ft^3/s}{0.0884\ ft^2} = 7.308\ ft/s$$

$$N_{R_1} = \frac{V_1 D_1}{\nu} = \frac{(7.308\ ft/s)(0.3355\ ft)}{4.38\times10^{-6}\ ft^2/s} = 559{,}779.45$$

$$f_1 = \frac{0.25}{\left(\log\left(\frac{1}{3.7(D/\epsilon)} + \frac{5.74}{N_R^{0.9}}\right)\right)^2} = \frac{0.25}{\left(\log\left(\frac{1}{3.7\left(\frac{0.3355\ ft}{1.5\times10^{-4}\ ft}\right)} + \frac{5.74}{(559779.45)^{0.9}}\right)\right)^2} = 0.0173$$

$$h_{L_1} = f\frac{L}{D_1}\frac{V_1^2}{2g} = 0.0173\left(\frac{10\ ft}{0.3355\ ft}\right)\left(\frac{(7.308\ ft^2/s)^2}{2(32.2\ ft/s^2)}\right) = 0.428\ ft$$

$$V_2 = \frac{0.646\ ft^3/s}{0.006\ ft^2} = 107.67\ ft/s$$

$$N_{R_2} = \frac{(107.67\ ft^2)(0.0874\ ft)}{4.38\times10^{-6}\ ft^2/s} = 2{,}148{,}483.56$$

$$f_2 = \frac{0.25}{\left(\log\left(\frac{1}{3.7\left(\frac{0.0874\ ft}{1.5\times10^{-4}\ ft}\right)} + \frac{5.74}{(2{,}148{,}483.56)^{0.9}}\right)\right)^2} = 0.0226$$

$$h_{L_2} = (0.0226)\left(\frac{30\ ft}{0.0874\ ft}\right)\left(\frac{(107.67\ ft/s)^2}{2(32.2\ ft/s^2)}\right) = 1396.44\ ft$$

$$V_3 = \frac{0.646\ ft^3/s}{0.05132\ ft^2} = 12.588\ ft/s$$

$$N_{R_3} = \frac{(12.588\ ft/s)(0.2557\ ft)}{4.38\times10^{-6}\ ft^2/s} = 734{,}874.79$$

$$f_3 = \frac{0.25}{\left(\log\left(\frac{1}{3.7\left(\frac{0.2557\ ft}{1.5\times10^{-6}\ ft^2/s}\right)} + \frac{5.74}{(734{,}874.79)^{0.9}}\right)\right)^2} = 0.0180$$

$$h_{L_3} = (0.018)\left(\frac{40\ ft}{0.2557\ ft}\right)\left(\frac{(12.588\ ft/s)^2}{2(32.2\ ft/s^2)}\right)(12) = 83.140\ ft$$

Minor losses:

$h_{L\,elbow_{1+3}} = \frac{L_e}{D} \cdot f_{T_3} \cdot \frac{V_3^2}{2g} = 30(0.017)\left(\frac{(12.588\ ft/s)^2}{2(32.2\ ft/s^2)}\right) = 1.255\ ft \times 4 = 5.02\ ft$

$h_{L\,elbow_2} = 30(0.022)\left(\frac{(107.67\ ft/s)^2}{2(32.2\ ft/s^2)}\right) = 118.808\ ft \times 2 = 237.617\ ft$

$h_{L\,GV_1} = 8(0.016)\left(\frac{(7.308\ ft/s)^2}{2(32.2\ ft/s^2)}\right) = 0.106\ ft \times 2 = 0.212\ ft$

$h_{L\,GV_2\,(closed)} = 10{,}000(0.022)\left(\frac{(107.67\ ft/s)^2}{2(32.2\ ft/s^2)}\right) = 39{,}602.832\ ft$ 31.68

$h_{L\,GV_3} = 8(0.017)\left(\frac{(12.588)^2}{2(32.2)}\right) = 0.335\ ft \times 2 = 0.67\ ft$

$h_{L\,CV_1} = 100(0.016)\left(\frac{(7.308)^2}{2(32.2)}\right) = 1.327\ ft \times 2 = 2.654\ ft$

$h_{L\,T_{2+3}} = 60(0.017)\left(\frac{(12.588)^2}{2(32.2)}\right) = 2.510\ ft \times 2 = 5.019\ ft$

$h_{L\,total} = 41{,}334.03\ ft$

$P_A = \gamma h = (61\ lb/ft^3)(4.5\ ft) = 274.5\ lb/ft^2$

$h_A = \frac{-274.5\ lb/ft^2}{61\ lb/ft^3} + \frac{(7.308\ ft/s)^2}{2(32.2\ ft/s^2)} + 15\ ft + 41{,}334.03\ ft$

$h_A = 41{,}345.36\ ft$

$P_A = (61\ lb/ft^3)(0.646\ ft^3/s)(41{,}345.36\ ft) = 1{,}629{,}255.26\ ft\text{-}lb/s = 2{,}962.28\ hp$

$P_{input} = \frac{P_A}{\eta} = \frac{2962.28\ HP}{0.70} = \boxed{4231.83\ HP}$

$h_A = \frac{-P_A}{\gamma} + \frac{V^2}{2g} + Z_B + h_{LAB} \rightarrow h_A = \frac{-P_A}{\gamma} + \frac{8Q^2}{g\pi^2 D^4} + Z_B + h_{LAB}$

$\hookrightarrow Q = \sqrt{\frac{(h_A + P_A/\gamma - Z_B - h_{LAB})(g\pi^2 D^4)}{8}}$

Summary

The pump power at 70% efficiency is 4231.83 HP.
The total flow rate for a fully open gate valve is 579.313 gpm, a 3/4 open is 579.488, a 1/2 open is 579.488, a 1/4 open is 579.88 gpm.

Materials

- Water
- Schedule 40 steel pipes

Analysis

I expected the flow rates to be more different, but it could be due to miscalculations.