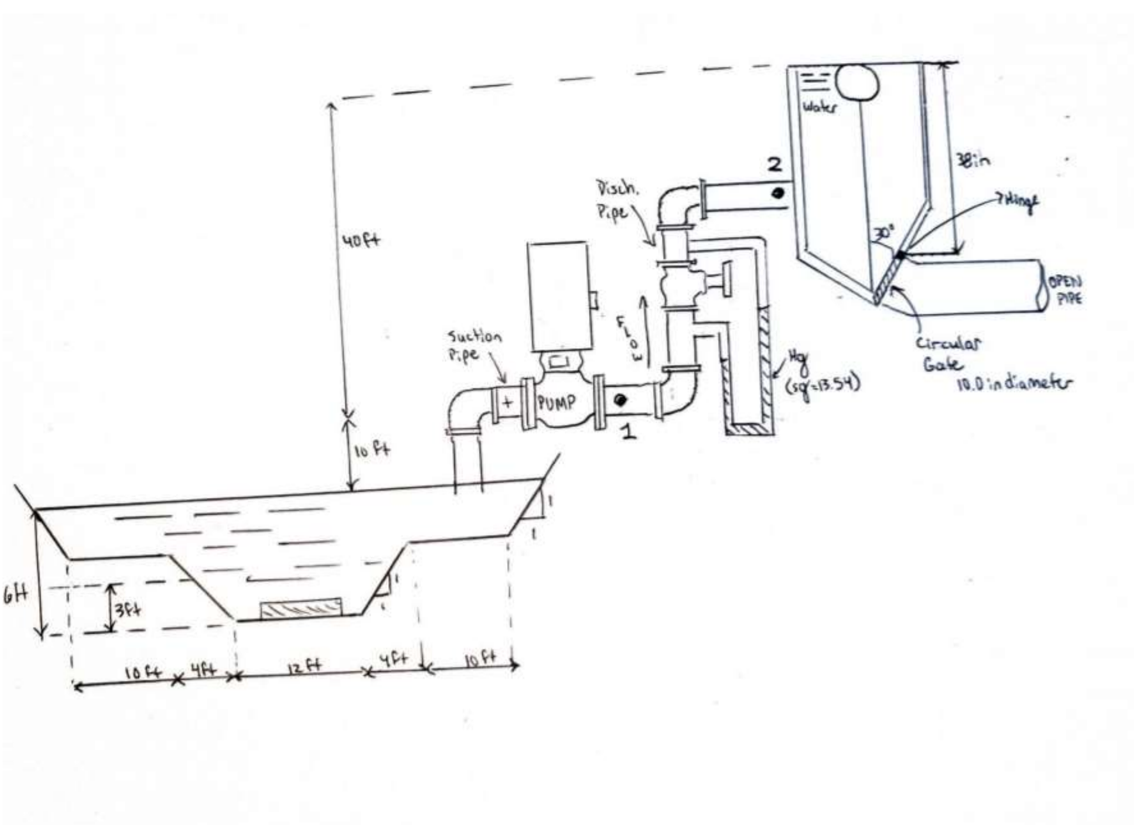
Chris Betton
MET 330
Test 2

Purpose:

The Purpose of this assignment is to ensure that the system designed to move water from a lower open channel to an upper channel meets the customers requirements. In part a it is required to ensure that the lower channel will not be pumped dry by the water transfer system. Secondly, it is required to make sure that the pump discharge piping is adequately supported by pipe hangers and other equipment to be installed by a civil engineer. To make sure the piping is supported, the horizontal and vertical forces on the piping must be determined. Thirdly, the customer has requested to install a flow meter in the piping. This flow meter will see a measurable pressure drop that will be determined. In this portion we want to maintain the same flow rate with the addition of the flow meter. The required pump power will have to be recalculated to account for the new flow nozzle addition to the system. In part d, we will determine how the system will react to a sudden closing of the discharge valve. This is important because we don't want the piping to rupture on an overpressure condition. In part e we will determine the appropriate buoyancy of a buoy that will act as a float attached to a gate valve to open the valve at a predetermined water level of 38 in. In part f, we will determine the appropriate weight to allow minimal friction for an object at the bottom of the open channel. In part g, the previous calculations will be simulated under various conditions.

Drawings and diagrams:



Sources:

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

Design Considerations:

- Constant Properties
- Incompressible Fluid
- Isothermal Conditions
- Steady State
- Newtonian Fluid

Materials:

- Water at 60 °F
- Steel pipe
- Flow Nozzle
- Spherical Buoy
- Flat object for lower channel

Data and Variables:

- T = 60 °F
- Slope = 0.00015
- Q_{sys} = 3.387 ft^3/s
- Nozzle/Pipe diameter ratio = 0.5
- Modulus of elasticity = 200 GPa
- Object specifications: Coefficient of friction = 0.60, 5x1 ft square cylinder
- Upper Channel water level = 38 in.

Procedure:

a. Determine the normal discharge of the lower channel using the Manning Equation by finding the variables in the equation as follows: Rearrange the flow rate equation for average velocity of uniform flow. Substitute the rearranged flow rate equation into the Manning Equation. Calculate the cross-sectional area of the lower open channel. Calculate the Wetted perimeter of the lower channel. Use the calculated cross-sectional area and wetted perimeter to determine the hydraulic radius. Use Table 14.1 to find value of Manning's constant for natural channel with light brush. Substitute all given and calculated variables into the Manning Equation. Compare the calculated discharge of the open channel with the Flow Rate of the system (3.387 ft^3/s).

b. For part B, it is necessary to find the total horizontal and vertical forces on the whole discharge pipe-elbows-valve system. To begin this, I had to place reference points at the pump discharge piping and the inlet to the upper channel. Then I used Bernoulli's equation to find pressure at point 1 (pump discharge) while accounting for the pipe losses, elbow losses and valve losses. It was assumed that the pressure at point 2 was 0 gage pressure. To calculate the forces in the elbows, I separated the reaction force into x and y components. The force in the x direction was due to the pressure of the fluid in the control volume as well as the force due to fluid motion in parameters of density, flow rate and velocity of the fluid. The forces in the y direction of the

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elbow were due to the weight of the fluid and the force due to the motion of fluid. In the straight piping the vertical force was due to the weight of the fluid only. All the force due to the motion of the fluid was manifested in the x direction. The total reaction force can then be found by taking the summation of forces in the x and y directions.

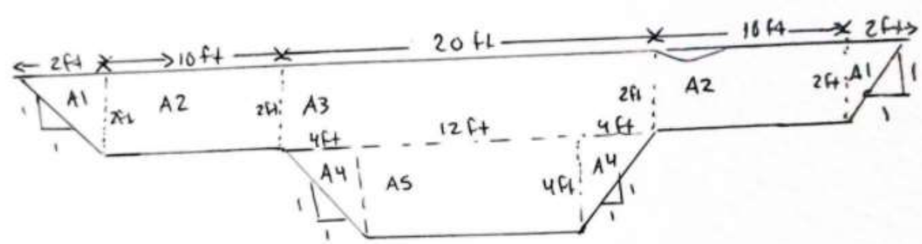
c. In part c it is necessary to consider the pressure drop due to the flow measuring nozzle. In the nozzle, the flow stream is decreased in diameter and expands back to the main pipe diameter after passing the restriction from the nozzle. We must first find the flow nozzle discharge coefficient which is a modification of energy loss. Next, reference points are considered in the large diameter pipe section and the decreased section of the nozzle. This new nozzle area must be determined. Finally, chapter 15 gives us a modification to Bernoulli's equation made specifically for finding pressure drop across a flow meter. Substitute area 1, area 2, specific weight, and velocity at point 1, and the discharge coefficient into the velocity of flow in the flow meter equation to determine the change in pressure.

d. Cavitation occurs when local static pressure is below vapor pressure of the fluid. Water hammer can occur on a high-pressure condition. In this step we first used equation 11-9 in the book to determine the minimum thickness for the piping specifications. Table F1 was used to find appropriate values for schedule 40 8 in piping. These values along with the Modulus of elasticity were substituted into equation 11-9 to find the minimum thickness. It was determined that the selected pipe thickness was well above the minimum thickness.

Calculations:

a.

(table 14.1) $n_{\text{open channel w/ light brush}} = 0.050$, $S = 0.00015$



$$\bullet\ WP = 2\sqrt{8} + 2(10\,ft) + 2(\sqrt{32}) + 12\,ft = 48.97056\,ft$$

$$\bullet\ 2 \times A_1 = 2 \cdot \tfrac{1}{2}(2)\,ft \cdot 2\,ft = 4\,ft^2,\quad 2 \times A_2 = 2 \times 2\,ft \cdot 10\,ft = 40\,ft^2,\quad A_3 = 20\,ft \cdot 2\,ft = 40\,ft^2$$

$$A_4 = 12\,ft \cdot 4\,ft = 48\,ft^2 \qquad 2 \cdot A_5 = \tfrac{1}{2} \cdot 4\,ft \cdot 4\,ft \cdot 2 = 16\,ft^2 \qquad A_{tot} = 148\,ft^2$$

$$\bullet\ Q = \frac{1.49}{n} \cdot A \cdot R^{2/3} \cdot S^{1/2} \quad \text{where} \quad R = \frac{A}{WP} = \frac{148\,ft^2}{48.97056\,ft} = 3.022223795\,ft$$

$$Q = \left(\frac{1.49}{0.050}\right) \cdot 148\,ft^2 (3.022223795\,ft)^{2/3} \cdot (0.00015)^{1/2} = 112.912326\,ft^3/s > 3.387\,ft^3/s$$

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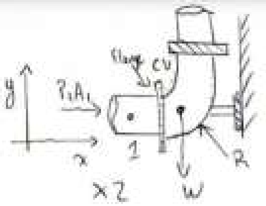
b.



Data & Variables

- $Q = 3.387\ \frac{ft^3}{s}$
- (Table F1): $d = 7.981\,in\ (0.6651\,ft)$, $A = 0.3472\,ft^2$
- $K_{valve} = 5.3$, $K_{elbow} = 30\,f_T$, $f_T = 0.014$
- Table A2: $\rho_{water} = 1.94\ \frac{slugs}{ft^3}$, $\nu_{water} = 1.21\times10^{-5}\ \frac{ft^2}{s}$
- $\gamma_{water} = 62.4\ \frac{lb}{ft^3}$

- Find the pressure at point 1:

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_{L1-2} \therefore \frac{P_1}{\gamma} - z_2 = h_{L1-2}$$

$$h_{L1-2} = f\frac{L}{D}\left(\frac{V^2}{2g}\right)_{pipe} + K_{valve}\left(\frac{V^2}{2g}\right)_{valve} + \left(K_{elbow}\left(\frac{V^2}{2g}\right)2\right),\quad Re = \frac{vD}{\nu} = \frac{9.755\frac{ft}{s}(0.6657ft)}{1.21\times10^{-5}\frac{ft^2}{s}}$$

$Re = 5.36\times10^5$ & $\frac{D}{\epsilon} = \frac{0.6651ft}{1.5\times10^{-4}ft} = 4434$, so $f = 0.01557$

$$h_{L1-2} = 0.01557\left(\frac{40ft}{0.6651ft}\right)\left(\frac{(9.755\frac{ft}{s})^2}{2(32.2\,ft/s^2)}\right) + 5.3\left(\frac{(9.755\frac{ft}{s})^2}{2(32.2\frac{ft}{s^2})}\right) + 30(0.014)\left(\frac{(9.755\frac{ft}{s})^2}{2(32.2)}\right)\times 2$$

$h_{L1-2} = 9.83576\ ft$

$$\therefore P_1 = (h_{L1-2} + z_2)\cdot\gamma_{water}$$

$$P_1 = 3109.751713\ \frac{lb}{ft^2}\left|\frac{1\,ft^2}{(12^2)\,in^2}\right. = 21.59\,psi$$

- Calculate forces in x & y directions in the elbows & straight pipe sections.

F_x elbows

$$P_1A_1 - R_x = \rho Q(V_{2x}^{\,0} - V_{1x}) \therefore R_x = P_1A_1 + \rho QV_1 = 3109.75\frac{lb}{ft^2}(.3472\,ft^2) + \left(1.94\frac{slugs}{ft^3}\right)\left(3.387\frac{ft^3}{s}\right)(9.755$$

$R_x = 1143.8\ lb$

F_y elbows

$$-P_2A_2 - W + R_y = \rho Q(V_{2y} - V_{1y}^{\,0}) \quad R_y = P_2A_2 + W + \rho QV_2 =$$

$$3109.75\frac{lb}{ft^2}(.3472\,ft^2) + 1.94\frac{slugs}{ft^3}\left(3.387\frac{ft^3}{s}\right)\left(9.755\frac{ft}{s}\right)$$

$R_y = 1143.8\,lb$

F_x straight pipe

$$\Sigma F_x = \rho Q(V_{2x} - V_{1x}) \therefore -R_x + P_1A_1 - P_2A_2 = 0 \therefore R_x = \frac{P_1 - P_2}{A}$$

F_y straight pipe

$$\Sigma F_y = \rho Q(V_{2y}^{\,0} - V_{1y}^{\,0}) - W + R_y = 0 \therefore R_y = W$$

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c.

Given Data & Variables

$\beta = 0.5 \quad D = 0.6651\,ft\ (\text{part a}) \quad V_1 = 9.755\,\frac{ft}{s}\ (\text{part a})$

$d = 0.5(D) \qquad N_R = 5.36\times10^5\ (\text{part a})$

$d = 0.33255\,ft$

$A_1 = 0.3472\,ft^2$

$C = 0.9975 - 6.53\sqrt{\frac{\beta}{N_R}} \qquad A_2 = \frac{\pi}{4}(d)^2 = \frac{\pi}{4}(0.33255\,ft)^2 = 0.0868556\,ft^2$

$C = 0.99119$

$$V_1 = C\sqrt{\frac{2g(P_1-P_2)\gamma}{(A_1/A_2)^2-1}} \quad \therefore (P_1-P_2) = \left(\frac{V_1}{C}\right)^2 \cdot \frac{\gamma\,(A_1/A_2)^2-1}{2g}$$

$$\Delta P = \left(\frac{9.755\,ft/s}{0.99119}\right)^2 \cdot \frac{62.4\,\frac{lb}{ft^3}\left(\frac{0.3472\,ft^2}{0.0868556\,ft^2}\right)-1}{2\left(32.2\,\frac{ft}{s^2}\right)}$$

$$\boxed{\Delta P = 1409.212\,\frac{lb}{ft^2}}$$

d.

Data & Variables

$S = 200\,GPa \cdot \frac{145038\,lb/in^2}{GPa}$

$S = 29007600\,psi$

(Table F1) $D_{out} = 8.625\,in$

$T_{wall} = 0.322\,in$

$E_{steel} = 1.00$

$Y_{steel} = 0.40$

$P = 21.59\,psi$ (part a)

Calculations

$$t = \frac{PD}{2(SE+pY)} = \frac{21.59\,lb}{in^2} \cdot 8.625\,in \cdot \frac{in^2}{2(29007600\,lb(1.00) + 21.59\,lb(0.40))}$$

$t = 0.0000032\,in < 0.322\,in$

∴ The thickness of the piping chosen is good enough for the system. So, the pipe would not fail.

Analysis:

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Since the calculated open channel discharge is significantly higher than the system flow rate, the system configuration will not dry out the open channel. The flow nozzle selected by the customer will not significantly decrease the system pressure. In part e, the buoy will be stable while pulling the gate because it will be submerged but it will rise at a consistent rate with the water level.

Summary:

The requested additions to the system by the customer will improve overall system operability. By adding piping support there will be less stress on the system piping. By selecting the appropriate size buoy, the system will be able to maintain the required water level in the upper channel. This will help prevent an overflow of this tank.