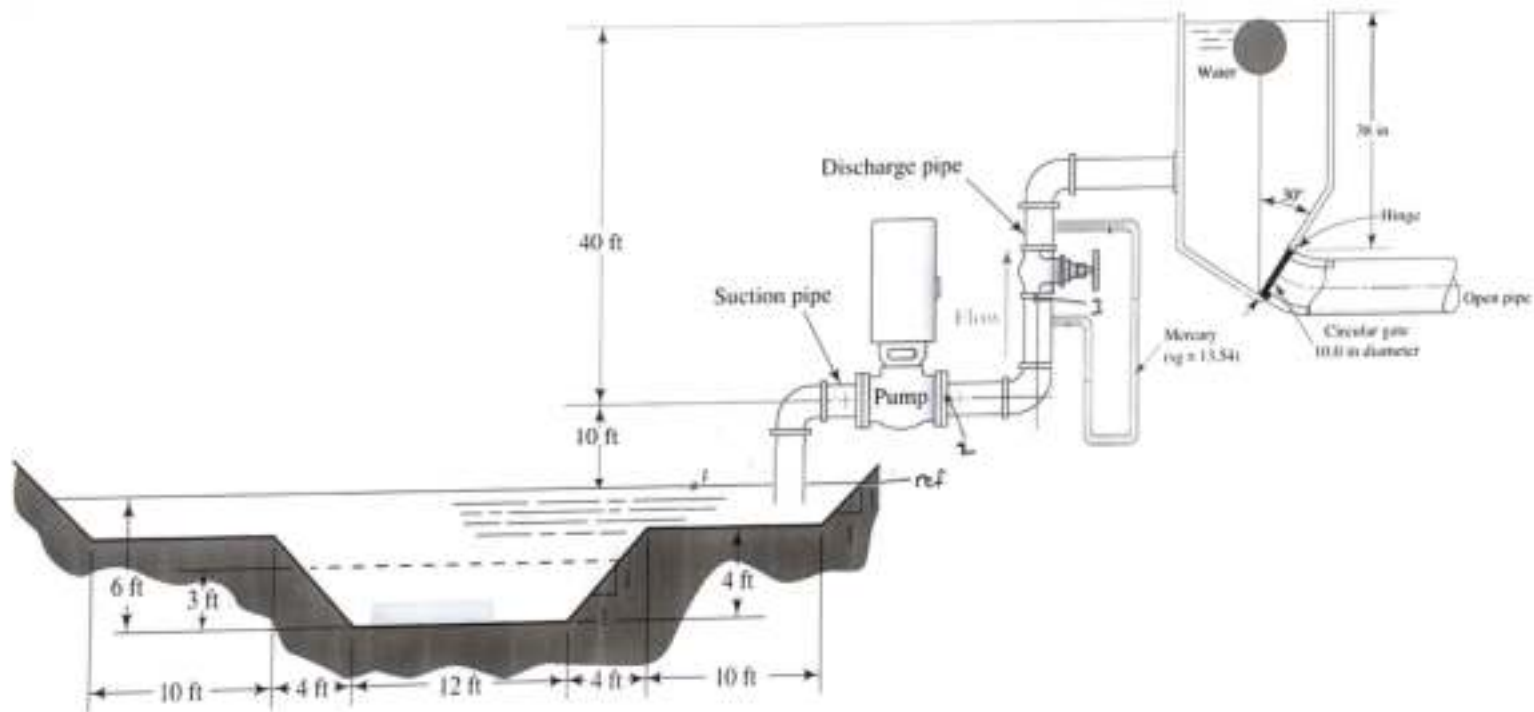


Purpose:

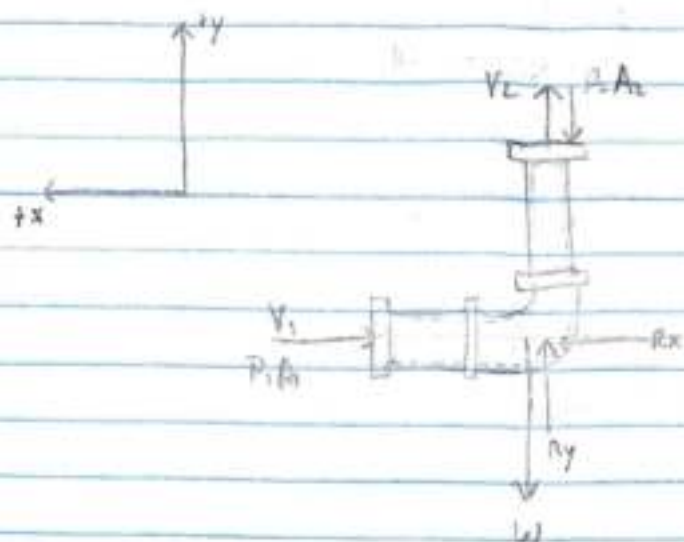
- For the system shown, determine if the pumped water is negligible compared to the flow rate coming through the channel.
- Calculate horizontal and vertical forces in discharge pipe.
- By adding in a flow nozzle, what is the pressure drop? How much should the pump power increase?
- What is the pressure increment if sudden closing of the valve? verify there is no cavitation in the system.
- How large should the buoy be for it to open a gate that is used to seal the open end of a pipe? Is the buoy stable when pulling the gate and why?
- What is the minimum object weight so fluid slides it along the bottom surface of the open channel?
- Create a spreadsheet to compare hand calculations to computer calculations.

Drawings and diagrams:

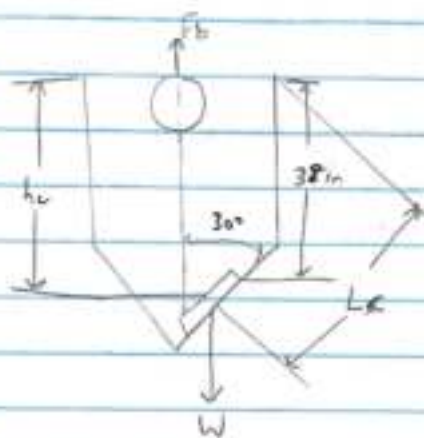
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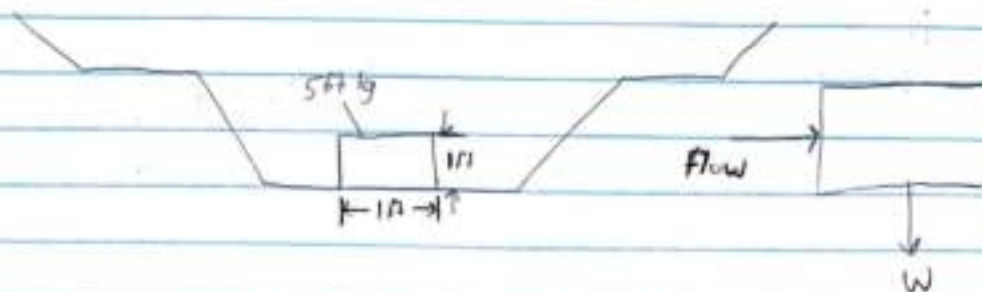
b.)



c.)



d.)



Procedure:

- a) Use Manning equation to calculate flow rate of the water in the channel, then compare to flow rate in system.
- b) I will use Bernoulli's equation to calculate the pump outlet pressure and the friction losses due to the elbows and valve, then calculate elevated channel inlet pressure by adding the pump outlet pressure multiplied by ggh . The horizontal and vertical forces will then be calculated using the force equation in the x and y direction.
- c) To determine pressure drop across the nozzle the equation to calculate the velocity of flow will be used, which is dependent on the distance in the pressure head. Then to calculate the pump increase the new pump power is found by the new pump head times flow rate, which the new pump head is the original pump head + the pressure increase.
- d) I will verify the design in case of water hammer or cavitation by using $\Delta P = \rho c V$ and then determining if the pipe would fail by comparing thickness of pipe chosen using the equation from the book.
- e) To calculate the buoy's radius I will find the depth of the gate, area of the gate, volume of water displaced and the buoyant force on the gate, then to determine if it is stable I will calculate the metacenter of the buoy.
- f) I will use the flow rate of the channel water to calculate velocity, then calculate the force on the object which will be used to find the weight of the object.

Sources:

Mott, R. Untere, J.A. "Applied Fluid Mechanics," 7th Edition. Pearson, 2015.

Design Considerations (for all parts):

Steady flow

Incompressible fluid

Constant properties

Data and Variables:

$$S = 0.00015$$

Open channel, natural with light brush

$$n = 0.050$$

$$Q = 3.787 \text{ ft}^3/\text{s}$$

Water at 60°F

$$V = 9.755 \text{ ft/s}$$

$$h_a = 148.43 \text{ ft}$$

$$p = 1.94 \text{ slug/ft}^3$$

$$A = 0.3772 \text{ ft}^2$$

$$\gamma = 62.4 \text{ lb/ft}^3$$

$$h_{water} = 7.87 \text{ ft}$$

$$h_{res} = 1.27 \text{ ft}$$

Pipe: 8" Sch 40, $\phi = 8.625$ "

Calculation:

$$a) A_1 = (b + zy)y$$

$$A_1 = (12\text{ ft} + (1\text{ ft})(4\text{ ft}))(4\text{ ft})$$

$$A_1 = 64\text{ ft}^2$$

$$A_2 = (b + zy)y$$

$$A_2 = (40\text{ ft} + (1\text{ ft})(2\text{ ft}))(2\text{ ft})$$

$$A_2 = 84\text{ ft}^2$$

$$A_1 + A_2 = 64\text{ ft}^2 + 84\text{ ft}^2 = 148\text{ ft}^2$$

$$WP_1 = b + zy\sqrt{1 + z^2}$$

$$WP_1 = 12\text{ ft} + 2(4\text{ ft})\sqrt{1 + (1\text{ ft})^2}$$

$$WP_1 = 23.31\text{ ft}$$

$$WP_2 = b + zy\sqrt{1 + z^2}$$

$$WP_2 = 20\text{ ft} + 2(2\text{ ft})\sqrt{1 + (1\text{ ft})^2}$$

$$WP_2 = 25.66\text{ ft}$$

$$WP_1 + WP_2 = 23.31\text{ ft} + 25.67\text{ ft} = 48.97\text{ ft}$$

$$R = \frac{A}{WP} = \frac{148\text{ ft}^2}{48.97\text{ ft}} = 3.02\text{ ft}$$

$$Q = \left(\frac{1.49}{n} \right) A R^{2/3} S^{1/2}$$

$$Q = \left(\frac{1.49}{0.050} \right) (148) (3.02)^{2/3} (0.00015)^{1/2}$$

$$Q = 112.86\text{ ft}^3/\text{s}$$

Pressure at pump outlet:

$$b) h_A = \frac{P_1}{\rho} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho} + \frac{V_2^2}{2g} + z_2 + h_A + h_{L,22}$$

$$147.53 = \frac{P_2}{62.4} + \frac{9.76^2}{2(32.2)} + 10 + .62$$

$$P_2 = 8451 \text{ lb ft}^2/\text{ft}^2$$

$$Q = 3.387 \text{ ft}^3/\text{s}$$

$$V = 9.76 \text{ ft/s}$$

$$A = .3472 \text{ ft}^2$$

$$h_A = 147.53 \text{ ft (from test 1)}$$

$$h_{L,22} = .62 \text{ ft (from test 1)}$$

$$F_x = p Q (V_{1x} - V_{2x})$$

$$F_x = R_x - p_1 A_1$$

$$V_{2x} = 0$$

$$V_{1x} = 9.76 \text{ ft/s}$$

$$R_x - p_1 A_1 = p Q (0 - (V_1))$$

$$R_x = p Q V + p_1 A_1$$

$$R_x = (1.94)(3.387)(9.76) + (8451)(.3472)$$

$$R_x = 2998.3 \text{ lb}$$

$$F_y = p Q (V_{2y} - V_{1y})$$

$$F_y = R_y - p_2 A_2$$

$$V_{2y} = V_2$$

$$V_{1y} = 0$$

$$p_1 = p_2 \text{ and } V_2 = V_1$$

$$R_y = p Q V_2 + p_2 A_2$$

$$R_y = (1.94)(3.387)(9.76) + (8451)(.3472)$$

$$R_y = 2998.3 \text{ lb}$$

c) Pipe 8" Sch 40: $A_1 = .347 \text{ ft}^2$

$$D = .6651 \text{ ft}$$

Flow nozzle: $d = .333 \text{ ft}$

$$A_2 = \pi r^2 = \pi (.1665)^2 = .087 \text{ ft}^2$$

$$V_1 = \frac{Q}{A_1}$$

$$A_1$$

$$V_1 = \frac{3.387}{.347}$$

$$.347$$

$$V_1 = 9.76 \text{ ft/s}$$

Water at 60°F : $\eta = 2.35 \times 10^{-5} \text{ lb-s/ft}^2$

$$Re = \frac{V \cdot D}{\eta}$$

$$\eta$$

$$Re = \frac{(9.76)(.6651)}{2.35 \times 10^{-5}}$$

$$2.35 \times 10^{-5}$$

$$Re = 276228.77$$

$$B = 0.5$$

$$B = \frac{d}{D}$$

$$D$$

$$0.5 = \frac{d}{.6651}$$

$$.6651$$

$$d = .333$$

$$C = 0.9975 - 6.53 \sqrt{B/Re}$$

$$C = 0.9975 - 6.53 \sqrt{.5/276228.77}$$

$$C = .9887$$

$$V_1 = C \sqrt{\frac{2g(p_1 - p_2)/\gamma}{(A_1/A_2)^2 - 1}}$$

$$\left(\frac{V_1}{C}\right)^2 = \frac{2g(p_1 - p_2)/\gamma}{(A_1/A_2)^2 - 1}$$

$$\left(\frac{V_1}{C}\right)^2 (A_1/A_2)^2 - 1 = \frac{2g(p_1 - p_2)}{\gamma}$$

$$p_1 - p_2 = \left(\frac{V_1}{C}\right)^2 \frac{\gamma [(A_1/A_2)^2 - 1]}{2g}$$

$$p_1 - p_2 = \left(\frac{9.76}{3.887}\right)^2 \frac{62.4 [(3.47/.087)^2 - 1]}{2(32.2)}$$

$$p_1 - p_2 = 97.45 \times 930.27 / 64.4$$

$$p_1 - p_2 = 1407.68 \text{ lb/ft}^2$$

$$p_1 - p_2 = \gamma h_L$$

$$1407.68 = 62.4 h_L$$

$$h_L = 22.56 \text{ ft}$$

$$\text{From test 1: } h_A = 147.53 \text{ ft}$$

$$h_{A_{\text{new}}} = h_A + h_L = 147.53 + 22.56 = 170.09 \text{ ft}$$

$$\text{Pump power} = \frac{\gamma Q h_A}{\eta} = \frac{(62.4)(3.887)(170.09)}{0.6} = 59913.86 \text{ lb}\cdot\text{ft/s} = 110.45 \text{ HP}$$

$$\begin{aligned} & (\text{New pump power} - \text{original pump power}) / (\text{original pump power}) \times 100 \\ & = (110.45 - 94.48) / (94.48) \times 100 = 16.9\% \end{aligned}$$

$$d) C = \frac{E_o}{P}$$

$$C = \frac{43,200,000}{1.94}$$

$$C = \frac{1 \cdot (43,200,000)(.719)}{(41 \times 10^9)(.027)}$$

$$C = 4718.9$$

$$1.1316$$

$$C = 4170.1$$

$$E_o = 300,000 \text{ psi} = 43,200,000 \text{ lb/ft}^2$$

$$\rho = 1.94 \text{ slug/ft}^3$$

$$E = 200 \text{ GPa} = 41 \times 10^9 \text{ lb/ft}^2$$

$$\delta = .322 \text{ in} = .027 \text{ ft}$$

$$D = 8.625 \text{ in} = .719 \text{ ft}$$

$$\Delta P = \rho c V$$

$$\Delta P = (1.94)(4170.1)(9.76)$$

$$\Delta P = 78958.34 \text{ lb/ft}^2$$

Bernoulli's Eq to find P_2 at valve inlet:

Assume $z_2 = 20 \text{ ft}$

$$h_L = 1.24 \text{ ft}$$

$$h_A = 147.53 \text{ ft}$$

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

$$147.53 = \frac{P_2}{62.4} + \frac{9.76^2}{2(32.2)} + 20 + 1.24$$

$$P_2 = 7788.2 \text{ lb/ft}^2$$

$$P_{max} = P_0 + \Delta P$$

$$P_{max} = 7788.2 + 78958.34$$

$$P_{max} = 86746.54 \text{ lb/ft}^2$$

$$t = PD$$

$$2(SE + PY)$$

$$t = (54)(8.625)$$

$$2((20 \times 1) + (54 \times 1))$$

$$t = 5.60 \text{ in}$$

$$t = .322''$$

$$D = 8.625''$$

$$S = 20 \text{ ksi}$$

$$E = 1$$

$$Y = 0.40$$

$$P = 7788.2 \text{ lbf/ft}^2 = 57 \text{ psi}$$

$$c) \text{ Area} = \pi r^2 = \pi (5)^2 = 78.54 \text{ in}^2$$

$$y = \frac{D}{2} \cos \theta$$

$$y = \frac{10}{2} \cos 70^\circ$$

$$y = 4.33 \text{ in}$$

$$h_c = 39 \text{ in} + 4.33 \text{ in} = 42.33 \text{ in}$$

$$L_c = \frac{h_c}{\cos \theta}$$

$$L_c = \frac{42.33}{\cos 70^\circ}$$

$$L_c = 48.89 \text{ in}$$

$$F_R = \rho h_c A$$

$$F_R = (62.4)(3.53)(.545)$$

$$F_R = 120.05 \text{ lb}$$

$$I = \frac{\pi D^4}{64} = 490.87 \text{ in}^4$$

Volume displaced by gate

$$V_d = (A_g)(h_c)$$

$$V_d = (.545)(3.53)$$

$$V_d = 1.92 \text{ ft}^3$$

$$F_b = V_d \gamma$$

$$F_b = (1.92)(62.4)$$

$$F_b = 119.81 \text{ lb}$$

$$R_{avg} = \frac{f_b}{\sqrt{8\pi r^2 h_c}}$$

$$R_{avg} = \frac{119.81}{\sqrt{(62.4)\pi(5)^2(7.53)}}$$

$$R_{avg} = .083 \text{ ft} = .99 \text{ in}$$

$$f.) f = 0.60$$

$$Q_{\text{object}} = YA$$

$$\text{From part A, } Q = 112.86 \text{ ft}^3/\text{s}$$

$$112.86 = V(148)$$

$$V = .76 \text{ ft/s}$$

Force on object:

$$F = \rho Q V$$

$$F = (1.94)(112.86)(.76)$$

$$F = 166.4 \text{ lb}$$

$$W = \frac{F}{f}$$

$$W = \frac{166.4 \text{ lb}}{.6}$$

$$W = 277.3 \text{ lb}$$

Summary:

Using manometry equation the calculated flow rate of the open channel is $112.86 \text{ ft}^3/\text{s}$ which is negligible amount compared to the pumped flow rate of $3.787 \text{ ft}^3/\text{s}$ in the system. The horizontal and vertical forces in a pipe is calculated to determine the appropriate pipe supports. The R_x and R_y forces are caused by the 90° elbow. A flow nozzle is added to the system in order to measure the flow, with the nozzle diameter to pipe diameter given as 0.5, the pressure drop was calculated to be $1407.68 \text{ lb}/\text{ft}^2$ with an energy loss of 22.56 ft . In the event of water hammer the pressure increment from sudden closing is $447631.05 \text{ lb}/\text{ft}^2$. In order to avoid spillage, a buoy is used to open and close a gate. When the water reaches 30 inches, the buoy goes the gate, for that to happen it was found that the length of the buoy needed to be 1.98 inches. If there was an object at the bottom of the channel, the heaviest it could weigh would be 277 lb or else it wouldn't move from the flow of the water.

Materials:

8 NPS Sch 40 Steel pipe
Water at 60°F

Analysis:

For a proper working system it is critical to take into account all potential failures and consider all forces within the system. The flow rate of the system, compared to the open channel, is negligible because the flow rate of the open channel is significantly higher than the system. If the flow rate of the system exceeded the channel then it could dry up. The flow rate of the channel is also dependent on the area and shape of it. To find the forces exerted on the discharge pipe the pressure after the pump was required and then used to find R_x and R_y . With the addition of a flow nozzle, the standard equation was used to find C and then solved for the pressure drop to then calculate energy loss. In the case of water hammer, it is critical to know the system can withstand the maximum pressure it is were to occur. Water hammer occurs only if a valve closes instantly, not gradually. This is a typical water hammer problem to find celerity and used to find the change in pressure. To avoid spillage in the elevated channel, a circular gate was used and opened by a buoy. The force acting on the gate needed to be less than the vertical force acting on the buoy. The size of the buoy needed to be large enough to pull the gate open when the height of the water reached 38". If there were an object at the bottom of the channel, the flow of water would be able to push it if it were to weigh 277 lb. If the velocity of the water was less, then it would fail to move the object or if the object weighed more it would not move.