Test 2- Fluids

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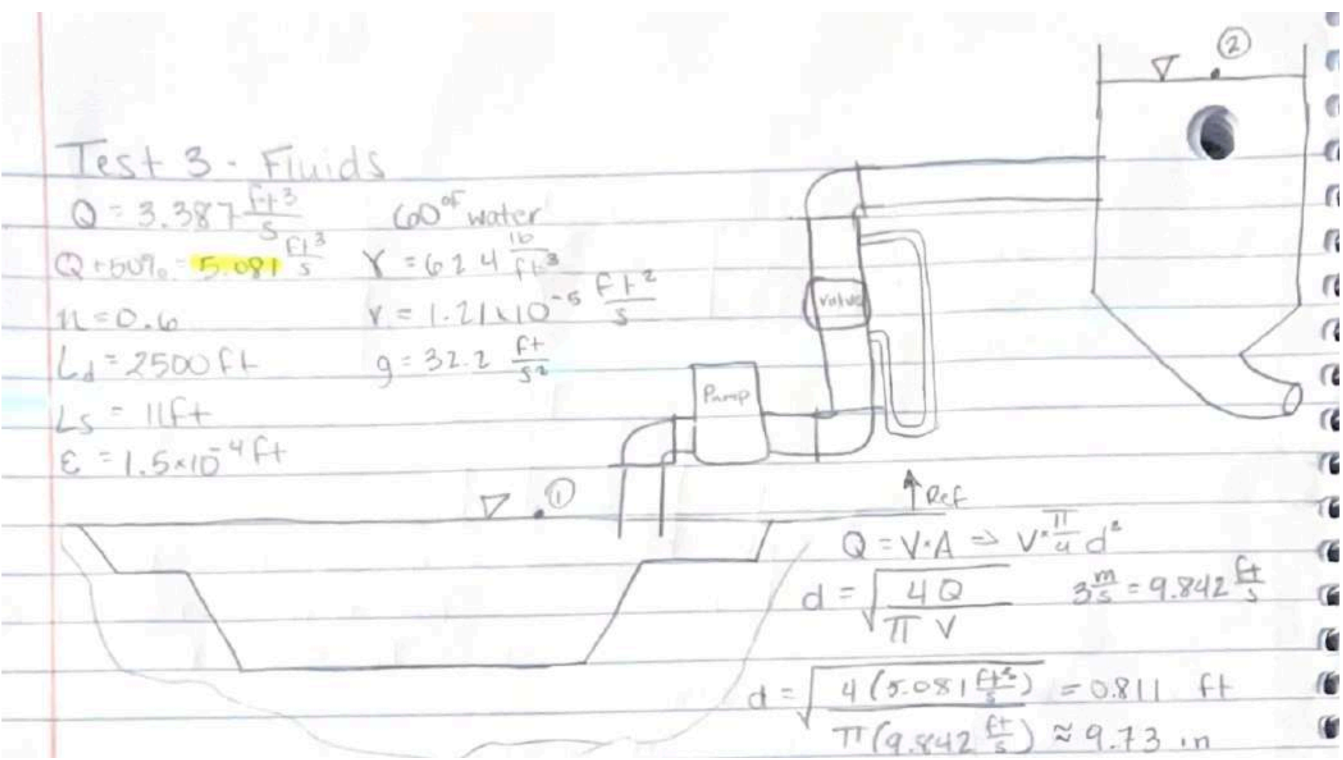
<u>**A**</u>

Purpose

The purpose of the first question is to redesign a pipeline system to deliver at least 50% more of the original flow rate and account for all minor losses. Also, to resign with two options; increasing the pump to a larger one and using that same pump but increasing the pipe sizes.

Drawings & Diagrams



Sources

- My notes
- Applied Fluid Mechanics 8th Edition, Robert L. Mott & Joseph A. Untener
- Canvas Module slides

Design Considerations

- 50% more flow rate
- Suction pipe length = 11 ft
- Discharge pipe length - 2500 ft
- Water at 60F

Data and Variables

Volumetric Flow Rate	Q = 5.081 ft^3/s
Velocity	V = 14.6 ft/s
Change in Pressure	ΔP
Density of Water	ρ_w = 62.4 lb/ft^3
Area	A= 0.3472 ft^2
Gravity	g = 32.2 ft/s^2
Pump Head	hA= 260 ft
Energy loss due to friction	hL= $h_{L_{sution}} + 3 \cdot h_{L_{elbows}} + h_{L_{valve}} + h_{L_{disrchage}}$
Reynolds Number	Re= 802397
Friction Factor	f= 0.0152
Friction Coefficient	fT= 0.014
Length Suction	11 ft

Length Discharge	2500 ft

Procedure

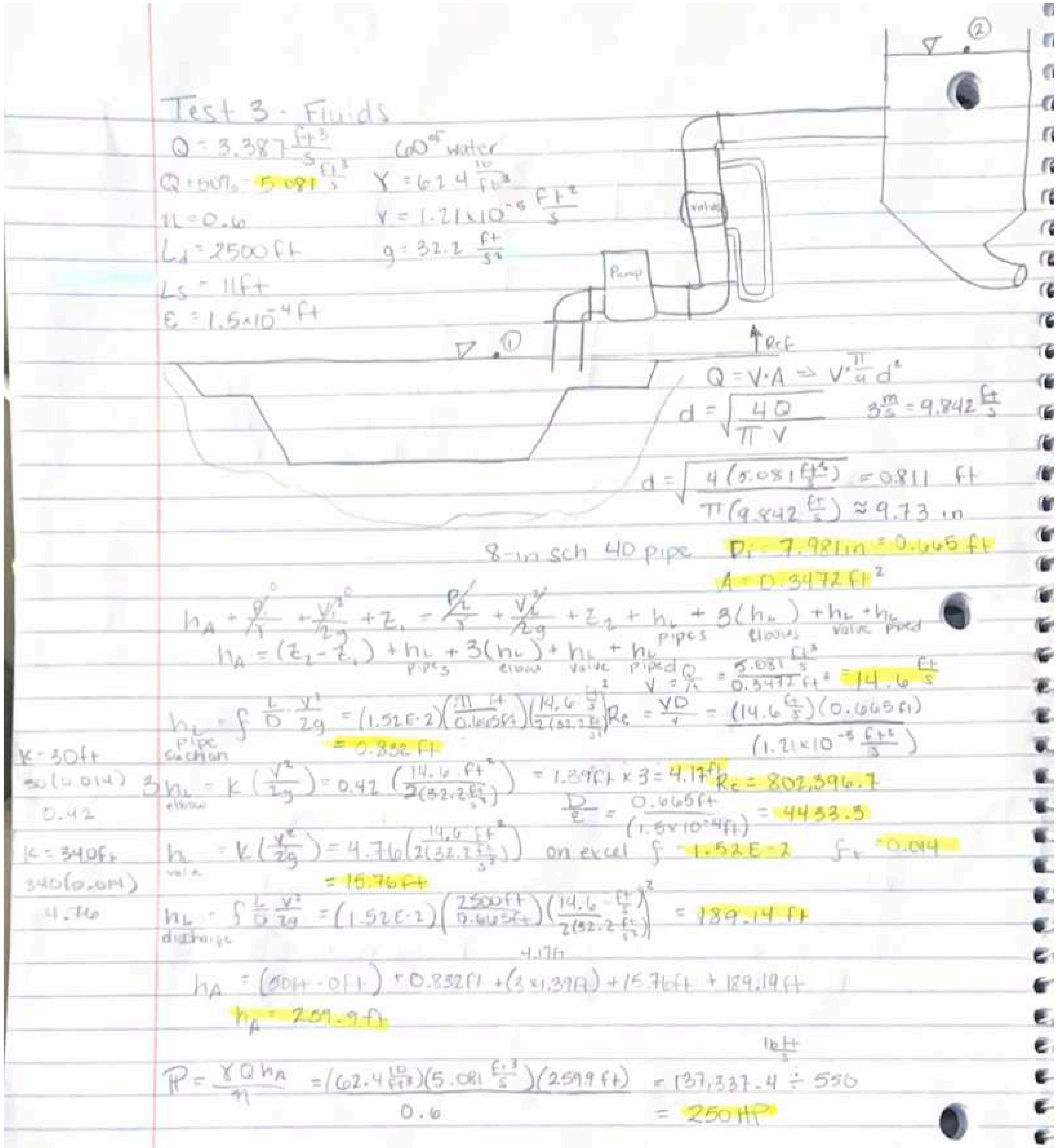
1. First I calculated Q+50%, then I used an 8-in schedule 40 steel pipe like test 2.
2. Next, I used Bernoulli's equation to account for all the minor losses and solved for the pump head.
3. I had to calculate the $\frac{D}{\varepsilon}$, Reynolds number, friction factor and friction coefficient to solve for hL.
4. After finding all my minor losses, then I could calculate the hA and use the to solve for pump power.

For the redesign:

A. We replaced our pump with a large one that can compensate for the increased pump power and kept the diameter the same and adjusted our excel sheet.

B. We used the pump power calculated in test 2, and increased our pipe diameters and determined a better size pipe for the increased flow using an iteration process.

Calculations



Test 3 - Fluids

$Q = 3.387\ \frac{ft^3}{s}$ — 60°F water

$Q + 50\% = 5.081\ \frac{ft^3}{s}$ — $\gamma = 62.4\ \frac{lb}{ft^3}$

$\eta = 0.6$ — $\nu = 1.21\times10^{-5}\ \frac{ft^2}{s}$

$L_d = 2500\ ft$ — $g = 32.2\ \frac{ft}{s^2}$

$L_s = 11\ ft$

$\varepsilon = 1.5\times10^{-4}\ ft$

$Q = V\cdot A \Rightarrow V\cdot\frac{\pi}{4}d^2$

$d = \sqrt{\frac{4Q}{\pi V}}$ — $3\frac{m}{s} = 9.842\frac{ft}{s}$

$d = \sqrt{\frac{4(5.081\frac{ft^3}{s})}{\pi(9.842\frac{ft}{s})}} = 0.811\ ft \approx 9.73\ in$

8-in sch 40 pipe — $D_i = 7.981\ in = 0.665\ ft$

$A = 0.3472\ ft^2$

$$h_A + \frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_{L,pipes} + 3(h_{L,elbows}) + h_{L,valve} + h_{L,piped}$$

$$h_A = (z_2 - z_1) + h_{L,pipes} + 3(h_{L,elbow}) + h_{L,valve} + h_{L,piped}$$

$V = \frac{Q}{A} = \frac{5.081\frac{ft^3}{s}}{0.3472\ ft^2} = 14.6\ \frac{ft}{s}$

$h_{L,\text{pipe suction}} = f\frac{L}{D}\cdot\frac{V^2}{2g} = (1.52E\text{-}2)\left(\frac{11\ ft}{0.665\ ft}\right)\left(\frac{(14.6\frac{ft}{s})^2}{2(32.2\frac{ft}{s^2})}\right) = 0.832\ ft$

$Re = \frac{VD}{\nu} = \frac{(14.6\frac{ft}{s})(0.665\ ft)}{(1.21\times10^{-5}\frac{ft^2}{s})}$

$K = 30 f_T$, $30(0.014)$, 0.42

$3h_{L,elbow} = K\left(\frac{V^2}{2g}\right) = 0.42\left(\frac{(14.6\ ft)^2}{2(32.2\frac{ft}{s^2})}\right) = 1.39\ ft \times 3 = 4.17\ ft$

$Re = 802{,}396.7$

$\frac{D}{\varepsilon} = \frac{0.665\ ft}{(1.5\times10^{-4}\ ft)} = 4433.3$

$K = 340 f_T$, $340(0.014)$, 4.76

$h_{L,valve} = K\left(\frac{V^2}{2g}\right) = 4.76\left(\frac{(14.6\ ft)^2}{2(32.2\frac{ft}{s^2})}\right) = 15.76\ ft$

on excel $f = 1.52E\text{-}2$ — $f_T = 0.014$

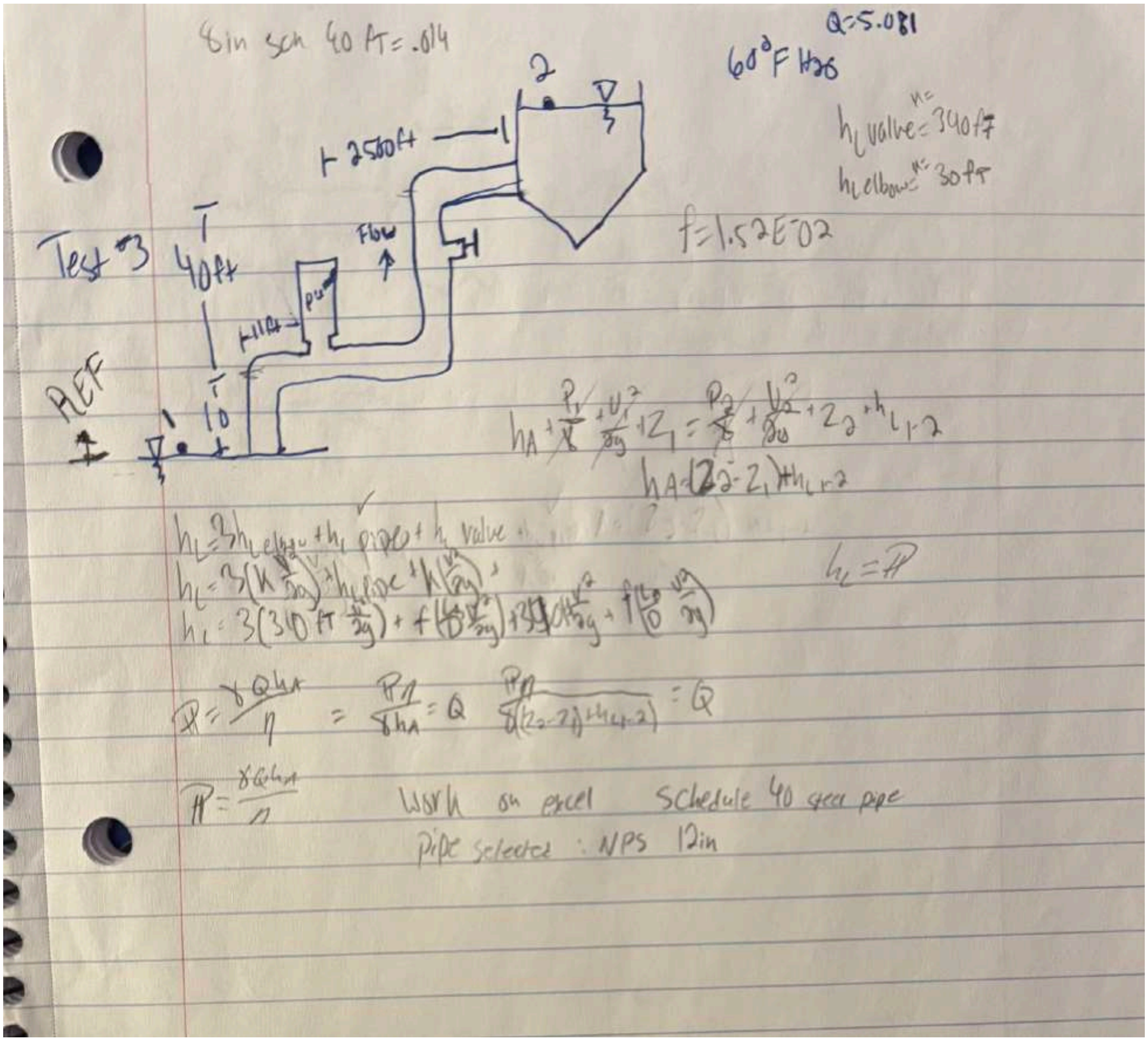
$h_{L,discharge} = f\frac{L}{D}\frac{V^2}{2g} = (1.52E\text{-}2)\left(\frac{2500\ ft}{0.665\ ft}\right)\left(\frac{(14.6\frac{ft}{s})^2}{2(32.2\frac{ft}{s^2})}\right) = 189.14\ ft$

$h_A = (50\ ft - 0\ ft) + 0.832\ ft + (3\times1.39\ ft) + 15.76\ ft + 189.14\ ft$ (4.17 ft)

$h_A = 259.9\ ft$

$P = \frac{\gamma Q h_A}{\eta} = \frac{(62.4\frac{lb}{ft^3})(5.081\frac{ft^3}{s})(259.9\ ft)}{0.6} = 137{,}337.4\ \frac{lb\,ft}{s} \div 550$

$= 250\ HP$



Materials

- Water at 60F
- 60% efficient pump
- 10-in schedule 40 steel pipe

Summary & Analysis

When considering redesign options for the given fluid system, there are three main approaches: increasing the flow rate with the current system, upgrading to a larger pump, or maintaining the current pump and replacing the pipes with larger ones. Each option impacts the system differently and has its advantages and challenges. If the flow rate is increased while keeping the current pump and pipe sizes, the system will face a significant rise in head loss, which increases with the square of the flow rate. This higher resistance will demand more energy from the pump, potentially exceeding its capacity and leading to decreased flow delivery or pump failure.

Replacing the pump with a larger one allows the system to handle higher flow rates effectively. The larger pump provides additional energy to overcome the increased head losses caused by higher flow rates. However, this requires greater pump power, resulting in higher operating costs.

Alternatively, maintaining the current pump and increasing the pipe diameter is a more cost-effective and efficient solution for moderate flow increases. Larger pipes significantly reduce head loss, as frictional losses decrease with the fifth power of the diameter. This reduction in head loss allows the pump to deliver higher flow rates without exceeding its power rating. Additionally, larger pipes lower the flow velocity, reducing wear and vibration, and improving system reliability.

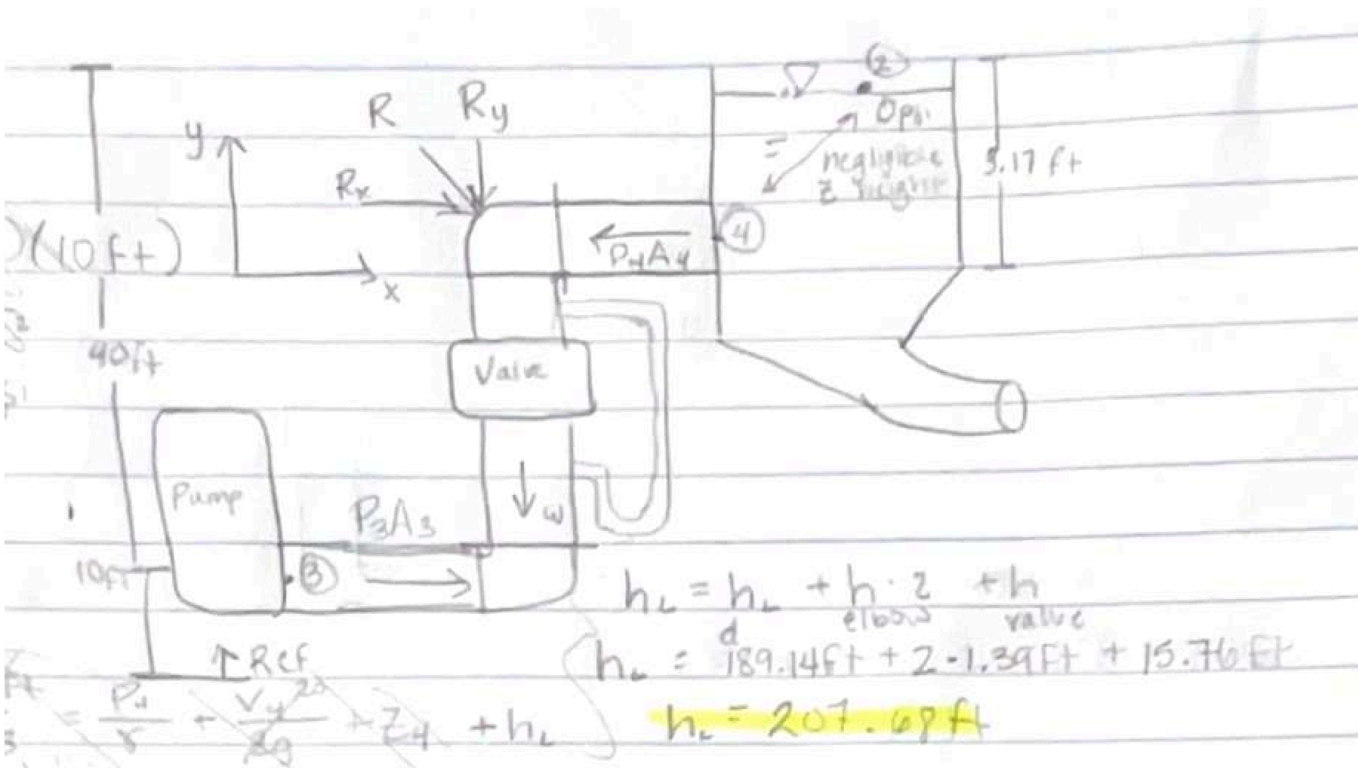
In summary, increasing flow rate without system modifications is not advisable due to the strain it places on the pump and pipes. For small to moderate flow increases, replacing the pipes with larger ones is the most efficient and cost-effective solution.

B

Purpose

The purpose of part b is to quantify the total horizontal and vertical focus in the whole discharge pipe-elbows-valve system for our civil colleague.

Drawings & Diagrams



Sources

- My notes
- Applied Fluid Mechanics 8th Edition, Robert L. Mott & Joseph A. Untener
- Canvas Module slides

Design Considerations

- Inlet of tank had negligible height
- Whole Discharge pipe (pipe-elbows-valve system)
- System in equilibrium (Force = 0)

Data and Variables

Volumetric Flow Rate	Q = 5.081 ft^3/s
Velocity	V = 14.6 ft/s
Change in Pressure	ΔP
Density of Water	ρ_w = 62.4 lb/ft^3
Area	A= 0.3472 ft^2
Gravity	g = 32.2 ft/s^2
Pump Head	hA= 260 ft
Energy loss due to friction	hL= $h_{L_{sution}} + 3 \cdot h_{L_{elbows}} + h_{L_{valve}} + h_{L_{disrchage}}$
Reynolds Number	Re= 802397
Friction Factor	f= 0.0152
Friction Coefficient	fT= 0.014
Length Suction	11 ft
Length Discharge	2500 ft

Procedure

1. First I made a FBD of the forces and reaction acting on the pipe and wrote out Bernuolli's equation.

2. Then I calculated the new hL with the appropriate fittings and valve losses and calculated P3 using Bernoulli's.
3. Using our P3, I derived the equations from Newton’s first law to get Rx and Ry.

Calculations

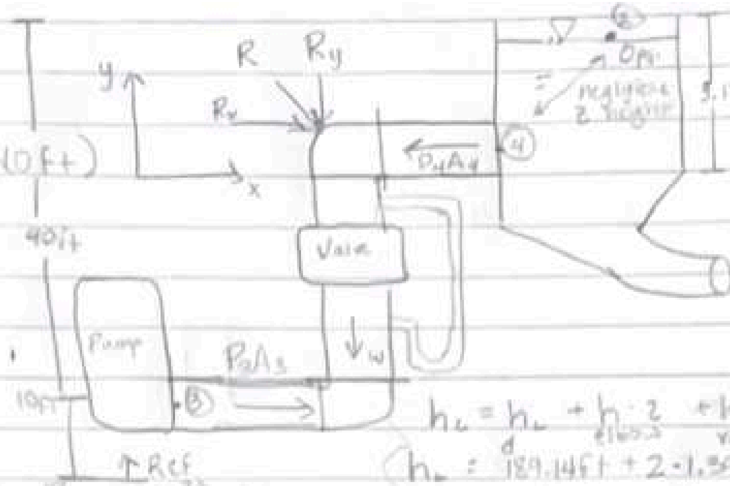
b)

$-P_3 = \gamma h$

$-P_3 = (62.4\ \frac{lb}{ft^3})(10\ ft)$

$= 624\ \frac{lb}{ft^2}$

$\approx -4.33\ psi$



$h_L = h_{L_d} + h_{elbow} \cdot 2 + h_{valve}$

$h_L = 189.14\ ft + 2 \cdot 1.39\ ft + 15.76\ ft$

$h_L = 207.69\ ft$

$\frac{P_3}{\gamma} + \frac{V_3^2}{2g} + z_3 = \frac{P_4}{\gamma} + \frac{V_4^2}{2g} + z_4 + h_L$

$z_4 = \left(\frac{P_3}{\gamma} - \frac{P_4}{\gamma}\right) + 10\ ft - h_L$

$z_4 = (-624\ \frac{lb}{ft^2} - 0\ \frac{lb}{ft^2}) + 10\ ft - 94.37\ ft$

$z_{total} = z_2 - z_3 = 50\ ft - 10\ ft = 40\ ft$

$z_4 = -94 \cdot 62.4\ \frac{lb}{ft^3}$ 0 psi

$\frac{P_3}{\gamma} + \frac{V_3^2}{2g} + z_3 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L$

$\Delta P = \rho g h$

$= (62.4\ \frac{lb}{ft^3})(32.2\ \frac{ft}{s^2})(30\ ft)$

$= \frac{60278.4}{144} = 418.6\ psi$

$P_3 = \gamma \left[\frac{V_2^2}{2g} + (z_2 - z_3) + h_L\right]$

$P_3 = (62.4\ \frac{lb}{ft^3})\left[\frac{(12.12\ ft/s)^2}{2 \cdot 32.2\ ft/s^2} + 40\ ft + 207.68\ ft\right]$

$= 15549.1\ lb/ft^2$

$A = \frac{\pi}{4}(0.665\ ft)^2$

$P_3 = 108\ psi$

$= 0.347\ ft^2$

$\Sigma F_x = \rho Q \Delta \vec{V}$

$\Sigma F_y = \rho Q \Delta \vec{V}$

$F_x = \rho Q(V_{4x} - V_{3x})$

$F_y = \rho Q(V_{2y} - V_{4y})$

$\Sigma F_x = P_3A_3 - P_4A_4 + R_x + \rho Q(V_4 - V_3)$

$F_y = -W - R_y + \rho Q(V_{2y} - V_{4y})$

$P_3A_3 + R_x - P_4A_4 = 0$

$R_y = -W$

$R_x = P_4A_4 - P_3A_3 \Rightarrow A(P_4 - P_3)$

$W = \gamma V = \gamma A L$

$R_x = 0.347\ ft^2\ (0 - 108\ psi)$

$R_y = -(62.4\ \frac{lb}{ft^3})(0.347\ ft^2)(2500\ ft)$

$R_x = -5{,}395.5\ lb$

$\approx 15549.1\ \frac{lb}{ft^2}$

$R_y = -54{,}132\ lb$

Materials

- Water at 60F
- 60% efficient pump
- 10-in schedule 40 steel pipe

Summary & Analysis

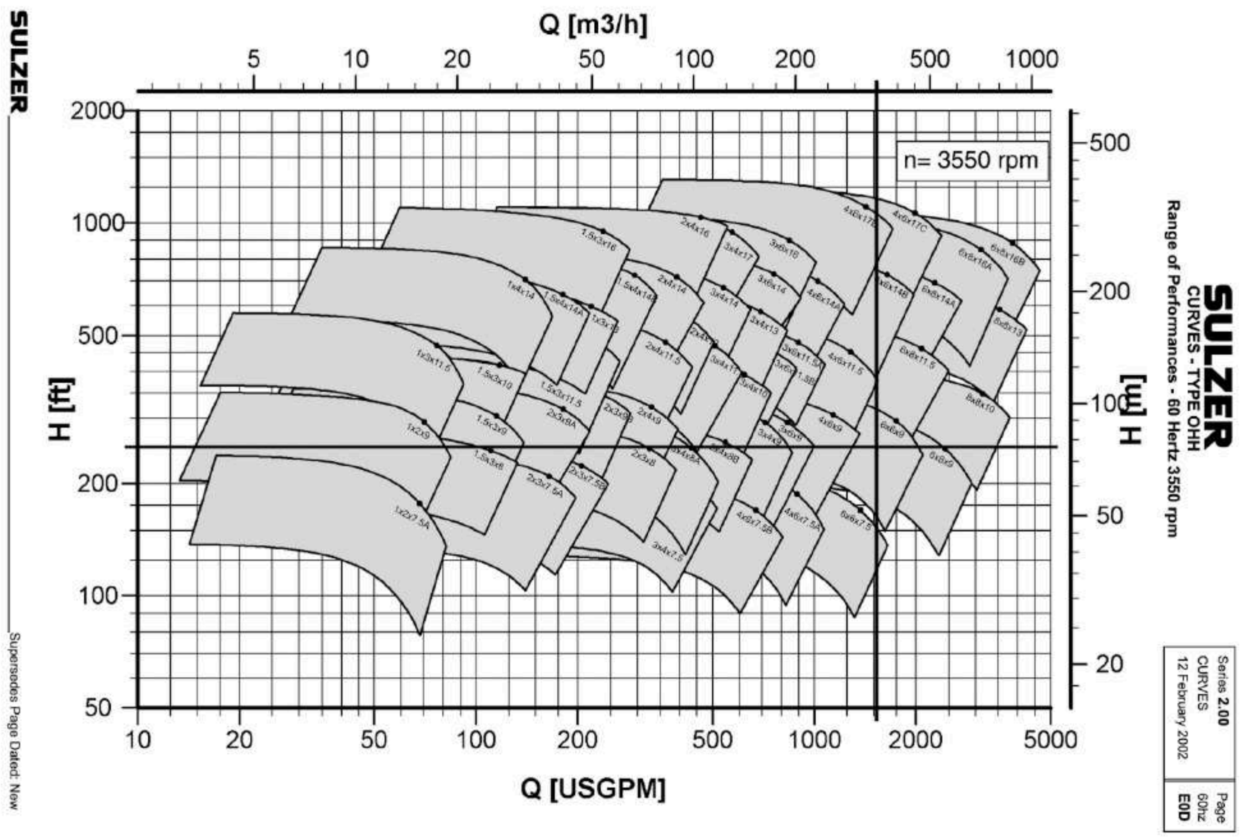
The calculations for Rx and Ry determine the reaction forces acting on the pipe system, which are essential for ensuring structural stability. Rx, the horizontal reaction force, accounts for forces generated by pressure differences between the pump outlet and the elevated tank inlet, as well as the momentum flux from the fluid flow as it changes direction. This force is necessary to maintain horizontal equilibrium and prevent lateral movement of the pipe system. Ry, the vertical reaction force, balances the weight of the water in the pipes, along with any vertical contributions from pressure or flow-induced momentum changes. It ensures vertical stability, preventing sagging or displacement due to gravity and dynamic forces. Together, Rx and Ry guide the design and placement of supports to prevent structural failure and ensure safe operation under the system's operating conditions. These values are critical for selecting appropriate support systems, such as anchors or brackets, to counteract both static and dynamic loads.

C

Purpose

The purpose of the last question is to introduce us to the selection process for pumps with certain criteria.

Drawings & Diagrams



Sources

- My notes
- Sulzer chart
- Applied Fluid Mechanics 8th Edition, Robert L. Mott & Joseph A. Untener
- Canvas Module slides

Design Considerations

- Constant properties
- Incompressible fluid
- Isothermal Conditions
- Steady state
- Newtonian Fluid

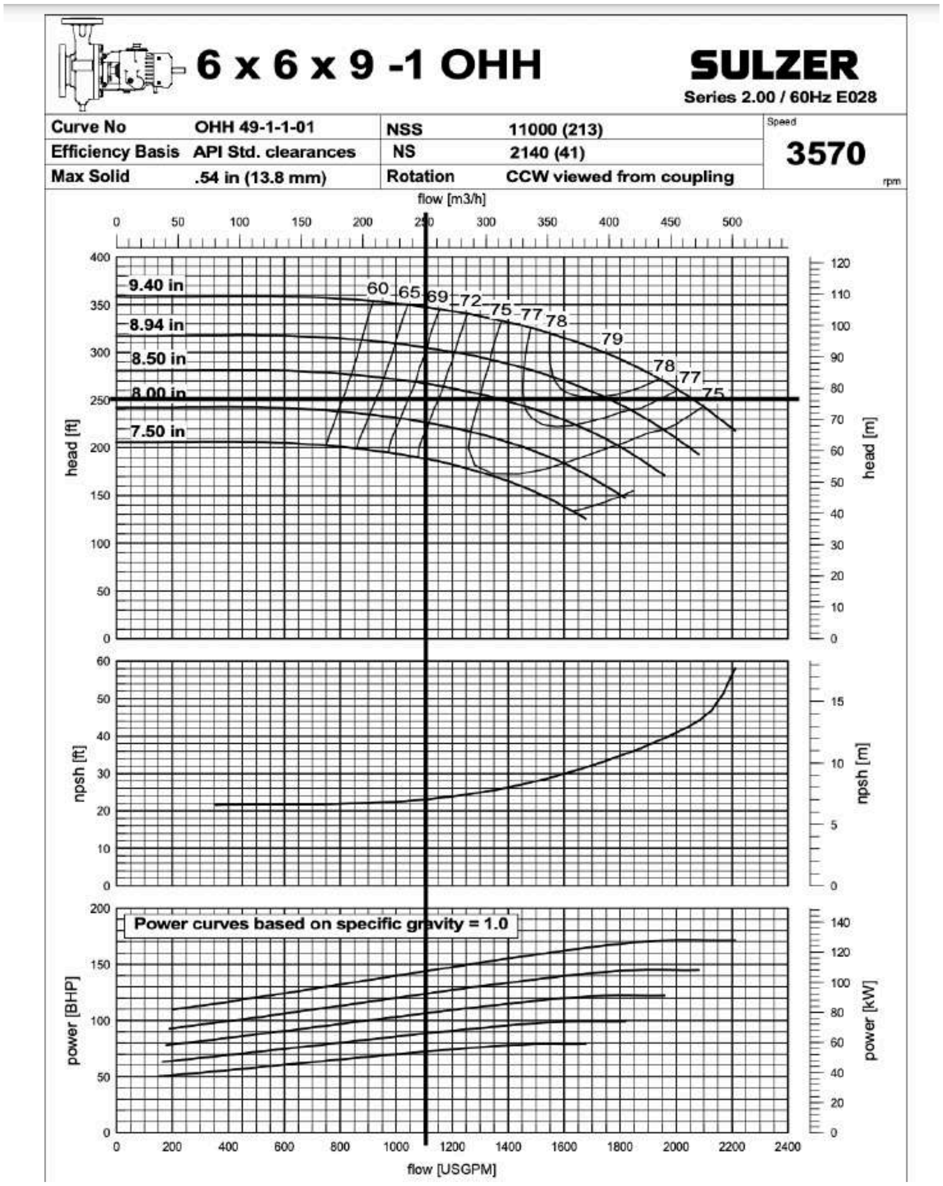
Data and Variables

Volumetric Flow Rate	Q = 1520 USGPM
Pump Head	hA = 261 ft

Procedure

- Used the pump head and flow rate to locate the best pump accordion to the Sulzer chart
- Found the specific chart to the desired pump and took necessary data from it

Calculations



Summary

I. The pump suction, discharge, and impeller size is 6 x 6 x 9.

II. The approximated required impeller diameter is 8.3 in.

III. The approximated power is 100 BHP and efficiency is 67%

IV. The actual pump size is 36 in and weight is 680 lbs

V. Yes, the 60% was an accurate assumption

Materials

- Water at 60F
- selected pump
- 10-in schedule 40 steel pipe

Analysis

A kinetic pump is required instead of a positive displacement pump because it offers flexibility in handling variable flow rates, requires less maintenance, and is more efficient for large-volume, low-pressure fluid movement. A radial pump is the best choice for this system because it uses centrifugal force to move fluid efficiently, has a simple design, is cost effective, and can adapt to changing flow demands.