

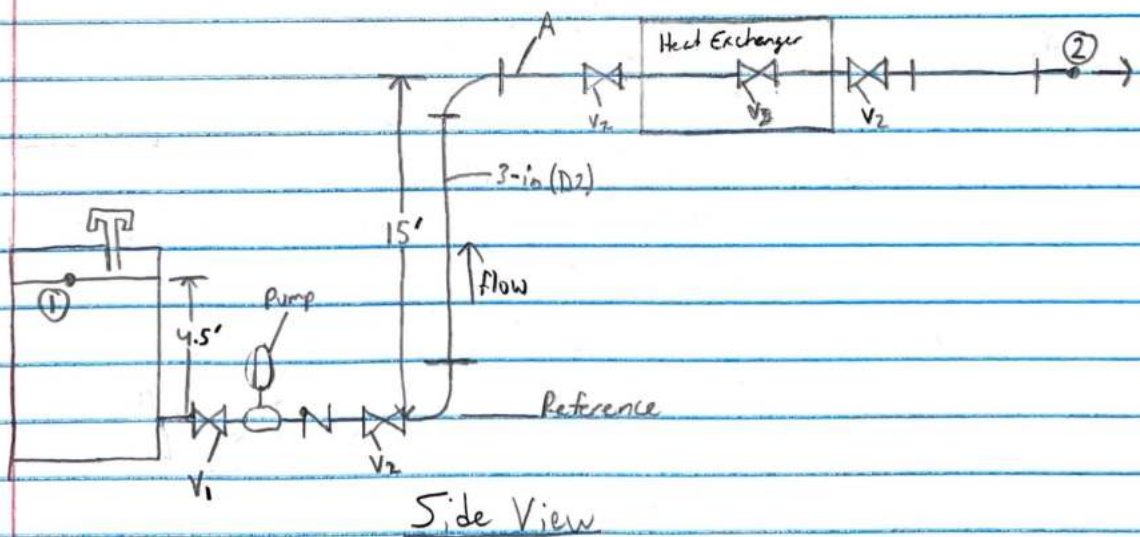
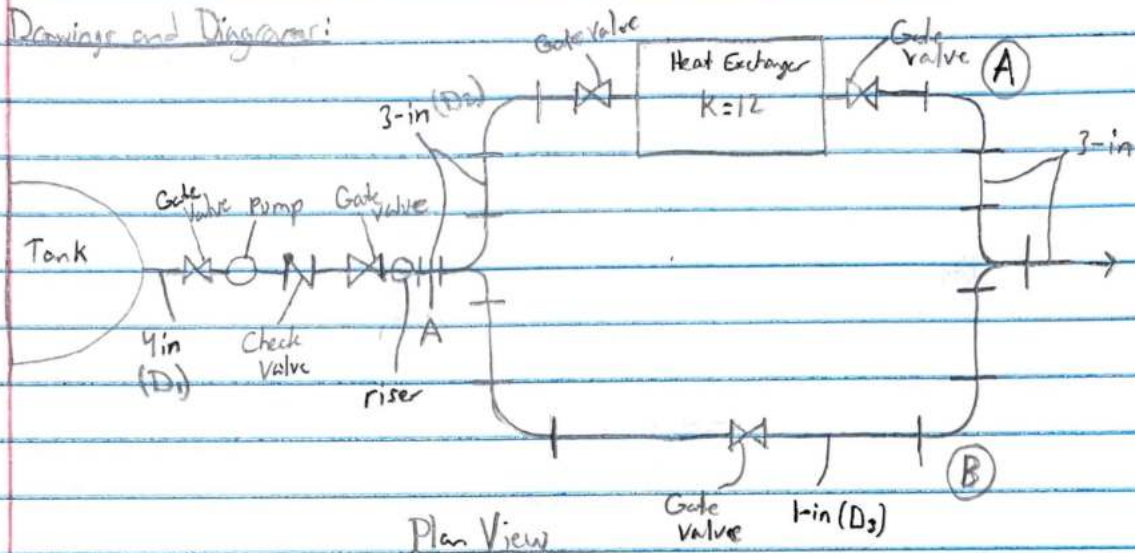
Camera Station

Test #3

Purpose:

- Calculate pump power when gate valve in bypass is closed.
- Calculate total flow rate if the bypass gate valve is $\frac{1}{4}$ open, $\frac{1}{2}$ open, $\frac{3}{4}$ open and fully open.

Drawings and Diagrams:



Sources:

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

Design Considerations (for all parts):

Steady State
Incompressible fluid
Constant properties

Data and Variables:

Water @ 160°F

Suction Line: $D_1 = 4.026 \text{ in} = 102.3 \text{ mm}$ | $L_1 = 10 \text{ ft} = 3048 \text{ mm}$

Discharge Line: $D_2 = 3.068 \text{ in} = 77.9 \text{ mm}$ | $L_2 = 90 \text{ ft} = 27192 \text{ mm}$

All pipes are Sch 40 Steel

Branch A: $D_A = 3.068 \text{ in} = 77.9 \text{ mm}$ | $L_A = 8 \text{ ft} = 2438.4 \text{ mm}$

Branch B: $D_B = 1.049 \text{ in} = 26.6 \text{ mm}$ | $L_B = 30 \text{ ft} = 9144 \text{ mm}$

Heat exchanger: $k = 12$

$Q = 275 \text{ gpm} = 0.0173 \text{ m}^3/\text{s}$

$\eta = 70\%$

$\gamma_{\text{water}} = 61.0 \text{ lb/ft}^3 = 9.58 \text{ kN/m}^3$

$\nu = 4.38 \times 10^{-6} \text{ ft}^2/\text{s} = 4.05 \times 10^{-7} \text{ m}^2/\text{s}$

Procedure:

First, reference points will be selected. Next, fluid velocity will be calculated using the heat exchanger's minimum flow rate. The friction factor of the suction and discharge pipe will be computed using Darcy Weisbach's equation, then the energy losses in the heat exchanger, valves, and fittings will be found. Once the system's total energy losses have been calculated, they will be entered into Bernoulli's equation to solve for pump head, then the power of the pump will be determined. To find the overall flow rate, Bernoulli's equation will be applied to each branch of the pipeline. Using the computed equations, I will create an excel spreadsheet and calculate the various values of Q total for the following states of the gate valve: fully open, $\frac{1}{2}$ open, $\frac{1}{4}$ open and $\frac{3}{4}$ open.

Calculations:

$$a) \quad h_A + \frac{P_A}{\rho g} + \frac{V_A^2}{2g} + z_A = \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + z_B + h_{L1-2}$$

$$h_A + z_A = z_B + h_{L1-2}$$

$$\textcircled{1} \quad h_A = 115 + h_{L1-2}$$

$$\textcircled{2} \quad h_{L1-2} = 4h_{L\text{valve}} + 4h_{L\text{elbow}} + h_{L\text{checkvalve}} + 2h_{L\text{tee}} + h_{L\text{pipe (suc)}} + h_{L\text{pipe (dis)}}$$

Suction pipe:

$$Q = VA$$

$$0.0173 \text{ m}^3/\text{s} = V(8.213 \times 10^{-3})$$

$$V = 2.11 \text{ m/s}$$

$$Re = \frac{VD}{\nu} = \frac{(2.11)(.1023)}{4.05 \times 10^{-7}} = 539632.5$$

$$\frac{D}{\epsilon} = \frac{.1023 \text{ m}}{4.6 \times 10^{-5} \text{ m}} = 2224$$

$$f = \frac{.25}{\left[\log \left(\frac{1}{3.7(D/\epsilon)} + \frac{5.74}{Re^{0.9}} \right) \right]^2}$$

$$f = \frac{.25}{\left[\log \left(\frac{1}{3.7(2224)} + \frac{5.74}{539632.5^{0.9}} \right) \right]^2}$$

$$f = .0174$$

$$h_L = f \times \frac{L}{D} \times \frac{V^2}{2g}$$

$$h_L = \frac{.0174 \times 3.048 \text{ m} \times (2.11 \text{ m/s})^2}{.1023 \text{ m} \times 2(9.81 \text{ m/s}^2)}$$

$$h_L = .118 \text{ m}$$

Discharge pipe and branch A pipe:

$$Q = VA$$

$$0.0177 \text{ m}^3/\text{s} = V(4.768 \times 10^{-3})$$

$$V = 3.63 \text{ m/s}$$

$$Re = \frac{VD}{\nu} = \frac{(3.63)(.0779)}{1.05 \times 10^{-7}} = 698214.8$$

$$\frac{D}{\epsilon} = \frac{.0779 \text{ m}}{4.6 \times 10^{-5} \text{ m}} = 1693.5$$

$$f = \frac{.25}{\left[\log \left(\frac{1}{3.7(D/\epsilon)} + \frac{5.74}{Re^{0.9}} \right) \right]^2}$$

$$f = \frac{.25}{\left[\log \left(\frac{1}{3.7(1693.5)} + \frac{5.74}{698214.8^{0.9}} \right) \right]^2}$$

$$f = .018$$

$$h_L = f \times \frac{L}{D} \times \frac{V^2}{2g}$$

$$h_L = \frac{.018 \times (12.192 + 2.4384 \text{ m})}{.0779} \times \frac{(3.63 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)}$$

$$h_L = 2.27 \text{ m}$$

Gate Valve: (2 - 4 in valves)

$$h_L = \frac{8 \text{ ft } V^2}{2g}$$

$$h_L = \frac{8(.016) \times 2.11^2}{2(9.81)}$$

$$h_L = .029 \text{ m}$$

Gate valve: (2 - 3 in valves)

$$h_L = \frac{8 \text{ ft } V^2}{2g}$$

$$h_L = \frac{8(.017) \times 3.63^2}{2(9.81)}$$

$$h_L = .091 \text{ m}$$

Check valve:

$$h_L = \frac{100 \text{ ft } V^2}{2g}$$

$$h_L = \frac{100(.016) \times 2.11^2}{2(9.81)}$$

$$h_L = .363 \text{ m}$$

Elbows: (4)

$$h_L = \frac{30 \text{ ft } V^2}{2g}$$

$$h_L = \frac{30(.018) \times 3.63^2}{2(9.81)}$$

$$h_L = .363 \text{ m}$$

Tee: (2)

$$h_L = \frac{60 \text{ ft} \cdot v^2}{2g}$$

$$h_L = \frac{60(.018) \times \frac{3.63^2}{2(9.81)}}$$

$$h_L = .725 \text{ m}$$

Heat exchanger:

$$h_L = \frac{k v^2}{2g}$$

$$h_L = \frac{12 \times \frac{3.63^2}{2(9.81)}}$$

$$h_L = 8.06 \text{ m}$$

$$\begin{aligned} \textcircled{2} \quad h_{L1-2} &= 2h_{L \text{ valve}} + 2h_{L \text{ valve}} + h_{L \text{ elbow}} + 4h_{L \text{ elbow}} + 2h_{L \text{ tee}} + h_{L \text{ HE}} + h_{L \text{ pipe (SU)}} + h_{L \text{ pipe (DIS)}} \\ h_{L1-2} &= 2(.029 \text{ m}) + 2(.091 \text{ m}) + .363 \text{ m} + 4(.763 \text{ m}) + 2(.725 \text{ m}) + 8.06 \text{ m} + 1.18 \text{ m} + 2.27 \text{ m} \\ h_{L1-2} &= 13.95 \text{ m} \end{aligned}$$

$$\begin{aligned} \textcircled{1} \quad h_A &= 15 + h_{L1-2} \\ h_A &= 15 + 13.95 \\ h_A &= 28.95 \text{ m} \end{aligned}$$

Pump power:

$$P = \frac{\dot{Q} h_A}{\eta} = \frac{(9580 \text{ N/m}^3)(.0177 \text{ m}^3/\text{s})(28.95 \text{ m})}{.7} = 6854.3 \text{ W} = 6.85 \text{ kW}$$

$$B) \quad h_A + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_{L1-2} \quad V^2 = \frac{16Q^2}{\pi^2 D^4}$$

$$\frac{P_1 - P_2}{\gamma} = z_2 - z_1 - h_A + h_{L1-2}$$

Branch A:

$$h_{L1-2} = 2h_{v1} + h_{L\text{check valve}} + 2h_{v2} + f_{D1} L_{D1} \frac{V_{D1}^2}{2g} + f_{D2} L_{D2} \frac{V_{D2}^2}{2g} + 4h_{L\text{elbow}} + h_{L\text{HE}} + 2h_{L\text{tee}}$$

$$h_{L1-2(A)} = 2K_{v1} \frac{V^2}{2g} + K_{L\text{check valve}} \frac{V^2}{2g} + 2K_{v2} \frac{V^2}{2g} + f_{D1} L_{D1} \frac{V_{D1}^2}{2g} + f_{D2} L_{D2} \frac{V_{D2}^2}{2g} + 4K_{L\text{elbow}} \frac{V^2}{2g} + K_{L\text{HE}} \frac{V^2}{2g} + 2K_{L\text{tee}} \frac{V^2}{2g}$$

$$h_{L1-2(A)} = 2K_{v1} \frac{16Q^2}{\pi^2 D_T^4} + K_{L\text{check valve}} \frac{16Q^2}{\pi^2 D_T^4} + 2K_{v2} \frac{16Q^2}{\pi^2 D_T^4} + f_{D1} L_{D1} \frac{16Q^2}{\pi^2 D_1^4} + f_{D2} L_{D2} \frac{16Q^2}{\pi^2 D_2^4} + 4K_{L\text{elbow}} \frac{16Q^2}{\pi^2 D_A^4} + K_{L\text{HE}} \frac{16Q^2}{\pi^2 D_A^4} + 2K_{L\text{tee}} \frac{16Q^2}{\pi^2 D_T^4}$$

$$h_{L1-2(A)} = \frac{8Q^2}{\pi^2 D_T^4} (2K_{v1} + K_{L\text{check valve}} + 2K_{v2} + f_{D1} L_{D1} + f_{D2} L_{D2} + 2K_{L\text{tee}} + 2K_{L\text{elbow}}) + \frac{8Q^2}{\pi^2 D_A^4} (2K_{L\text{elbow}} + K_{L\text{HE}} + f_{D2} L_{D2})$$

Branch B:

$$h_{L1-2(B)} = \frac{8Q^2}{\pi^2 D_T^4} (2K_{v1} + K_{L\text{check valve}} + 2K_{v2} + f_{D1} L_{D1} + f_{D2} L_{D2} + 2K_{L\text{tee}} + 2K_{L\text{elbow}}) + \frac{8Q^2}{\pi^2 D_B^4} (2K_{L\text{elbow}} + f_{D3} L_{D3} + K_{v3})$$

$$Q_T = Q_A + Q_B$$

Branch A:

$$\circ \quad \frac{\Delta P}{\gamma} = 4.572 + 1.3716 + 28.95 - \frac{8Q_T^2}{\pi^2 D_T^4} (2K_{v1} + K_{L\text{check valve}} + 2K_{v2} + f_{D1} L_{D1} + f_{D2} L_{D2} + 2K_{L\text{tee}} + 2K_{L\text{elbow}}) = \frac{8Q_A^2}{\pi^2 D_A^4} (2K_{L\text{elbow}} + K_{L\text{HE}} + f_{D2} L_{D2})$$

Branch B:

$$\circ \quad \frac{\Delta P}{\gamma} = 4.572 + 1.3716 + 28.95 - \frac{8Q_T^2}{\pi^2 D_T^4} (2K_{v1} + K_{L\text{check valve}} + 2K_{v2} + f_{D1} L_{D1} + f_{D2} L_{D2} + 2K_{L\text{tee}} + 2K_{L\text{elbow}}) = \frac{8Q_B^2}{\pi^2 D_B^4} (2K_{L\text{elbow}} + K_{v3} + f_{D3} L_{D3})$$

Branch A:

$$25.75 = \frac{8Q_T^2}{\pi^2 (.0779)^4} \left(2(.130) + 1.63 + 2(.179) + f_{D1} \left(\frac{3.048}{.1023} \right) + f_{D2} \left(\frac{12.192}{.0789} \right) + 2(1.07) + 2(.52) \right) = \frac{8Q_A^2}{\pi^2 (.0779)^4} \left(2(.52) + 1.2 + f_{D1} \left(\frac{2.453}{.0779} \right) \right)$$

$$25.75 = \frac{8Q_T^2}{3.63 \times 10^{-9}} \left(f_{D1}(29.79) + f_{D2}(156.51) + 5.288 \right) = \frac{8Q_A^2}{3.63 \times 10^{-9}} \left(f_{D2}(31.3) + 13.04 \right)$$

$$8(f_{D2}(31.3) + 13.04)$$

$$Q_A = \sqrt{\frac{(3.63 \times 10^{-9}) 25.75 - 8Q_T^2 (f_{D1}(29.79) + f_{D2}(156.51) + 5.288)}{8(f_{D2}(31.3) + 13.04)}}$$

Branch B:

$$25.75 = \frac{8Q_T^2}{\pi^2 (.0779)^4} \left(f_{D1}(29.79) + f_{D2}(156.51) + 5.288 \right) = \frac{8Q_B^2}{\pi^2 (.0266)^4} \left(1.07 + 1.86 + f_{D3} \left(\frac{9.144}{.0266} \right) \right)$$

$$25.75 = \frac{8Q_T^2}{3.63 \times 10^{-9}} \left(f_{D1}(29.79) + f_{D2}(156.51) + 5.288 \right) = \frac{8Q_B^2}{4.94 \times 10^{-6}} \left(1.22 + f_{D3}(343.76) \right)$$

$$4.94 \times 10^{-6} \left(\frac{25.75 - 8Q_T^2}{3.63 \times 10^{-9}} \left(f_{D1}(29.79) + f_{D2}(156.51) + 5.288 \right) \right) = 8Q_B^2 (1.22 + f_{D3}(343.76))$$

$$Q_B = \sqrt{\frac{4.94 \times 10^{-6} \left(\frac{25.75 - 8Q_T^2}{3.63 \times 10^{-9}} \left(f_{D1}(29.79) + f_{D2}(156.51) + 5.288 \right) \right)}{8(1.22 + f_{D3}(343.76))}}$$

$$Q_T = Q_A + Q_B$$

Summary:

When the bypass gate is closed and the heat exchanger required a minimum flow rate of 275 gpm, the pump's power is 6.85 kW (9.2 HP). Through estimation of the friction factor of the suction, discharge, bypass and Q total, followed by a comparison of the LHS and RHS to confirm that the value is 1% or less, the total flow rate with the bypass gate valve fully open is found to be $.034 \text{ m}^3/\text{s}$, where $1/4$ open is $.043 \text{ m}^3/\text{s}$, $1/2$ open is $.036 \text{ m}^3/\text{s}$ and $3/4$ open is $.034 \text{ m}^3/\text{s}$.

Materials:

Steel piping Sch 40

Water @ 160°F

Analysis:

The water velocity through the suction and discharge pipes were computed using the heat exchanger specified minimum flow rate. Afterward, upon figuring out the overall energy loss in the system while the bypass valve was closed, the pump head was found using Bernoulli's equation, which was then applied in the pump power equation.

Pump power is directly related to head and flow rate, while the system energy losses, pressure, and elevation all affect pump head. When the valve on branch B was opened to the specified values, additional energy losses were introduced into the calculation. The pipeline's overall flow rate increases in the presence of a parallel branch. Branch A's flow rate increased when branch B's valve is fully closed, which stops any flow through that branch. On the other hand, when branch B's valve is open, the flow rate through branch A decreases. It is important to remember that the flow rate is affected by the energy losses in the system, that the flow rate

decreases as the pipe's friction factor increases, and that the flow rate will always be the same right before the tee where the piping splits into the branches and the point where it rejoins into a single pipe.