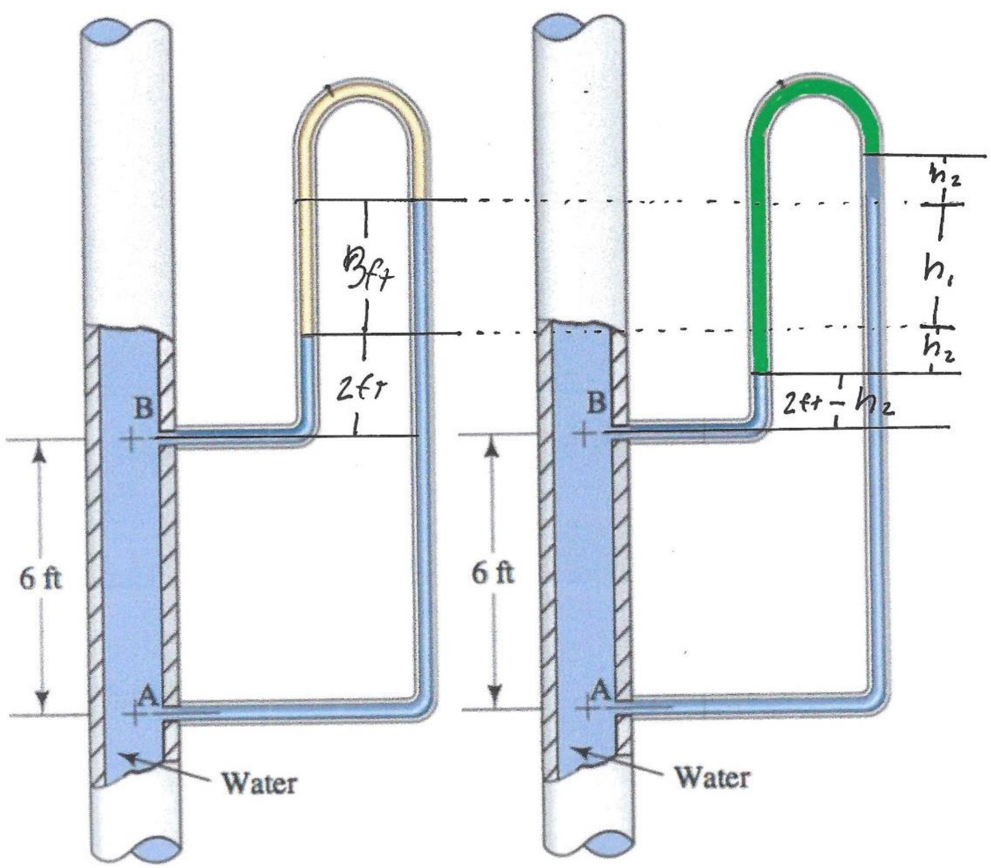
Devin Clarke
MET 330
10/03/2022

Test 1

Problem 1

Purpose: To determine the deflection of the provided manometer with gasoline and mercury as the manometric fluid. In addition to also determine the minimum height required if using gasoline as the manometric fluid.

Drawings and Diagrams:



Sources:

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

Design Considerations:

- Constant Properties
- Incompressible Fluids

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Test 1

Data and Variables:

$$\gamma_{H_2O} = 62.4 \frac{lb}{ft^3}$$

$$\Delta p = 2.7177\, psi$$

$$sg_{oil} = 0.90$$

$$sg_{gas} = 0.68$$

$$sg_{mercury} = 13.54$$

Procedure:

a. The first step is writing the equation for change in pressure $\Delta p = \gamma h$ because this is a manometer problem, with changes in height and specific weight due to different fluids.
b. Since Δp is already given and assumed to not change, then the next set is to draw a diagram outlining the difference between the oil and gasoline.
c. Once this is complete an equation will need to be written for h_1 and h_2 with h_1 being the initial deflection and h_2 being half of the additional deflection.
d. At this point solve for h_2 allows for the determination of the new deflection $Deflection = h_1 + 2h_2$
e. Using the deflection determine the required minimum size of the manometer.
f. Then using excel determine the same for mercury as the fluid.

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Calculations:

Initial Equation for Manometer with Oil as the Manometric Fluid:

$$P_a = P_b - \gamma_{H_2O}(2\,ft) - \gamma_{oil}(3\,ft) + \gamma_{H_2O}(11\,ft)$$

$$P_a - P_b = -\gamma_{oil}(3\,ft) + \gamma_{H_2O}(9\,ft)$$

$$\Delta P = -\gamma_{oil}(3\,ft) + \gamma_{H_2O}(9\,ft)$$

$$h_1 = 3\,ft$$

Equation for Manometer with a different fluid:

$$P_a = P_b - \gamma_{H_2O}(2\,ft - h_2) - \gamma_{fluid}(h_1 + 2h_2) + \gamma_{H_2O}(6\,ft) + \gamma_{H_2O}(h_1 + h_2) + \gamma_{H_2O}(2\,ft - h_2)$$

$$P_a - P_b = -\gamma_{H_2O}(2\,ft) + \gamma_{H_2O}(h_2) - \gamma_{fluid}(h_1 + 2h_2) + \gamma_{H_2O}(6\,ft) + \gamma_{H_2O}(h_1) + \gamma_{H_2O}(h_2) + \gamma_{H_2O}(2\,ft) - \gamma_{H_2O}(h_2)$$

$$\Delta P = -\gamma_{fluid}(h_1 + 2h_2) + \gamma_{H_2O}(6\,ft) + \gamma_{H_2O}(h_1) + \gamma_{H_2O}(h_2)$$

$$\Delta P = -\gamma_{fluid}(h_1) - \gamma_{fluid}(2h_2) + \gamma_{H_2O}(6\,ft) + \gamma_{H_2O}(h_1) + \gamma_{H_2O}(h_2)$$

$$\Delta P + \gamma_{fluid}(h_1) - \gamma_{H_2O}(6\,ft) - \gamma_{H_2O}(h_1) = -\gamma_{fluid}(2h_2) + \gamma_{H_2O}(h_2)$$

$$\Delta P + \gamma_{fluid}(h_1) - \gamma_{H_2O}(6\,ft) - \gamma_{H_2O}(h_1) = h_2(-2\gamma_{fluid} + \gamma_{H_2O})$$

$$\boxed{\frac{\Delta P + \gamma_{fluid}(h_1) - \gamma_{H_2O}(6\,ft) - \gamma_{H_2O}(h_1)}{(-2\gamma_{fluid} + \gamma_{H_2O})} = h_2}$$

Solving for the deflection if the manometric fluid was gasoline:

$$\gamma_{gas} = sg_{gas}\gamma_{H_2O} = 0.68(62.2\frac{lb}{ft^3}) = 42.296\frac{lb}{ft^3}$$

$$\gamma_{H_2O} = 62.2\frac{lb}{ft^3}$$

$$\frac{\Delta P + \gamma_{fluid}(h_1) - \gamma_{H_2O}(6\,ft) - \gamma_{H_2O}(h_1)}{(-2\gamma_{fluid} + \gamma_{H_2O})} = h_2$$

$$h_2 = \frac{391.3488\frac{lb}{ft^2} + 42.296\frac{lb}{ft^3}(3\,ft) - 62.2\frac{lb}{ft^3}(6\,ft) - 62.2\frac{lb}{ft^3}(3\,ft)}{(-2(42.296\frac{lb}{ft^3}) + 62.2\frac{lb}{ft^3})}$$

$$h_2 = 0.4913$$

New Deflection $= h_1 + 2h_2 = 3\,ft + 2(0.4913\,ft) = \boxed{3.98\,ft}$

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Summary:

- With a new manometric fluid being used, it was determined that the new deflection would be equal to h_1+2h_2, by using the $P=\gamma h$ equation. The deflection for gasoline was determined to be 3.98ft.
- With the deflection being 4 ft, the current manometer would still prevent the gasoline from entering the system by about 6 inches.
- Using excel, the deflection was calculated with Mercury as the manometric fluid, and the result was a deflection of 0.2ft.

Materials:

- Manometer
- Water
- Oil
- Gas
- Mercury

Analysis:

The deflection that was determined for gasoline was greater than the deflection that was given from the oil. The deflection that was determined for mercury was significantly larger than the initial deflection of the oil. This indicates that the higher the specific gravity, and therefore specific weight, of the manometric fluid the lesser the deflection.

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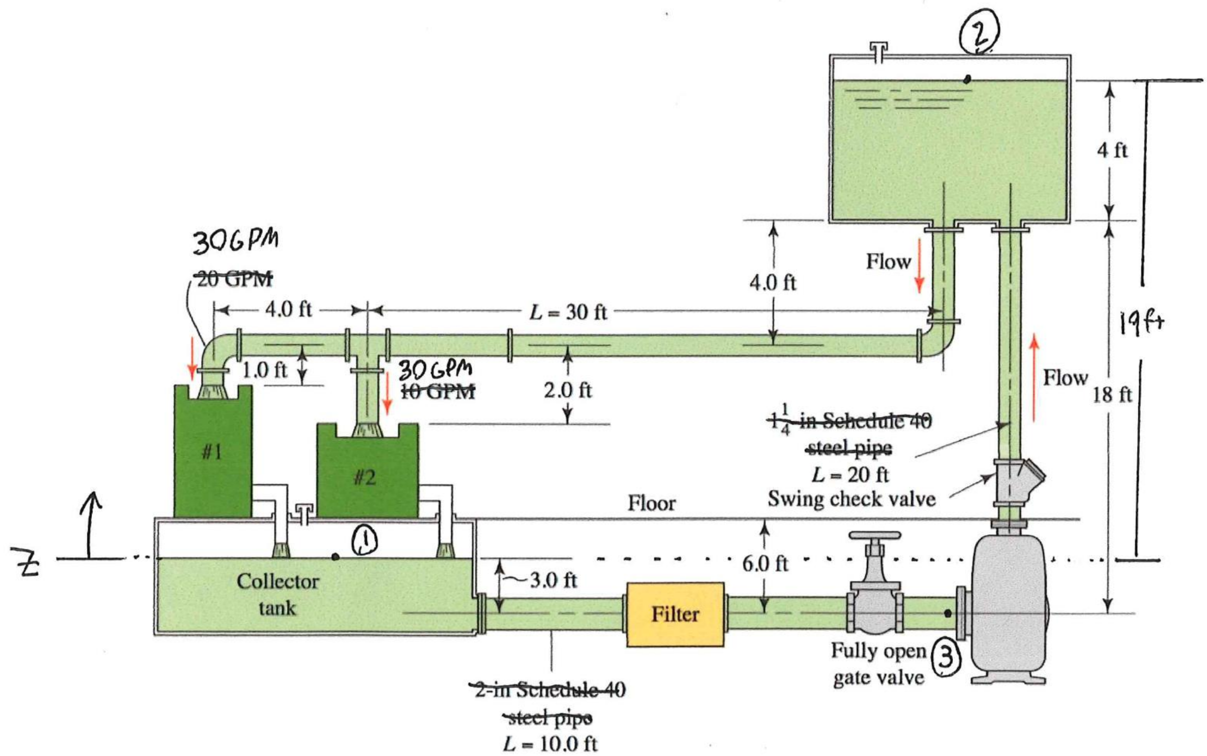
Problem 2

Purpose: To determine the best pipe size for the provided system by calculating the power usage of the pump along with cost.

Drawings and Diagrams:



Sources:

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Design Considerations:

- Constant Properties
- Incompressible Fluids

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Test 1

Data and Variables:

$sg_{coolant} = 0.92$

$Q = 60GPM$

$\nu = 3.6 \cdot 10^{-5} \frac{lb \cdot s}{ft^2}$

$k_{filter} = 1.85$

$k_{inlet} = 0.5$

$k_{outlet} = 1.0$

$k_{gatevalve} = 8 f_T$

$k_{checkvalve} = 100 f_T$

$\varepsilon_{steel} = 1.5 \cdot 10^{-4}\ ft$

Electricity cost per kW = $730

Procedure:

1. Use the flow rate equation Q=VA along with the required flow rate and provided velocity to determine the area of the pipe. Using this area and the chart in the book select which schedule 40 steel pipe most closely matches.
2. Determine Reynolds number.
3. Determine the friction factor.
4. I selected 2 points, 1 at each of the 2 tanks since the pressure was known, and velocity was negligible
5. Write Bernoulli's equation and remove the 0 values and the negligible values. This leaves me with: $h_a = h_L + z_2$
6. The energy losses must be calculated. This includes for friction in the pipe, inlet, the filter, gate valve, check valve, and outlet.
7. Once this is done the pump head can be determined. Then the pump head is used to determine pump power: $P = \gamma Q h_a$
8. Then excel will be used to determine the pump power for 4 different sizes of piping. Then the cost of installation along with operation for 2 years will need to be listed for each size of piping.
9. Determine the best size of piping for this system.

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Test 1

Calculations:

Determine the prefered area of pipe:

$$Q = VA$$

$$Q = 60GPM = 0.1337\, ft^3/s$$

$$V = 3m/s = 9.843\, ft/s$$

$$A = \frac{Q}{V} = \frac{0.1337\, ft^3/s}{9.843\, ft/s} = 0.01358\, ft^2 = \boxed{1.956 in^2}$$

Selected Schedule 40 $1\frac{1}{2}$ in Steel Pipe

$$A = 0.01414 \text{ft}^2$$

$$D = 0.1342\, ft$$

$$V = Q/A = \frac{0.1337\, ft^3/s}{0.01414 \text{ft}^2} = 9.455\, ft/s$$

Determine Reynolds Number:

$$\text{Re} = \frac{\rho V D}{\eta}$$

$$\rho_{coolant} = sg_{coolant} \cdot \rho_{H_2O} = 0.92 \cdot 1.94 \frac{\text{slug}}{ft^3} = 1.7848 \frac{\text{slug}}{ft^3} = 57.47 \frac{lb}{ft^3}$$

$$\eta = 0.000036 \frac{lb \cdot s}{ft^2}$$

$$\text{Re} = \frac{\rho V D}{\eta} = \frac{57.47 \frac{lb}{ft^3} \cdot 9.455\, ft/s \cdot 0.1342\, ft^2}{0.000036 \frac{lb \cdot s}{ft^2}} = 2,025,710.78$$

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Determine the Friction Factor:

$$f = \frac{0.25}{\left[Log\left(\frac{1}{3.7\left(\frac{D}{\varepsilon}\right)} + \left(\frac{5.74}{\mathrm{Re}^{0.9}}\right)\right)\right]^2} = \frac{0.25}{\left[Log\left(\frac{1}{3.7\left(\frac{0.1342\,ft}{0.00015\,ft}\right)} + \left(\frac{5.74}{2,025,710.78^{0.9}}\right)\right)\right]^2} = \boxed{0.02038}$$

$$\mathrm{h}_a + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} + \mathrm{z}_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + \mathrm{z}_2 + h_L$$

Both P_1 and P_2 are open to the atmosphere and are therefore 0 psig. Since both points are also at the surface of a tank both velocity values are negligible. Also based on the reference z_1 is also 0.

$$\mathrm{h}_{a1} = z_2 + h_L$$

$$h_L = h_{L,Friction} + h_{L,inlet} + h_{L,filter} + h_{L,gatevalve} + h_{L,checkvalve} + h_{L,outlet}$$

$$h_{L,Friction} = f\,\frac{L}{D}\cdot\frac{V^2}{2g} = 0.02038\cdot\left(\frac{30\,ft}{0.1342\,ft}\right)\cdot\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 6.323\,ft$$

$$h_{L,inlet} = k\cdot\frac{V^2}{2g} = 0.5\,ft\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 0.694\,ft$$

$$h_{L,filter} = k\cdot\frac{V^2}{2g} = 1.85\,ft\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 2.568\,ft$$

$$h_{L,gatevalve} = k\cdot\frac{V^2}{2g} = 8\,ft\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 11.106\,ft$$

$$h_{L,checkvalve} = k\cdot\frac{V^2}{2g} = 100\,ft\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 138.828\,ft$$

$$h_{L,outlet} = k\cdot\frac{V^2}{2g} = 1\,ft\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 1.388\,ft$$

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$$h_L = h_{L,Friction} + h_{L,inlet} + h_{L,filter} + h_{L,gatevalve} + h_{L,checkvalve} + h_{L,outlet}$$

$$h_L = 6.323\,ft + 0.694\,ft + 2.568\,ft + 11.106\,ft + 138.828\,ft + 1.388\,ft = 160.909\,ft$$

$$\mathrm{h}_{a1} = z_2 + h_L = 19\,ft + 160.909\,ft = 179.909\,\frac{lb-ft}{ft}$$

$$Power = Q\gamma h = Q \cdot sg_{coolant} \cdot \gamma_{H_2O} \cdot h_a = 0.1337\,\frac{ft^3}{s} \cdot 0.92 \cdot 62.2\,\frac{lb}{ft^3} \cdot 179.909\,\frac{lb-ft}{lb}$$

$$\boxed{Power = 1376.455\,\frac{lb-ft}{s} = 2.503hp = 1.866kW}$$

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Compute the pressure at the inlet of the pump:

$$\mathrm{h}_a + \frac{P_1}{\gamma} + \frac{V_1^{\,2}}{2g} + \mathrm{z}_1 = \frac{P_3}{\gamma} + \frac{V_3^{\,2}}{2g} + \mathrm{z}_2 + h_L$$

There is no pump between points 1 and 3 therefore there is no pump head. Point 1 is at the surface of a tank, therefore the pressure is 0 psig and velocity is negligible. The elevation of point 1 is at the refrence.

$$0 = \frac{P_3}{\gamma} + \frac{V_3^{\,2}}{2g} + z_2 + h_L$$

$$P_3 = \gamma(-\frac{V_3^{\,2}}{2g} - z_2 - h_L)$$

$$V_3 = Q / A = 9.455\, ft / s$$

$$h_L = h_{L,Friction} + h_{L,inlet} + h_{L,\,filter} + h_{L,gatevalve}$$

$$h_{L,Friction} = f\,\frac{L}{D}\cdot\frac{V^2}{2g} = 0.02038\cdot\left(\frac{10\,ft}{0.1342\,ft}\right)\cdot\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 2.11\,ft$$

$$h_{L,inlet} = k\cdot\frac{V^2}{2g} = 0.5\,ft\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 0.694\,ft$$

$$h_{L,\,filter} = k\cdot\frac{V^2}{2g} = 1.85\,ft\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 2.568\,ft$$

$$h_{L,gatevalve} = k\cdot\frac{V^2}{2g} = 8\,ft\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) = 11.106\,ft$$

$$h_L = 2.11\,ft + 0.694\,f + 2.568\,ft + 11.106\,ft = 16.476\,ft$$

$$P_3 = \gamma(-\frac{V_3^{\,2}}{2g} - z_2 - h_L)$$

$$P_3 = 0.92\cdot 62.2\,\frac{lb}{ft^3}(-\left(\frac{(9.455\,ft/s)^2}{2\left(32.2\,ft/s^2\right)}\right) + 3\,ft - 16.476\,ft)$$

$$\boxed{P_3 = -850.586 lb / ft^2 = -5.91 psig}$$

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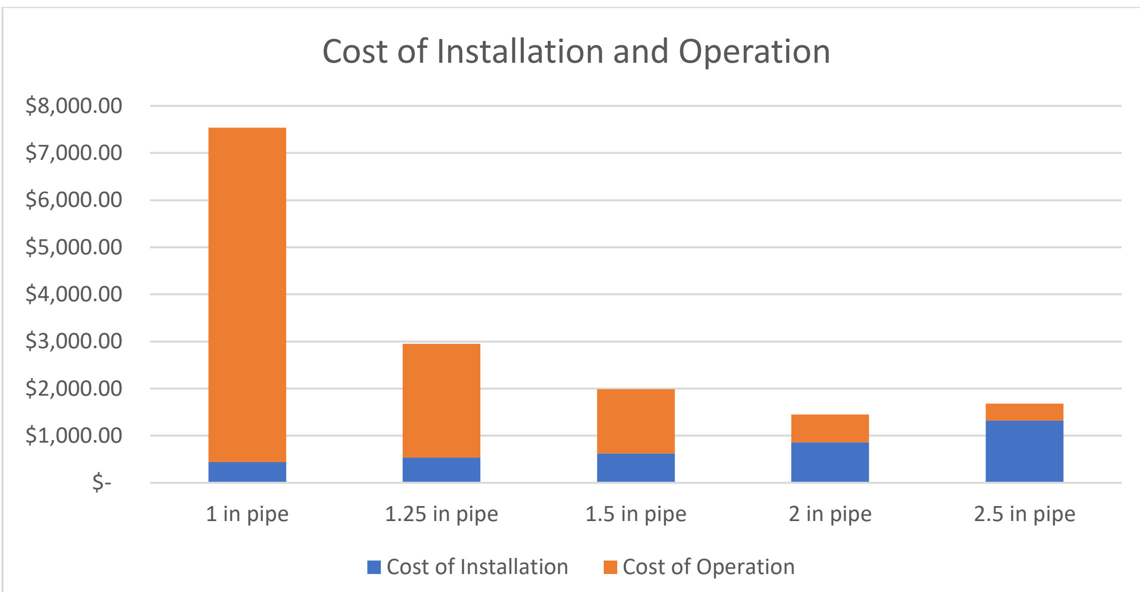
Summary:

a) Using the given target velocity and supplied required flow rate, using the continuity equation I calculated the required area and used that to select Schedule 40 1.5 inch Steel Pipe with an area of 0.0141 ft^2.
b) The pump head was calculated using Bernoulli's equation, finding the Reynolds number, and solving for energy losses. This was calculated to be 179.91ft.
c) The hand calculations were moved into excel and replicated for 4 additional steel pipes sizes.
d) The cost of each pipe size was calculated:

Total Cost Calculations			
Pipe Type	**Cost of Installation**	**Cost of Operation**	**Total Cost**
1 in pipe	$ 439.28	$ 7,098.07	$ 7,537.35
1.25 in pipe	$ 530.99	$ 2,419.24	$ 2,950.23
1.5 in pipe	$ 622.70	$ 1,362.34	$ 1,985.04
2 in pipe	$ 861.14	$ 586.84	$ 1,447.98
2.5 in pipe	$ 1,319.68	$ 360.59	$ 1,680.28



Materials:

- Steel piping
- Pump
- Filter
- Fittings (Gate valve and check valve)
- Tanks

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- Coolant

Analysis:

After determining the cost of operation, cost of installation, power, pump head, and energy losses for the different schedules of piping, the data that I calculated makes sense. As the diameter of the pipe decreases the velocity increases. And as that happens the Reynolds number also increases, meaning the flow is more turbulent. Increased turbulence leads to increased energy losses due to friction. The data that I calculated reflects this with the smallest diameter pipe requiring 521% more power than the initially selected 1.5 in pipe.

I determined that the best pipe size to use for this system would be the Schedule 40 2.5in Steel Pipe. Looking at the operating costs for 2 years, I eliminated the 1 in and 1.25 in pipe immediately. The yearly operating costs are too expensive. From the three remaining pipe sizes I chose the 2.5 in piping because it was the most cost effective overall span while still providing the flow rate required by the machines. The 2in pipe has the lowest cost over 2 years, but after an additional year the 2.5 in becomes the most cost effective.