PIPELINE SYSTEM DESIGN PROJECT

CONTINENTAL AG

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Abstract

Continental AG is opening a new manufacturing facility in Deer Park, Illinois. The system will be designed to transport coolant from the time it arrives to the facility by train to the time it leaves the facility by trucks. This report covers a complete design for the transfer of coolant from train to a 15,000 gallon reservoir tank, the transfer of coolant from the reservoir to a 1,000 gallon process tank, the transfer of waste coolant to a 8,000 gallon dump tank, and the transfer of waste coolant to trucks that will empty the dump tanks. The factors to be considered during the design of the systems are: location of tanks, layout of piping system, flow rate, equipment, and fittings. Additionally, the design should also include a possible expansion of the facility.

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Job site location:
Deer Park, IL

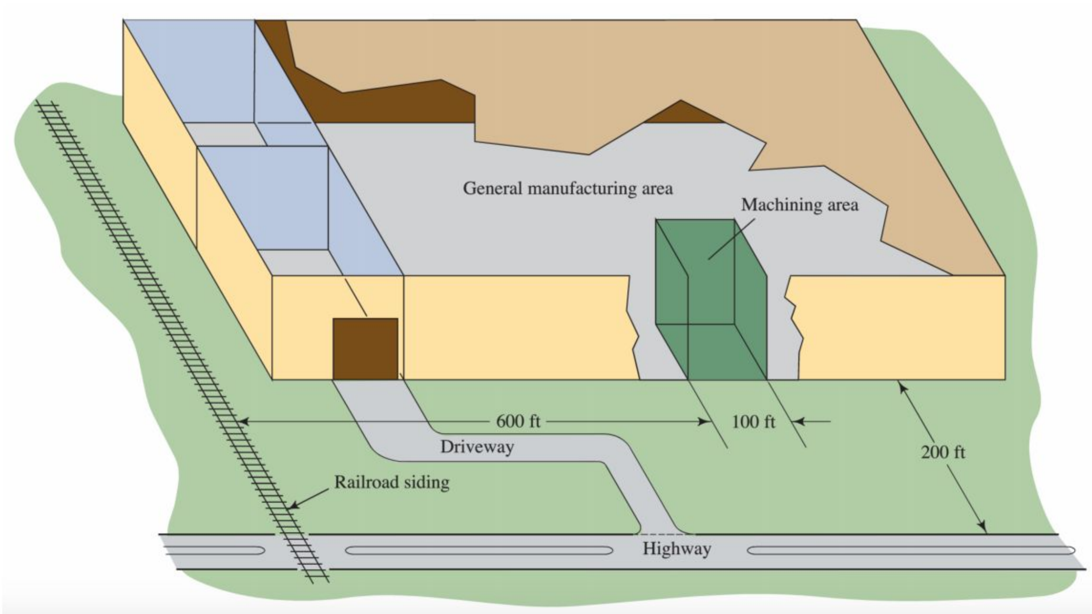


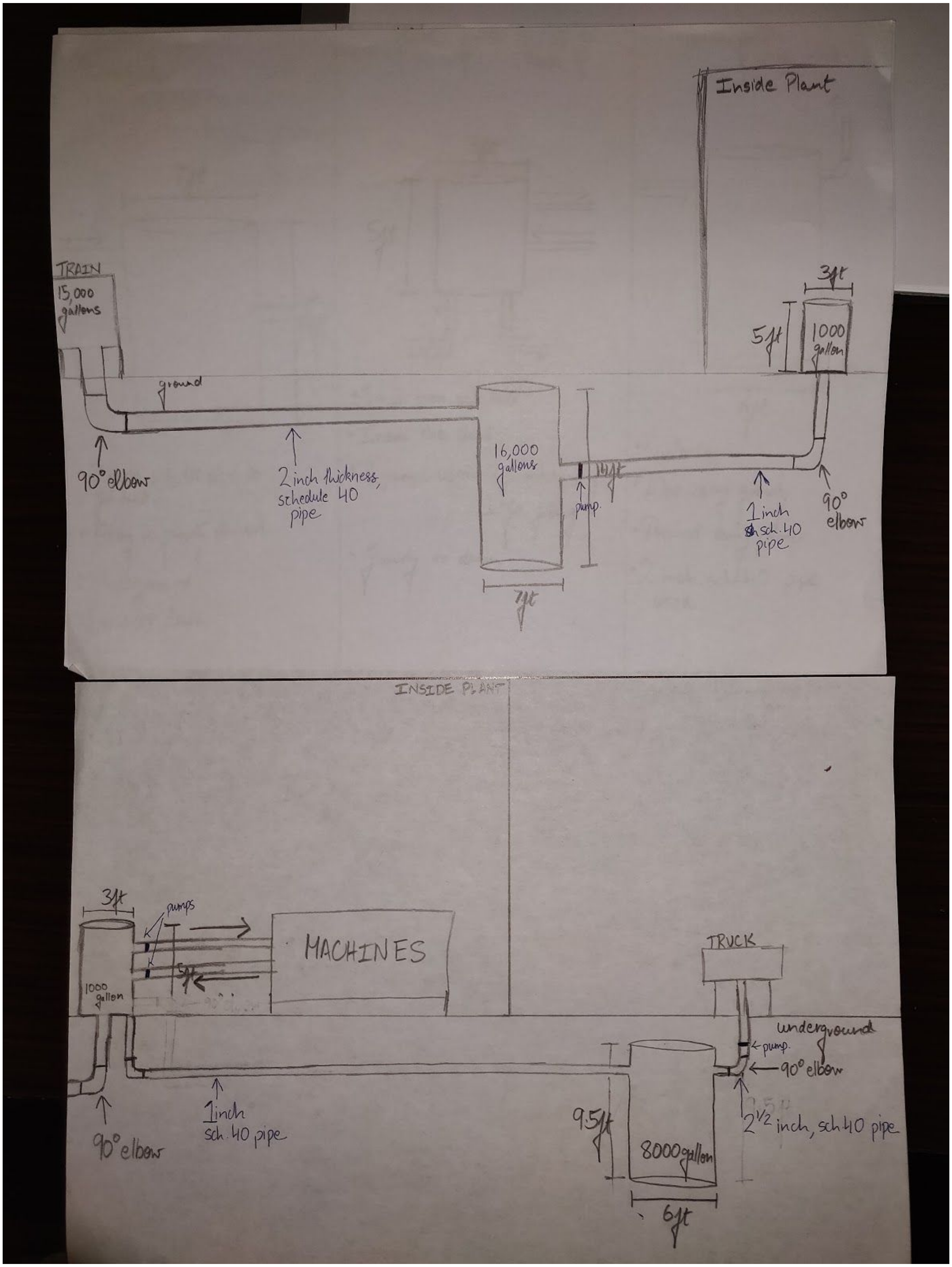
FIGURE 1. Plot plan of a hypothetical factory building for the design problem.

Design Philosophy:
The system will use two pump driven systems and two gravity driven systems. The reservoir tank will be outside and underground. This tank will be filled using gravity and will be drained using a pump. The process tank will be inside the plant and will be filled using a pump and drained to the waste tank using gravity. The dump tank will be outside and underground next to the reservoir and will be emptied using a pump.

Sources: Mott, R., Untener J.A., "Applied Fluid Mechanics," 7th ed. Pearson Education Inc. (2005).

Materials and specifications
Stainless Steel for tanks and pipes (schedule 40)

Preliminary drawings and sketches (Figure 2)



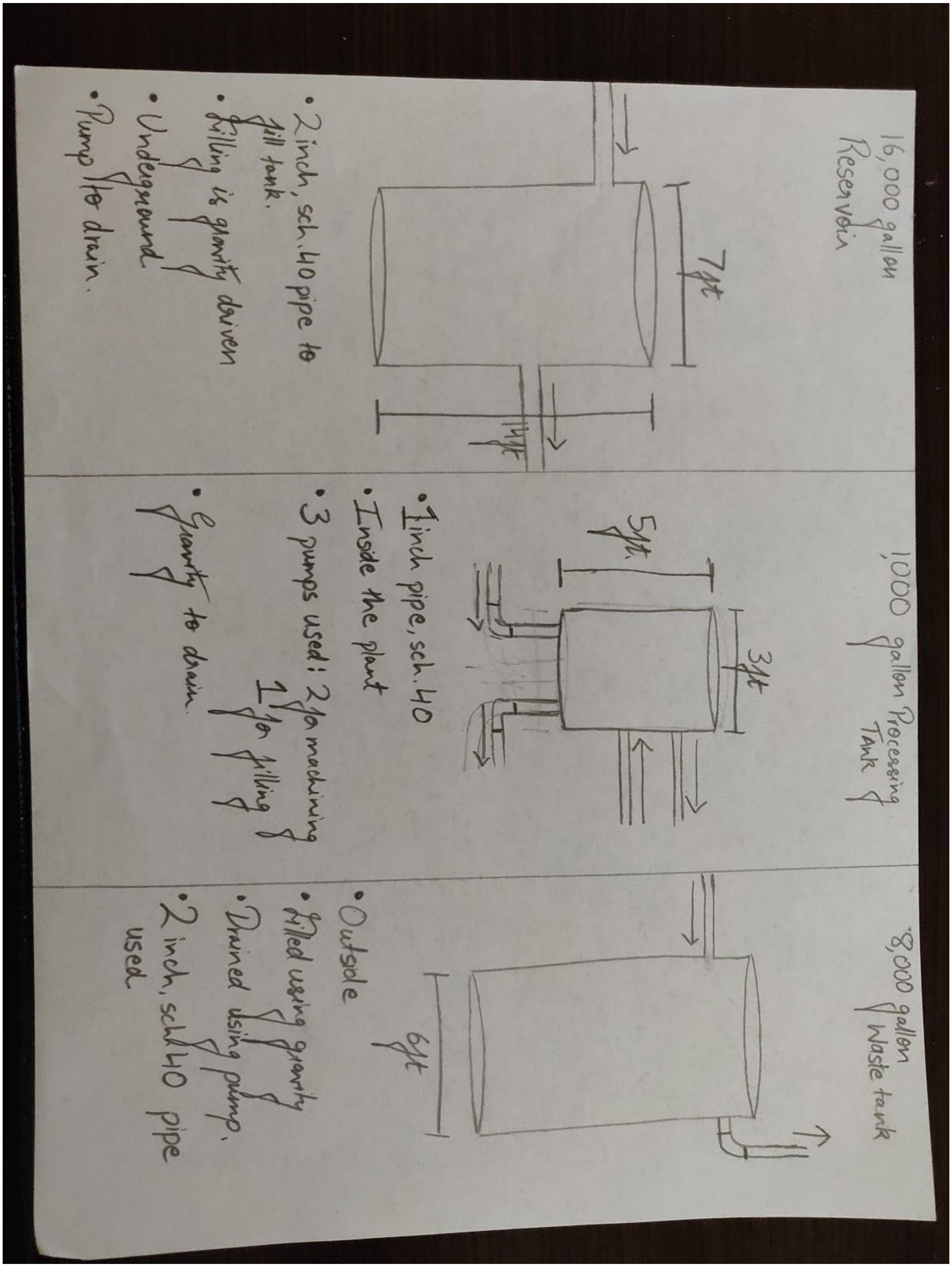

16,000 gallon Reservoir
7ft
14ft
• 2 inch, sch. 40 pipe to fill tank.
• Filling is gravity driven
• Underground
• Pump to drain.
1,000 gallon Processing Tank
3ft
5ft.
• 1 inch pipe, sch. 40
• Inside the plant
• 3 pumps used: 2 for machining
1 for filling
• Gravity to drain.
8,000 gallon Waste tank
6ft
• Outside
• Filled using gravity
• Drained using pump.
• 2 inch, sch 40 pipe used

Figure 3.

Design Calculations

Location
16,000 gallon Reservoir: Outside the plant and underground.
1,000 gallon process tank: Inside the plant
8,000 gallon waste tank: Outside the plant and underground

Size design
Purpose: To determine the sizes of each tank, respectively.

Drawings:

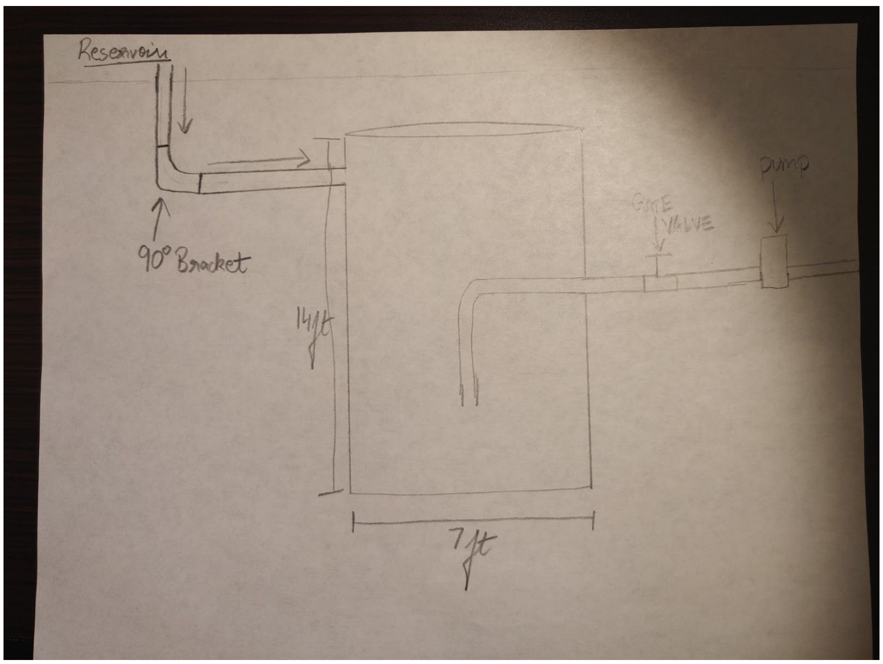


Figure 4.

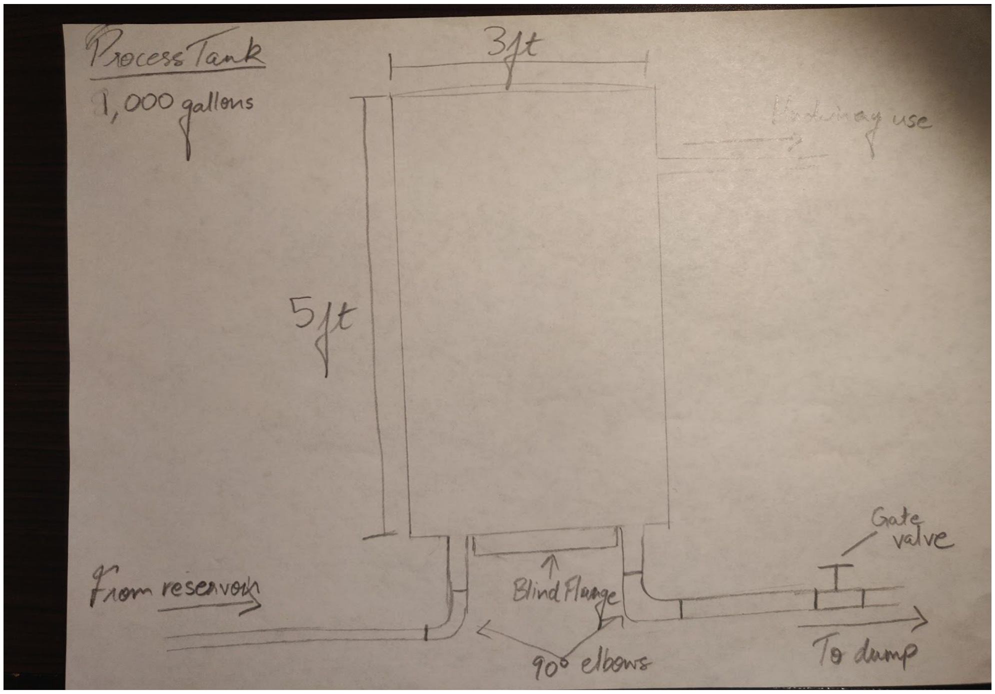


Figure 5.

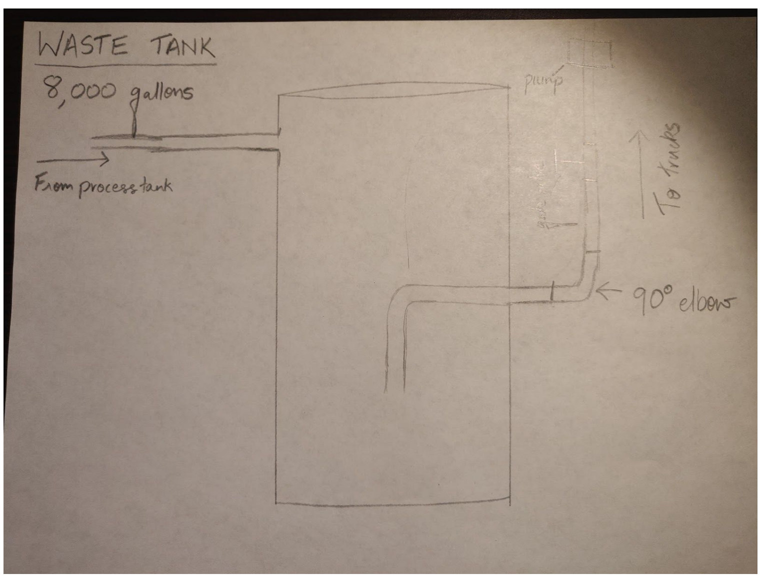


Figure 6.

Sources: Mott R, Unterer J. “Applied Fluid Mechanics.” 7th edition. Pearson Education, Inc. (2015)

Design Considerations:

- Shape of tank
- Material of tank
- External Pressure on tank
- Internal Pressure on tank

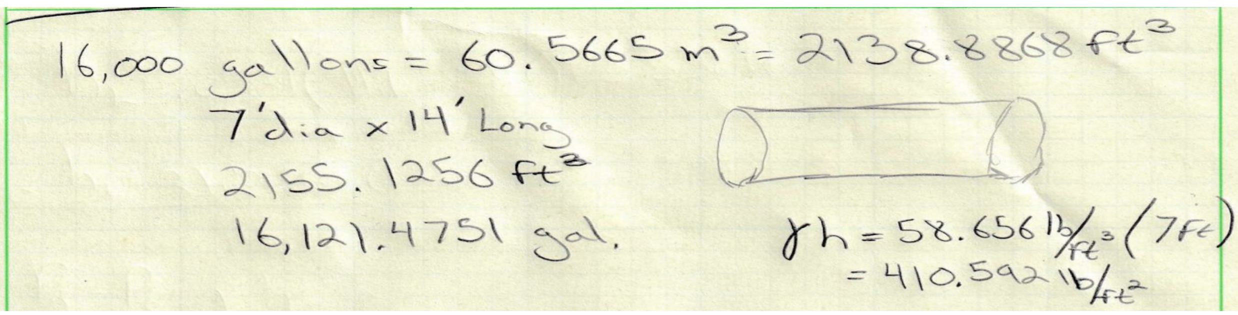
Data and variables:

- γh = pressure head
- Ri = Radius (internal)
- S = allowable stress
- EL = 0.85

Procedure:

- Determine the volume of the tank by defining the diameter and calculating the height of the tank
- Determine pressure head by considering the diameter of the tank.
- Height is determined by assuming and the diameter is calculated accordingly using volume formula.

Calculations



16,000 gallons = 60.5665 m^3 = 2138.8868 ft^3

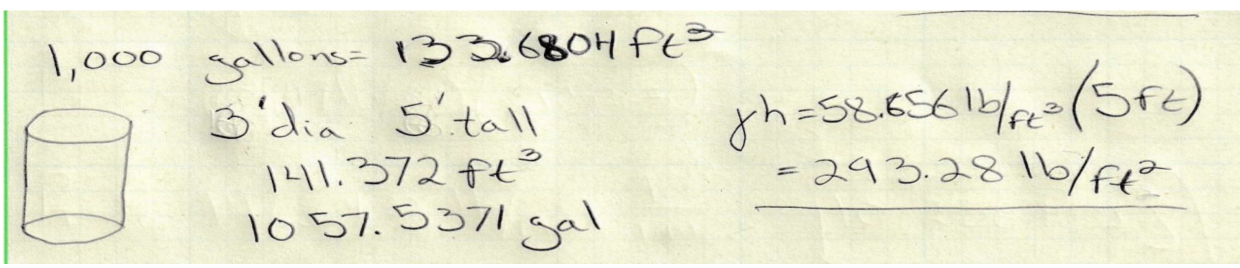
7' dia x 14' Long

2155.1256 ft^3

16,121.4751 gal.

$\gamma h = 58.656\ lb/ft^3\ (7ft)$

$= 410.592\ lb/ft^2$



1,000 gallons = 133.6804 ft^3

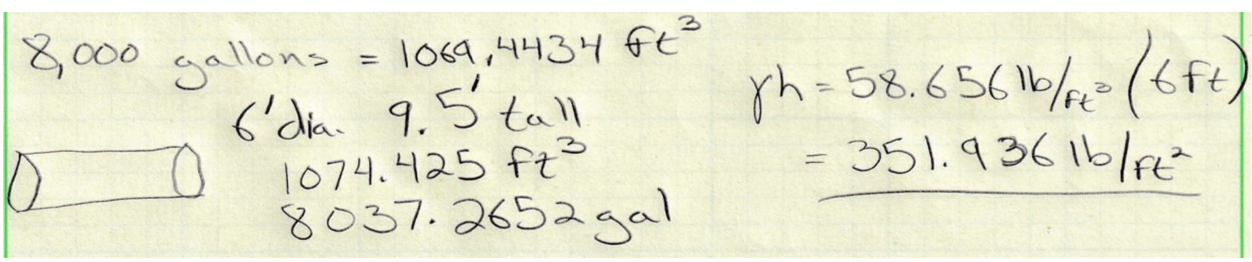
3' dia 5' tall

141.372 ft^3

1057.5371 gal

$\gamma h = 58.656\ lb/ft^3\ (5ft)$

$= 293.28\ lb/ft^2$



8,000 gallons = 1069.4434 ft^3

6' dia. 9.5' tall

1074.425 ft^3

8037.2652 gal

$\gamma h = 58.656\ lb/ft^3\ (6ft)$

$= 351.936\ lb/ft^2$

Summary

Reservoir	7 feet diameter X 14 feet height	16,121 gallons
Process Tank	3 feet diameter X 5 feet height	293 gallons
Waste Tank	6 feet diameter X 9.5 feet height	8037 gallons

Materials: Stainless Steel (schedule 40)

Analysis: The location of the tank plays an important role in determining the shape of the tank. The volume of the tank is a little more than required for convenience of having whole numbers as dimensions.

Tank thickness

Purpose: To determine the wall thickness of each tank

Sources: Mott R, Unterer J. “Applied Fluid Mechanics.” 7th edition. Pearson Education, Inc. (2015)

Design Considerations:

- Shape of tank
- Material of tank
- External Pressure on tank
- Internal Pressure on tank

Data and variables:

γh = pressure head
Ri = Radius (internal)
S = allowable stress
EL = 0.85

Procedure:

- Determine tank thickness by using the relationship between radius, pressure, allowable stress, and EL.

Calculations:

$\gamma h = 410.592\ \text{lb/ft}^2 = 2.85\ \text{psig}$

Tank Thickness

$$t = \frac{P \cdot R_i}{(S \cdot EL - 0.6 \cdot P)}$$

$$= \frac{2.85(12\text{in} \times 7\text{ft})}{(20{,}000\text{psi} \cdot .85 - 0.6(2.85))}$$

$t = .014\ \text{in}$

R_i = Radius Internal (in)

P = Pressure

S = Allowable Stress

EL = .85

* = Pressures require very little thickness Recommend .125in or .250 in thickness

$\gamma h = 293.28\ \text{lb/ft}^2 = 2.037\ \text{psig}$

$$t = \frac{2.037(12 \cdot 3)}{(20{,}000 \cdot .85 - .6(2.037))}$$

$t = .004\ \text{in}$

$$\gamma h = 351.936\ \mathrm{lb/ft^2} = 2.444\ \mathrm{psig}$$

$$t = \frac{2.444(12.6)}{(20{,}000 \cdot .85 - .6(2.444))}$$

$$\boxed{t = .01\ \mathrm{in}}$$

Summary

Reservoir	Process Tank	Waste Tank
0.125” - 0.250”	0.125” - 0.250”	0.125” - 0.250”

Materials: Stainless Steel (schedule 40)

Analysis: Pressures on each tank don’t require very thick walls. However, to keep the walls consistent, it is recommended to have 0.250 inches wall thickness.

Future drain connection - blind flange design

Purpose: To design a blind flange for possible expansion in the future.

Drawings:

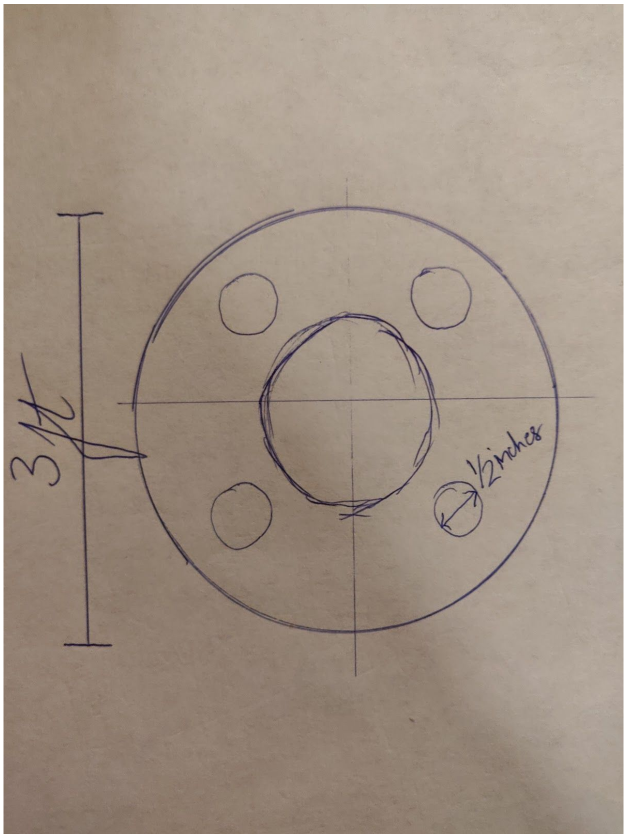


Figure 7.
Sources: Mott R, Unterer J. “Applied Fluid Mechanics.” 7th edition. Pearson Education, Inc. (2015)

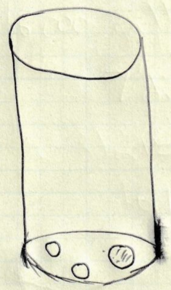
Design Considerations:

- Tank that has potential for expansion
- Tank material
- Thickness of flange

Procedure:

- Calculate pressure head of flange
- Determine thickness of flange
- Determine forces on flange
- Choose size according to forces acting on flange.

Calculations:



$$\gamma h = 293.29\ lb/ft^2 \cdot \frac{ft^2}{144 in^2}$$

$$\gamma h = 2.037\ psig$$

All Flanges will be on bottom of Vertical Standing tank.

Flange Thickness

$$t = d_g \cdot \sqrt{\frac{3P}{16S}}$$

$$t = 4 \cdot \sqrt{\frac{3(2.037)}{16(20000)}}$$

$$t = .017 in$$

d_g = Gasket Diameter = 4in

S = Allowable Stress = 20,000 psi

P = Pressure = 2.037 psig

* Again Pressure requires very thin flange. Suggest at least .125in or .250 in.

ASME B16.5

Force on Flange

$$F = \pi r^2 \cdot P$$

$$= \pi (2)^2 \cdot 2.037 psig$$

$$F = 25.598 lbs$$

* 4 - ½in 316 SS. Bolts will be used. Pressure requires much less but smaller than ½in dia. are easily over-stressed.

Summary

Blind Flange will be attached to the 1000 gallon process tank

Pressure: 2.037 psig	Force on flange: 25.6 lbs
Flange Thickness: 0.017” (0.125” or 0.250” recommended)	Therefore, Four ½” bolts

Material: Stainless Steel

Analysis: 4 bolts, each ½” diameter are required. The pressure requires less, but ½” is recommended to avoid failure.

Wind load

Note: Two of the tanks are underground and one of the tanks is indoors, so there is no wind load to account for.

Open channel for drainage

Purpose:
An open channel is to be added to the property to act as emergency drainage for the process tank.

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

Drawings & Diagrams:

TABLE 14.3. Most efficient sections for open channels

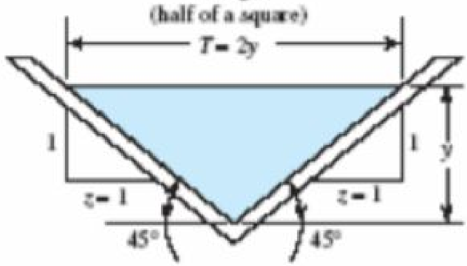
Section	Area A	Wetted Perimeter WP	Hydraulic Radius R
Triangle (half of a square) 	y^2	$2.83y$	$0.354y$

Figure 8.

Data & Variables:
Q = Volumetric Flow Rate (0.297 ft^3/sec)
A = Cross Sectional Area of Channel
S = Slope of Channel (1.2%)
R = Hydraulic Radius
n = Manning's Number (0.017)
Y= Depth of Channel

Design Considerations:

· The channel will be pump fed and will be designed for the established flow rate for draining the process tank.
· The layout of the plant and surrounding property will be taken into consideration.
· The channel will be constructed using unfinished concrete.
· The channel will carry the fluid 2000 ft. to a holding pond on the edge of the property.
· The channel will be constructed with a 1.2% slope.
· A Triangle (half of a square) channel will be the shape used, being designed to be most efficient.

Procedure:

· An assumed Y will be chosen.
· The hydraulic Radius will be calculated using the assumed Y: $R = 0.354y$
· A will be calculated using: $A = y^2$
· Using the assumed area and Manning's Equation, the flow rate will be calculated. $Q = 1.49/n \, * AS^{1/2}R^{2/3}$
· The calculated flow rate will be compared to the established flow rate using error percentage.
· A new assumed Y will be chosen until there is less than 1 percent error. (Iterative Process)
· These calculations will be performed using an Excel Spreadsheet.

Calculations:

Triangular Open Channel Drain

Established Q = **0.297** **ft^3/sec**

n = **0.017**

S = **0.012**

	Assumed Y (ft)	Area (ft^2)	R (ft)	Q (ft^3/sec)	Error (%)
Trial 1	0.5	0.25	0.177	0.756688	-154.78 %

Trial 2	0.25	0.0625	0.0885	0.11917 09	59.88%
Trial 3	0.3	0.09	0.1062	0.19378 5	34.75%
Trial 4	0.35	0.1225	0.1239	0.29231 08	1.58%
Trial 5	0.355	0.12602 5	0.12567	0.30357 95	-2.22%
Trial 6	0.3521	0.12397 4	0.12464 3	0.29701 12	0.00%

(Table 1)
Y = .3521 ft or <u>4.225 inches</u>

Materials:
Unfinished Concrete

Summary:
The triangle open channel will have a depth of 4.225 inches and a width of 8.45 inches.

Analysis:
The open channel is designed to accommodate the same flow rate that exists when draining the process tank normally. In cases of an emergency, requiring this flow rate to be exceeded, the channel will not be able to accommodate the increased flow. A possible option to accommodate a reduced drain time would be to increase the depth and width of the channel to accommodate higher flow rates.

Tank fill/empty times

Purpose: To estimate and calculate desired time required to fill and empty the tanks, as well as, the frequency.

Sources: Mott, R., Untener, J.A., “Applied Fluid Mechanics” 7th Edition Pearson Education Inc. (2015)

Data and Variables:
- Time = T
- Volume
- Critical velocity V

Procedure:
- The draining and filling time must be assumed
- Using critical velocity, we must determine A=Q/V

Calculations:

For 16,000 gallon reservoir;
Time= 4 hours
Therefore, 3750 gal/hr = 0.1393 ft^3/s
Critical velocity V= 3m/s = 9.8425 ft/s

For 1,000 gallon process tank;
Time= 2 hours (Note: drained and filled during 8-hour maintenance shift)
Therefore, 1000 gal/hr = 0.0371 ft^3/s
Critical velocity V = 3m/s = 9.8425 ft/s

For 8,000 gallon waste tank;
Time = 1 hour
Therefore, 8000 gal/hr = 0.297 ft^3/s
Critical Velocity = 3m/s = 9.8425 ft/s

Materials: Stainless Steel tanks and pipes (schedule 40)

Summary:

16,000 gallon tank	4 hours to drain/fill
1,000 gallon tank	2 hours to drain/fill
8,000 gallon tank	1 hour to drain/fill

Analysis:
The tanks are going to be filled and drained relatively quickly. Of course, the pumps and electrical motor will be selected accordingly later. The 1,000 gallon tank will be drained and filled during the 8-hour shift to save time and extra maintenance time and cost.

Piping layout

Purpose: To specify the layout of the piping system, as well as, the material and sizes of each pipe.

Sources: Mott R, Unterer J. “Applied Fluid Mechanics.” 7th edition. Pearson Education, Inc. (2015)

Diagrams: Figure 9.

Procedure:
Use the layout of the plant and tank locations to determine the length of the pipe and material.

Calculations:
Material used: Schedule 40 stainless steel

Summary: Pipes will be stainless steel

Materials: Schedule 40 stainless steel

Analysis: The pipes are mostly underground, other than the section that drains the train. Every pipe will be stainless steel so it lasts longer underground.

Pipe diameter and lengths & Pipe thickness

Purpose: To determine the diameter and lengths of pipes required.

Sources: Mott R, Unterer J. "Applied Fluid Mechanics." 7th edition. Pearson Education, Inc. (2015)

Diagrams:

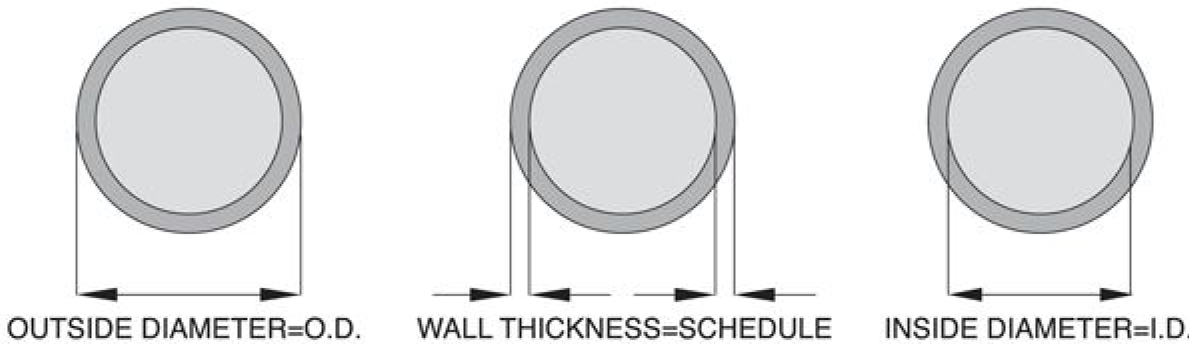


Figure 10.

Procedure:
Using the flow rate calculated for drain/fill times for tanks and the velocity, we can determine the cross sectional area and select pipe diameter accordingly.

Calculations:

For 16,000 gallon tank;

$$A = \frac{Q}{V} = \frac{0.1393\ ft^3/s}{9.8425\ ft/s}$$

$$A = 0.01415\ ft^2$$

* recommend 2in Sch. 40 Pipe to drain rail car Since calculated Area is slightly larger than 1½ in

For 1,000 gallon tank;

$$A = \frac{Q}{V} = \frac{0.0371\ ft^3/s}{9.8425\ ft/s}$$

$$A = 0.003769\ ft^2$$

* recommend 1in Sch. 40 pipe to fill and drain process tank

For 8,000 gallon tank;

$$Q = VA$$

$$A = \frac{Q}{V} = \frac{0.297\ ft^3/s}{9.842\ ft^3/s} = 0.0301\ ft^2$$

* recommended $2\frac{1}{2}$ schedule 40 pipe to fill & drain pro tank.

Summary:

16,000 gallon tank	A= 0.01415 ft^2	2 inch pipe recommended
1,000 gallon tank	A= 0.003769 ft^2	1 inch pipe recommended
8,000 gallon tank	A= 0.0301 ft^2	2 ½ inch pipe recommended

Materials: schedule 40 stainless steel

Analysis: The pipes have a higher thickness than required to avoid failure. Thick stainless steel pipes will also help with any water hammer problems.

Fittings

Purpose: To determine required fittings in the systems.

Sources: Mott R, Unterer J. "Applied Fluid Mechanics." 7th edition. Pearson Education, Inc. (2015)

Diagrams:

Figure 11.

Figure 12.

Procedure: Every bend will have a 90 degrees elbow and every system will have a gate valve.

Calculations:
Train to reservoir = 1 90 degree elbow
Reservoir to Process Tank = 1 90 degree elbow and 1 gate valve
Process Tank to Waste tank = 1 90 degree elbow and 1 gate valve.
Waste tank to trucks = 1 90 degree elbow and 1 gate valve

Summary:

90 degrees elbows	Gate valves
4	4

Materials: Stainless Steel schedule 40

Analysis: Every change in direction will need an elbow, and a 90 degree elbow is used most commonly.

Water Hammer Problem

Purpose: To determine if any water hammer problem exists and make sure that the design is suitable for it.

Sources: Sources: Mott R, Unterer J. "Applied Fluid Mechanics." 7th edition. Pearson Education, Inc. (2015)

Diagrams:

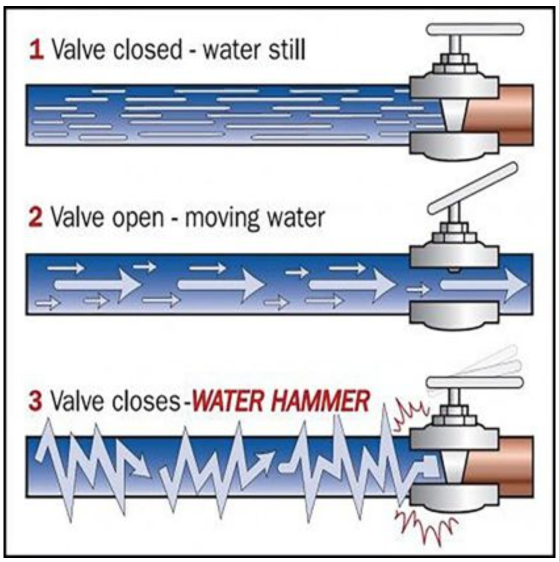


Figure 13.

Design Considerations:

- Pipe material
- Pipe thickness
- Type of valve
- Pump Type

Data and Variables:

- ΔP = Change in pressure
- E_0 = Bulk Modulus
- E = Elastic modulus of pipe material
- ρ = Density

- D = Pipe Diameter
- δ = pipe thickness
- t =Calculated pipe thickness

Procedure:

· Use ΔP formula to determine the change in pressure.

· Use elastic modulus, fluid density, pipe diameter, bulk modulus, and pipe thickness to determine C.

· Compute total pressure

· Use wall thickness formula to determine if the pipe can withhold the pressure or not.

· Suggest changes/solutions accordingly.

Calculations:

(Performed for section 2)

$E = 1.8E+11\ N/m^2$

$\rho = 940\ Kg/m^3$

$D = 0.0266446\ m$

$E_0 = 1.3E+9\ N/m^2$

$\delta = 0.0254\ m$

$\Delta P = \rho CV$

$C = (\sqrt{E_0/\rho})/(\sqrt{1 + E_0 D/E\delta})$

$C = 1{,}175.888017\ m/s$

$\Delta P = 940 * 1175.888017 * 3 = 3.316E+6\ Pa$

$P_{max} = 3316 + 6964 =$ **10.28 MPa**

t = (10.28*26.6446)/2(34.172*1 + 10.28*0.4) = **3.57 mm**

Materials:

Stainless Steel schedule 40

Summary:

For the maximum pressure (10.28 MPa) that might occur in the pipe, the thickness should be 3.57 mm at least.

Analysis:

The pipe will fail if the total pressure occurs, so there would be steps that need to be taken to avoid failure. Since the thickness of the pipe in our design is 3.38 mm and it needs to be 3.57 mm to handle the max pressure, the operator could slowly close the vale. There could be a design to inject air into the pipe, and lastly, a water hammer arrestor could be used. It will be installed between the valve and the incoming fluid supply to absorb the momentum from the incoming fluid.

Pipeline Support Info

Purpose: To determine the forces on the supports of a specified pipe.

Sources: Mott R, Unterer J. “Applied Fluid Mechanics.” 7th edition. Pearson Education, Inc. (2015)

Drawings & Diagrams:

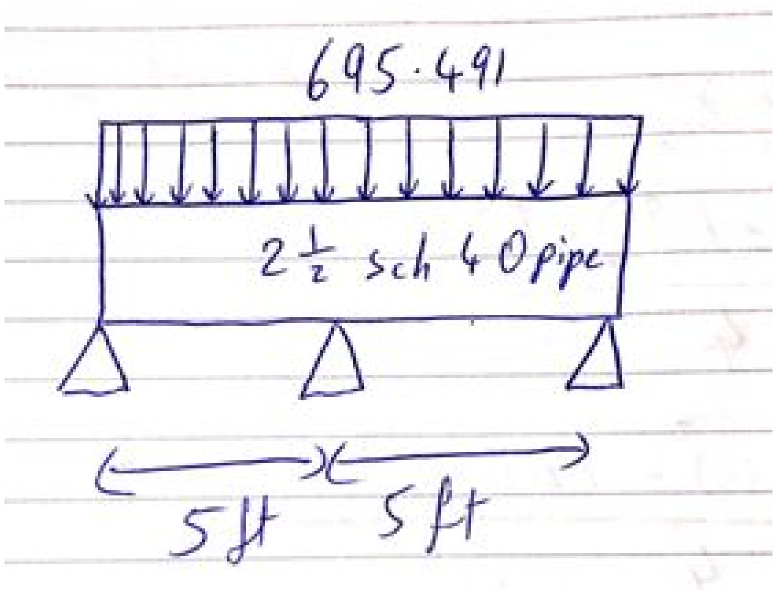


Figure 14.

Design Considerations:
• Constant Properties
• Incompressible fluid

Data and variables:
Outside Diameter= 0.2395 ft
Inside Diameter= 0.2058 ft
γ steel = 490 lb/ ft3

γ coolant = 58.656 lb/ft3
L= 90ft

Procedure:

- Find Inner and Outer diameter of the pipe from Appendix F
- Solve for the Volume of the pipe
- Solve for weight of the pipe with volume and specific weight
- Solve for volume and weight of the coolant.
- Add coolant and weight.
- Divide the total weight by number of supports

Calculations:

$\rightarrow W_{pipe} = V_{pipe} \times \gamma_{steel}$

$$V_{pipe} = \frac{\pi \times (D_o^2 - D_i^2) \times L}{4}$$

$$V_{pipe} = \frac{\pi \times \left((0.2395)^2 - (0.2058)^2\right) \times 90}{4}$$

$V_{pipe} = 1.06\ ft^3$

$\rightarrow W_{pipe} = (1.06) \times (490) = 519.887\ lbs$

$W_{coolant} = \gamma \times V = \gamma \times \frac{\pi}{4} \times D^2 \times L$

$W_{coolant} = (58.656) \times \frac{\pi}{4} \times (0.2058)^2 \times 90 = 175.604\ lbs$

$W_{total} = W_{pipe} + W_{coolant} = 519.887\ lbs + 175.604\ lbs = 695.491\ lbs$

There will roughly be a support every 5 ft $\Rightarrow \frac{90ft}{5ft} = 18$ supports

$\therefore \frac{695.491\ lbs}{18} = 38.638\ lbs$ per support

Summary:

Weight of Pipe	519.887 lbs
Weight of coolant	175.604 lbs
Total Weight of pipe and coolant	695.491 lbs
Number of supports	18
Weight on each support	38.638 lbs

Materials: Stainless Steel (schedule 40)

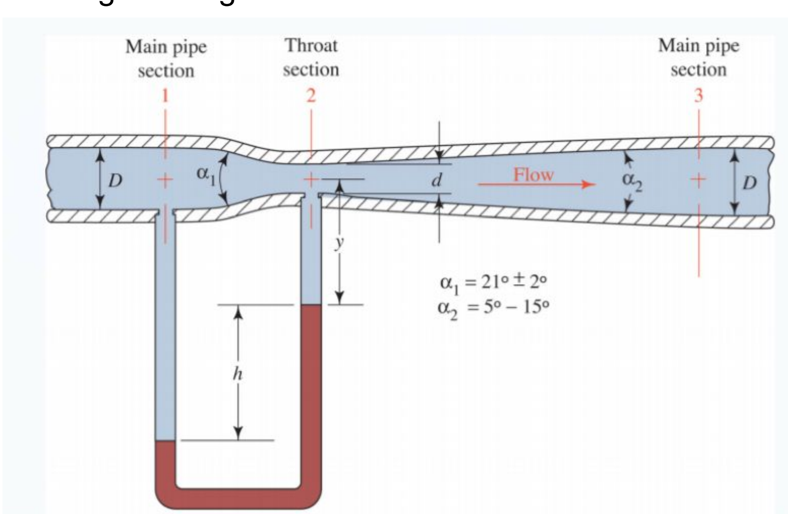
Analysis: There would be 18 supports and about 38.638 lbs on each support.

Flow Measurement Instrument

Purpose:
Provide flow measurement and pressure devices for the filling of the process tank from the storage tank.

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

Drawings & Diagrams:



Data & Variables:

Q = Volumetric Flow Rate (0.0371 ft^3/sec.)

D = Pipe Diameter (0.0876 ft.)

A_1 = Area of Pipe (0.006 ft^2)

d = Throat Diameter

A_2 = Area of Throat

h = Height of Manometer (1ft)

Re = Reynold's Number

C = Discharge Coefficient

v = Kinematic Viscosity (1.06 10^{-5} ft^2/sec.)

γ_m = Specific Weight of Mercury (844.9 lb/ft^3)

γ_f = Specific Weight of Fluid (58.656 lb/ft^3)

P = Working Pressure

P_{atm} = Atmospheric pressure

Design Considerations:

· For this venturi flow-meter we will use a manometer with a height of 1 foot.

· Mercury will be the fluid used in the manometer.

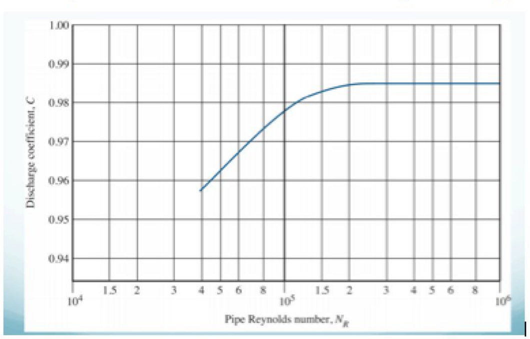
· As the Pipe Diameter is already set, the throat diameter is the unknown value for the flow meter.

Procedure:

- Reynolds Number (Re) will be calculated.

$$R_e = \frac{vD}{\nu}$$

- Reynold's Number will be used to obtain the Discharge Coefficient (C).



- A_2 will be solved for:

$$Q = CA_1 \sqrt{\frac{2gh[\left(\frac{\gamma_m}{\gamma_f}\right) - 1]}{\frac{A_1}{A_2} - 1}}$$

- Using A_2, we will solve for d, the throat diameter.

$$A_2 = \pi d^2/4$$

- To specify the pressure gage, bernoulli's will be applied from the pump outlet to the top of the process tank.

$$P = \frac{Z + h_L - \frac{V_1^2}{2g}}{\gamma}$$

Calculations:

$$R_e = \frac{6.183 \times 0.0876}{1.06 \times 10^{-5}} = 51097.245$$

C = 0.963

$$0.0371 = (0.963)(0.006)\sqrt{\frac{2(32.2)(1)[\left(\frac{844.9}{58.656}\right) - 1]}{\frac{0.006}{A_2} - 1}}$$

$A_2 = 1.75 \times 10^{-5}$

$$d = \sqrt{\frac{4A_2}{\pi}} = 0.00473 \text{ ft}$$

$$P = \frac{12 + 20.983 + \frac{9.8425^2}{2 \times 32.2}}{58.656} = .588\ {}^{lb}/_{ft^2} = 84.67\ {}^{lb}/_{in^2}$$

Materials:
Acrylic Manometer tube
Stainless Steel Formed Venturi
Pressure Gage

Summary:
The venturi flow-meter will have the following dimensions:
D = 0.0876 ft
d = 0.00473 ft
h = 1 ft
A 0-150 psig gage will be used.

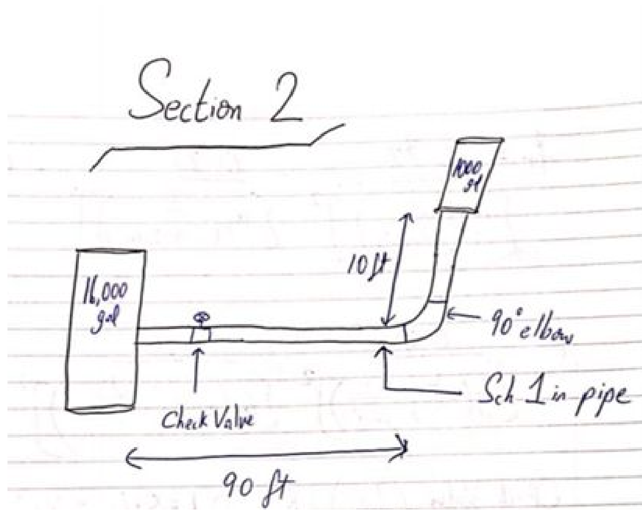
Analysis:
As configured, the manometer is the minimum height to accommodate the flowrate. To reduce the risk of the mercury being lost out of the manometer, d- the throat diameter could be increased slightly, or the taller manometer tube could be used. This would allow for some variation without risk of mercury loss into the system. A 0-150 psig gage is selected as the working pressure falls in the middle of that range.

Energy losses

Purpose: To develop the hydraulic analysis of all parts of the system: includes energy losses due to friction and minor losses.

Sources: Mott R, Unterer J. “Applied Fluid Mechanics.” 7th edition. Pearson Education, Inc. (2015)

Drawings & Diagrams:



Design Considerations:

- Energy Losses in pipe, elbows and valves
- Laminar or Turbulent flow
- Schedule 40 Steel Pipes were used

Data and variables:

D= 0.0874 ft

Kinematic Viscosity = 1.06x10-5 ft2/s

Q= 0.0371 ft3/s

L= 100ft

Procedure:

- Find the Reynolds number specific to the system by dividing the product of density, velocity and diameter by the viscosity.
- Calculate Friction Factor
- Turbulent flow friction factor was used as Reynolds number was above 2100

- Find head loss due to pipes, valves and elbows.
- Add all the head losses from each system to give you the total head loss.

Calculations:

$$V = \frac{4 * Q}{\pi D^2} = \frac{4 \times 0.0371}{\pi (0.0874)^2} = \boxed{6.1838 \text{ ft/s}}$$

$$N_r = \frac{V * D}{\nu} = \frac{6.1838 \times 0.0874}{1.06 \times 10^{-5}} = \boxed{5.10 \times 10^4}$$

$$D/\varepsilon = \frac{0.0874}{0.00015} = \boxed{582.6667}$$

$$f_T = \frac{0.25}{\left[\log\left(\frac{1}{3.7(D/\varepsilon)}\right)\right]^2} = \frac{0.25}{\left\{\log\left(\frac{1}{3.7(582.6667)}\right)\right\}^2} = 0.022496$$

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7(D/\varepsilon)} + \frac{5.74}{(N_r)^{0.9}}\right)\right]^2} = \frac{0.25}{\left\{\log\left(\frac{1}{3.7(582.667)} + \frac{5.74}{(5.10 \times 10^4)^{0.9}}\right)\right\}^2} = 0.026036$$

$$\text{Check Valve } \left(\frac{L_e}{D}\right) = 8 \Rightarrow K = 8 * f_T = 8 \times 0.022496 = 0.179968$$

$$90^\circ \text{ elbow } \left(\frac{L_e}{D}\right) = 30 \Rightarrow K = 30 * f_T = 30 \times 0.022496 = 0.67488$$

- $H_L \text{ Check Valve} = K\left(\frac{v^2}{2g}\right) = 0.179968\left(\frac{(6.1838)^2}{2g}\right) = 2.003674 \text{ ft}$
- $H_L \text{ Elbow} = K\left(\frac{V^2}{2g}\right) = 0.67488\left(\frac{(6.1838)^2}{2g}\right) = 0.40073 \text{ ft}$
- $H_L \text{ Entrance} = K\left(\frac{V^2}{2g}\right) = 0.5\left(\frac{(6.1838)^2}{2g}\right) = 0.29658 \text{ ft}$

- $H_L \text{ Exit} = K\left(\frac{V^2}{2g}\right) = 1\left(\frac{(6.1838)^2}{2g}\right) = 0.593779 \text{ ft}$
- $H_L \text{ Pipe} = f \times \left(\frac{L}{D}\right) \times \frac{V^2}{2g} = 0.026036 \times \left(\frac{100}{0.0875}\right) \times \left(\frac{(6.1838)^2}{2g}\right) = 17.6883$

$\therefore H_L \text{ Section } (2) \Rightarrow H_L CV + H_L elb + H_L ent + H_L exit + H_L pipe$

$\therefore H_L \text{ Section } (2) \Rightarrow 2.0036 + 0.40073 + 0.29688 + 0.593779 + 17.6883$

$\Rightarrow \boxed{H_L \text{ Section } (2) = 20.9834 \text{ ft}}$

Summary:

	H_L GV	H_L Elbows	H_L Entrance	H_L Exit	f	D (ft)	Velocity (ft/s)	H_L Pipe	H_L (1)	fT
Section 1	0.243096	0.911611	0.75297441	1.505949	0.022331	0.1342	9.848	25.05912	28.472754	0.020178
	H_L CV	H_L Elbows	H_L Entrance	H_L Exit	f	D (ft)	Velocity (ft/s)	H_L Pipe	H_L (2)	fT
Section 2	2.003649	0.40073	0.29688962	0.593779	0.026036	0.0874	6.1838	17.68837	20.983418	0.022496
	H_L GV	H_L Elbows	H_L Entrance	H_L Exit	f	D (ft)	Velocity (ft/s)	H_L Pipe	H_L (3)	fT
Section 3	0.382735	1.435257	1.25972688	2.519454	0.020619	0.1723	12.73785	30.1501	35.74727	0.018989
	H_L CV	H_L Elbows	H_L Entrance	H_L Exit	f	D (ft)	Velocity (ft/s)	H_L Pipe	H_L (4)	fT
Section 4	3.380579	0.676116	0.61891558	1.237831	0.020269	0.2058	8.9284	12.19125	18.104695	0.018207
									H_L Total (ft)	103.308137

(Table 2.)

Materials: Stainless Steel (schedule 40)

Analysis: Section 1 & 3 are gravity driven systems while sections 2&4 are pump driven systems. All flows are turbulent.

Pump requirements (Pump Type)

Purpose:
To specify the number of pumps required, their types, flow capacities, head requirements, and power required.

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

Drawings & Diagrams:

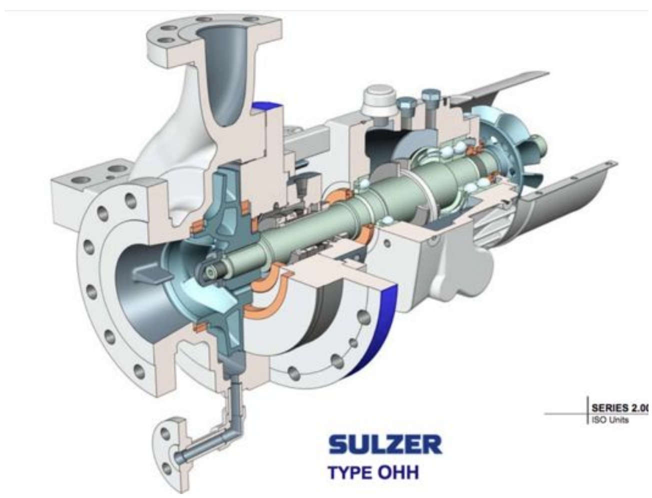


Figure 15.

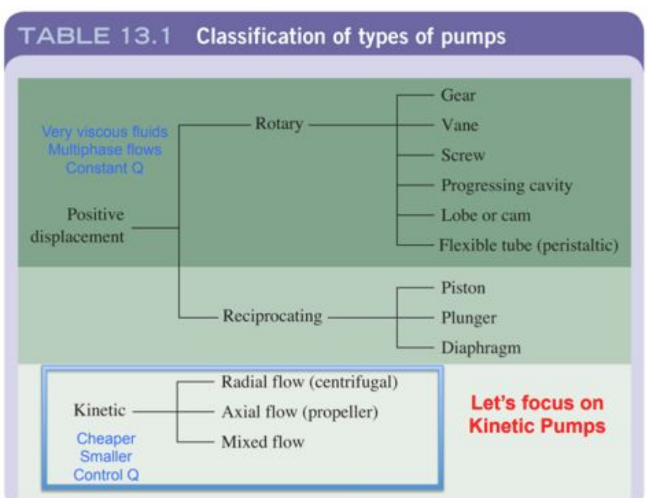
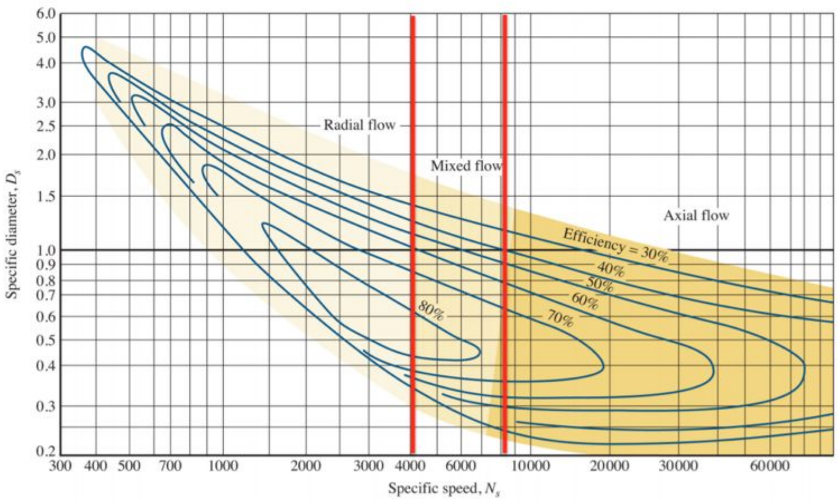


Figure 16.



Data & Variables:
Q = Volumetric Flow Rate
H_a = Required Pump Head
HP = Horsepower
N_s = Specific Speed
γ = Specific Weight

Design Considerations:

- There are two pipe circuits in this project that will require a pump.
- The tanks being drawn from by the pumps are below ground.
- The pumps will be placed below ground also to reduce the suction pipe length.

Procedure:

- Flow rate will be converted to Gallons per Minute 1 ft^3/sec = 448.831 gal/min
- Specific Speed will be calculated: $Ns = \frac{N\sqrt{Q}}{h_a 3/4}$
- Pump type will be selected using the specific speed chart and consideration for flow control, size, budget.
- Head Requirement was calculated in a separate task. (Section 5.f.v)
- Power required will be calculated: $P = \frac{\gamma Q h_a}{\eta}$

Calculations:

Pump 1 (Storage/Receiving Tank to Process Tank)

$$Q = 0.0371\, {}^{ft^3}/_{sec} \times 448.831 = 16.652\, {}^{gal}/_{min}$$

$$N_s = \frac{N\sqrt{Q}}{h_a^{\frac{3}{4}}} = \frac{3500\sqrt{16.652}}{30.983^{3/4}} = 1087.574$$

$$P = \gamma Q h_a = 58.656 \times 16.652 \times 30.983 = {}^{30262.327}/_{3960} = 7.642\ HP$$

Pump 2 (Waste Tank to Truck)

$$Q = 0.297\, {}^{ft^3}/_{sec} \times 448.831 = 133.303\, {}^{gal}/_{min}$$

$$N_s = \frac{N\sqrt{Q}}{h_a^{\frac{3}{4}}} = \frac{3500\sqrt{133.303}}{28.104^{3/4}} = 3310.640$$

$$P = \gamma Q h_a = 58.656 \times 133.303 \times 28.104 = {}^{219745.76}/_{3960} = 55.491\ HP$$

Materials:
Sulzer Pumps

Summary:
Number of required pumps: 2
Pump 1 (Storage/Receiving Tank to Process Tank):
- Pump Type: Kinetic, Self-Priming, Radial
- Flow Capacity: 16.652 gal/min
- Head Requirement: 30.983 ft.
- Power Required: 7.642 Horsepower

Pump 2 (Waste Tank to Truck):
- Pump Type: Kinetic, Self-Priming, Radial
- Flow Capacity: 133.303 gal/min
- Head Requirement: 28.104 ft.
- Power Required: 55.491 Horsepower

Analysis:
As currently configured, the pump requirement to drain the waste tank to the truck is more substantial. This could be reduced by extending the time to drain the tank which would reduce the flow rate capacity. The time is currently 1 hour. This could easily be extended to 2 or 3 hours. Kinetic pumps were chosen due to size, cost, and the ability to control flow.

Pump curves, and system curves with operating point

Purpose:
Specify the characteristics of the chosen pumps, point of operation, size and weight.

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

Drawings & Diagrams:

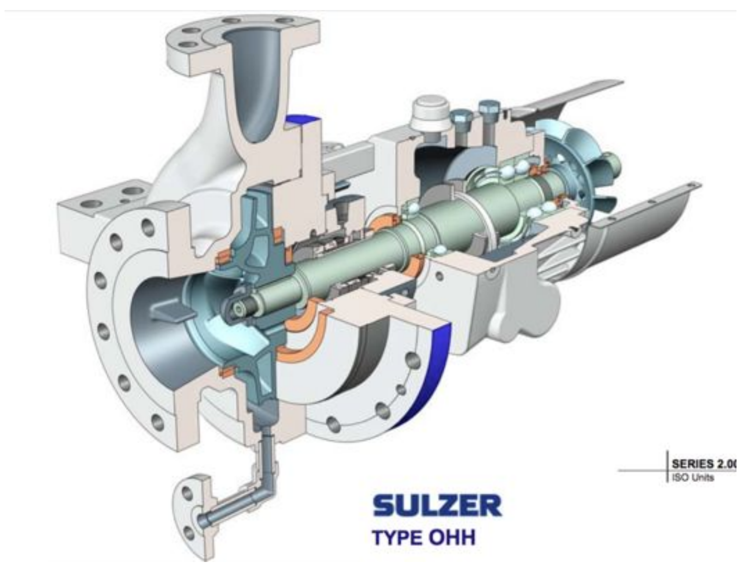


Figure 17.

Data & Variables:
Q = Volumetric Flow Rate (gal/min)
H_a = Pump Head (ft)

Design Considerations:

· Pumps will be Radial, Self-Priming
· Pumps will be placed below ground surface to reduce Pipe length and Height. Difference from bottom of tank to pump inlet.

Procedure:

· Using Q and h_a, select a pump from the Sulzer catalog.
· Pump chart is not given at required rpm. 3520 rpm chart will be scaled.
· Using data from the hydraulic analysis plot the system curve.
· Specify Point of Operation
· Obtain all other pump characteristics from Sulzer catalog

Sample Calculations:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad Q_2 = Q_1 \times \frac{N_2}{N_1} = 100 \times \frac{1170}{3520} = 33.238$$

$$\frac{h_{a_1}}{h_{a_2}} = \frac{N_1}{N_2}^2 \qquad h_{a_2} = h_{a_1} \times \frac{N_2}{N_1}^2 = 100 \times \frac{1170^2}{3520} = 11.05$$

$$\frac{P_1}{P_2} = \frac{N_1}{N_2}^3 \qquad P_2 = P_1 \times \frac{N_2}{N_1}^3 = 30 \times \frac{1170^3}{3520} = 1.102$$

Materials:
Sulzer Pumps

Summary:
Pump 1:

Sulzer 1.5 x 3 x 8 – 1 OHH at 1170 rpm
Impeller Size: 8.20 in. (This will provide a slightly increased flow rate)
Weight: 335 lbs
Length: 32.01 in Width: 18.11 in
Point of Operation: Flow of 17 gal/min – 31 ft of head

Pump 2:

Sulzer 3 x 4 x 8B – 1 OHH at 1170 rpm

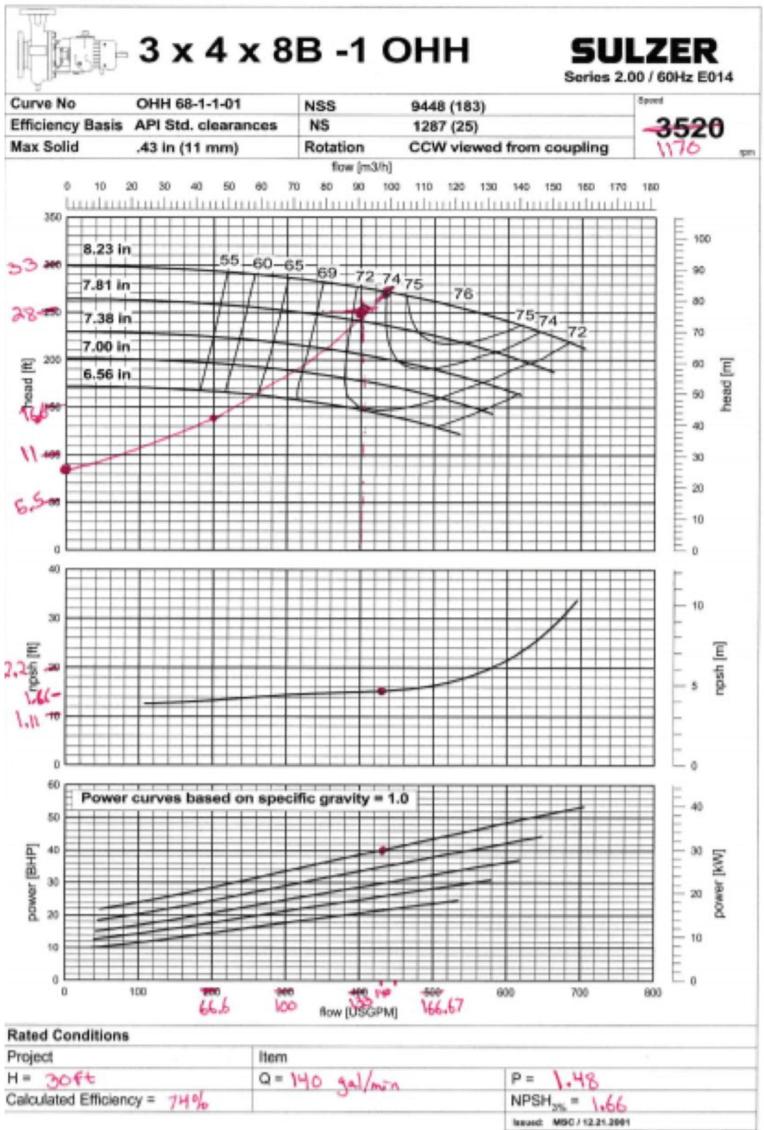
Impeller Size = 8.23 in. (This will provide a slightly increased flow rate)

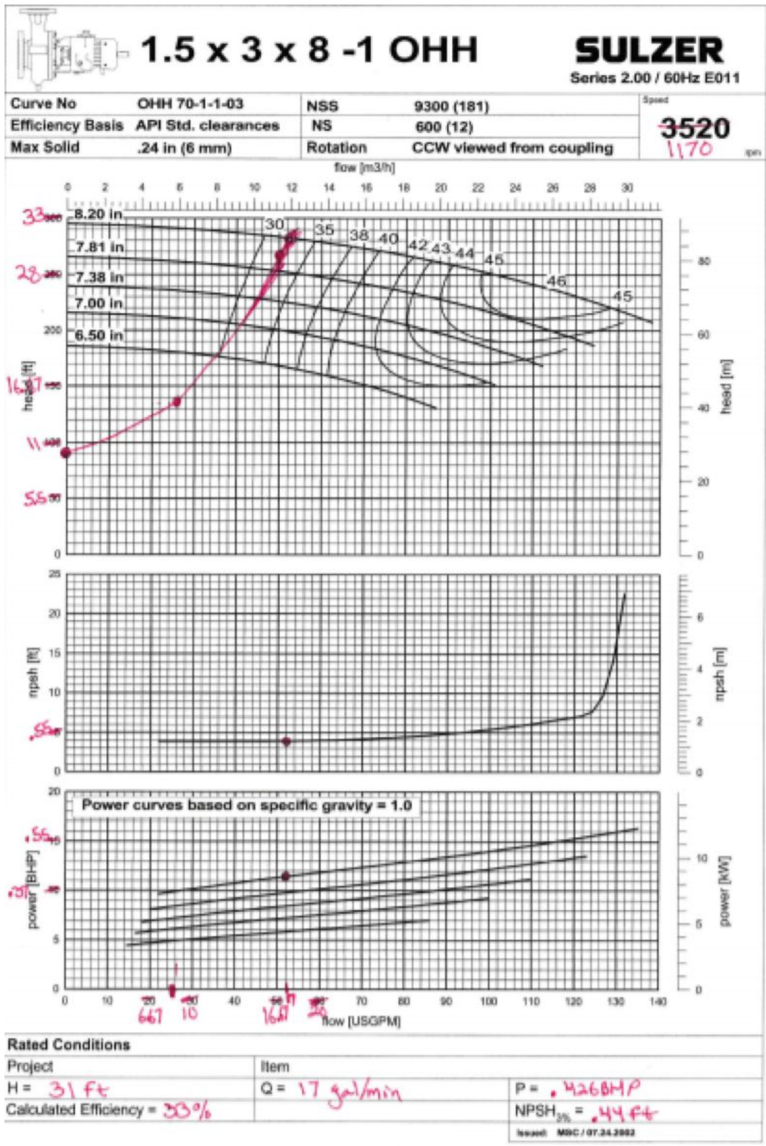
Weight: 370 lbs

Length: 33.03 in

Width: 18.90 in

Point of Operation: Flow of 140 gal/min – 30ft of head





Analysis:

Pump one is not an ideal selection but is the closest available pump of this classification. The sizes and weights of the pumps are very similar. This should enable civil engineering design a single foundation to be used for both pumps. Both pumps are using the next larger impeller size. This does produce a slightly increased flow rate which will slightly reduce the time required for filling / draining of tanks. This is agreed to be a more desirable situation. If any further increases to flow rate are required, these pumps will not be suitable as they are at the largest available impeller size.

Electrical Motor Requirement

Purpose:
Specify the electrical motor requirements for the pumps.

Sources:
Mott, R., Untener, J.A., “Applied Fluid Mechanics” 7th Edition
Pearson Education Inc. (2015)

Drawings & Diagrams:

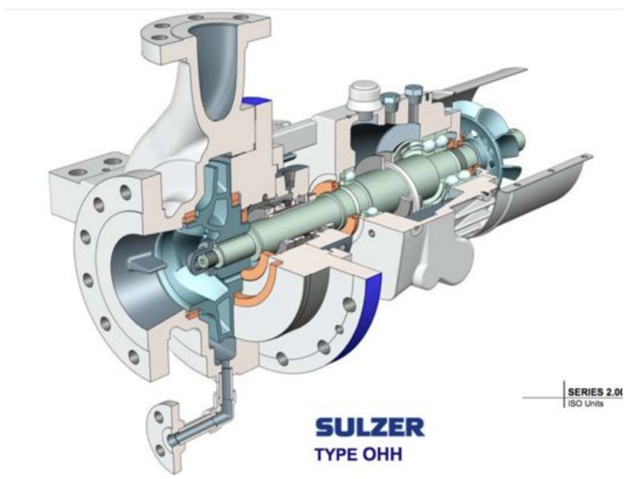


Figure 18.

Data & Variables:
P_{calc} = Calculated Power
P_{mech} = Required Mechanical Power
P = Electrical Power (HP)
η = Pump Efficiency
η_{mech} = Mechanical loss (0.83-0.95)

Design Considerations:
· Electrical Power requirements will be specified at 1.10 times the Mechanical Power requirement
· There are mechanical losses between motor and pump
· Pump efficiency is unchanged by scaling of pump selection charts

Procedure:

- The required power will be calculated Using the point of operation and pump effeciency

$$P_{calc} = \frac{\gamma Q h}{\eta}$$

- The mechanical losses between the motor and the pump will be factored in using η_{mech}.

$$P_{mech} = \frac{P_{calc}}{\eta_{mech}}$$

- The Electrical Power required will be calculated

$$P = P_{mech} \times 1.10$$

Calculations:

Pump 1:

$$P_{calc} = 58.656 \times 17 \times 31 = \frac{30911.71}{3960} = \frac{7.806HP}{.33} = 23.65HP$$

$$P_{mech} = \frac{23.65}{0.87} = 27.18HP$$

$$P = 27.18 \times 1.10 = 29.9HP$$

Pump 2:

$$P_{calc} = 58.656 \times 140 \times 30 = \frac{246355.2}{3960} = \frac{62.21HP}{.74} = 84.07HP$$

$$P_{mech} = \frac{84.07}{0.87} = 96.63HP$$

$$P = 96.63 \times 1.10 = 106.29HP$$

Materials:
Sulzer Pumps
Electric Motors

Summary:
Electrical Power Required for Pump 1: *29.9 Horsepower*

Electrical Power Required for Pump 2: *106.29 Horsepower*

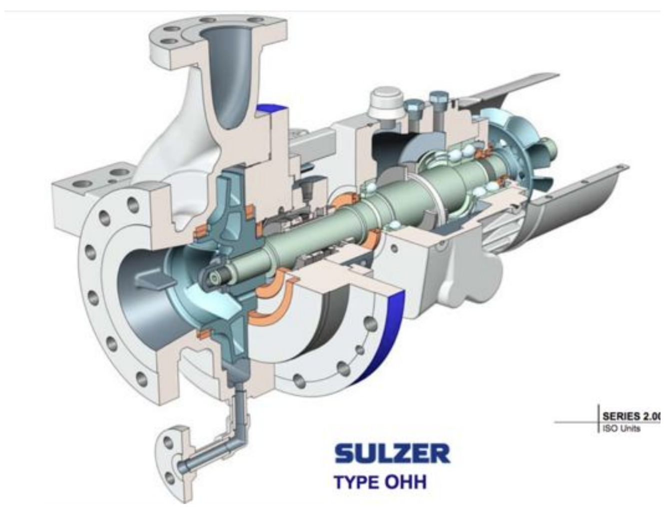
Analysis:
Again, there is a much larger power demand for pump 2. This could be reduced by increasing the drain/fill time and thus reduced the required flow capacity.

Summary of selected pumps (includes values at operating point, NPSH_req, pump size, pump weight, pump required power, electrical motor power)

Purpose:
Demonstrate that pumps have an acceptable NPSH and will not cavitate

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

Drawings & Diagrams:



(Figure 19.)

TABLE 13.2 Vapor pressure and vapor pressure head of water

Temperature °C	Vapor Pressure kPa (abs)	Specific Weight (kN/m^3)	Vapor Pressure Head (m)	Temperature °F	Vapor Pressure (psia)	Specific Weight (lb/ft^3)	Vapor Pressure Head (ft)
0	0.6105	9.806	0.06226	32	0.08854	62.42	0.2043
5	0.8722	9.807	0.08894	40	0.1217	62.43	0.2807
10	1.228	9.804	0.1253	50	0.1781	62.41	0.4109
20	2.338	9.789	0.2388	60	0.2563	62.37	0.5917
30	4.243	9.765	0.4345	70	0.3631	62.30	0.8393
40	7.376	9.731	0.7580	80	0.5069	62.22	1.173
50	12.33	9.690	1.272	90	0.6979	62.11	1.618
60	19.92	9.642	2.066	100	0.9493	62.00	2.205
70	31.16	9.589	3.250	120	1.692	61.71	3.948
80	47.34	9.530	4.967	140	2.888	61.38	6.775
90	70.10	9.467	7.405	160	4.736	61.00	11.18
100	101.3	9.399	10.78	180	7.507	61.58	17.55
				200	11.52	60.12	27.59
				212	14.69	59.83	35.36

Table 3.

Data & Variables:

$NPSH_{avail}$ = Net Positive Suction Head Available

$NPSH_{req}$ = Net Positive Suction Head Required

P_v = Vapor Pressure

P_{atm} = Atmospheric Pressure

H_L = Losses in Suction Pipe

γ = Specific Weight

ΔZ = Height of pump above tank

Design Considerations:

- Pressures in these equations are absolute pressure
- Tanks are placed below ground surface to minimize ΔZ and H_L
- For these equations, properties of water will be assumed
- In order to prevent cavitation, $NPSH_{avail} > NPSH_{req}$
- $NPSH_{req}$ is obtained from individual pump selection charts
- Temperature is 60°F

Procedure:

- $NPSH_{avail}$ will be calculated

$$NPSH_{avail} = \frac{P_{atm}}{\gamma} - \frac{P_v}{\gamma} - \Delta Z - H_L$$

- $NPSH_{avail}$ will be compared to $NPSH_{req}$

$$NPSH_{avail} > NPSH_{req}$$

Calculations:

Pump 1:

$$NPSH_{avail} = \frac{2116.21}{62.37} - .5917 - 2 - 0.35$$

$$30.99ft > 0.44ft$$

Pump 2:

$$NPSH_{avail} = \frac{2116.21}{62.37} - .5917 - 2 - .24$$

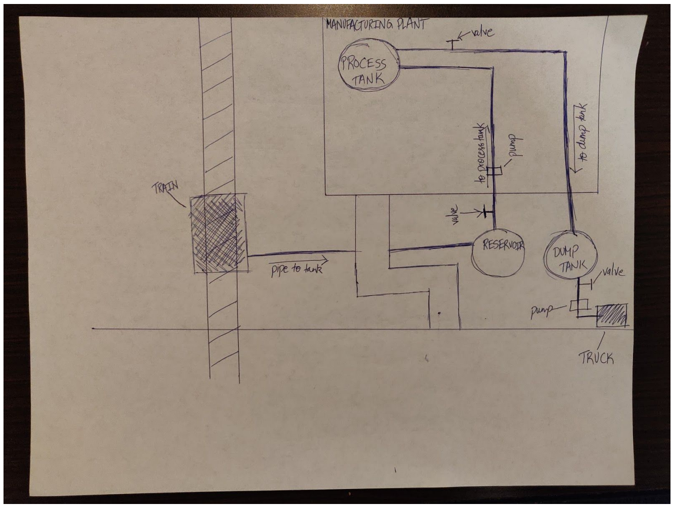
$$31.10ft > 1.66ft$$

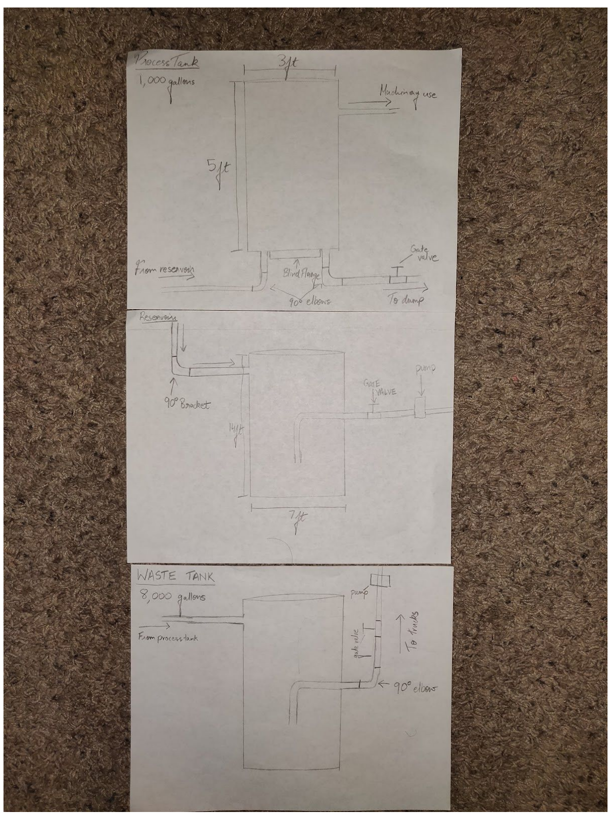
Materials:
Sulzer Pumps

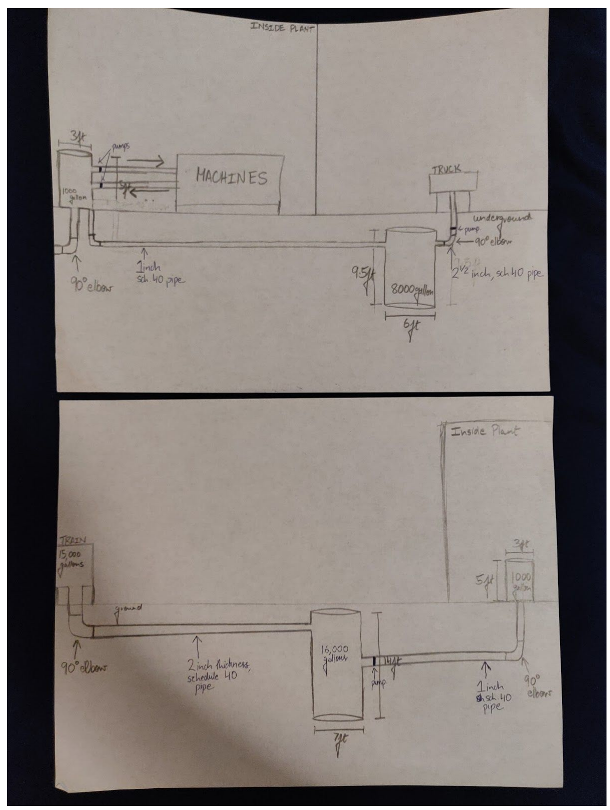
Summary:
Pump 1: There is sufficient NPSH available. The pump will not cavitate
Pump 2: There is sufficient NPSH available. The pump will not cavitate

Analysis:
In both cases, Pump 1 and 2, there is sufficient Net Positive Suction Head available. Neither of these pumps will cavitate.

Final Plot Plan, Isometrics, Elevation View







Bill Of Materials

Part/Equipment	Quantity	Type
Pipe	4 x 10 feet 4 x 90 feet	SS schedule 40
Pump	2	Sulzer Type OHH
90° elbow	4	Stainless Steel (sched. 40)
Gate Valve	4	Stainless Steel
Water Hammer Arrestor	4	SS with Brass Adapter
Pipe Support	18	Stainless Steel with clamp
Bolts	4	½ inch SS

Final Remarks (Reflection)

By Ruchil Kamat

This project taught us a lot things. We didn't just learn the material, but also learned to use it practically, which is more important than just learning the material. Additionally, working in groups helped us understand that people have different strengths and they could be used to work on projects in a professional setting. On the contrary, group work helps build each other's weaknesses as well. All the material we learned might be used in entry level jobs at manufacturing firms because fluid systems are almost everywhere. To explain the project in a job interview, I would describe it as a theoretical design project of fluid systems in a manufacturing firm, and would add to that by explaining how we had to design the complete system- choose the tanks, materials, piping layout, location, etc. Even smaller things like fittings and water hammer problems were addressed. Overall, it was an all-round project that taught us everything that is considered while designing fluid systems. My main strengths include good communication and time management, and that is something I extensively used during the project. I was in constant contact with the group members about our tasks and making sure everyone is on track and doing what they were supposed to. Setting personal deadlines and deadlines for the group helped us a lot at finishing the final report on time and having enough time to go through it and fix any errors. My weaknesses were understanding some of the material, but I put in the extra work and asked for help from my group members and my professor to make sure I am on the right track. Our project's strengths include logical reasoning behind choosing each part/equipment. The materials (Stainless Steel) we used are expensive, but will last a long time and have low maintenance costs. Our placement of the tanks is in a logical sequence, as well, which would help with the complete flow of things. If I had to pick a weakness, it would be the fact that the tanks are placed underground, so that would be a hassle to maintain or if anything was to go wrong the maintenance engineers would have to go underground to fix it. To conclude, if I am starting the class over, I would definitely try to stay ahead of the schedule to ensure that I am on top of things like I should be. There were times when I had to catch up and it made it difficult to absorb so much material at once.

By Thomas George

I really enjoyed Fluid Mechanics as a class and professor Ayala did a really great job in explaining the subject in class and their real-life applications. I am really thinking of going into the oil & gas industry like my father. I got to learn a lot about pipeline systems which sparked an interest in me. I truly believe that whatever I learned in class will be very useful in my professional career especially in the oil & gas industry. If I were to go into the design phase, then I can show them our project where we had to design the full pipeline system to a manufacturer’s plant. I would explain to a potential employer that the goal of the project was to move the coolant from the supplier (train) through various tanks to picking it up by trucks at the end of the coolant use. The project was distributed between my team members and we were all willing to help each other when needed. It was a struggle at the beginning but then we worked diligently through the various tasks and got to the finish line successfully. I think my strengths was that I was willing to learn and help my team members. When I first started the project, I honestly didn’t know what to do and where to start but I took some time and sat down with my team members to strategize which ended up being helpful at the end of the semester where we did not have much work to do. One of my weaknesses was the time constraint, I was not able to give my other subjects enough time to do assignments and sometimes would end up missing a lecture from Fluids which only hindered progress as a lot of concepts for the project were taught in those lectures. After our exams, my team members helped us to understand the tasks and what it expected from us. The project weakness is that a lot of the system is underground and only vertical pipes were on top of the ground that led to the tanks or trucks . If I were to give myself some advice, it would be that I have to put in more time so that I can understand the concepts which would enable me to do the project more easily. Ask more questions to the professor as he has had decades worth of experience in this field.

By Bryant Teagle

While my situation is a little different, being in my career for almost 25 years, I do think what I have learned is valuable. I am currently an Engineering Analyst in the Components Manufacturing Dept. at Continental Automotive. Machining in recent years has turned to high pressure oil delivered through the cutting tool to the point of contact. As I already perform actual cutting tool design, the material learned in this class is certainly relevant. I would explain this project as the somewhat consuming task that it was. I would stress the importance of teamwork and communication. These are all real-world skills that are highly desirable. My strengths are my attention to detail and my drive to always achieve goals that seem beyond my reach. My key and very crucial weakness in this project was my schedule. Working 50+ hours per week and trying to take 4 classes consumed all of my time. It led to me feeling very out of control the entire semester. I feel our entire team suffered from our own schedule issues. In all honesty I feel our project is technically better in the later tasks. This has a great deal to do with our learning and mastering of the material. If I were to start the class over, one of two things would have to happen. Either my schedule outside of this class would have to be more favorable or I am afraid, I would not choose the path of the project. In reality, the root of all of my struggles in this class were due to available time. Overall, I think the project is a good thing. I do think the mixing of Online and In-Class students presents its own set of obstacles within the project. I am sure I will look back on this experience in a good light.